BRNO UNIVERSITY OF TECHNOLOGY

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FACULTY OF MECHANICAL ENGINEERING

FAKULTA STROJNÍHO INŽENÝRSTVÍ

INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

ÚSTAV KONSTRUOVÁNÍ

EXTERIOR AND INTERIOR DESIGN OF A SEMI-AUTONOMOUS TRAM CABIN

DESIGN EXTERIÉRU A INTERIÉRU KABINY SEMI-AUTONOMNÍ TRAMVAJE

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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VEDOUCÍ PRÁCE

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BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF MECHANICAL ENGINEERING

Master's Thesis Assignment

Institute:	Institute of Machine and Industrial Design
Student:	**Bc. Miroslav Pleskal**
Degree programm:	Industrial Design
Branch:	no specialisation
Supervisor:	**M. A. Tanguy Hervé André Pierre Prévot**
Academic year:	2025/26

As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Master's Thesis:

Exterior and interior design of a semi–autonomous tram cabin

Brief Description:

The third–level semi–autonomous tram (GoA3) is an autonomously controlled system, but there is still a human factor in the person of the steward/driver, who supervises the safety and smoothness of the ride, has the ability to influence the door control, provides information and assistance to passengers and, if necessary, is qualified to drive the tram in an emergency.

Type of work: development – design
Output of work: applied result (Fužit, Fprum, Gprot, Gfunk, R)
Project: Specific university research

Master's Thesis goals:

Design the exterior and interior of the semi–autonomous tram cabin to improve the quality of tram transport services while simultaneously taking advantage of the opportunities brought by thenature of semi–autonomous operation.
Partial objectives of the diploma thesis:
– identify the opportunities and risks of the new role of steward/driver, including the impact of the absence of a driver's cabin on all users,
– propose partial solutions to individual problems and evaluate their degree of benefit for the global goal,
– implement the selected solutions into the design of the exterior and interior of the semi–autonomous tram cabin,
– validate the resulting solution with the customer Škoda Group, argue the benefits realized in the design.

Required outputs: accompanying report, summary poster, technical poster, ergonomic poster, design poster, model photo, physical model.
Scope of work: approx. 72,000 characters (40 – 50 pages of text without images).
The time schedule, work structure and accompanying report template are binding:
https://www.ustavkonstruovani.cz/texty/magisterske–studium–ukonceni/

Recommended bibliography:

MORRIS, Richard. The fundamentals of product design. Lausanne: AVA, c2009. ISBN 978-2-940373-17-8.

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LIDWELL, William; HOLDEN, Kritina a BUTLER, Jill. Univerzální principy designu: 125 způsobů jak zvýšit použitelnost a přitažlivost a ovlivnit vnímání designu. Brno: Computer Press, 2011. ISBN 978-80-251-3540-2.

Deadline for submission Master's Thesis is given by the Schedule of the Academic year 2025/26

In Brno,

L. S.

prof. Ing. Martin Hartl, Ph.D. Director of the Institute	doc. Ing. Jiří Hlinka, Ph.D. FME dean

ABSTRACT

This diploma thesis focuses on the exterior design and driver's cab interior of a semi-autonomous tram. It responds to the gradual development of automation in public transport and to the need for vehicles that can adapt to both conventional and future autonomous operation.

The design is based on an analysis of current tram vehicles, relevant standards, ergonomic requirements, and operational conditions. Special attention is given to the changing role of onboard staff, especially the transition from a driver to a steward.

The result is the ANTRA concept, a bidirectional three-section tram designed for a minimum 30-year life cycle. Its key feature is a modular driver/steward workplace, which allows operation in different levels of automation and can be adapted during the vehicle's service life.

The concept demonstrates how tram design can respond to long-term changes in urban rail transport. It may serve as a design study for future semi-autonomous tram vehicles with an emphasis on modularity, safety, ergonomics, and operational flexibility

KEYWORDS

Tram, public transport, semi-autonomous, steward, light rail vehicle

ABSTRAKT

Tato diplomová práce se zaměřuje na design exteriéru a interiéru kabiny řidiče poloautonomní tramvaje. Reaguje na postupný rozvoj automatizace ve veřejné dopravě a na potřebu vozidel, která se dokážou přizpůsobit jak konvenčnímu, tak budoucímu autonomnímu provozu.

Návrh vychází z analýzy současných tramvajových vozidel, norem, ergonomických požadavků a provozních podmínek. Zvláštní pozornost je věnována měnící se roli palubního personálu, zejména přechodu z role řidiče na roli stewarda.

Výsledkem je koncept ANTRA, obousměrná třídílná tramvaj navržená pro minimální životnost 30 let. Jejím klíčovým rysem je modulární pracoviště řidiče/steward, které umožňuje provoz v různých úrovních automatizace a lze jej přizpůsobovat během životnosti vozidla.

Koncept ukazuje, jak může design tramvají reagovat na dlouhodobé změny v městské kolejové dopravě. Může sloužit jako konstrukční studie pro budoucí poloautonomní tramvajová vozidla s důrazem na modularitu, bezpečnost, ergonomii a provozní flexibilitu.

KLÍČOVÁ SLOVA

Tramvaj, veřejná doprava, poloautonomní, steward, lehká kolejová vozidla

BIBLIOGRAPHIC REFERENCE

PLESKAL, Miroslav. *Exterior and interior design of a semi-autonomous tram cabin*. Online, master's Thesis. Tanguy Hervé André Pierre PRÉVOT (supervisor). Brno: Brno University of Technology, Faculty of Mechanical Engineering, 2026. Available at: https://www.vut.cz/en/students/final-thesis/detail/174151. [accessed 2026-05-22].

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis supervisor, M. A. Tanguy Hervé André Pierre Prévot, for his professional guidance, valuable advice, constructive feedback, support, and motivation throughout the development of this diploma thesis. The knowledge, experience, and perspective he shared with me will be a valuable asset in my future professional career.

AUTHOR'S DECLARATION OF ORIGINALITY

I hereby declare that I have written this thesis independently, under the academic supervision of M. A. Tanguy Hervé André Pierre Prévot. I also declare that all sources of visual and textual information I have used are properly cited in the bibliography. Generative artificial intelligence tools were used in the preparation of this thesis, specifically for text translation, linguistic and stylistic editing of formulations, noise removal, and minor corrections of errors in visualizations and renders.

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Author
Signature

CONTENTS

1 INTRODUCTION

Public transportation is one of the fundamental components of modern cities. With growing population density, increased private car traffic, and a shortage of parking spaces in city centers, the importance of efficient, high-capacity, and sustainable modes of transportation is becoming increasingly apparent. In this regard, tram transportation offers a number of advantages. Thanks to its rail-based operation, the ability to use dedicated lanes, and high transport capacity, it can serve a large number of passengers in a relatively short time, even in congested urban areas.

Just as automobile transport has undergone significant development in recent years—particularly in the areas of electrification, digitalization, and automation—public transport is also undergoing a gradual transformation. Automated control systems, assistance technologies, and intelligent operational solutions are gradually making their way into the field of rail vehicles as well. For this reason, it is important to address the issue of semi-autonomous tram operation and its impact not only on the vehicle's technical design but also on its spatial, ergonomic, and operational layout.

This thesis deals with the design of the exterior and interior of the driver's cab of a semi-autonomous tram. The thesis topic was assigned by the Škoda Group and continuously consulted with MgA. Tomáš Chludil. The aim of the thesis is to explore what a tram designed for operation in a partially automated mode might look like, what requirements this type of operation places on the vehicle's technical design, and how it influences the design of the driver's cab, the passenger area, and the overall concept of the tram. The thesis focuses primarily on the design of a vehicle that responds to current trends in urban transport while taking into account the realistic possibilities for the gradual introduction of automation.

The thesis will explain the principle of a semi-autonomous tram and its operation in the context of individual levels of automation, particularly GoA 3. The solution will include an analysis of current tram technology, a review of competing vehicles, and an evaluation of the advantages and disadvantages of semi-autonomous operation. Attention will also be paid to the role of the steward, who can replace some of the traditional driver's tasks during the transitional phase of automation. Their role may include overseeing safety, assisting passengers, monitoring operations within the vehicle, or handling emergency situations.

The thesis will also focus on comparing the technological vision with the realistic possibilities of current operations. An important question is whether it makes sense to design a tram purely for semi-autonomous mode, or whether it is more appropriate to consider a flexible solution that allows for a combination of automated operation with human supervision. The result of this work will be a design proposal that integrates technical, ergonomic, safety, and aesthetic requirements and offers a possible direction for the development of urban tram transport in the near future.

2 RESEARCH

2.1 Research methods

The research phase was conducted systematically to ensure a sufficiently broad and relevant set of information sources. The main objective of the research was to understand current developments and trends in public transportation, autonomous and semi-autonomous rail vehicles, and the transformation and role of the steward—the service staff in public transportation.

The formulation of the research question was preceded by the definition of the main thematic areas. These included, in particular, public transport, urban mobility, autonomous driving, modern tram vehicles, the interiors of public transport vehicles, and passenger comfort. Based on these areas, keywords were identified to search for specialized and inspirational sources. Key terms included, for example, public transport, urban mobility, sustainable transport, passenger experience, smart city, semi-autonomous, autonomous driving, AI-driven control, LIDAR and sensor fusion, tram, light rail vehicles, modern tram design, low-floor accessibility, public transport interior, ergonomics, user-centered design, accessibility standards, human-machine interaction, space optimization, and passenger flow optimization. The search was conducted in both Czech and English to enable the integration of international technical knowledge with the local operational and legislative context.

The ScienceDirect and ResearchGate platforms were primarily used to search for academic articles. The main focus was on articles addressing autonomous trams, the emergence of autonomous driving in public transportation, changes in the role of the driver or steward in semi-autonomous vehicles, and the steward's role and its psychological and emotional impact on passengers.

Another part of the research consisted of information from websites and available materials from tram manufacturers, particularly the Škoda Group, Siemens Mobility, CAF, Alstom, and others. The research included standards, technical limitations, and requirements related to tram vehicle design. Based on these, standards and legislative documents applicable to the Czech and European contexts were further identified.

Another group of sources consisted of articles from cities, transit companies, and organizations involved in the development of urban mobility. To research the tram driver's workflow, job responsibilities, and insights into specific types of trams, practical audiovisual materials were also utilized, such as videos, livestream recordings, vlogs, and interviews with tram drivers. The sources monitored included Dominik Doubek's profile on the Dobrovolný šalinář channel, Josef Chodounský's former Rezistor channel, the JaroslavManTV channel, and recordings from the TramTramMeneer channel. These materials served as a supplementary source for understanding real-world operations, passenger behavior, and the demands of the driver's job.

In connection with the topic of assisting passengers, communication, and handling non-standard situations, an interview was also conducted with trolleybus driver Jaroslav Matějka from the Jihlava Public Transport Company. The interview contributed to an understanding of the potential tasks a steward could perform in a future semi-autonomous vehicle, such as safety supervision, assisting passengers, maintaining order, or communicating during emergencies.

From the sources obtained, a group of the most relevant materials was gradually selected, which were then used in the design section of the thesis. Primary sources included technical articles, standards, legislative documents, materials from manufacturers and transport system operators, and information obtained through collaboration with the Škoda Group. Secondary and supplementary sources consisted primarily of articles by transportation companies, urban strategies, audiovisual materials, and interviews with practitioners. The combination of these sources made it possible to integrate theoretical knowledge, technical requirements, and practical operational experience.

2.2 Analysis of Standard

First, I analyzed the standards and restrictions for tram operation so that I could define shapes and designs in advance.

2.2.1 Railway applications- Vehicle end design for trams and light rail vehicles with respect to pedestrian safety CEN/TR 17420

This standard addresses the shaping of the tram's front end to minimize the impact of collisions with pedestrians, primarily to reduce the risk of head injury and to ensure the front end is shaped to deflect pedestrians to the side rather than causing a direct frontal impact.

The standard specifies the minimum angle formed by the tangent to the front contour of the front end. In the 15–50% width range, the angle must be at least 15°; in the 50–75% range, the angle must be at least 30°; and in the 75–100% range, the angle must be at least 60°. The rounding is assessed up to a height of 1750 mm. [1]

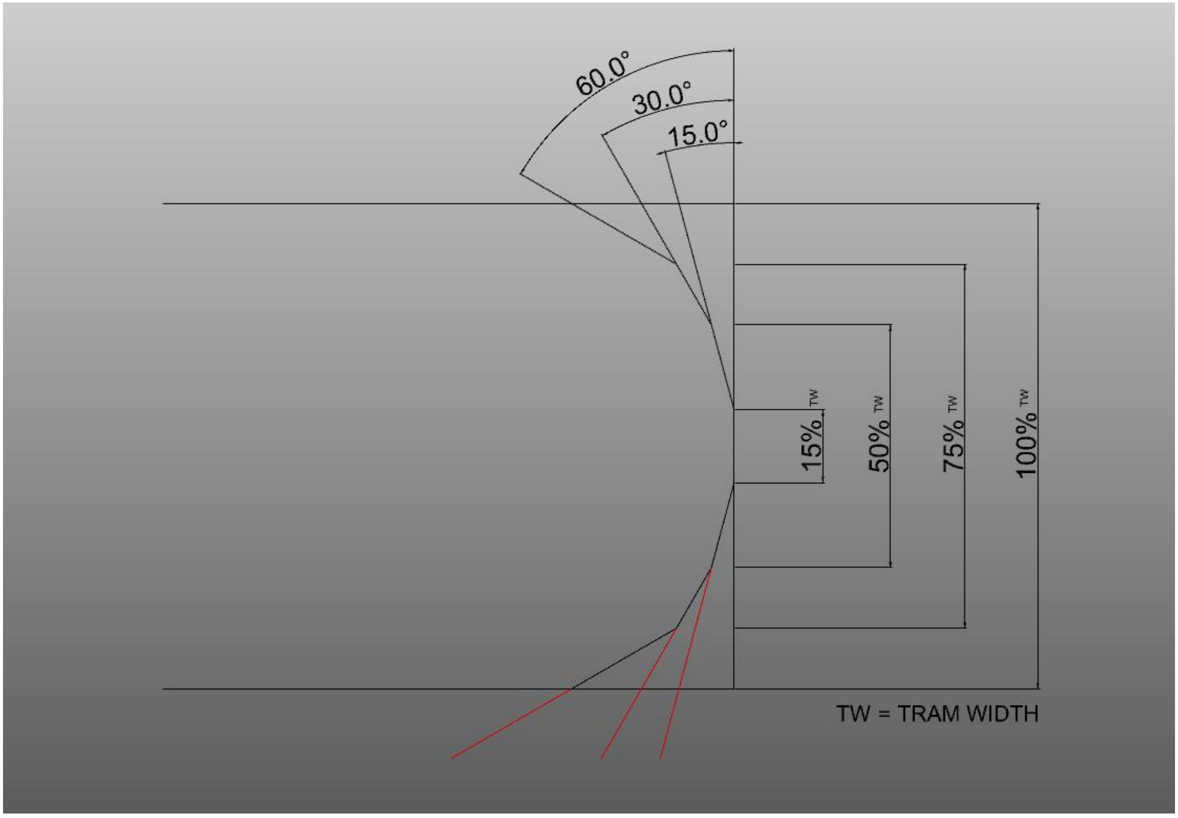

Fig. 2- 1 Visualization of CEN/TR 17420

2.2.2 Cab views and ergonomics

Visibility from the driver's cab, its ergonomics, and the layout of controls are specified by the ČSN EN 16186 standard—specifically in Parts 5–8. Part 5 (+A1) focuses on visibility from the tram, requiring the driver to be able to see the top surface of a test cylinder with a diameter of 300 mm and a height of 1100 mm, the center of which is located 650 mm from the front of the tram. The cylinder must be visible within a horizontal range of 165°.

It further specifies that the minimum forward view through the windshield must be 70°, but at least 90° is recommended. A 25° upward view must also be provided so that the driver can see external signals. [2]

As part of my research, I also studied the French methodological document STRMTG – Safety in Tramway Driver's Cab, which also addresses the safety and ergonomics of the tram driver's cab and recommends that A-pillars not obstruct more than 6° of the field of view. [5] Section 6 addresses the placement and colors of controls and the optimal preferred field of view. For example, all controls should be within a 120° horizontal and 60° vertical field of view for the driver. [3]

Section 7 addresses the design of display units, but since the work does not include a digital interface design. Section 8 addresses the ergonomics of the driver's seat, including armrests and legroom. It includes a table with mandatory and recommended dimensions for the driver's seat.[4]

2.2.3 Dimensions

The dimensions of tram vehicles are specified by the ČSN 28 0318 standard. This standard defines the vehicle's basic outline, which determines the maximum permissible dimensions. The maximum width is 2,650 mm, and the outline may only be exceeded by turn signals, external camera housings, and rearview mirrors (by a maximum of 60 mm). According to information from a consultant at the Škoda Group, a width between 2450 and 2520 mm is commonly used. The maximum height is 3600 mm (without the pantograph) and 6000 mm with the pantograph. The standard also specifies the track gauge, which is 1435 mm (standard gauge). [6]

The starting point for the design was a reference tram model provided by the Škoda Group. The basic dimensional parameters of the vehicle were taken from this model. It was a double-ended, bidirectional, three-section tram, whose proportions and structural layout served as the basis for the subsequent design solution. The reference model shares the same basic design as the new Škoda 45T trams in Brno. [12]

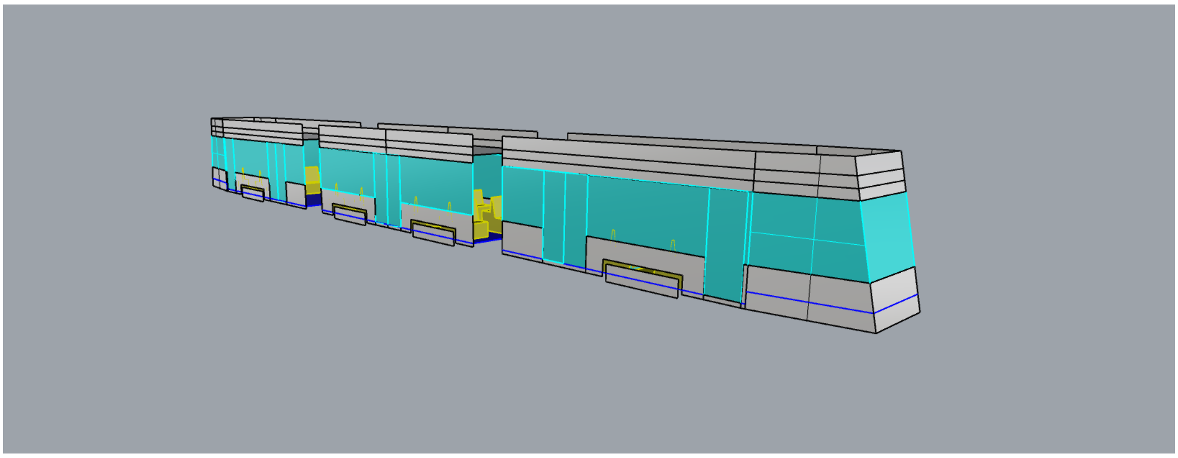

Fig. 2- 2 Reference model provided by Škoda Group [12]

2.2.4 Light Placement

The position of lights is regulated by UNECE Regulation No. 48, primarily for motor vehicles and trailers.

UNECE Regulation No. 48 defines the principles for the placement and use of external lighting and light signaling devices on vehicles. It deals primarily with requirements regarding the number, color, position, height, lateral placement, geometric visibility, and electrical wiring of individual lighting elements. It provides an overview distinguishing between front, side, and rear lighting and specifies which elements are mandatory or optional for individual vehicle categories. For the purposes of this work, the regulation serves as an analytical basis for understanding the principles of clear and safe lighting placement on a vehicle. A document from Hella simply illustrates the space for the placement of individual lights.

Fig. 2- 3 Lighting according to UN No. 48 1

2.2.5 Levels of autonomy according to UITP

GoA0 – No automation, no safety features [8].

GoA1 – The driver controls starting and stopping, operation of doors, etc. Overtaken signals due to human error are safeguarded by train protection systems [8] [10].

GoA2 – Driving and stopping are automated; the driver sets the train in motion, operates the doors, handles disruptions, and is responsible for driving the tram [8][10].

GoA3 – The train or tram runs automatically between stations without a driver in the cab. However, a staff member is still present on board to operate the doors, supervise passengers, and handle emergencies [8] [10].

GoA4 – Driving, doors, everything is fully automated without any staff on board [8].

The intermediate level GoA2.5 is also frequently mentioned—this assumes that, for legislative reasons, the driver will remain responsible for tram operations even though the tram is capable of operating autonomously. A gradual transition is also anticipated thanks to autonomous sections that will be established on individual routes—for example, in sections where the tram is not in service.

GoA2.5 - The vehicle operates automatically, but a staff member remains on board, often in the cab, to monitor the track, detect obstacles, perform emergency stops, and assist passengers [8] [10].

