Electric car Dubina Evo and its production

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Abstract

This unique edition presents the Dubina Evo electric sports car and its small-scale manufacturing at a mini-factory. The book is designed for anyone interested in electric vehicle engineering, industrial design, manufacturing management, and the creation of production facilities. The material is presented with a practical focus and can be used as a textbook, a conceptual project, or a blueprint for a real-world enterprise. It provides a consistent and detailed description of the car's design, operating principles, and the mini-factory ecosystem. The text offers an accessible explanation of the physicochemical processes occurring within the car. It covers revolutionary technologies destined to elevate electric car to the next level and usher in a new era of autonomous electric machines. Reading this book will be an extraordinary journey into the world of advanced manufacturing and technology.

Contents

Preface

We live in a world of evolving technologies. They enhance devices, making them more efficient and environmentally friendly. Some believe that everything has already been invented, that civilization has reached its peak and there is nothing left to discover, yet new breakthroughs occur constantly. When man first created fire, it provided warmth, light, and protection—it seemed nothing could be better. However, as time passed, humanity devised new solutions. Electricity replaced fire for lighting. LED lamps replaced incandescent bulbs. In my childhood, I imagined robots and transformers powered by the energy of atomic bonds, in my vision, there was no room for liquid fuel or firewood. A car is a technical device consisting of many components that evolve alongside technology. Today, there are over a billion internal combustion engine vehicles registered worldwide. The liquid fuel required for these vehicles produces toxic substances upon combustion. Hydrocarbons, aldehydes, and sulfur dioxides contained in exhaust gases cause respiratory diseases and cancer in urban populations. People stuck in traffic jams for hours are most vulnerable to the harmful effects of exhaust fumes. An electric car does not pollute the atmosphere. In many ways, it is superior to an internal combustion engine vehicle. Unlike an internal combustion engine car, the construction of an electric car lacks large mechanical units such as a starter, carburetor, or gearbox. A car with an electric motor accelerates faster, changing the motor's rotation speed is achieved electronically at the software level using a microcontroller rather than mechanically.

In 2012, I was surprised by the absence of electric cars in cities. People could come home from work and plug in their car to charge overnight when electricity rates are lower, and in the morning, set off again without wasting time at a gas station, yet for some reason, they did not. Perhaps it is because there are so few electric car models in the world. Therefore, I decided to create an exceptional electric car. That was when I began working on the electric car project. Electric cars were rare back then. I considered various types of vehicles and initially chose an economy-class electric city car. To keep costs low, economy-class cars do not possess outstanding technical specifications. Their materials are inexpensive, motors are not powerful, and the design and parts are intended for mass production. The most advanced technologies are used in racing cars. To achieve high speed, high power, and low weight, they utilize the best components and materials. I changed my choice and began designing a racing car. When engineering the car, I relied on rules that refine the construction. The desire to create the ideal racing car helped me find new technologies not used in other vehicles. I named this car Evo, derived from the word "evolution." A racing car evolves; it becomes faster, lighter, and more powerful. A distinctive feature of the Evo is that it is designed for two people with the convenience of operation on public roads. The Evo is an all-wheel-drive electric supercar, with each wheel equipped with an electric motor. The Evo utilizes fast-charging technology as well as engine braking. Thanks to the use of four electric motors, the car is capable of rotating around its own axis. The car's construction is presented in this book part by part. Images of the car and its components are rendered from a 3D model used in a 3D constructor. The assembly of the 3D model in the video game is performed by solving tasks based on the operating principles and properties of the parts.

The Dubina Evo electric supercar is a complex and expensive vehicle, requiring significant material investment for its production. Such cars are assembled for auto racing or commissioned for private collections. While designing the Evo, I thought about how to manufacture it and what technologies and equipment would be required. I dreamed of my own production and planned for small-scale manufacturing. As the project progressed, the factory layout was reimagined and altered. The result is a production building of the most minimal size possible in which a car can be manufactured. The structural form of the building arises from the technological process requirements and meets standards for strength, stability, and durability. For construction, the latest production methods are used to satisfy requirements for material efficiency, industrial manufacturing, and rapid assembly. Standard products made via the latest production methods are widely used in the structure. Production and domestic facilities fit within a single building with a total area of 960 m². The layout of the rooms, the organization of the assembly area, the arrangement of production stages, and the choice of engineering systems were formed based on the actual tasks of small-scale car production. By reading this book, you will learn how modern manufacturing is organized. Here, the production process possesses flexibility, innovation, and the ability to rapidly refine the design during the work process. You will see the factory from the inside, from the sturdy steel framework and workshops flooded with natural light to the director’s office, where the enterprise’s course is charted. The book introduces the mini-factory personnel, consisting of sixteen people working harmoniously, like a single sports team. Special attention is paid to the interaction of the people involved in production, the role of each specialist, and how their joint work turns an idea into a finished product. This book is a guide to a world where engineering thought takes shape, where every nut and every byte of software code matters, and where a small team is capable of creating large and complex machines.

1 Electric car Dubina Evo

1.1 General Information about the Dubina Evo car

The Dubina Evo is not merely a car, but a symbol of engineering mastery and futuristic vision (Figure 1). Every element has been thought out to the smallest detail. The car is designed for both the racing track and city driving. The streamlined body is created for maximum aerodynamic efficiency, with a drag coefficient of 0.25. Body parts made of carbon fiber have significantly reduced weight and increased structural rigidity. With a mass of 1200 kg, the car is capable of accelerating to 100 km/h in just 2.7 seconds, reaching a top speed of 300 km/h. The car's dimensions are 4.6 m in length, 2 m in width, and 1.2 m in height. The wide axle improves handling and increases stability by reducing body roll during cornering. Additionally, the wide axle allows for the use of wider tires, increasing the contact patch with the road.

Figure 1 – Dubina Evo electric car

The car features a monocoque structure. The monocoque acts as a load-bearing element, distributing stresses throughout the entire structure. It includes windows for routing electrical wiring and mounting holes for attaching front and rear frames with double-wishbone suspension. The front and rear frames are made of circular and square section aluminum profiles. An electric power steering mechanism is attached to the front of the monocoque. Two electric powertrains, consisting of four motors in total, are installed on the monocoque—one at the front and one at the rear. Their combined power is 800 kW. Having one electric motor per wheel provides not only high power but also ideal torque distribution. The brushless motor features an eight-pole rotor with neodymium permanent magnets and a twelve-winding stator. To reduce motor weight and increase torque, the rotor is hollow and made of composite material. Each motor has an electronic control unit. This control unit allows for variable speed control of the operating electric motor. It is responsible for timely switching of the winding supply voltage based on the rotor's rotation, utilizing rotor position sensors. A distinctive feature of this motor is the capability for braking through the reverse control of a three-phase asynchronous motor. The motor can operate briefly with peak current, providing immense force for short periods. When the car coasts or moves downhill without power, the motor continues to rotate, acting as a generator. The generated current is returned to the battery, allowing for energy recovery rather than wasting it in the motor control circuit. This configuration enables energy recuperation. Having a motor on each wheel increases maneuverability by varying the rotation speed of the wheels depending on the steering angle. During a turn, the wheel on the outer radius rotates at a higher frequency than the inner wheel, proportional to the steering angle. Each motor has a separate reduction gearbox. Cooling of the electric motors is provided during movement by the airflow passing under the car's underbody. The electric motors are powered by an 85 kWh lithium-ion battery pack mounted at the rear of the monocoque (Figures 2, 3).

Figure 2 – Dubina Evo with the front-mounted powertrain.