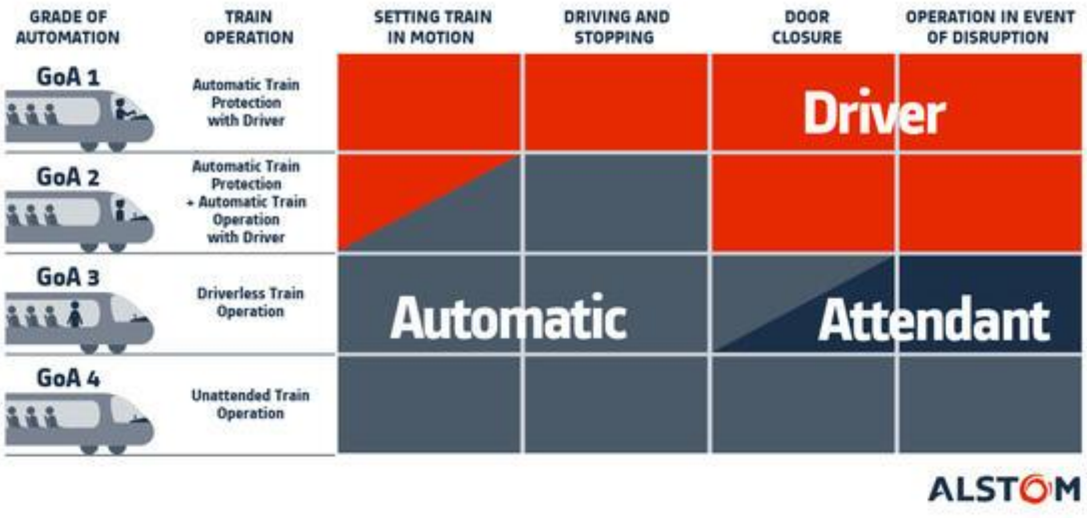

Fig. 2- 4 Grade of automation by Alst

2.3 Steward vs. Driver

The primary responsibility of a tram driver is to operate the vehicle, but this role also includes a number of additional tasks. At stops, the driver checks signals and verifies that switches have been set correctly. In the event of a malfunction, the driver must manually change the switch, as passing through an incorrectly set switch may result in penalties. The driver also checks and, if necessary, adjusts stop announcements, monitors passenger boarding and alighting, assists people with reduced mobility—for example, by operating the deployable ramp—and supervises the situation inside the vehicle and at stops.

The driver’s duties also include communicating with passengers, maintaining order, and handling unusual situations, such as interactions with people under the influence of addictive substances, which occur more frequently on night routes. The driver must also adhere to the schedule and checkpoints, communicate with the dispatch center, and perform a vehicle inspection before departure, such as checking the amount of sand in the sanding system [15][16].

In GoA3 operations, the steward no longer has to manually drive the tram. The steward only takes control in exceptional situations, such as an accident or other unexpected event. Their main role therefore shifts to passenger care, assisting passengers as they board and alight, providing information, and ensuring safety and order inside the vehicle.

However, the steward retains some duties originally associated with the driver's role, such as supervising the doors, making stop announcements, and handling situations at stops. Since this position has not yet been clearly defined in regular tram operations, one of the aims of this thesis will be to propose the steward's duties, workflow, and workplace layout. The role of the steward may therefore partly resemble that of a train conductor, while also offering new services, such as partial ticket inspection [11][12].

2.4 Design analysis

Location

Since tram vehicles are generally designed and manufactured to suit a specific city, it is necessary for the purposes of this thesis to clearly define the environment for which the design will be intended. Based on recommendations, a well-known city with a long-established tram system was selected. Brno was selected for this thesis, where tram transport has a strong historical and operational tradition, and where the fleet is currently being modernized through the acquisition of new Škoda 45T trams.

In the following considerations, the design will therefore be conceived as a vehicle intended for operation in Brno, or rather as a hypothetical design for the needs of DPMB.

History

The history of trams dates back to the 19th century, when horse-drawn trams began to be used in cities as a more convenient form of public transportation. They were later replaced by steam and, above all, electric trams, which spread rapidly throughout Europe and America from the late 19th century onward. Trams became an important part of urban mobility. The first electric tram was introduced by Siemens & Halske in 1881. It was 2.4 km long, and electricity was supplied via the tracks.

Fig. 2- 5 Horsecar [13]

Fig. 2- 6 First electric tram [14]

Another focus of the research was an examination of existing trams and their design analysis. Trams are usually customized for a specific city, so it is necessary to include the city in which they operate alongside the model name, as the same tram on the same platform may differ from one delivered to another city

2.4.1 Škoda 45T Brno

Exterior

A bidirectional articulated tram with a capacity of up to 233 passengers, a width of 2.5 meters, and a fully low-floor design. The tram still uses classic side mirrors. The windshield provides good visibility and, for a more modern look, is framed by a black panel that extends to the side windows. The 45T does not use an all-black window line like some trams but separates them with color, for example between the cab and the windows, or with a white door frame.

Its color scheme follows the new version of the Brno livery used since the Škoda 13T, then on the EVO2, and now on the 45T.

Fig. 2- 7 Exterior of Škoda 45T [17]

Interior

The interior is not particularly surprising and offers what we are accustomed to in Czech trams: durable materials, plastic seat frames with fabric upholstery, and a gray-and-white color scheme that appears very neutral. The advertising space is provided by a classic leaflet clip attached to the ceiling.

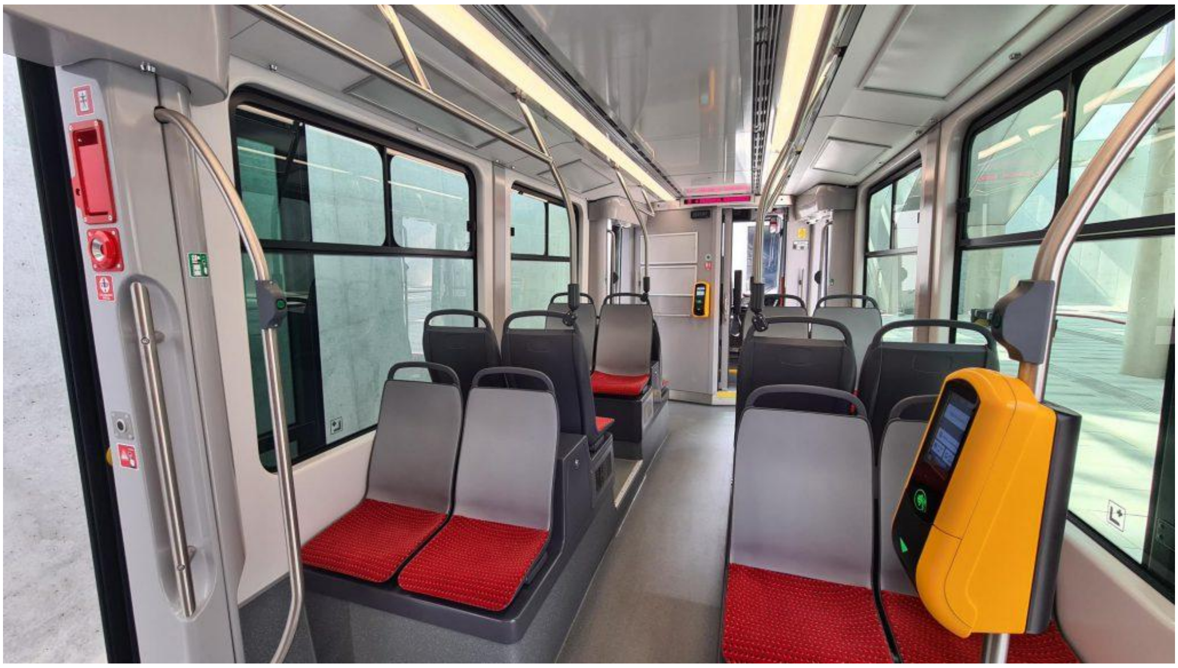

Fig. 2- 8 Interior of Škoda 45T [18]

Driver’s cabin

The driver’s cabin is designed for cost-effectiveness. The three control modules are mounted on a flat dashboard and do not form an integrated unit.

Fig. 2- 9 Driver’s cabin of the Škoda 45T [18]

2.4.2 Škoda 52T Prague

Exterior

The latest model from Škoda. The tram has a very modern appearance with clean, simple lines. The black front grille adds to its modern look. The lighting is very well executed; although it is assembled from off-the-shelf parts, it gives the impression that it was custom-designed specifically for this tram. The driver has a separate door to the cabin and therefore does not have to enter through the passenger compartment. The modern appearance is further enhanced by the asymmetrical color scheme in the colors of the Prague Public Transport Company.

Fig. 2- 10 Exterior of Škoda 52T [19]

Interior

Unlike the 45T, a slightly lighter shade of gray is used, and since this tram uses a different type of undercarriage—the steering axles are located under the cab and the middle axles are non-steering—it does not require such massive platforms for the seats, which adds more space to the interior and creates a more airy impression.

Fig. 2- 11 Interior of Škoda 52T [19]

Driver's cabin

The cabin is very similar to that of the 45T model. In the Škoda 52T tram, the driver's cabin space is designed primarily with functionality, durability, affordable production costs, and easy maintenance in mind. As a result of this practical approach, however, the cabin lacks some of the visual modernity and design continuity evident in other parts of the tram.

Fig. 2- 12 Driver's cabin of Škoda 52T [20]

2.4.3 Škoda ForCity Smart Artic Tampere

Exterior

This tram features a modern look thanks to its black panels. From the front, this black panel unifies the front grille, headlights, and information display into a single unit. The tram even uses a cover for the upper section, so that when viewed from above, the air conditioning units and electrical components are not visible, but rather a single smooth surface, which is why the ventilation openings are located on the side. The information displays above the doors are seamlessly integrated. This model does not use traditional mirrors; instead, they are replaced by a camera system. In addition to the headlights, the front section features ambient lighting under the windshield, which glows red at the rear.

Fig. 2- 13 Exterior of Škoda ForCity Smart Artic Tampere [21]

Interior

Here we see a marked difference between domestic interiors and those of trams exported to the West. The interior is much more colorful, which has a more uplifting effect on passengers; instead of plastic parts, we find wood trim. The placement of folding seats in the door area and in the space for a wheelchair or stroller is very practical, allowing the space to be fully utilized depending on the specific situation. This information is provided not only on the floor but also via pictograms located on the window pillars.

Fig. 2- 14 Interior of Škoda ForCity Smart Artic Tampere [21]

Driver’s cabin

We also find a difference in the driver’s cabin—instead of three separate panels, there is a single integrated dashboard and a display on the A-pillars for the rearview mirrors. Even the seat appears to be from a higher trim level compared to the 45T and 52T.

Fig. 2- 15 Driver’s cabin of the Škoda ForCity Smart Artic Tampere [21]

2.4.4 Stadler Tina

Exterior

The headlights and front grille may appear slightly aggressive, perhaps even sporty, which I don't think is the look we want from a city tram. Unlike its competitors, it features large windows, which not only provide passengers with a good view but also add an interesting dimension to the tram's side profile.

Fig. 2- 16 Exterior of the Stadler TINA

Interior

The interior is very simple and clean; the wooden seats convey a greater sense of luxury compared to plastic ones. The designers also considered connectivity during the design process, so there are USB ports and standard power outlets throughout the interior. An interesting feature is the single-seat concept combined with storage space . The interior feels airy and open.

Fig. 2- 17 Interior of Stadler TINA [22]

Driver's cabin

The cabin represents a significantly modernized environment ready for the integration of digital systems. All controls are logically arranged into two groups for the left and right hands, along with a large display. An interesting feature is the placement of the rearview mirror displays in the center panel, rather than on the A-pillar, as we are accustomed to from other manufacturers.

In reality, the right armrest is equipped with six buttons, likely used to control the doors.

Fig. 2- 18 Driver's cabin of the Stadler TINA (render) [22]

2.4.5 Alstom Citadis X05 Sydney and Nice

Exterior

Alstom was the first tram manufacturer to introduce a light-based visual identity for its trams; in the model delivered to Sydney, the entire A-pillars are ambiently backlit and connect to the headlights, giving the vehicle a fresh look. The rest of the exterior is clean and simple, adding to its elegance.

Fig. 2- 19 Exterior of the Alstom Citadis X05 in Sydney (left) [23] and in Nice (right) [24]

Interior

Compared to interiors we are familiar with from the Czech Republic, we immediately feel a sense of luxury upon entering. However, the interior is still made of durable, hygienic materials that meet safety standards for the use of durable and hygienic materials. A drawback, however, is that the dark color palette makes the space feel visually cramped.

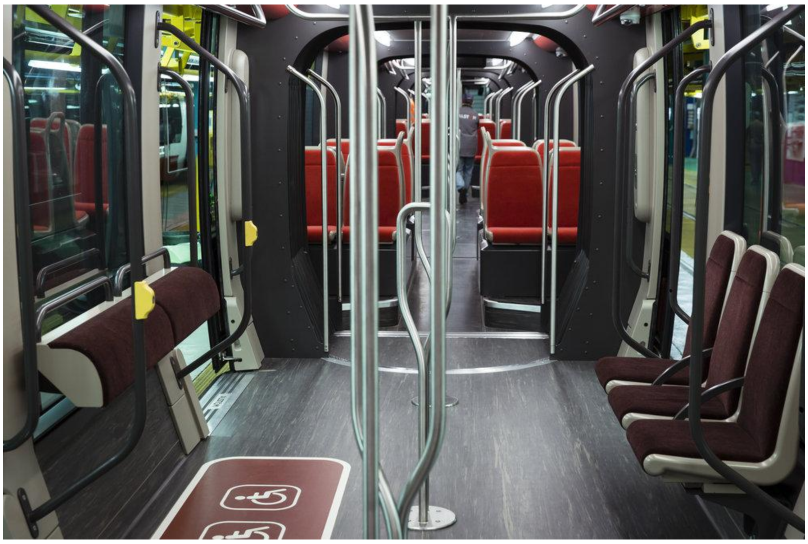

Fig. 2- 20 Interior of Alstom Citadis X05 Nice [24]

Driver’s cabin

The Citadis X05 features innovations in both the exterior and interior, but there are no surprises in the driver’s cabin. The utilitarian design is divided into two large panels, yet the view from the cabin appears spacious, and the pillars do not appear bulky enough to obstruct the view.

Fig. 2- 21 Driver’s cabin of the Alsto Citadis X05 Nice [24]

2.4.6 Alstom Citadis 3 (405) Strasbourg

Exterior

This tram stands out from its competitors primarily due to its exterior design, which may resemble a train more than a tram. This is mainly due to the steeper angle of the front end, which is estimated to be up to 25 degrees, whereas standard tram designs typically use an angle of around 10–12°. [12] However, this raises the question of whether it is necessary to convey a sense of speed for a tram that travels at speeds of around 50 km/h in an urban environment. Otherwise, the overall design looks modern.

Fig. 2- 22 Exterior of Alstom Citadis 405 [26]

Interior

Thanks to its light colors and large windows, the interior feels truly airy, and since this is a seven-car tram, it offers several configurations, providing ample space for standing passengers as well as a sufficient number of seats. A distinctive and practical feature is the handrail consisting of two arcs. This allows multiple people to grip it from all directions, so they don’t have to crowd around a single pole but can hold on comfortably.

Fig. 2- 23 Interior of Alstom Citadis 405 [25]

2.4.7 CAF SL-18 Oslo

Exterior

The exterior design gives the tram a distinctive and recognizable character without appearing aggressive. Its very smooth, continuous surfaces create a calm and modern expression, while the rounded front and softly integrated custom-looking headlamps support a more friendly and approachable appearance. The color scheme also connects the exterior with the interior, helping to create a unified visual identity.

Fig. 2- 24 Exterior of CAF SL-18 Oslo [27]

Interior

The interior color scheme visually follows the exterior design of the tram, creating a consistent and unified visual identity. Highly contrasted yellow handrails improve orientation and safety, while the bright surfaces, large windows, and open layout support a clear, spacious, and airy atmosphere.

Fig. 2- 25 Interior of the CAF SL-18 Oslo [27]

2.4.8 Alstom Citadis TW20 Paris

Exterior

One of the most futuristic-looking trams in Europe. In addition to elements painted in glossy black, Alstom uses a light strip as a key design feature, which extends from the front mask along the entire length of the tram. This strip changes color: the front section glows white when moving forward or red when moving backward, as shown in the figure. It is also divided above the door frames, and a green or red light indicates whether the doors are opening or closing. The main LED headlights are cleverly concealed in the lower part of this light strip, so they do not disrupt the clean lines of the design. Overall, the visual identity stands out most at night, when this lighting element dominates the exterior.

Fig. 2- 26 Exterior of Alstom Citadis TW20 Paris [28]

Interior

The interior complements the modern exterior. Here, too, there is an element of functional lighting—on the ceiling, where the light extends from the door and glows green or red depending on the door's status. The interior features black accents, but thanks to the predominance of light colors, it remains airy. However, the combination of white and blue elements can come across as a bit cold. I consider the fragmented color scheme of the seats to be a drawback; in one section, we find a combination of green and blue seats, and in the next section, there are suddenly red seats that do not color-coordinate with any other element.

Fig. 2- 27 Interior of Alstom Citadis TW20 Paris [28]

Driver’s cabin

The Citadis TW20 is the successor to the X05 model we discussed earlier; not only does it carry over the lighting elements, but it has also fully adopted the driver’s cabin, which is identical to that of the X05 model.

Fig. 2- 28 Driver’s cabin of the Alstom Citadis TW20 Paris [29]

2.4.9 CAF Urbos 3 Luxembourg

Exterior

The CAF Urbos 3 Luxembourg is among the more visually interesting and futuristic-looking trams currently in production. Unlike some Alstom vehicles, however, it achieves this impression not through striking lighting elements, but primarily through the body’s shape and contrasting color combination. The side sections feature extensive black-tinted surfaces that visually blur the boundary between the windows and the side panels. This makes the side of the vehicle appear more compact and visually cleaner. The dominant feature of the exterior is the bevel at the front of the body, which flows smoothly into a wavy line and clearly separates the front fascia from the side of the tram. This detail adds dynamism to the vehicle and at the same time creates its distinctive design identity.

Fig. 2- 29 Exterior of CAF Urbos 3 Luxembourg [30]

Interior

The interior builds on the tram's exterior identity and feels airy, high-quality, and modern. Light-colored materials, large windows, and clean lines create a pleasant and open space for passengers. The only problematic element is the colored film on the boarding doors in shades of magenta, green, and blue. While these elements enhance the visual originality of the interior, they also tint the interior lighting, reduce the natural quality of the light, and limit passengers' view of the surrounding urban environment.

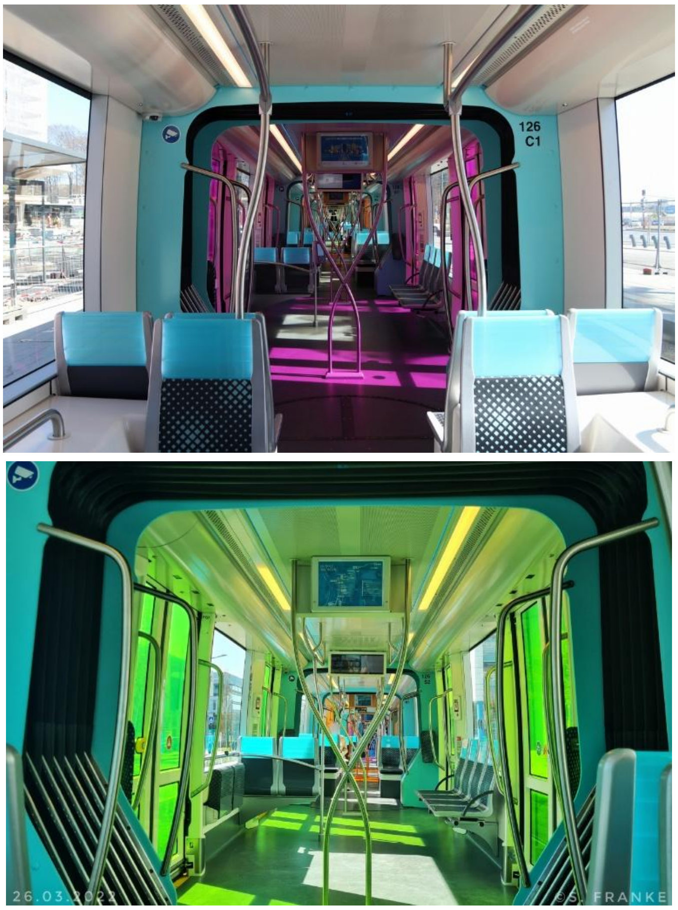

Fig. 2- 30 Interiors of CAF Urbos 3 Luxembourg [30]

Driver's cabin

The driver's cabin of the CAF Urbos 3 Luxembourg tram differs from conventional designs primarily in the layout of the control panel. It is not designed as a single compact unit, but as a system of three separate floating modules arranged around the driver. This arrangement creates the partial impression of an interconnected dashboard while simultaneously reinforcing the cockpit-like character of the workspace. The visual lightness of the console and the effort to achieve a more modern cabin design can be viewed positively.