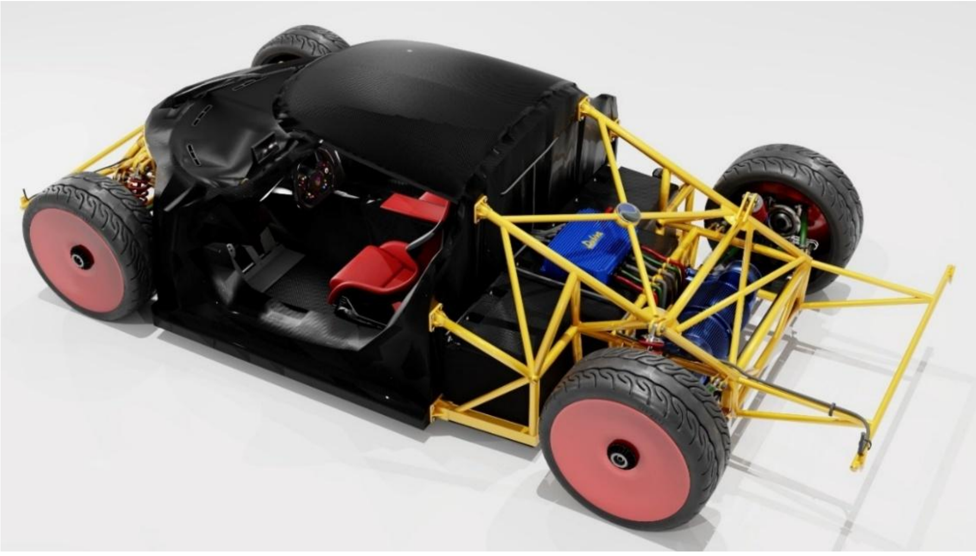


Figure 3 – Dubina Evo with the rear-mounted powertrain

The speed controller is located on the battery pack. The battery provides a range of approximately 400 kilometers at a moderate driving pace. The interior of the car is simple yet high-tech, designed for comfort and convenience. Screens display charge levels, routes, and energy-saving tips. The driver's seat is engineered so that all necessary controls are within easy reach. A digital dashboard and touchscreen displays provide full information on the vehicle's status. Lightweight sports seats are installed in the monocoque. Luxurious materials and high-quality finishing create an atmosphere of exclusivity (Figures 4, 5). The car is operated via two pedals: an accelerator (current) pedal and a brake pedal. The pedal construction is simple and reliable, made of aluminum alloy. The pedals are 28 cm long, with the entire pedal assembly measuring 43 × 43 × 28 cm, mounted on the monocoque floor. The operating principle involves changing the resistance of a slide potentiometer connected to the pedal at a right angle. The potentiometer sends a signal to the controller, and the travel controller manages the motors. The Evo steering wheel is designed for sporty driving with a diameter of 310 mm. The small diameter increases steering speed. The steering wheel travel is 180°, allowing the driver's hands to remain in one position. The wheel is made of carbon fiber and features control buttons. On the right side of the steering wheel, there is a five-button pad for navigating menu settings. The horn button is located in the center. Signals from the buttons are transmitted to shift registers located inside the steering wheel housing. The car's central processor is programmed to receive signals from these shift registers.

Figure 4 – Dubina Evo with open doors

Figure 5 – Dubina Evo with open doors

1.2 Car engineering and design

Software forms the foundation of all design activities. Various programs serve as tools for engineering, each performing a distinct function. The creation of the information model for the Dubina Evo car began with a conceptual sketch. This sketch was created in Krita, a free raster graphics editor. It is an open-source software, part of the KDE suite, developed primarily for artists and photographers and distributed under the GNU GPL. Krita supports non-destructive layer and mask editing, various color spaces, and models such as RGB, CMYK, and LAB in modes ranging from 8 to 32-bit floating point per channel. Additionally, it features popular filters, adjustment layers, masks, dynamic filters, and a series of retouching tools. The developers' main priority is providing extensive capabilities for artists. The conceptual sketch presented the car's vision, overall dimensions, and structural features. After defining the primary dimensions and design characteristics, drawings of the future car were produced. These drawings were created using LibreCAD, a cross-platform, open-source 2D CAD application based on QCad. LibreCAD is designed for 2D engineering tasks such as preparing technical and architectural drawings, schematics, and plans. It runs on Linux, Windows, and Mac OS X, and is distributed under the GNU General Public License version 2. The source code is written in C++ using Qt libraries. Subsequently, a three-dimensional model was built based on these drawings. Blender was used for 3D modeling (Figure 6).

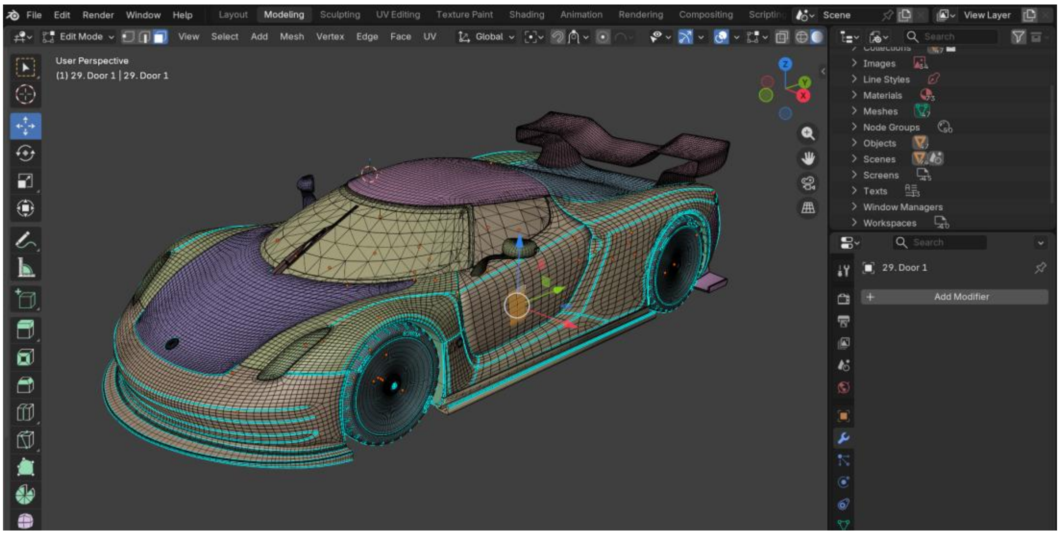


Figure 6 – Blender software interface

It is a comprehensive suite combining all modern 3D modeling capabilities. The program is not demanding on computer hardware, it can be used for industrial design, organizing assembly structures, and preparing models for 3D printing. It supports all major types of modeling: free-form sculpting, solid body work (including direct editing), parametric dimensioning, and support for OBJ and STL formats as imported geometry. All modeled elements can serve as templates for future work. The software supports various 3D file formats for import and export, including Alembic, 3D Studio (3DS), Filmbox (FBX), Autodesk (DXF), SVG, STL (for 3D printing), UDIM, USD, VRML, and WebM.

Three-dimensional models of individual parts were grouped into sub-assemblies and then joined into the car's main sections. The car body was constructed using sculpting mode. The build began with a single polygon, which was subdivided into four equal polygons. By adding polygons one by one, the body shape was formed. In areas requiring more detail, polygons were subdivided further. After building and editing one longitudinal half of the body, a symmetry modifier was applied. This modifier creates a symmetrical copy of the part that reflects any changes made to the original. Joining the two symmetrical halves resulted in a complete body where modifying one side automatically updates the other. To ensure smooth, even lines on the body, 3D templates (French curves) were used. A cylinder was utilized to create the precise circular arcs of the wheel arches, acting as a template to align the polygon lines. Rectangular planes were used to construct the straight lines on the doors and side sills. These 3D templates allow for checking the straightness of polygon lines from all angles. Additionally, glossy materials are used to visually verify the smoothness of the surface. Not only the material type but also its color affects the visual assessment of surface quality.