Fig. 2- 31 Driver’s cabin of CAF Urbos 3 (Saint-Étienne) [31]

2.4.10 Alstom TNG Brussels

Interior

With this tram, we’ll start—somewhat unusually—with the interior. It feels very high-quality and elegant, and compared to many standard tram interiors, it has a significantly more refined character and a design that echoes the Brussels Metro. A key factor here is the combination of warm brown tones, wood accents, and softly curved elements, which lend the space a slightly retro atmosphere that feels modern rather than dated. TNG won the Red Dot Award specifically for its Art Nouveau-inspired design. I must also commend the design of the handrails, which not only feature this Art Nouveau curve but are also designed practically so that the lower mounting of most of them is secured to the side wall rather than the floor, which facilitates cleaning the tram.

Fig. 2- 32 Interior of Alstom TNG Brussels [32]

Exterior

A weaker point is a certain mismatch between the very well-executed interior and the exterior. While the interior appears well-thought-out, elegant, and almost premium, the vehicle's exterior styling is not as convincing. Although the exterior draws on Brussels' identity and the organic curves of older trams, the design looks very outdated considering the tram first entered service in 2023.

Fig. 2- 33 Exterior of Alstom TNG Brussels [32]

2.4.10.1 Driver’s cabin

The driver’s cabin of the Alstom TNG Brussels tram, with its layout and wide dashboard, may slightly resemble the cabin of a railway vehicle. Nevertheless, it offers several high-quality ergonomic and design solutions. The main controls are located directly in the seat armrests, allowing the driver to reach them naturally without having to stretch toward the dashboard. This solution also visually streamlines the main instrument panel, which is not cluttered with a large number of controls. Another positive aspect is the coordination of the driver’s seat material with the material used for the passenger seats, which contributes to the unified and refined character of the entire interior.

Fig. 2- 34 Driver’s cabin of the Alstom TNG Brussel [33]

2.4.11 Škoda design identity

A common feature of newer Škoda trams is the use of distinctive black front graphics, which have become one of the main elements of their visual identity. The black surface wraps around the windshield, the information panel, and the upper part of the cabin, creating the impression of a single, rounded module. This element minimizes the technical segmentation of the front and gives the vehicle a more compact and contemporary character. Škoda also uses rounded shapes that contribute to the vehicle’s neutral or friendly appearance. Another common feature is the dark band of side glazing that unifies the windows and door surfaces, into which information panels are partially integrated.

Fig. 2- 35 Škoda trams [34]

2.4.12 Brno’s Tram Fleet

The DPMB tram fleet is very diverse in terms of both age and type. In 2025, DPMB reported a total of 287 trams. The oldest types currently in regular service are mainly modernized T3/T3R, T6A5, and KT8D5 cars, while operation of the legendary K2 articulated trams was discontinued in April 2026 after 59 years of service. In terms of design, the fleet consists of single-section T3, T6A5, and Vario LF cars; two-section EVO2 Drak trams and the former K2; three-section bidirectional KT8D5 cars and the new Škoda 45T; as well as multi-section low-floor Škoda 13T trams. Overall, the fleet consists of a combination of older, modernized vehicles and a new generation of low-floor, air-conditioned trams. Additional 45T trams are scheduled to be delivered by the end of 2026, and 40 of them are expected to be in service by the end of this year [35] [39].

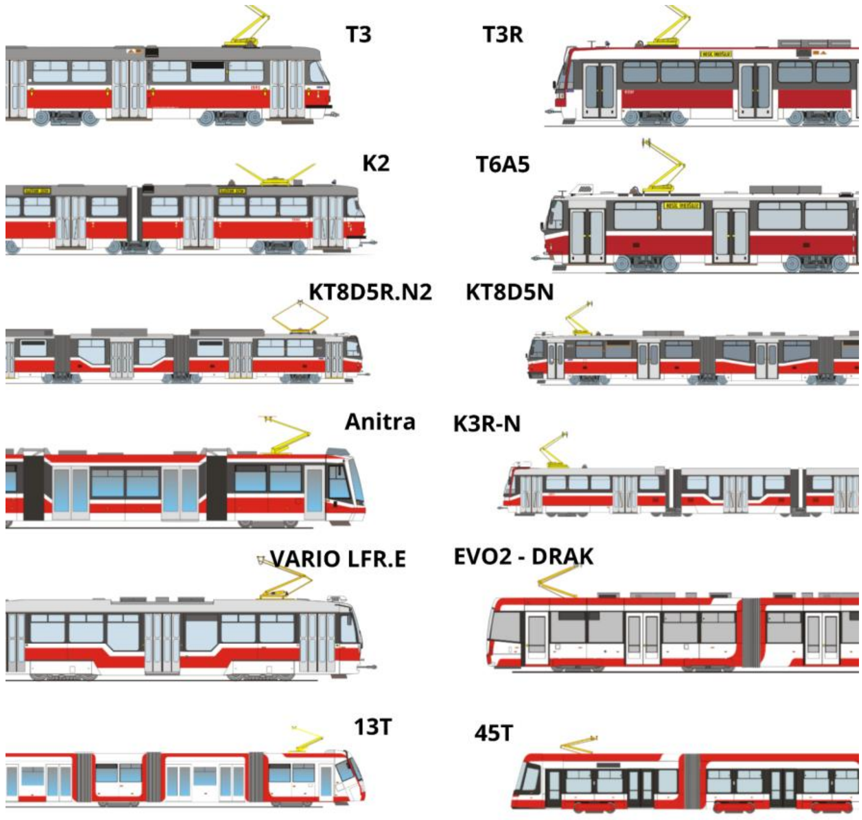

Fig. 2- 36 Škoda trams [35]

2.5 Technical Analysis

2.5.1 Power Supply

Currently, most modern trams are equipped with compact single-arm pantographs, which are controlled electronically, pneumatically, or by a combination of both. Additionally, a traction converter is mounted on the roof next to the pantograph, which converts power from the traction network to a voltage suitable for electric motors. It is also common today for trams to be equipped with a "small" battery pack used for travel on short sections without overhead lines or for emergency range. These batteries can also store energy generated by regenerative braking. The batteries are recharged while the tram is traveling under the overhead lines. The advantage of a battery system is greater operational flexibility and the ability to limit overhead catenary in sensitive urban areas. The disadvantages include increased weight, cost, cooling complexity, and the need to monitor battery status [40][41].

2.5.2 Chassis

A solution corresponding to the **Škoda 45T** tram was selected for the design, as it is a proven vehicle intended for Brno. This tram uses **four swiveling two-axle bogies**, with all eight axles being driven. This solution is particularly advantageous for urban operation with frequent starts, stops, and a hilly track profile, which is also found in Brno.

The main advantage of **swivel bogies** is improved cornering. Because the bogie can rotate relative to the vehicle body, the wheels are guided more smoothly along the track. This reduces friction and lateral forces between the wheel and the rail, which has a positive effect on reducing wear on both wheels and rails while also minimizing noise when navigating curves [36][37].

The main disadvantage of swivel bogies is their greater space requirements. The vehicle design must allow sufficient space for the bogie frame to rotate and for the wheels to move. In low-floor trams, bogies are therefore often placed in the space beneath raised interior sections, such as under seating platforms. The space required for the bogie to turn is thus partially hidden under the seats, while a low-floor passageway can be maintained in the central part of the vehicle [36][37].

Low-floor design is further achieved by using smaller wheel diameters, approximately in the range of **600–680 mm**, a compact arrangement of traction motors, and appropriate gearbox mounting. Smaller wheels reduce the axle height above the top of the rail, thereby allowing the floor level in the space above the bogie to be lowered. The result is improved vehicle accessibility, barrier-free boarding, and more comfortable movement for passengers inside the vehicle [36].

Overall, the chosen solution **of low-floor powered bogies** can be considered a suitable compromise between accessibility requirements, ride quality, and operational reliability. Swivel bogies improve cornering and reduce infrastructure wear, while the fully powered configuration supports good vehicle traction in more demanding urban conditions [36][37].

Fig. 2- 37 Škoda low-floor bogie for the Škoda 46T [38]

2.6 Ergonomics

We described driver ergonomics in Section 2.2.2, so in this part we will focus primarily on passenger ergonomics.

Buttons and controls

Primary button axis height (door opening, STOP): 900–1100 mm above the floor.

Diameter of the active button surface: 25–35 mm; tactile feedback, high contrast.

Handrails and grips

Diameter of handrails (vertical and horizontal): 30–40 mm; 35 mm recommended.

Clearance behind the handrail (for gripping): ≥ 45 mm.

Height of horizontal handrails within reach while standing: 900–1100 mm above the floor.

Height of ceiling handrails/straps: 1800–2000 mm above the floor.

Seats

Seat height: 450–480 mm above the floor.

Seat depth: 420–450 mm.

Clear width of seating area: 440–460 mm.

[42][43]

3 PROBLEM ANALYSIS AND OBJECTIVE OF THE THESIS

In this chapter, we will examine the challenges of semi-autonomous transportation and the transition of the driver from a steward.

3.1 Product name and classification

Low-floor urban tram for bidirectional operation. The tram is designed as a three-car unit with cabs at both ends, doors on both sides of the body, and swivel bogies. The vehicle is equipped with features enabling autonomous operation in GoA 3 mode with a steward, as well as operation at other levels of automation.

3.1.1 Customer

The customer is the city's public transport company; in my case, the Brno Public Transport Authority. The company selects vehicles based on an internal quality standard that specifies requirements for the technology, interior, and exterior. For example, the Prague Public Transport Company has a public document containing all requirements for trams. [43] Price and Life-Cycle Cost (LCC) are also important to the customer, as the service life of trams is typically around 30 years, sometimes even longer (in Brno, trams that had been in service for 59 years were decommissioned this year, though they underwent several modernizations during that period). [12][35] Modular design and preparation for autonomous systems can contribute to optimizing LCC. Furthermore, reliability is important within the context of LCC, as are low maintenance costs and the resistance of materials to wear and tear and vandalism.

3.1.2 Consumer

In our design, we have two types of users.

One is the driver/steward—for them, comfort in the cabin, adherence to ergonomic principles, and simple, intuitive control of all systems are important. Additionally, a good view from the vehicle and the ability to monitor both the surroundings and the interior of the vehicle are important to them. Human-centric design is also important, as is the aesthetic quality of the cabin, which should convey the user's own value while featuring a well-designed workflow that does not unnecessarily exhaust or tire them.

The second type of consumer is the passenger, who represents a very broad group of users, including people of different ages, physical abilities, and levels of experience with public transportation. Therefore, the tram interior design must primarily consider clarity, accessibility, and comfort. Key aspects include clear presentation of information, easy-to- -orientation within the vehicle, and intuitive connections between boarding and exit areas.

Another important factor is barrier-free and smooth boarding, sufficient maneuvering space, and the ergonomic design of seats, handrails, and support elements. The overall quality of travel is influenced not only by the functional layout of the passenger compartment, but also by its visual character. Colors, materials, and lighting should contribute to a sense of calm, safety, and a pleasant environment during the journey.

3.1.3 Market Specification

The proposed tram concept is intended for custom small-batch production as part of a broader family of low-floor tram vehicles based on a shared modular platform with variable vehicle lengths and equipment specifications. The expected production volume is approximately 5–10 vehicles per year, with an estimated production cycle of 4–6 years. (Estimated for the city of Brno based on orders for the Škoda 45T) [45].

From a market perspective, the design is primarily aimed at medium-sized cities in Central Europe, where tram transport plays a key role in sustainable urban mobility. Current European trends emphasize fully low-floor vehicles, modularity, accessibility, passenger comfort, and energy-efficient operation. These requirements strongly influence the development of modern tram platforms and their adaptation to the specific needs of each city.

The global market for light rail vehicles (LRV), including new vehicles and aftermarket services, reached an estimated value of approximately EUR 6.5 billion annually in 2023. This confirms the continuing importance of tram transport within the urban mobility sector [44].

3.1.4 Problem definition

A gradual transition, a long lifespan, the shift from driver to steward, a sense of safety, and the emotional experiences associated with the steward role burnout.

Currently, most trams operating in Europe are in GoA1 mode, and modern trams are gradually transitioning to GoA2 mode. The introduction of GoA3 is estimated to occur around 2035–2040. Until then, vehicles will likely operate in a transitional phase, often referred to as GoA2.5, where the tram is controlled by an automated system, but the driver must still monitor operations because they bear responsibility. The introduction of GoA4 is estimated to occur between 2040 and 2045, though it is possible that in some parts of the world, a steward will remain on board the vehicle for longer.

The life cycle of a tram is typically around 30 years, often even longer. In Brno, for example, it is possible to encounter cars that have been in service for nearly 60 years, although they have undergone several modernizations during that time. Designing a tram solely for the semi-autonomous GoA3 mode therefore makes little sense, as operation in this mode will likely last much shorter than the tram's total lifespan.

Automation of tram operations will likely not be implemented all at once across the entire network. The first candidates are the closed or semi-closed environments of depots, turning loops, and easily controlled sections without regular traffic. This will create sections of a single line where the tram will operate autonomously, but upon entering a section with regular traffic, the driver will take over control.

The transition to higher levels of automation will be hindered not only by legislation but also by the slow development of smart city systems and modern information infrastructure for tram operations. An autonomous tram will require reliable communication with traffic signals, the control center, digital maps, stops, and infrastructure sensors. Without these systems, automation will primarily be feasible in limited and well-controlled operational situations.

From an interior design perspective, it is therefore necessary to anticipate a gradual shift in the driver's role toward that of a steward, operator, and safety officer. During transitional phases, a human will still be present, even though part of the control will be taken over by the automated system. However, this role is problematic because the human loses active driving duties but remains responsible for intervening in critical situations. Research on automated shuttle buses shows that the safety operator assists passengers, monitors vehicle functions, oversees safety inside and outside the vehicle, monitors the automated system, and intervenes in the event of a failure. At the same time, long-term monitoring of rare hazardous events is taxing for humans and can lead to a loss of attention.

The steward's role should therefore not be based solely on passive supervision. It should combine passenger assistance, ticket inspection, communication, monitoring for vandalism, handling emergencies, reporting malfunctions, and, where appropriate, active collaboration with the autonomous system. For example, a steward could confirm detected obstacles, flag unclear situations on the display, or validate the system's decisions. Such activities could partially replace the dead man's switch safety principle, as they would keep the human's attention engaged in an active and meaningful way.

Another important issue is passengers' subjective sense of safety. A study of autonomous buses in Oslo showed that passengers generally felt safe, but the results must be interpreted with caution because the vehicles were not fully autonomous and there was a human operator on board capable of intervening. The presence of a human therefore likely has a positive effect on passenger confidence.

It follows that the proposed tram should not be designed as a vehicle for a single specific level of automation, but as an adaptable platform capable of a gradual transition from human control through a steward mode to future autonomous operation at GoA4 . The main design challenge is therefore to create a vehicle and interior that can navigate a long technological, legislative, and social transition phase without compromising safety, passenger confidence, or the meaningful role of human operators.

3.2 Aim of thesis

3.2.1 Global objectives

The main objective of the development is to design a semi-autonomous tram that will serve as a transitional link between a conventionally driven vehicle and fully autonomous operation. The design must be functional in GoA2, GoA3, and GoA4 modes and reflect the gradual transformation of the driver's role into that of a steward, the change in their job description, and the evolution of responsibility across the various levels of automation. At the same time, the design should contribute to building the trust of passengers and other road users in the autonomous tram system.

3.2.2 Sub-goals

A secondary goal is to design a modular cabin solution that can be adapted to various GoA automation levels. The cabin should support conventional driving, supervisory mode, and future operation with limited or no driver presence. This will allow the vehicle to adapt to gradual technological and legislative developments throughout its lifecycle.

Another objective is to design a system for visual and, where appropriate, auditory communication with the vehicle's surroundings. The tram should be able to clearly inform pedestrians, cyclists, drivers, and passengers about its current mode, intentions, and operational status. The design may include lighting elements, information displays, color signals, sounds, or other communication elements. Emphasis will be placed on their legibility, comprehensibility, appropriate color scheme, and integration into the vehicle's overall styling.

The development also includes the design of the steward’s workflow. The goal is to define a job description that is not based solely on passive monitoring but actively supports safety, communication with passengers, and oversight of operations. The workflow should help maintain the steward’s attention, reduce the risk of fatigue, and prevent loss of situational awareness during long-term monitoring of the automated system.

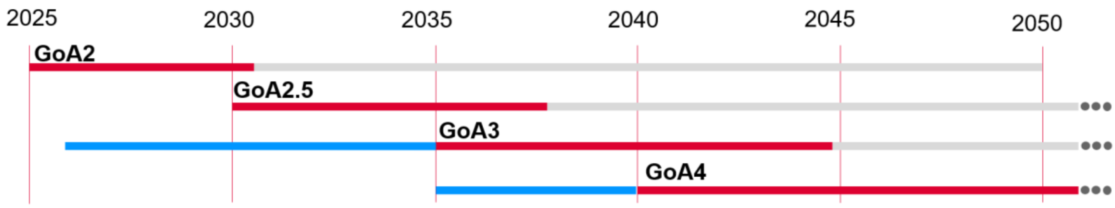

Fig. 3- 1 Expected GoA timeline

4 CONCEPTUAL DESIGN SOLUTION

In this chapter, we will analyze three conceptual designs for the driver's cabin interior that emerged as possible concepts based on our research, as well as three directions for the exterior design.

4.1 Analysis of Objectives and Specification of Constraints

The diagram (see Fig. 4-38) illustrates the main objectives of the semi-autonomous tram design, highlighting key aspects. The basic categorization is divided into the areas of functionality, design and construction, and ergonomics. The purpose of this breakdown was to analyze individual objectives and link them to the technical, operational, and user requirements of the project.

The constraint tree (see Fig. 4-1.) similarly illustrates the key constraints and requirements associated with the design of a semi-autonomous tram. Each of the three categories contains specific aspects, such as the technological capabilities of autonomous operation, dimensional limits, manufacturing constraints, and ergonomic requirements for the interior. These constraints were determined primarily by legislation, urban transport operating conditions, and the vehicle's structural requirements.

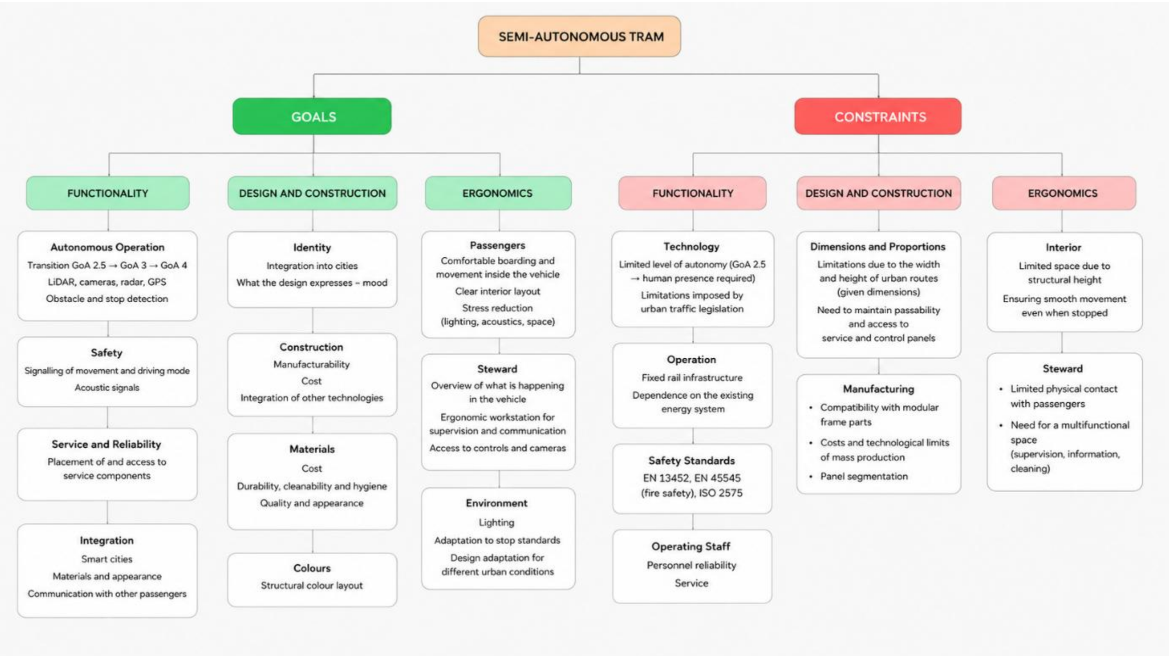

Fig. 4- 1 Fig. 4-1 Objectives and constraints tree

4.2 Technical functional analysis

This section describes and analyzes the key technical and functional elements of a semi-autonomous tram, primarily to illustrate their interrelationships. Their significance lies mainly in the integration of individual vehicle systems, the external environment, and users into a single functional unit, which forms the basis for the design of the final solution. Within the schematic overview, components were categorized based on their relationship to the surrounding infrastructure, operating conditions, and the vehicle itself. Additionally, the main inputs to the control and safety systems were documented, such as cameras, sensors, and information regarding traffic conditions, stops, switches, pedestrians, and weather conditions. Based on this, a comprehensive diagram (Fig. 4-2) was created, which captures the interconnection of the propulsion system, control, interior, exterior, communication elements, and links to passengers and the steward.