Mechanical components and reduction gearbox gears were designed in FreeCAD. This is a general-purpose parametric 3D CAD modeler with open source code (LGPLv2+ license). The foundation of solid modeling in FreeCAD is the Boundary Representation (B-Rep) principle, though it also supports polygon meshes. The geometric kernel of FreeCAD is OpenCASCADE. Beyond mechanical engineering, FreeCAD can be used for architectural design or finite element analysis (FEA). FreeCAD supports over 30 file formats for importing.

3D printing was employed to manufacture car parts. 3D printing technology is universal, with part size limited only by the printer's build volume. A 3D printer is a peripheral device that creates a three-dimensional object layer-by-layer from a digital 3D model. 3D printing requires no additional tooling; all types of parts can be made on the same printer. To print a part, the original 3D model format must first be converted into G-code. This is the standard programming language for computer numerical control (CNC) machines, established by the Electronic Industries Alliance in the early 1960s. The Slic3r program is used to convert STL files into G-code. This software allows the user to set print speed, infill density, and many other parameters. After conversion, the G-code file is loaded into the 3D printer. Due to the layer-by-layer additive process, parts of any complexity can be manufactured. Various materials are used for 3D printing, the most common being PLA, ABS, and PVA plastics, nylon, rubber, and metal powders. The most efficient 3D printing process is stereolithography (SLA). In stereolithography, a layer of material is formed across the entire surface simultaneously. Intense light beams from a projector strike a transparent glass plate at the bottom of a vat filled with liquid photosensitive resin. The projector beneath the glass transmits the cross-sectional image of each part layer. Thus, the material hardens on the glass and is pulled upward out of the vat, layer by layer.

The car's operation is managed by programs written in the Visual Studio Code (VS Code) integrated development environment. As a modern, light-weight, yet powerful IDE, VS Code is ideal for software development. Due to its flexibility, extensibility, and support for numerous programming languages, VS Code allows developers to efficiently create, debug, and test the code that powers the power electronics, motor control systems, sensors, and onboard services. The electric car's design utilizes various microcontrollers and control units, for which code is written in C, C++, Python, and Rust, alongside scripts for diagnostics and telemetry. VS Code provides full support for all these languages, including autocompletion, error highlighting, formatting, and static analysis. Managing the car's code requires strict discipline, as errors can lead to the malfunction of the motor or power units. VS Code features built-in Git support, enabling developers to create branches, compare changes, perform code reviews, and document firmware versions for different vehicle modules.

VS Code supports hardware debugging via JTAG/SWD adapters, USB-UART, and CAN buses. This is particularly vital for the Evo electric car, as many modules (e.g., BMS, inverter, motor controllers) communicate via CAN. Through extensions, one can monitor CAN messages directly from VS Code, perform logging, and test algorithms in real time. Regarding containers and DevOps: the Evo project uses a flexible build system involving Docker containers and automated firmware compilation. VS Code supports remote development, allowing projects to be opened within virtual machines or containers without the need for local environment setup. In addition to code, the Evo project includes technical documentation: schematics, protocol descriptions, and sensor settings. VS Code enables convenient work with Markdown, YAML, and JSON, facilitating project management and information exchange between programmers, electrical engineers, and designers.

1.3 Dubina Evo car construction

1.3.1 Monocoque

The monocoque is a single structural element, much like a butterfly's cocoon, bonded from woven high-strength carbon fibers (Figure 7). Inside the monocoque are the driver and passenger compartments. The term "monocoque" comes from the French word meaning "single shell" or "single hull." The defining characteristic of a monocoque is its specific strength: it is exceptionally strong, rigid, and lightweight. A carbon fiber monocoque provides excellent insulation for the passenger cabin against vibration and noise from mechanical components, as well as tire road noise. It is the most critical, resource-intensive, and expensive structural part of the car. Furthermore, a carbon fiber monocoque is corrosion-resistant. The use of carbon fiber composites allows for a unique, streamlined shape where the entire single shell absorbs all the loads acting on the vehicle during movement. It serves as the primary chassis for mounting and securing the car's systems and mechanisms, with both the motors and the frame attached directly to it.