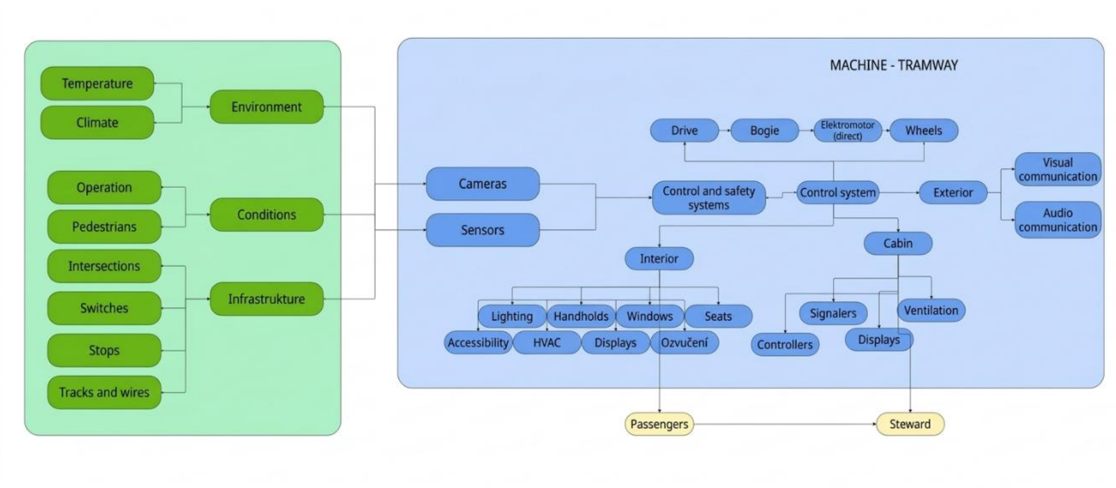

Fig. 4- 2 Glassbox

4.3 Design Concepts

In this section, let’s discuss the concepts for the interior and exterior design.

4.3.1 Interior – Driver’s Cabin

Based on a technical analysis, an analysis of the steward’s duties, and the gradual transition of the GoA autonomous driving mode, the following three concepts were proposed.

4.3.1.1 Non-rebuildable variant (Closed panel variant)

The first variant is designed in the simplest way possible so that any subsequent conversion is as cost-effective as possible. All displays and control elements are mounted on fold-out platforms that can be closed later, and the driver's seat is replaced either by a double passenger seat or the area is left as open space. The advantage is that if a double seat is installed, then in the event of an emergency, the operator can arrive, open the displays, and within a few minutes be able to fully operate the tram. However, this solution offers the lowest degree of modularity. From a design perspective, it would also be less visually refined, as the closed driver's equipment would remain clearly visible in the interior. At the same time, it would unnecessarily occupy space that could be used more effectively in later stages of automation, for example to increase passenger capacity (more seats or a larger standing area).

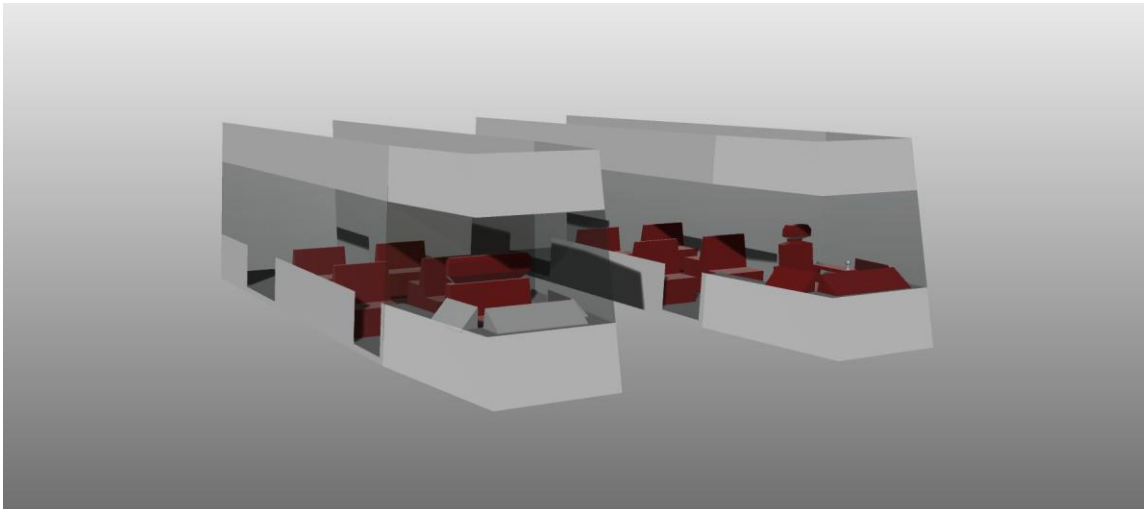

Fig. 4- 3 Non-rebuildable variant (Closed panel variant) front view

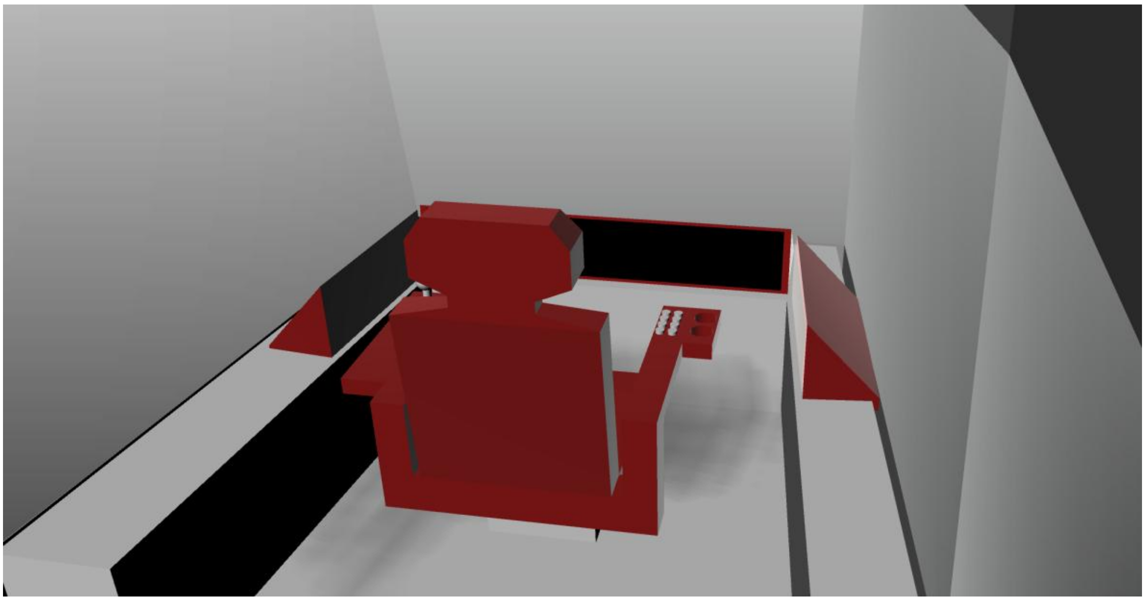

Fig. 4- 4 Non-rebuildable variant (Closed panel variant) rear view

4.3.1.2 Modular interior variant

The second variant is designed to use only a limited number of mounting points for the control panel and the driver's seat. During the conversion process, these components can be removed and replaced with a new seating arrangement, which is mounted to the same structural points. This approach creates a simple and cost-effective solution, as it reduces the need for major modifications to the vehicle body or interior structure. At the same time, it allows the driver's area to be transformed into passenger space in a relatively straightforward manner. Compared to the first variant, this solution offers a cleaner interior layout and a higher level of adaptability —while still keeping the conversion process technically simple and economically efficient.

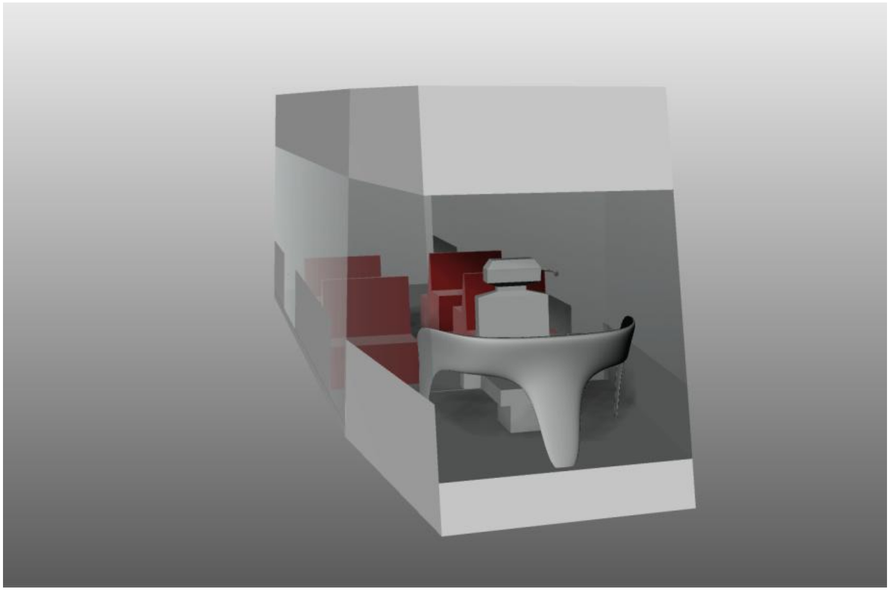

Fig. 4- 5 Modular interior variant, front view

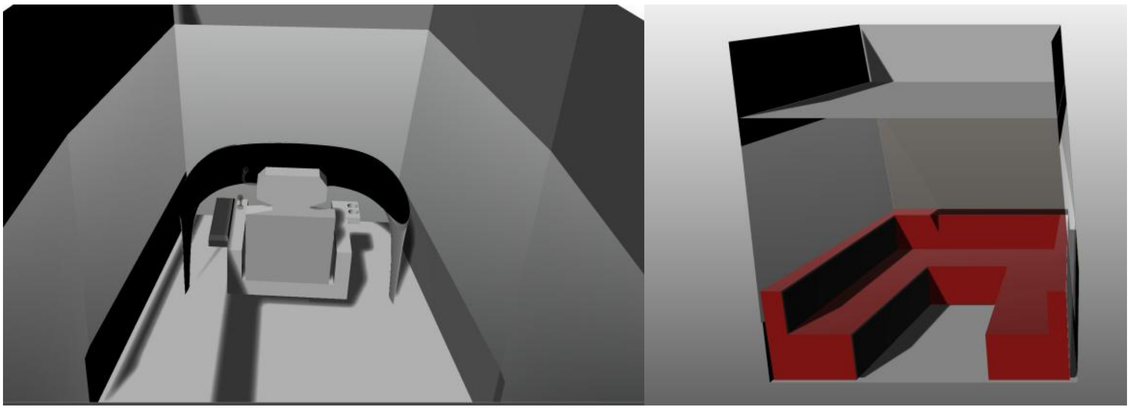

Fig. 4- 6 Modular interior variant, rear view

4.3.1.3 Modular cabin variant

Concept 3 introduces the most radical change. In this variant, the transformation involves not only individual interior elements, but the entire semi-cab module. The driver's position can therefore be removed as a complete unit and replaced with a passenger-oriented interior section. This makes it possible not only to convert the former driver's area in to passenger space, but also to carry out a partial facelift of the tram. The new module could give the vehicle a more modern appearance and more clearly communicate its transition toward autonomous operation.

The main advantage of this concept is its high degree of modularity and the potential for a more cohesive design transformation. However, it would also be the most challenging solution. The conversion would be costly and would require careful consideration of the structural strength and safety of the vehicle body.

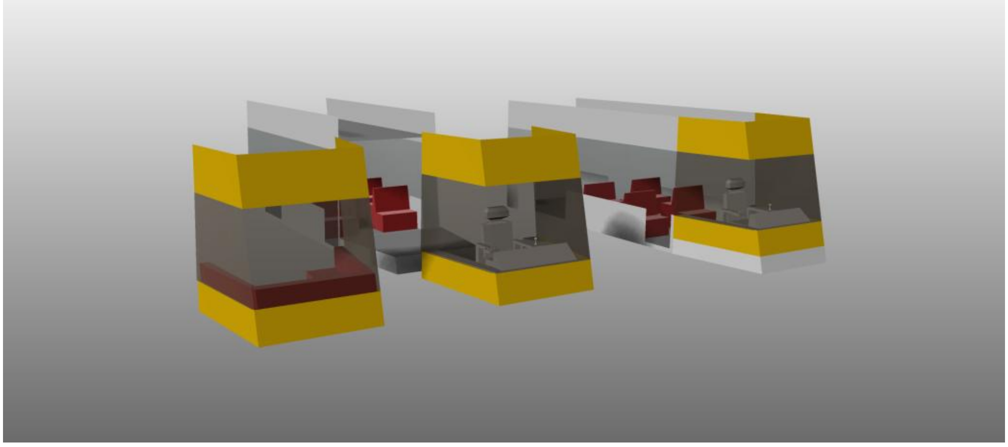

Fig. 4- 7 Modular cabin variant front view

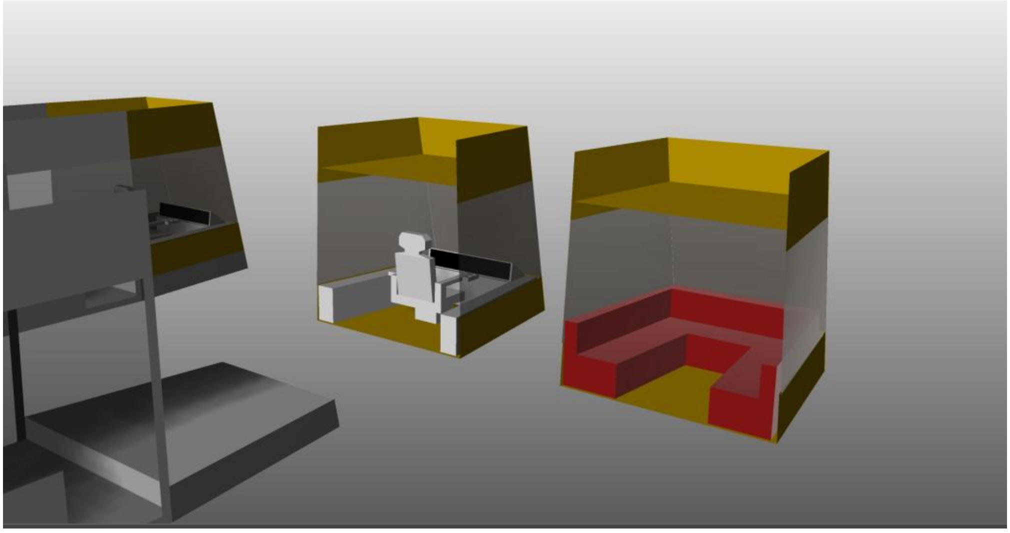

Fig. 4- 8 Modular cabin variant, rear view

4.3.1.4 Solution analysis and selection for the interior

Tab. 4- 1

Evaluation criterion	**VAR 1**	**VAR 2**	**VAR 3**
Aesthetics and identity	5	9	10
Ergonomics and visibility	6	9	9
Safety and readability	7	9	10
Technology integration	7	9	9
Modularity and convertibility	5	10	9
Manufacturing and certification feasibility	9	8	4
Operational efficiency	8	8	6
User communication	6	9	8
Originality and design progress	5	9	10
Overall contribution to autonomous operation	6	10	9
Total score	**63**	**90**	**84**

The evaluation showed that Interior Variant 2 is the most suitable solution. Variant 1 would be impractical and aesthetically lacking, and it would not fully utilize the possibilities for interior adaptation and modularity required for the transition between different levels of autonomy. Although it represents the simplest and cheapest approach, the final interior after the transformation would not appear sufficiently well thought-out or visually coherent. Although Variant 3 could offer the greatest potential during the transformation, especially due to its high degree of modularity and the possibility of a more significant design change, its overall costs would be considerably higher. This would apply not only to the conversion itself, but also to the development of a new modular platform and the necessary structural and safety verification. For this reason, Variant 3 was ranked second. Variant 2 therefore proved to be the most balanced solution, as it provides sufficient adaptability for the transition to autonomous operation while maintaining reasonable technical complexity and acceptable costs.

4.3.2 Exterior

Three conceptual approaches were selected for the exterior design, after which sketches were created and the best approach was chosen.

4.3.2.1 Retro-modern

This variant was inspired by a trend that has repeatedly resurfaced and has been growing in popularity for several years, for example in the automotive industry. The approach involves incorporating characteristic elements—or even drawing directly from original historical models. Therefore, this version incorporates features from older tram models, most notably the Tatra T2. This tram, like many other iconic historical tram models, was characterized by a distinctive signature element—a centrally positioned single headlamp. However, this is not possible today due to regulations, and therefore it can be interpreted as a main circular element, which will be backlit and will serve as the dominant feature.

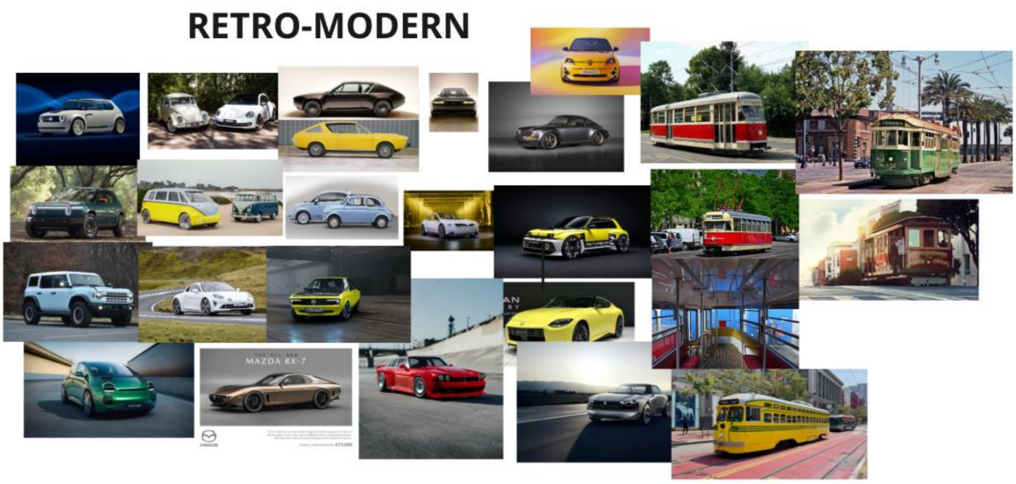

Fig. 4- 9 Moodboard for the retro-modern variant

Fig. 4- 10 Iconic old trams [51-54]

For the moodboard, I drew inspiration mainly from the automotive industry and retro-modern versions of new cars that pay homage to their famous predecessors; I also added old Tatra trams and the iconic cable cars of San Francisco.

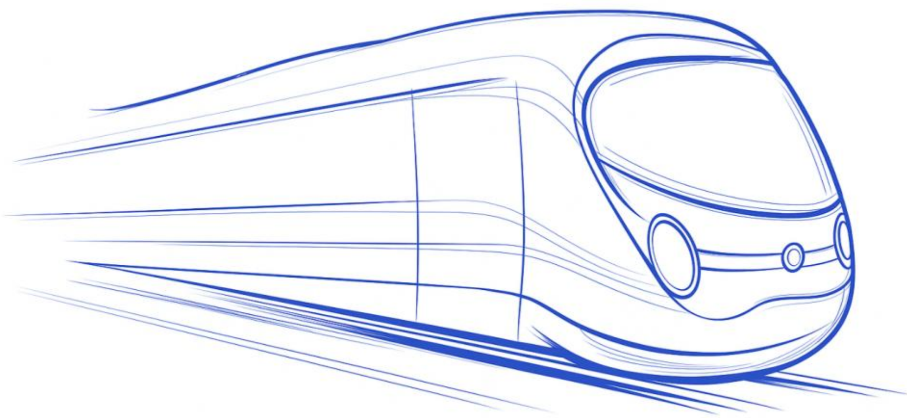

Fig. 4- 11 Sketch of retro-modern variant

Fig. 4- 12 3D render created from sketch using Vizcom AI, retro-modern variant

The retro-modern variant has the advantage of fitting both into a historic city center and into modern technology-oriented districts, because tram lines often connect these parts of cities.

4.3.2.2 Futuristic

The futuristic variant was developed with the aim of modernizing cities and showcasing advanced technology. It features aerodynamic lines and advanced lighting systems integrated into the car body. However, in this variant, the angle of the tram’s front end is unnecessarily exaggerated and resembles a train too closely; it evokes a sense of speed, which is not the main advantage of trams, and it unnecessarily reduces the available space in the driver’s cab.