Figure 7 – The Dubina Evo car monocoque

The engineering of the monocoque focuses on the most rational distribution of material to maximize its load-bearing capacity. The goal is to create a clear, continuous form that ensures the direct transfer of loads from the point of application to the point of reaction. The monocoque structure is rigid to ensure precise handling and lightweight to minimize inertial loads and oscillations of the sprung mass relative to the vertical axis. It is designed to be durable enough to withstand cyclic road loads, as well as stresses from the powertrain, driver, and passenger. A monocoque's design is evaluated based on its strength and stiffness, with studies focusing on its deformability. This monocoque exhibits no sagging or bending. Under a concentrated mid-load of 20 kN, the deflection at the center does not exceed 1 mm, and the deformation of the door aperture contours is no more than 0.5 mm. Since carbon fiber is not as stiff as steel or aluminum, reinforcing inserts and stiffening ribs are integrated into the design (Figure 8). The safety of the driver and passenger depends heavily on the monocoque. The front and rear sections of the car—consisting of bumpers, body panels, and frames—are less rigid than the monocoque and have lower impact resistance. Consequently, during a collision, the deformation of these outer sections absorbs the impact energy, protecting the passenger cell within the monocoque from deformation. This ensures a "survival space" for the occupants. The monocoque weighs 72 kg and is a non-detachable unit. It consists of a floor (base), roof, side panels, and front and rear sections. Assembly is performed on a specialized jig. Using epoxy adhesive and screws, the front and rear sections are bonded to the lower base, followed by the left and right halves, with the roof installed last.

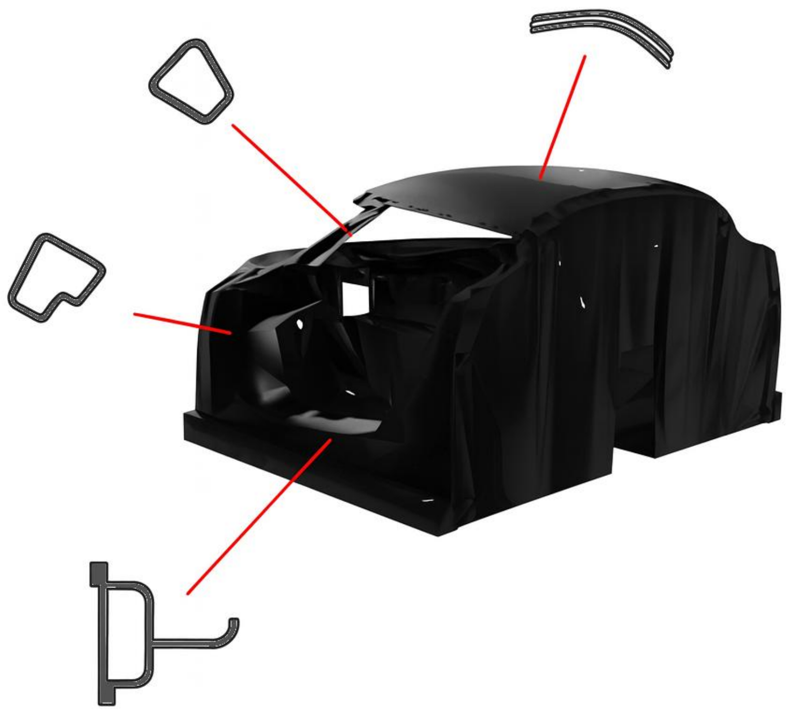


Figure 8 – Monocoque cross-sections

All parts of the monocoque are manufactured from prepreg using the hand lay-up method. Carbon fiber prepreg is used in rolls 1.25 m wide and 50 m long, with a density of 422 g/m². The molding process involves layering the prepreg into a matrix (mold). Since the outer surface of the monocoque experiences maximum stress during bending, high-modulus carbon fibers are laid in these areas. The first layer of carbon is the thinnest to ensure the smoothest possible finish. The carbon precisely follows all curves of the mold without delamination or air pockets. Cutting of the carbon fabric is performed by a plotter or according to a template. Templates are cut from a pattern sheet (Figure 9), where part numbers are indicated. Depending on the required thickness of the part, the necessary number of prepreg layers is prepared and stored in an accessible location in the order of their lay-up. Monocoque parts with complex geometries utilize cuts consisting of several individual elements and are manufactured in multi-part volumetric molds. A release agent, such as wax and PVA (polyvinyl alcohol), is applied to the mold surface to ensure safe extraction of the finished part after the resin cures. Once the carbon is laid into the prepared matrix, it is covered with a lid that matches the part's shape, pressing the prepreg firmly to ensure correct geometry. After the resin has cured, the part is removed from the mold and sent to the machining hall. The sanded, smooth, and glossy surface of the monocoque reveals the twill-weave carbon fabric beneath a layer of transparent polymer.