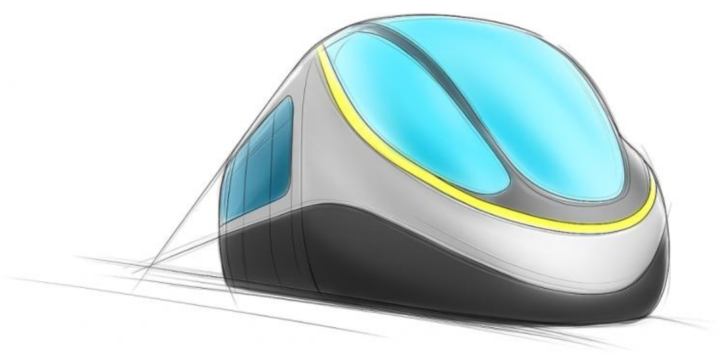

Fig. 4- 13 Sketch of futuristic variant

Fig. 4- 14 3D render created from sketch using Vizcom AI, Futuristic variant

4.3.2.3 Conservative

This variant was chosen as a so-called safe route. It is the most closely aligned with the design language of today's trams. Tram design is a highly conservative domain that relies on minimalism, in order to maximize the likelihood that the design will remain visually appealing throughout the tram's entire service life.

Fig. 4- 15 Sketch of conservative variant

Fig. 4- 16 3D render created from sketch using Vizcom AI, Futuristic variant

4.3.2.4 Solution analysis and solution selection for the exterior

Tab. 4- 2

Criteria / Evaluation	**VAR 1**	**VAR 2**	**VAR 3**
Aesthetics and Identity	10	9	8
Readability of Autonomy	8	10	7
Formal Purity	8	9	8
Manufacturing Feasibility	9	7	9
Integration of Sensors and Technology	8	9	8
Environmental Versatility	10	7	8
Public Perception and Acceptance	10	8	9
---	---	---	---
Total Points	**63**	**59**	**57**

I selected Exterior Variant I—retro-inspired—primarily because of its versatility. This design is more likely to appeal to people of all ages and can blend seamlessly into various urban settings, whether modern neighborhoods or historic city centers. At the same time, the retro-inspired character gives the tram a recognizable and approachable appearance, while still allowing it to be interpreted in a contemporary way. The aim is therefore not to create a purely historical-looking vehicle, but a modern tram with clearly visible and recognizable retro elements.

4.4 3D Sketches

This was followed by a series of 3D sketches to explore the possibilities offered by the retro- modern variant.

Fig. 4- 17 3D sketches blob style

Fig. 4- 18 3D sketches blob variants with cute expressions

Fig. 4- 19 3D sketches miminalstic more futuristic variants

5 PRELIMINARY DESIGN

5.1 Shape, Dimensions, and Materials

5.1.1 Shape

Two versions were created from the previous 3D sketches. The first was based on the more blob-like versions with a distinctive look, but I simplified the headlights so that stock lights could be used.

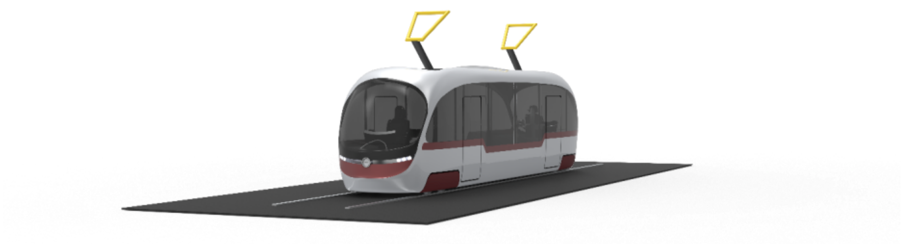

Fig. 5- 1 Blob variant

However, this version did not meet the aesthetic standards and needed to be modified; during the modifications, I leaned more toward a more modern style, and this version was created.

Fig. 5- 2 Progress variant in more modern style

This variant is more reminiscent of the classic designs we see on today's modern trams—it has a modern look, and its retro elements merely reference the old T2 trams, such as the central element, the color scheme, or the front bumper, which is black to evoke the missing coupler cover found on the T2.

For this variant, I used the concept of a chassis under the cab, since this way the chassis does not take up space in the cab. I based this on the Škoda 52T concept. However, after consulting with the Škoda Group, we concluded that I should stick to the design for Brno, as seen on the 45T, and I received a complete schematic model of the entire three-section tram. Variants with undercarriages behind the cab must have a narrowed front end due to larger turning radius, so a final remodeling was carried out, resulting in the final variant.

5.1.2 Analysis of Materials

The choice of materials is based on requirements for durability, fire safety, and ease of maintenance. The vehicle's load-bearing frame is typically a welded steel structure. In some modern trams, selected parts of the body may also be made of aluminum, but steel predominates. Since the Škoda Group also uses steel frames, steel will be used for my project as well.

The outer side panels are most often made of pressed sheet metal. The front panels, which have a more complex shape, are made of fiberglass. Other composite materials are sometimes used, but fiberglass is the most common. Roof covers for technical equipment can be made of metal or composite materials. In my design, I will use fiberglass, since the upper section is completely enclosed, so that the covers are as lightweight as possible during servicing.

The interior primarily features plastic, laminate, and composite trim. Metal handrails are made of stainless or painted steel. Seats may consist of a plastic shell with upholstery made of fabric or synthetic leather. In my design, I will use a combination of plywood, and the padding will be covered with dyed synthetic leather, as it is non-absorbent compared to fabric and results in less soiling.

The driver's console consists of a metal support structure, most commonly made of steel or aluminum, to which cover panels made of plastic, laminate, or composite are attached. Surface parts can be made of ABS plastic, HPL laminate, or painted sheet metal. These materials allow for easy shaping, integration of displays and controls, simple maintenance, and wear resistance.

5.2 Estimated production costs and production volume

Production costs and volume were based on the Škoda 45T that DPMB purchased from 2022 through the end of 2026.

5.2.1 Estimated production costs

The vehicle is designed for custom small-batch production, utilizing a shared technological platform for low-floor trams, which allows for flexibility in the length and equipment of the cars. The estimated annual production volume ranges from 5 to 10 units, with the duration of a single production series estimated at 4 to 6 years.

5.2.2 Selling Price and Market Context

To determine an indicative price for the proposed semi-autonomous tram, the price of the Škoda ForCity Smart 45T tram intended for Brno was used as a reference value. According to DPMB, the current price of a single vehicle slightly exceeds CZK 75 million, whereas the earlier price was reported at approximately CZK 60 million per vehicle and was later increased to CZK 75 million per vehicle. [51] As a rough estimate, it can be assumed that equipping the tram with autonomous/anti-collision equipment consisting of LiDAR, cameras, sensors, a computing unit, and software will increase the purchase price by approximately 3–6%; this estimate is based on general costs for autonomous vehicles and is increased by the necessary integration into the rail vehicle, testing, and certification. Adding a small battery pack for a short autonomous range, depot operations, or emergency travel can be estimated at approximately 3–8% of the purchase price. Overall, a tram with these two features may cost roughly 6–12% more than a conventional vehicle. [50]

Therefore, after factoring in these costs and projected inflation through 2030, the resulting price could reach approximately **CZK 90–95 million per vehicle**. This estimate is based on a base price of CZK 75 million, an increase of 6–12% for the battery and autonomous systems, and approximate cumulative inflation through 2030. However, the actual price could vary depending on the range, battery capacity, number of vehicles ordered, and testing and certification requirements.

6 DETAILED DESIGN

6.1 Exterior

The final design is therefore a bidirectional three-articulated tram with four swivel bogies. There are five doors on each side, three of which are double-leaf, and two side doors are single-leaf.

The final design combined elements of retro-modern styling with a classic, conservative approach. Care was taken to maintain the design language of Škoda Group trams.

The final concept is therefore modern, complemented by elements referencing iconic vehicles such as the Tatra T2 tram and the San Francisco cable car.

The main design element is the circular lighting fixture on the front fascia, intended to evoke the central headlight of older trams. Straight color lines were also used to echo the original historic paint schemes. Another design element can be found in the lower bumper, which is divided, with the black section mimicking the exposed coupler area characteristic of the Tatra T2, whose couplers were not covered.

The later Tatra T3 variant is distinguished by its pair of circular headlights, each with a diameter of 90 mm. The overall design is complemented by a lighting element that follows the contour of the windshield and continues as a line between the windows and the roof along the entire length of the vehicle. [Fig. 4-9]

Fig. 6- 1 Final variant in perspective

Fig. 6- 2 Final variant in scene

6.1.1 Dimensions

The total length of the tram is 31.3 m and the width is 2.5 m, which is the standard commonly used in the Czech Republic and other European countries, although the standard allows for up to 2.7 m. The height without the pantograph is 3.5 m. The distance between the first and second doors is 4.6 m. The distance from the middle door to the next door is 7.5 m.

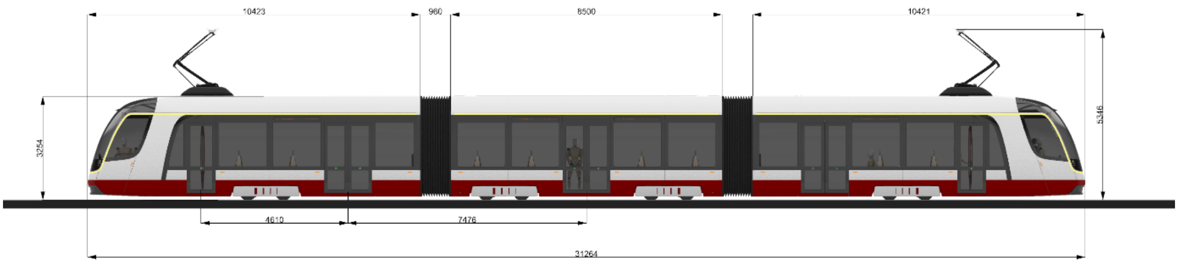

Fig. 6- 3 Dimensions - Side view

From the top view, we can see the tapering cab. In trams where the first bogie is located behind the driver's cab (this example), the tapering of the front end limits the overhang of the front part of the vehicle in curves and helps maintain the required clearance profile.

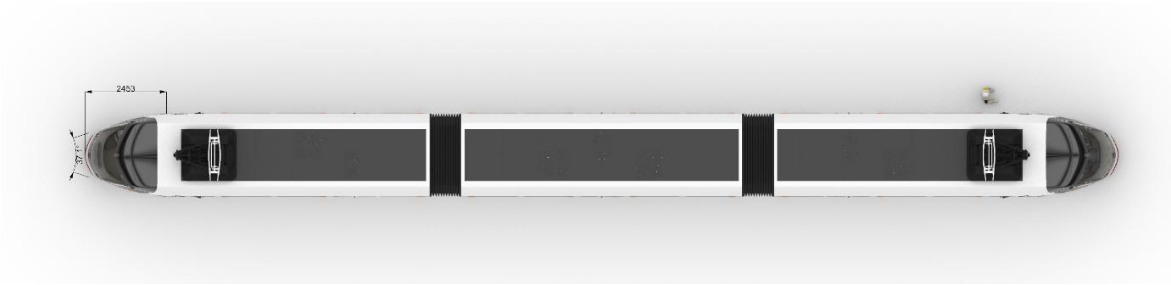

Fig. 6- 4 Dimensions - Top view

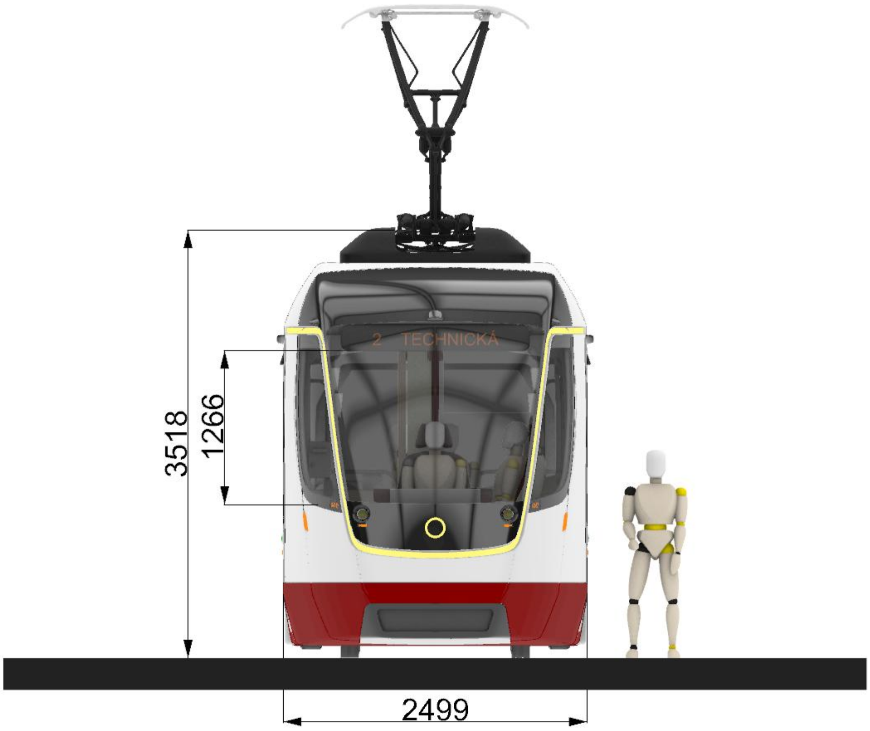

Fig. 6- 5 Dimensions - Front view

6.1.2 Construction and materials

The side panels are made of pressed sheet metal; the front end is made of fiberglass to allow for more organic shapes and cost-effective piece production. The front grille, part of the roof, and the area around the windows are made of durable glossy ABS. The windows are laminated for greater passenger safety.

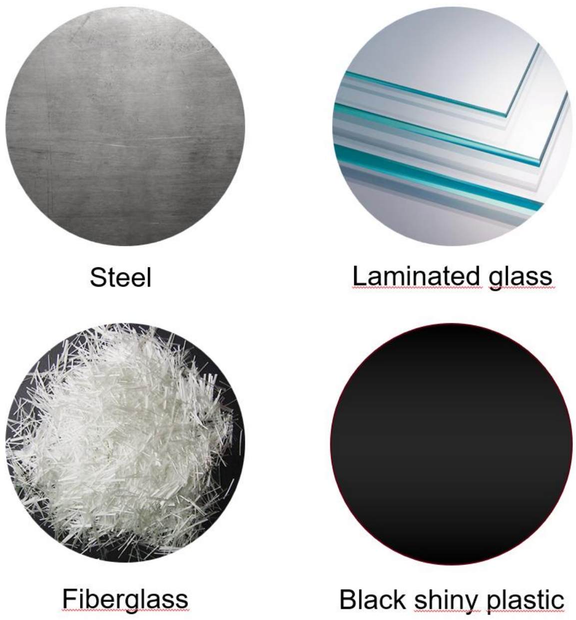

Fig. 6- 6 Materials

The front section from the bumper to the grille is divided into three parts to allow for easy removal if the coupler needs to be used. Furthermore, the side panels are also divided into smaller segments, as minor accidents involving the front of the tram are common; thus, the ability to replace only a smaller, less expensive panel is a benefit that cities often consider when selecting new trams. The side panels are also divided, and the roof covering, in particular, is divided into numerous sections to allow easy access for servicing the electrical equipment located on the roof.

Fig. 6- 7 Panel Division

As with most modern trams, all electrical equipment is located on the roof to maintain a low-floor design. On the roof, we find traction inverters for each bogie, as well as braking resistors. Also present are air conditioning units and a small 80 kWh battery, which can store energy from regenerative braking; alternatively, the tram can be used on routes with short sections without overhead lines and then recharged via regeneration or directly from the overhead lines. All cameras and lidars on the vehicle are marked in pink, including the pair of cameras for the side mirrors and the wide-angle cameras on each door, which provide complete coverage of the tram's surroundings. Of course, the vehicle also features current collectors (pantographs), a coupler on each side, and four low-floor drive bogies.

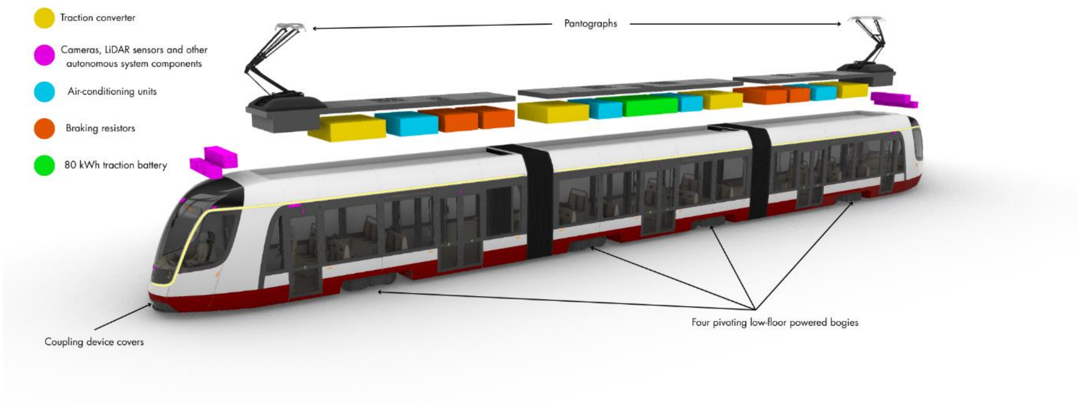

Fig. 6- 8 Cutaway diagram

The bogie covers feature an embossed design referencing the city of Brno's logo. It also emphasizes the dynamism of movement

Fig. 6- 9 Chassis covers

6.1.3 Lights

Headlights, position lights, and turn signals.

The lights were positioned to comply with ECE Regulation No. 48. Since in-house development of a headlight and its subsequent homologation is very costly, I used universal homologated lights from OE Industry and HELLA to reduce production costs. The headlights have a diameter of 90 mm and feature a colored LED ring, making them suitable for two-way traffic. Below them are light modules that combine daytime running lights with turn signals. Hella Shapeline turn signals are located on the sides.

Fig. 6- 10 Headlights and position lights

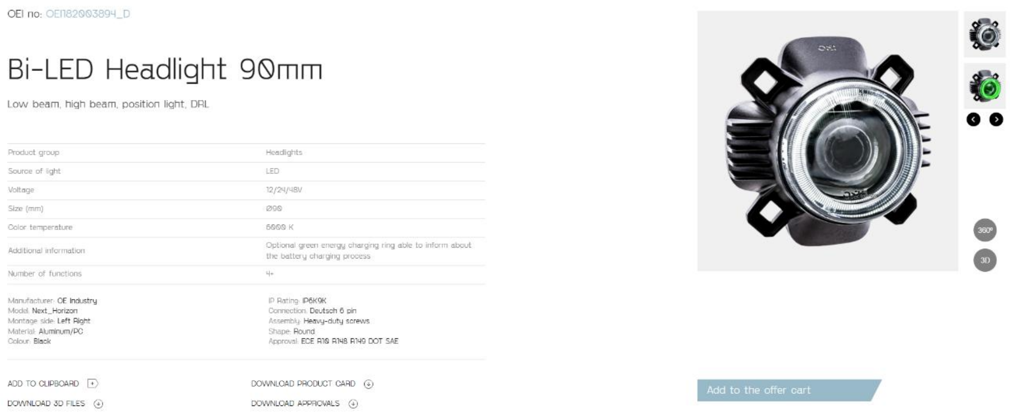

Fig. 6- 11 Screenshot from headlights manufacturer [55]

Fig. 6- 12 Screenshot from daytime running light manufacturer [56]

Ambient lights

The main feature that catches the eye at first glance is the light strip that runs along the entire length of the tram. When the tram is in manual mode, the front section glows yellow-white and the rear section is illuminated in red. When the vehicle is in autonomous mode, the lights change color to signal to the surrounding area that it is driving itself. It is often said that autonomous vehicles should indicate that they are in autonomous mode, for example through lighting, but there is currently no standardized color for autonomous driving. Green is often mentioned, but Mercedes, for example, has started using turquoise on its vehicles. [57]

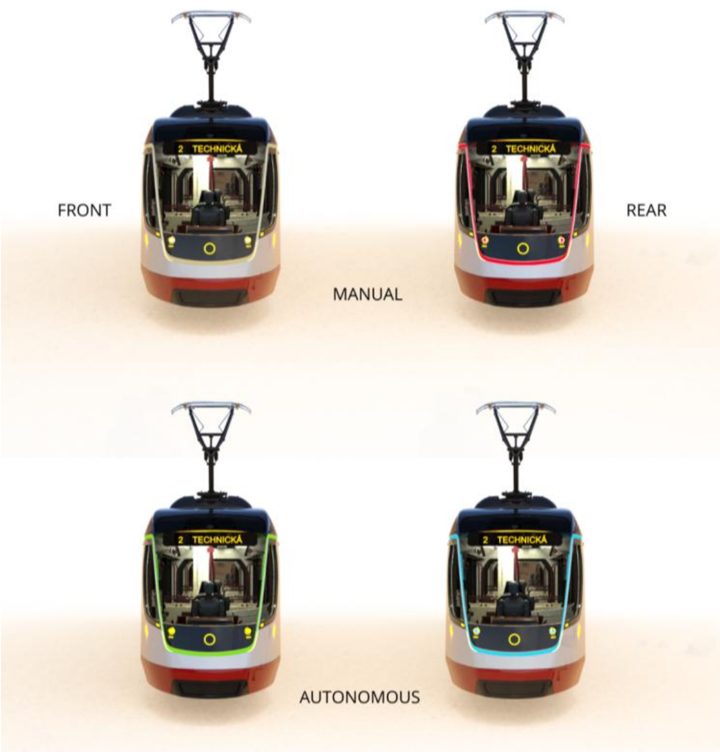

Fig. 6- 13 Colors of the light strip

Fig. 6- 14 Tram in autonomous mode

6.1.4 Color variants

Since the design is primarily intended for the city of Brno and the Brno Public Transport Authority (DPMB), the color scheme is largely determined by a combination of white and red. The main color of the design is white, for which a slightly warmer shade was chosen than that used on current DPMB vehicles. The warmer shade of white appears less technical and at the same time enhances the subtle retro character of the entire design.

The secondary color is red, which aligns with the visual identity of Brno's public transportation. Accent elements, such as door frames, body details, and other functional parts, are finished in glossy black. This creates a contrast against the light base while giving the design a more modern and distinctive look.

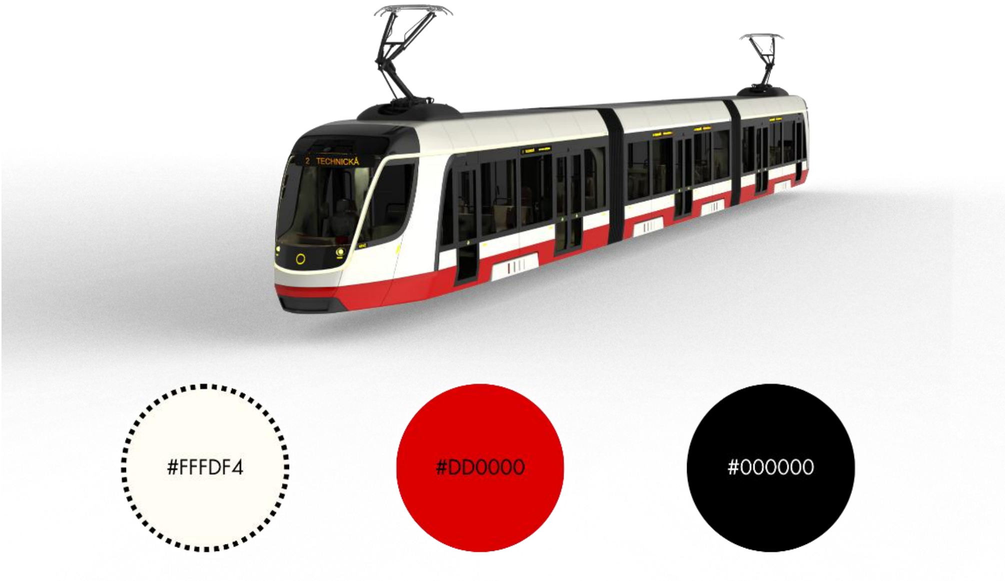

Fig. 6- 15 Colo palette

An alternative design for Brno could feature a red roof, or a design where red is the primary color and white is the secondary color for the lower section and the roof. In this version, I experimented with a burgundy shade of red.

The bottom two variants in Figure 6-14 are designs for the Ostrava Transport Company (DPO) that use blue as the primary color and white and yellow as accent colors.

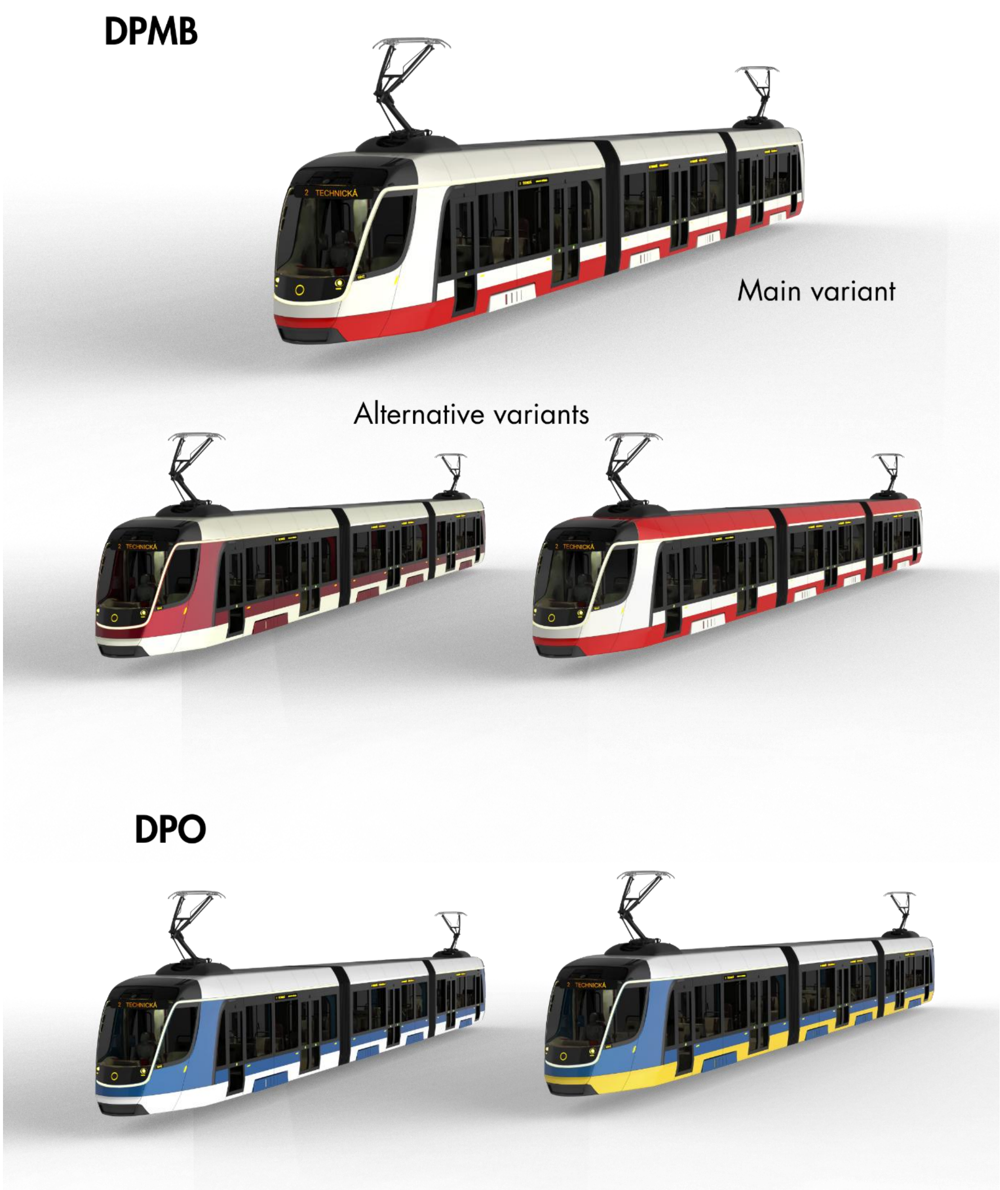

Fig. 6- 16 Color variants for DPMB and DPO.

6.2 Interior

6.2.1 Steward Workflw

The steward's transition will be gradual. At first, they will perform the traditional role of a driver, with the tram assisting with driving on certain sections; however, the driver will still need to remain alert. This raises the question of how to ensure they stay alert. In addition to monitoring via camera—similar to how cameras monitor drivers in modern cars—the driver could participate in training the autonomous systems, where a recording would appear on the screen labeling pedestrians, cars, etc., and the driver would have to confirm the accuracy or even assign them themselves, but this model is more suitable for later stages of autonomous driving, as the driver might lose focus on real-world traffic while making these assignments. In subsequent phases, when routes are still divided into manual and fully autonomous sections (with responsibility already resting with the machine), they can switch to steward mode. This means that the seat will slide back and rotate 90°; the steward/driver has a clear view of the cab and can monitor the rest of the vehicle via cameras on the displays. The third phase will be the deployment of full GoA3, during which the steward will remain in steward mode. At this point, the steward can remain in their seat or move freely throughout the vehicle. To ensure they maintain situational awareness and remain capable of controlling the tram even while moving around the vehicle, a tablet in a docking station is located in the left armrest of their seat. We will discuss the details in the next chapter

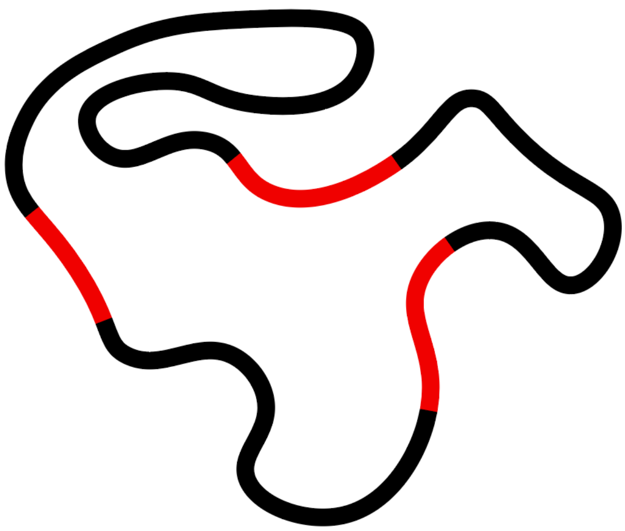

Fig. 6- 17 Diagram of a partially automated route

6.2.2 Driver's Cabin

The driver's cabin is designed to meet today's standards for driving as well as the steward's position.

The entire cabin is designed modularly so that when the fully autonomous GoA4 mode is implemented, it can be easily converted into passenger space. In these illustrations, we can see how the driver-operator switches from driver mode to steward mode. The seat slides backward, rotates 90°, and moves against the wall, giving the steward sufficient privacy while still allowing them to fully monitor what is happening in the vehicle either by looking around or using the displays built into the seat. The wall also includes a section with a pop-up window—similar to a classic car window. If a passenger needs help or advice, the steward lowers the window and can comfortably communicate with passengers. This solution ensures sufficient privacy for both passengers and the steward, while also offering openness for easy communication.

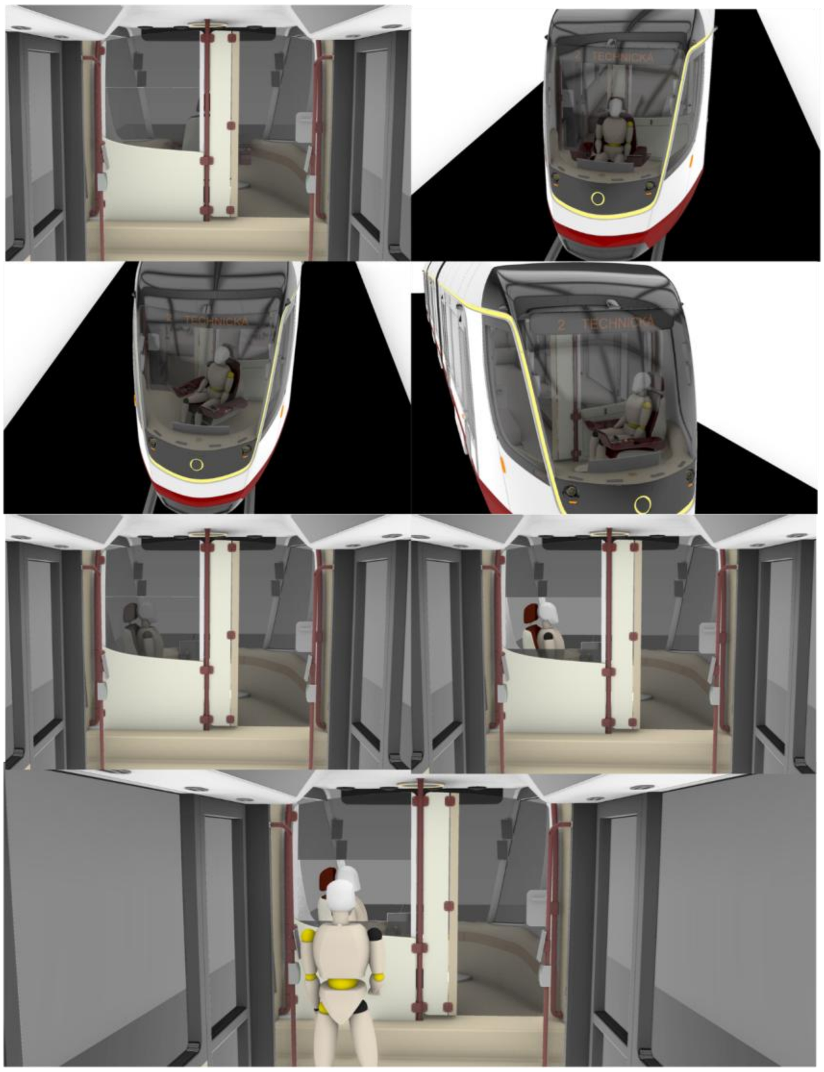

Fig. 6- 18 Mode switch from driver to steward

Fig. 6- 19 Driver seat movement

Transformation

The cabin is designed to be modular—therefore, the entire driver's wall is mounted on three rods and is fully removable. The rods then remain in place and serve as handrails. After removing the wall, the driver's seat, footrest, and mirrors are removed. The display is simply moved upward into a pre-installed mount and serves as an information panel for passengers rather than an advertising space. Then, a handrail is mounted on the left side and a passenger seat on the other side. The veneer trim is intentionally divided so that it can be replaced in sections, revealing the mounting points hidden behind it.

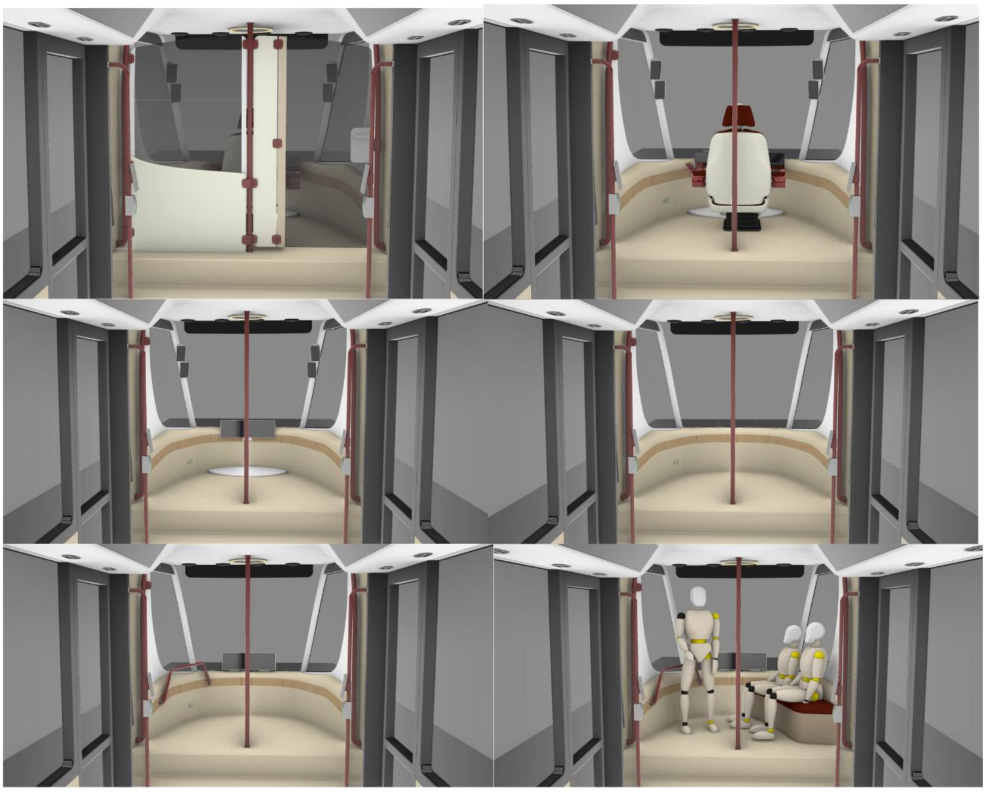

Fig. 6- 20 Modular cabin conversion from driver's cabin to passenger space

And this is what the fully converted passenger cabin looks like. The seat provides space for two passengers, and three more can stand on the left side.

Fig. 6- 21 Modular cabin conversion from driver's cabin to passenger space

Seat

The driver’s seat is designed as an all-in-one control station—all controls are located on the armrests along with two displays. I drew inspiration from the Smart Touch system manufactured by tractor maker Valtra.

Fig. 6- 22 Valtra Smart Touch [58]

– a classic touchscreen on the right armrest, and on the left armrest, the display is replaced by a tablet dock, allowing the steward to move around the entire vehicle. The right armrest is foldable to facilitate the driver’s entry. The armrests feature all the controls found in current trams. Based on a photo of the Škoda 52T control panel, I placed all the controls for doors, braking, sanding, energy recovery, etc. These controls are located on the right armrest. On the left is a panel with 12 programmable buttons, an emergency button, and of course the main control lever, the bell button, and the buttons for manually opening and closing the doors (red and green). In addition to the padding, there is also a cup holder here. The only thing not located on the seat is the main information display—it is mounted on the dashboard in front of it.

Fig. 6- 23 Front view of the driver's seat in the cab

On the left side of the dashboard is a compartment for the AED and mandatory equipment. Ventilation vents are located at the front of the dashboard and on the ceiling (Fig. 6-20).

Fig. 6- 24 Rear view of the driver's seat

Fig. 6- 25 Seat without driver

Fig. 6- 26 Detail of the right armrest

Fig. 6- 27 Detail of the right armrest

There is no so-called dead man button on the control panel or the footrest—the rearview mirror display features cameras that monitor the driver's alertness, similar to modern systems in cars.

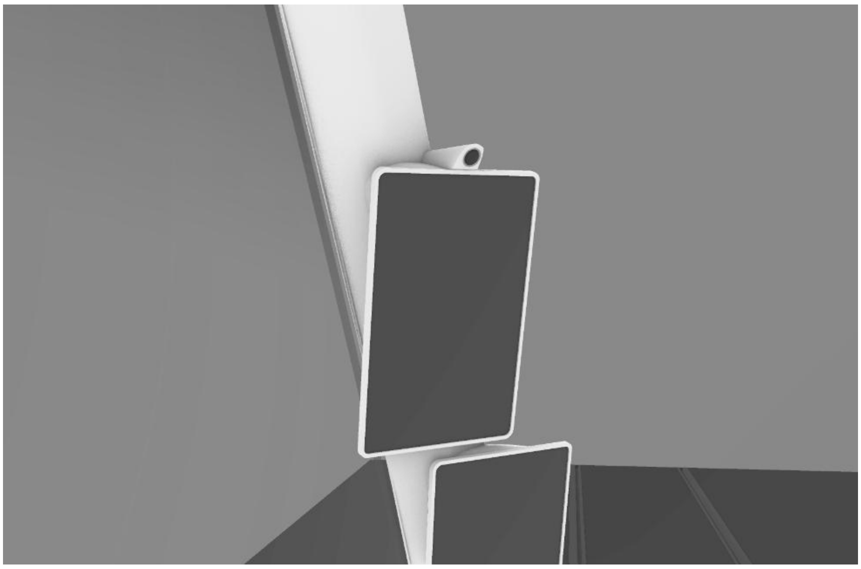

Fig. 6- 28 Rearview mirror displays with a camera monitoring the driver's alertness

6.2.3 Passenger compartment

Although the design of the passenger compartment was not the main focus of this work, it was developed at a basic conceptual level to create a cohesive impression of the entire vehicle. The passenger interior therefore serves primarily to complement the overall design and to suggest a possible spatial and visual solution. For this reason, it was not developed to the same level of detail as the main parts of the design on which the work primarily focuses.

In the front and rear sections, there is space for a stroller or wheelchair; on the other side, there is a backrest for a reclining seat.

Fig. 6- 29 Interior visualization

Seats

The seats are mounted on platforms, beneath which there is space for swivel casters

The seats are made of two pieces of plywood. They consist of two wooden parts—a complete backrest and a middle section with a cutout for padding. The padding is only on the sides. This is because fabric seats have the disadvantage of snagging material and being harder to clean. Wooden seats do not have this problem, but they are not as comfortable and are slippery, which can make boarding and alighting difficult for people with reduced mobility. That is why I created this combination, where I used a wooden center and added padded side supports covered with leatherette for support.

There are 8 seats on each platform, for a total of 64 seats.

Fig. 6- 30 Visualization of the platform with seats

Buttons, ads, and tickets

The door control button is backlit and features Braille.

Fig. 6- 31 Exterior door button

The doors have a backlit center strip that signals door opening and closing with a green or red light.

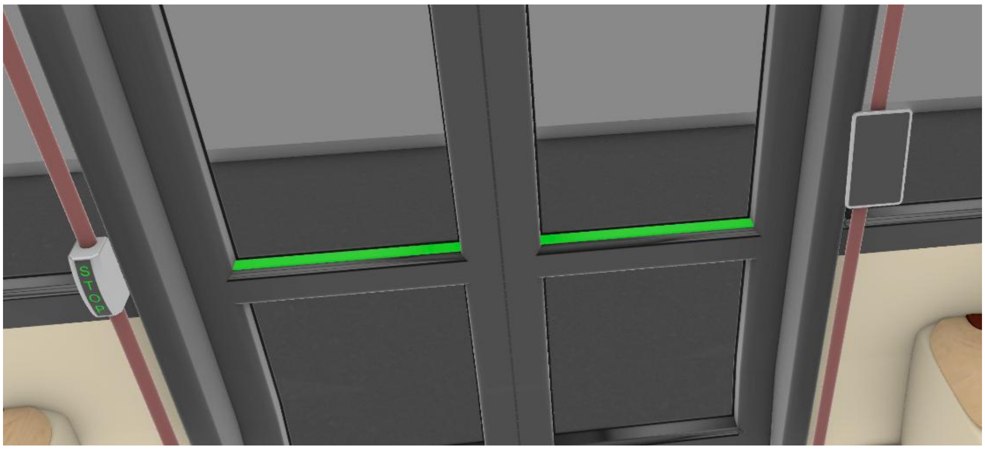

Fig. 6- 32 Door light signals

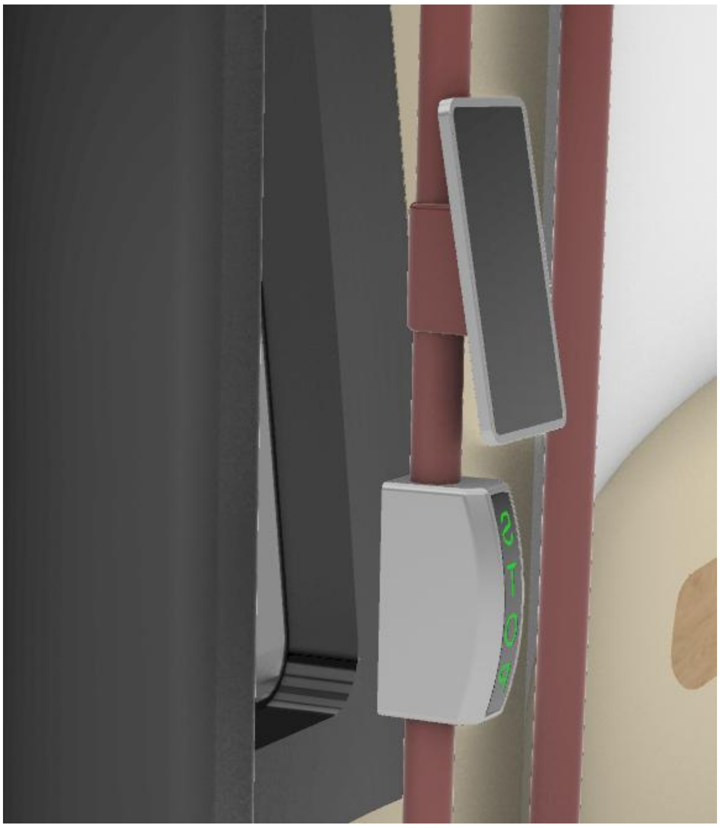

Fig. 6- 33 STOP button

6.3 Ergonomics

In this section, we will take a detailed look at ergonomics and important dimensions

6.3.1 View from the cab

Verification of the near-field view in front of the vehicle was performed in accordance with the ČSN EN 16186-5+A1 standard, specifically the requirement for near-field external visibility. The standard specifies a visibility test using a cylinder 1100 mm high and 300 mm in diameter, with its center located 650 mm in front of the very front of the tram’s front end at the level of the top of the rail. This element simulates a low obstacle or a person located in the immediate vicinity of the vehicle. In the design, a line of sight was drawn from the driver’s reference eye position to the upper surface of the cylinder. Verification shows that neither the lower edge of the front windshield nor the shape of the control panel restricts the view into the critical area in front of the vehicle [2].

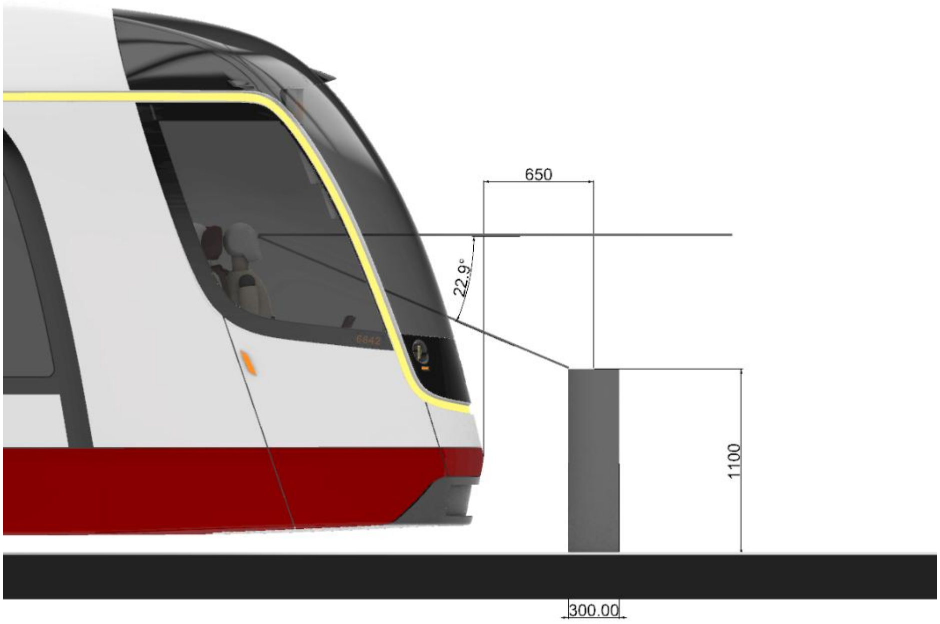

Fig. 6- 34 View from the cab

The plan view illustrates the horizontal range of visibility from the operator's workstation. The area marked in light color represents the field of view, which is determined by the shape of the front and side glazing. The design allows for a wide view of the area in front of the vehicle as well as to the sides, which is particularly important when passing through intersections, entering curves, and checking the area around a stop.

The figure shows the impact of the A-pillars of the front glazing, which obstruct approximately 4.5°. Generally, manufacturers set the maximum obstruction by the A-pillar to 6 degrees, so the view here is sufficient to minimize blind spots.

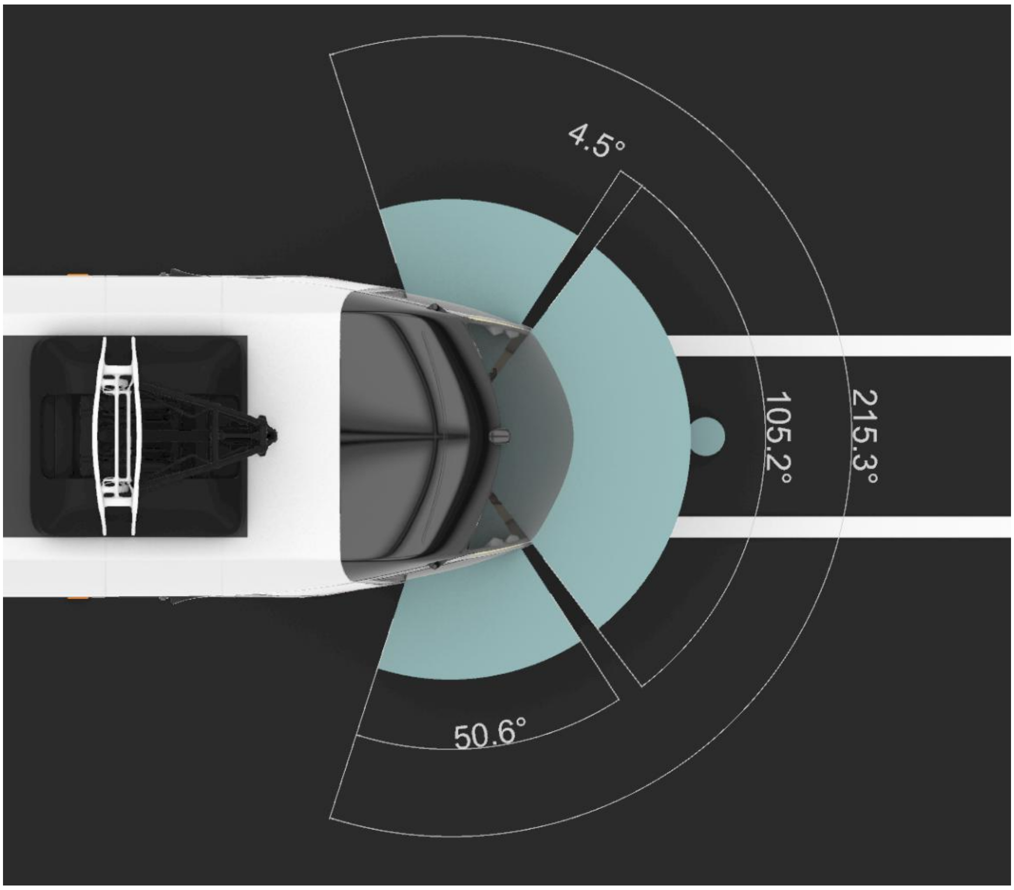

Fig. 6- 35 Horizontal view from the cab

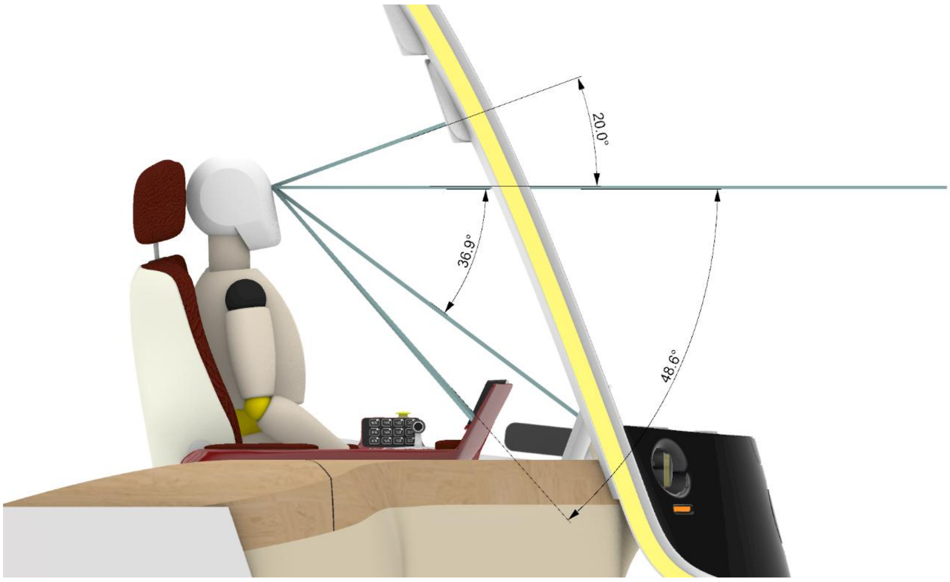

Fig. 6- 36 Side view of displays and controls

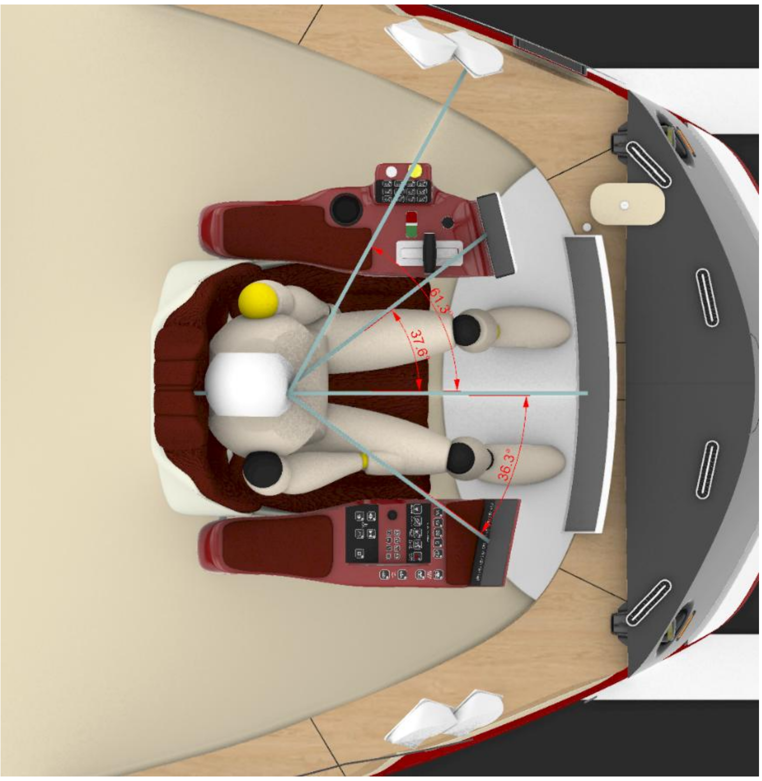

Fig. 6- 37 Horizontal view of displays and controls

6.3.2 Seating

Driver seat

The driver’s seat is designed as a compact, ergonomic workstation with an integrated armrest and side control panel. The body position corresponds to an upright sitting posture with the back, thighs, and feet supported, which promotes a stable working position during long-term driving. The seat height is approximately 430 mm, and the total height of the workstation is about 1200 mm. The controls are positioned within reach of the right hand, without requiring the driver to lean forward significantly. The seat is reclining and has an adjustable headrest. The armrests are foldable to facilitate entry. It complies with the ČSN EN 16186 standard.

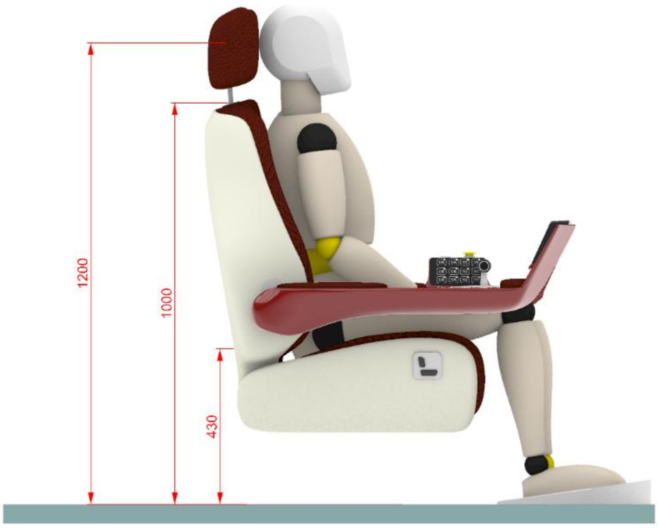

Fig. 6- 38 Driver's seat side view - dimensions

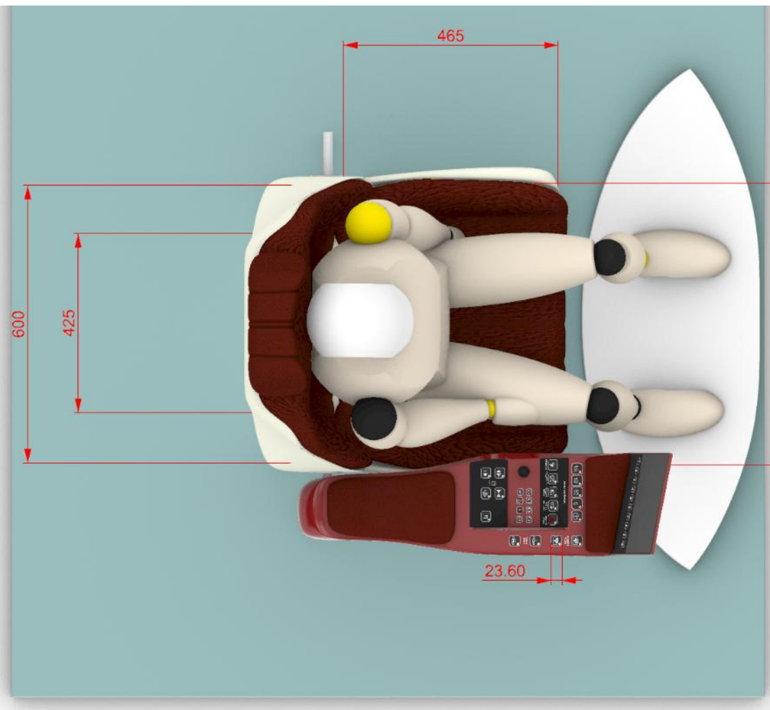

Fig. 6- 39 Driver's seat top view - dimensions

Passenger seats

The seat cushion height is approximately 420 mm, which corresponds to the standard seating position in public transport vehicles. The dimensions of the seat itself are approximately 438 × 475 mm, and the backrest is about 467 mm high. The side padding keeps the occupant in place and prevents slipping off the wooden part of the seat.

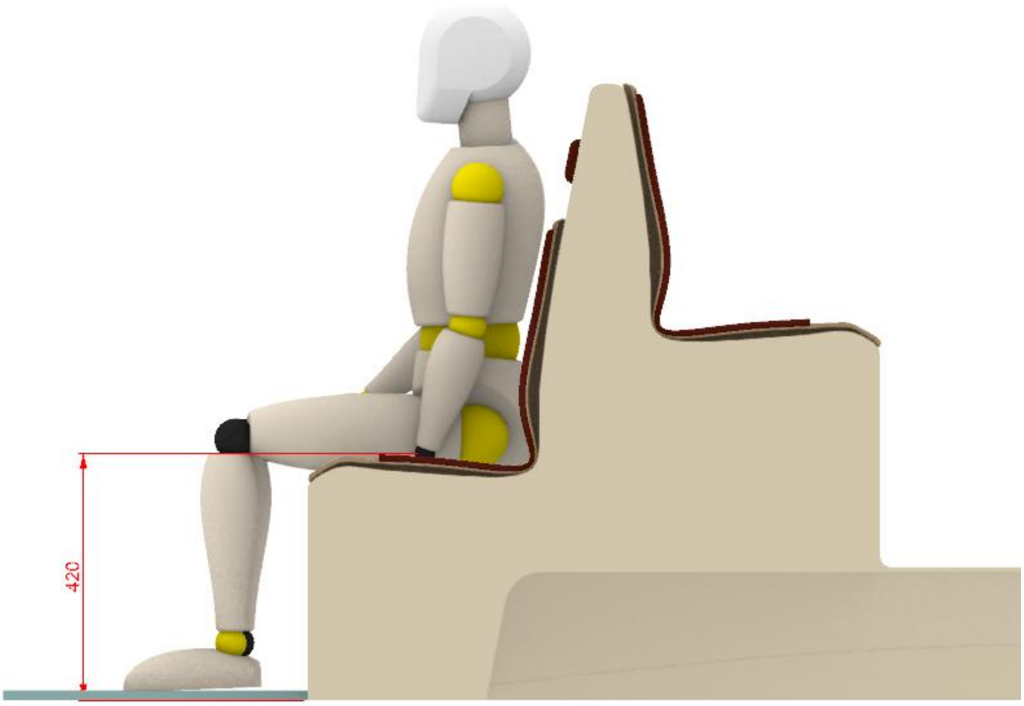

Fig. 6- 40 Passenger seat side view - dimensions

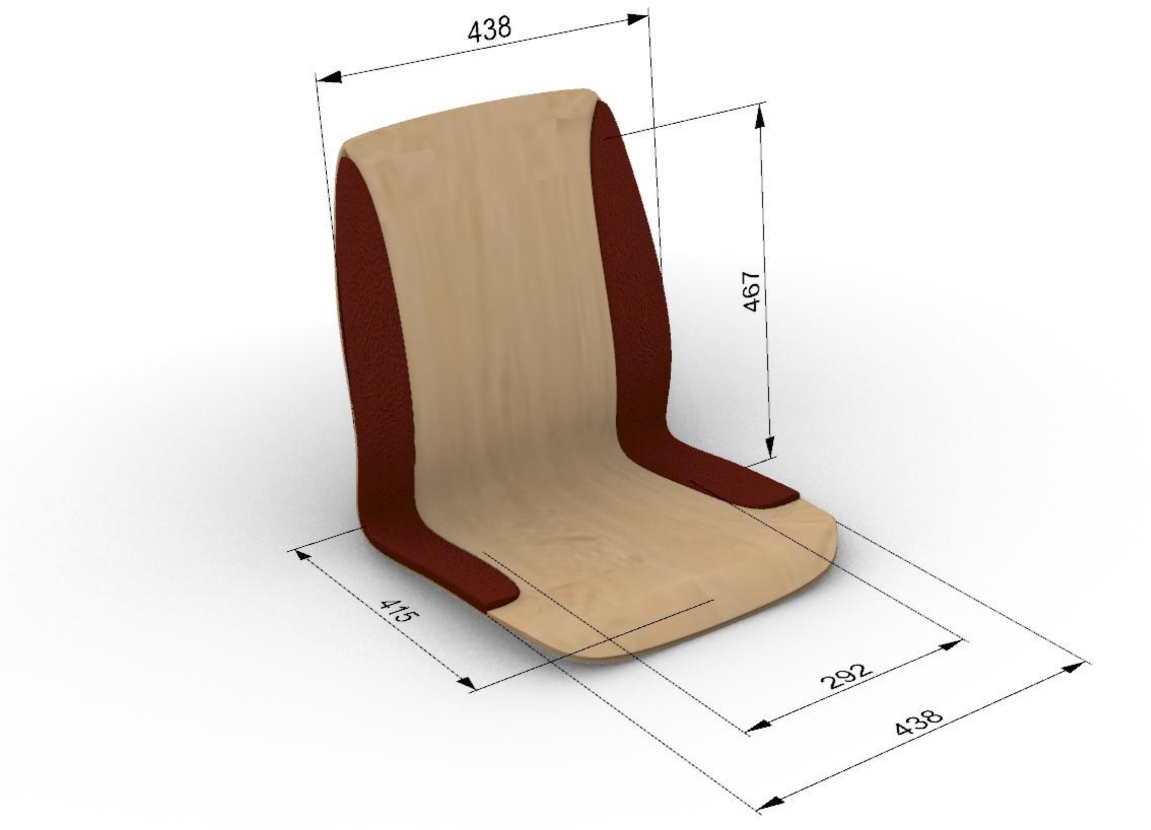

Fig. 6- 41 Passenger - dimensions

6.3.3 Boarding and Alighting

A STOP button and a ticket validation terminal are located in the door area. The STOP button is at a height of 1170 mm, and the terminal at a height of 1280 mm, which corresponds to the natural reach of a standing passenger. Vertical handrails with a diameter of 35 mm provide a secure grip when boarding, alighting, and during the ride.

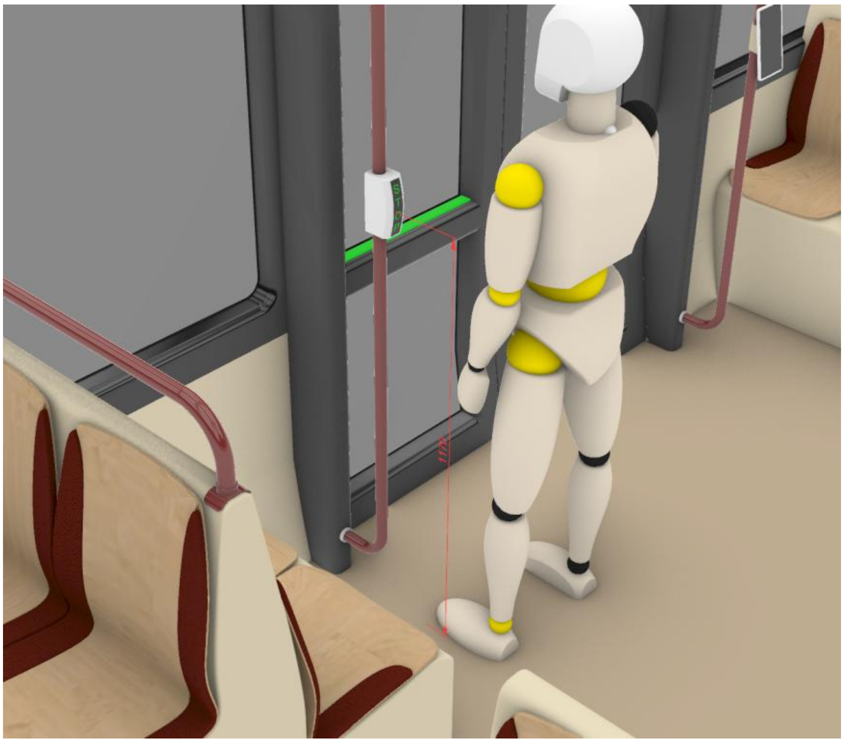

Fig. 6- 42 STOP button height

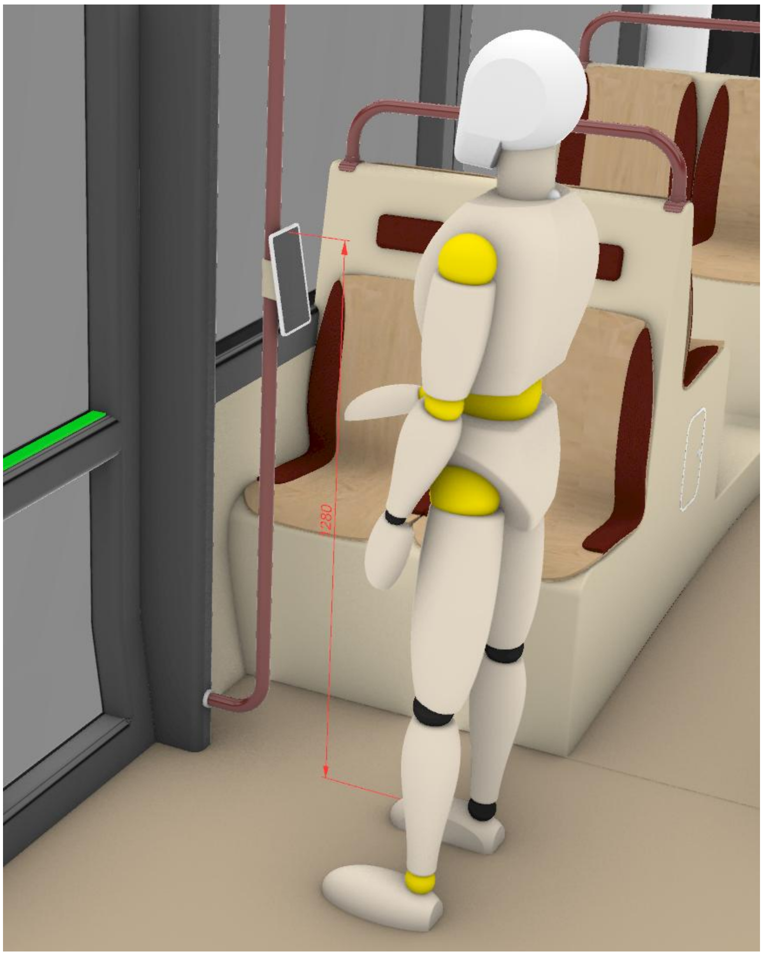

Fig. 6- 43Ticket station height

Three double-leaf doors and two single-leaf doors are designed on each side of the tram. The double-leaf doors have a total width of 1500 mm, with each leaf measuring 750 mm in width. The single-leaf doors are 750 mm wide. The door opening height is approximately 2190 mm, and the step height above the track level is 350 mm.

Fig. 6- 44 Door size

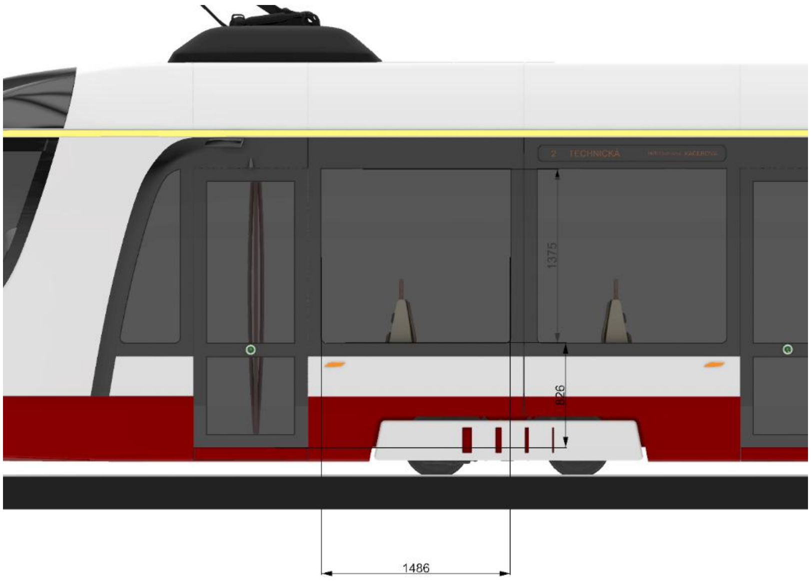

Fig. 6- 45 Window size

Low-floor design

85% of the passenger compartment area is low-floor (green section); the only raised sections are the converted parts of the cab, as the elevated cab provides better visibility for the driver. Two steps lead up to this platform, each 242 mm high and 300 mm long.

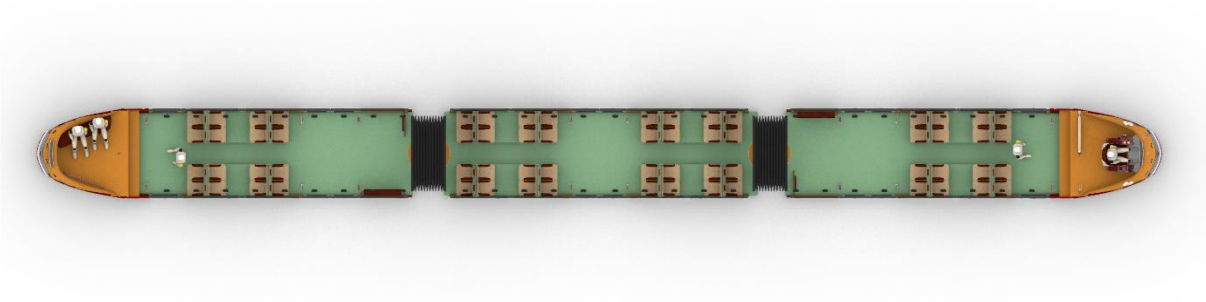

Fig. 6- 46 Low floor diagram

7 CONCLUSION

This thesis focused on the exterior and interior design of a semi-autonomous tram intended for a gradual transition from conventionally driven operation to fully autonomous operation. The main objective was to create a design that would not be limited to a single specific phase of automation, but would be capable of adapting to the long-term evolution of tram transport. For this reason, the tram was not designed solely as a vehicle for GoA3 mode, but as a flexible platform capable of operating in GoA2, GoA3, and GoA4 modes throughout its lifecycle.

The literature review analyzed the regulatory, technical, ergonomic, and operational requirements that fundamentally influence the design of a tram vehicle. An important part of the work was also a comparison of current trams and their exterior, interior, and driver's cab designs. This analysis revealed that, in addition to technical parameters, a modern tram must also respond to the changing relationship between the vehicle, the operator, passengers, and the surrounding urban environment. The role of the steward has therefore become a significant topic; during the transitional phase of automation, the steward does not merely assume passive oversight of the system but becomes a crucial element of safety, communication, and passenger trust. His workflow was analyzed based on current drivers and theory, and a solution was proposed accordingly

The proposed design for the driver/steward workstation represents one of the main parts of this work. The cabin was conceived as a modular space that allows for conventional driving, a monitoring mode, and future conversion into a passenger area. The driver's seat is designed as a compact control station with integrated controls in the armrests, a display, and the option to use a tablet, which the steward can carry while moving around the vehicle. This supports the active nature of their work while reducing the risk of loss of attention during long-term monitoring of the automated system. The cabin's adaptability also responds to the long service life of tram vehicles, which significantly exceeds the duration of individual technological phases of automation.

The tram's exterior was designed as a combination of contemporary technical expression and retro-modern elements referencing the history of urban tram transport. The design seeks to build on the identity of Škoda Group trams, while also introducing its own character through circular lighting elements, clean surfaces, and a light line encircling the vehicle. Lighting plays a particularly important role in a semi-autonomous vehicle, as it can clearly inform the surrounding environment of the tram's current operating mode. The design thus views lights not merely as an aesthetic detail, but as a communication tool between the vehicle, passengers, pedestrians, and other road users.

The passenger interior was conceptualized to support the overall unity of the design and meet requirements for clarity, durability, ease of maintenance, and comfort. Emphasis was placed on low-floor design, a sufficient number of doors, space for strollers and wheelchairs, clear door signaling, and material solutions suitable for public transport. The combination of wood and upholstered seat sections represents an effort to combine higher visual quality of the interior with practicality and resistance to soiling.

The resulting design demonstrates that the future of tram transport cannot be viewed merely as a technical transition toward autonomy. It is equally important to address the vehicle’s spatial layout, passenger confidence, communication with the surroundings, operator ergonomics, and the ability to gradually adapt to new operating conditions. The proposed tram therefore represents a possible direction for the development of an urban rail vehicle capable of combining technical readiness for autonomous operation with human supervision, safety, and high-quality design.

The objectives of the thesis were fulfilled by designing a comprehensive concept for a semi-autonomous tram, which includes the exterior, a modular driver/steward cabin, a basic interior design for passengers, vehicle communication elements, and ergonomic validation of the main parts of the design. The thesis also opens the door to further development, particularly in the areas of digital interfaces, detailed design of autonomous systems, testing of light communication with the surroundings, and more in-depth verification of the steward’s operational scenario in a real-world urban transport environment.

8 RESEARCH RESULT ACCORDING TO RIV

Tab. 8- 1

Result category	Functional sample
Result name	Semi-autonomous tram
Author	Bc. Miroslav Pleskal
Location of the Result Storage	VUT Brno

9 LIST OF REFERENCES (IN ACCORDANCE WITH THE ČSN ISO 690 STANDARD)

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10 LIST OF ABBREVIATIONS, SYMBOLS AND VARIABLES

Symbol	Meaning
mm	millimetre
m	metre
km	kilometre
kWh	kilowatt-hour
°	degree
%	percent
CZK	Czech koruna
EUR	euro

Abbreviation	Meaning
3D	Three-dimensional
ABS	Acrylonitrile butadiene styrene
AED	Automated external defibrillator
BUT	Brno University of Technology
CAF	Construcciones y Auxiliar de Ferrocarriles
CEN	European Committee for Standardization
CEN/TR	CEN Technical Report
ČSN	Czech technical standard

Abbreviation	Meaning
DPMB	Brno Public Transport Company / Dopravní podnik města Brna
DPO	Ostrava Public Transport Company / Dopravní podnik Ostrava
DRL	Daytime running light
ECE	Economic Commission for Europe
EN	European Standard
GoA	Grade of Automation
HPL	High-pressure laminate
LCC	Life-cycle cost
LED	Light-emitting diode
LiDAR / LIDAR	Light Detection and Ranging
LRV	Light rail vehicle
PID	Prague Integrated Transport
PRM	Persons with reduced mobility
ROPID	Regional Organizer of Prague Integrated Transport
STRMTG	Technical Agency for Ropeways and Guided Transport Systems
TNG	Tram New Generation
UITP	International Association of Public Transport
UN	United Nations
UNECE	United Nations Economic Commission for Europe

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Small-format posters

- Design poster (A4)
- Technical poster (A4)
- Ergonomic poster (A4)
- Summary poster (A4)

Separate supplements

- Design poster (B1)
- Technical poster (A1)
- Ergonomic poster (A1)
- Summary poster (A1)
- Physical model (scale 1:15)

14 APPENDICES

Semi-autonomní tramvaj

2026

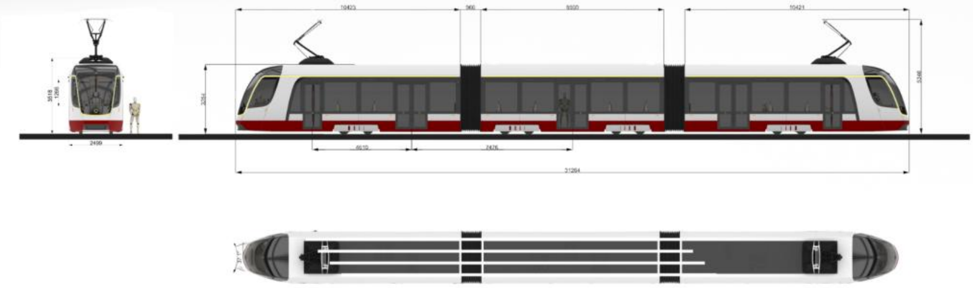
Miroslav Pleskal

vedoucí: M. A. Tanguy Hervé André Pierre Prévot

ANTRA je designový koncept poloautonomní obousměrné tramvaje navržený pro budoucí městskou dopravu v Brně. Projekt reaguje na postupný přechod od konvenčního řízení k automatizovanému provozu a nově definuje kabinu řidiče jako flexibilní pracoviště řidiče/stewarda. Modulární řešení interiéru kabiny umožňuje přizpůsobení různým stupňům automatizace během životního cyklu vozidla. Původní pracoviště řidiče tak může nadále sloužit jako stanoviště stewarda, nebo být přeměněno na další prostor pro cestující. Exteriér tramvaje propojuje moderní tvarování s odkazy na historické tramvaje, například prostřednictvím středového světelného prvku na čele vozidla. Návrh tak kombinuje výraznou vizuální identitu, ergonomické řešení interiéru, bezpečnostní požadavky a dlouhodobou modularitu.

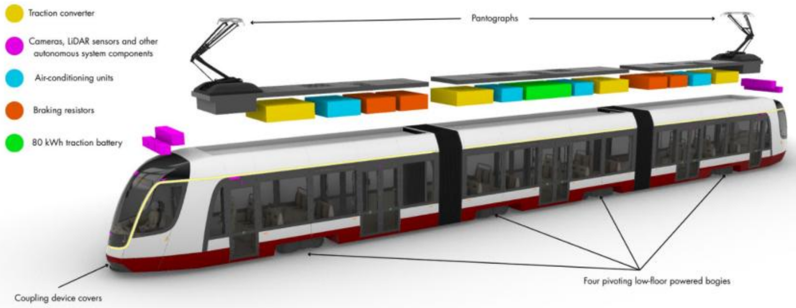
ANTRA

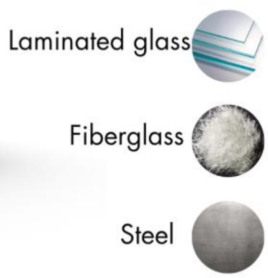
SEMI-AUTONOMOUS TRAM



TECHNICAL POSTER

ANTRA concept—a bidirectional, three-section, semi-autonomous tram. The vehicle is designed with four low-floor articulated bogies, which ensure suitable handling characteristics in urban traffic and good curve-negotiating ability. The basis of the design is a steel load-bearing frame to which steel and fiberglass body panels are attached. As with most modern trams, the main technical equipment is concentrated in the roof section of the vehicle. This is where the pantographs, traction converters, air conditioning units, braking resistors, and other auxiliary systems are located. This solution frees up space in the interior, facilitates service access, and allows the vehicle to maintain its low-floor layout.





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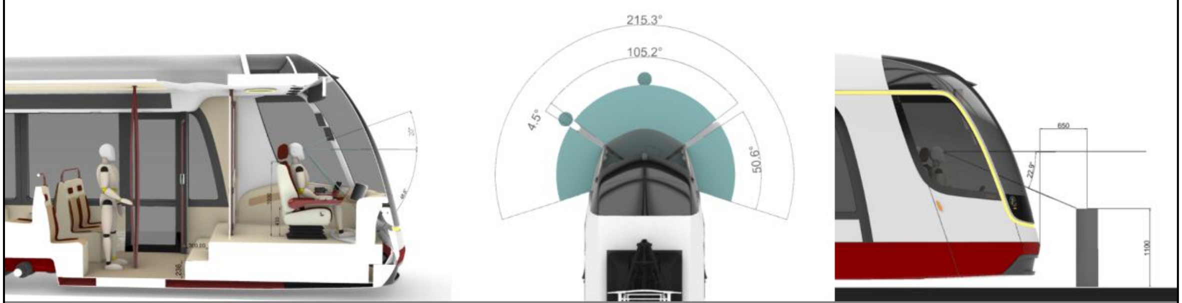
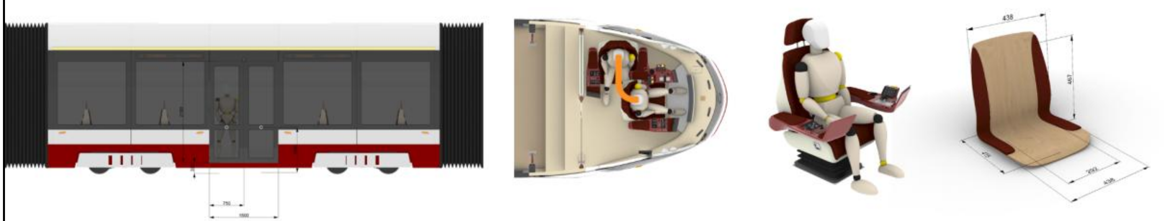
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ FAKULTA STROJNÍHO INŽENÝRSTVÍ

ÚSTAV KONSTRUOVÁNÍ

odbor průmyslového designu



ERGONOMICAL POSTER



The tram is 85% low-floor, with the passenger floor positioned 350 mm above the top of the rail. Raised areas are located mainly in the driver's cab section, which is accessed by two steps and is positioned 470 mm higher than the low-floor passenger area. This elevated position improves the driver's visibility and provides sufficient space for the integration of ergonomic controls. The combination of a large front windscreen and narrow A-pillars ensures a wide field of view in all directions. The driver's cab layout was designed in accordance with the relevant ergonomic and safety standards.

Low floor High floor + 470 mm

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ANTRA

SEMI-AUTONOMOUS TRAM

ANTRA is a design concept for a semi-autonomous bidirectional tram designed for future urban transport in Brno. The project responds to the gradual transition from conventional driving to automated operation and redefines the driver's cab as a flexible driver/steward workstation. The modular interior design of the cabin allows for adaptation to various levels of automation throughout the vehicle's lifecycle. The original driver's workstation can thus continue to serve as a steward's station or be converted into additional passenger space. The tram's exterior combines modern styling with references to historic trams, such as the central lighting element on the front of the vehicle. The design thus combines a distinctive visual identity, an ergonomic interior layout, safety requirements, and long-term modularity.

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