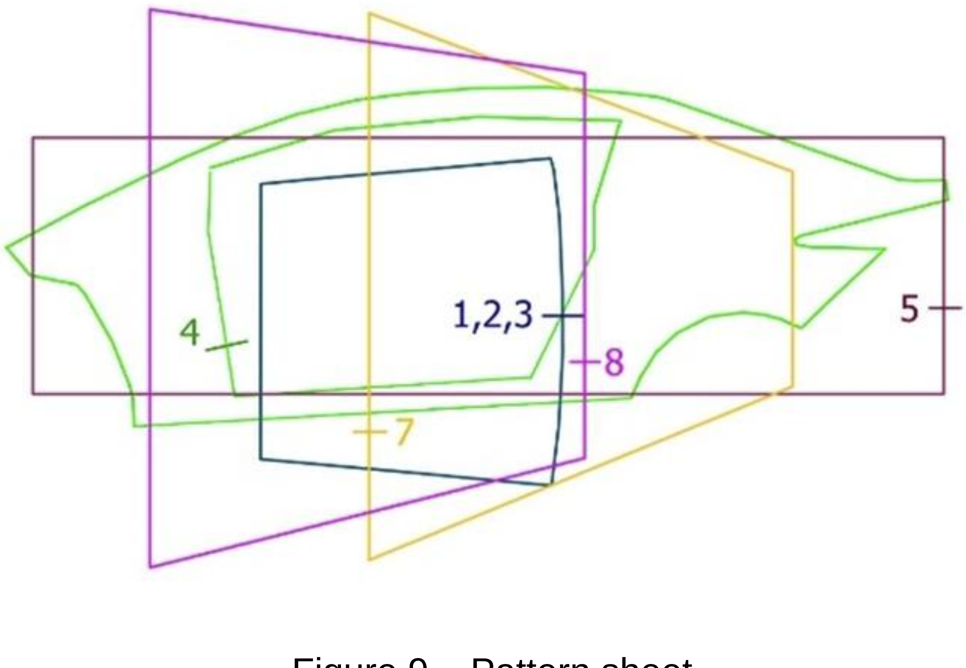


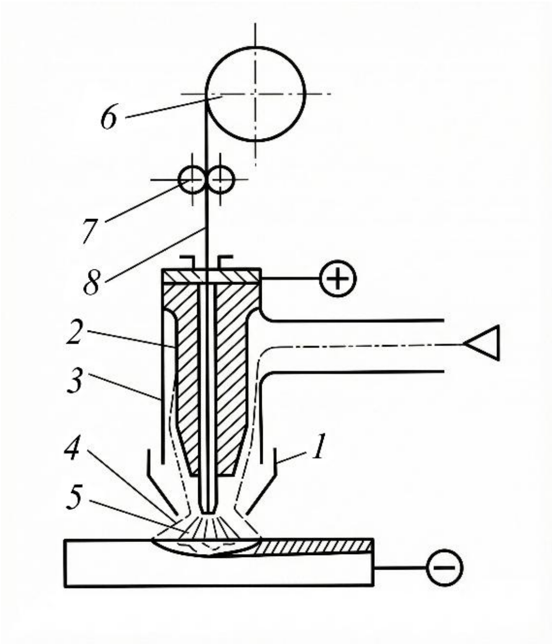
Figure 9 – Pattern sheet

1.3.2 Space frame

The car's frame consists of two parts: front and rear (Figure 10). They are attached to the monocoque at the front and rear respectively. The front frame houses the front suspension, anti-roll bar, front trunk, front bumper, and headlights. The rear frame carries the rear motors, battery pack, rear suspension, anti-roll bar, rear trunk, rear bumper, and taillights. The frame design is based on full triangulation of all planes. Triangulation is the process of dividing a complex polygonal area into a set of triangles. The advantage of this type of construction is the combination of lightweight with high rigidity and strength. During the frame's engineering, load-bearing points were carefully considered, and nodes were placed in these locations to distribute loads evenly across all parts of the frame. To increase the rigidity of the rear frame, a crossmember is installed between the shock absorber mounts.

Figure 10 – Space frame on the Evo monocoque

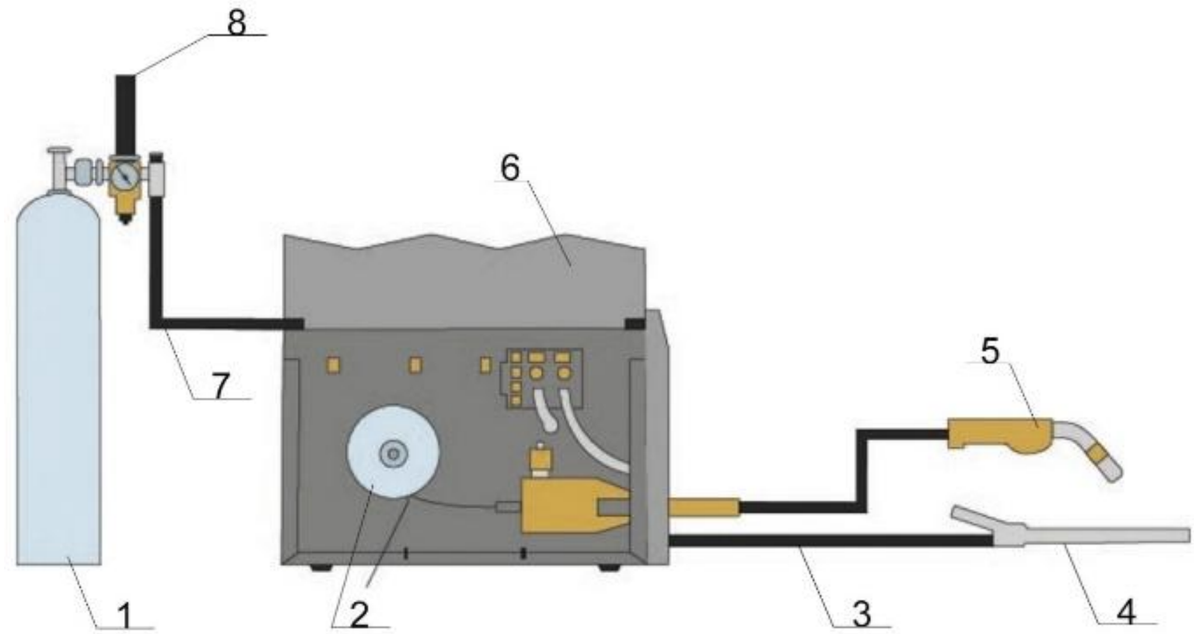
The frame is manufactured from 6061 structural aluminum alloy. Aluminum offers several advantages over other metals: low weight, high strength, good weldability, corrosion resistance, and resistance to temperature fluctuations. Alloy 6061 possesses a good combination of mechanical properties and can withstand significant loads before failure. Its ultimate tensile strength is 310 MPa, and its modulus of elasticity is 68.9 GPa. Alloy 6061 undergoes heat treatment to increase strength and becomes tougher after tempering. This alloy is easily joined by welding, machined by milling or drilling, and readily deformed into desired shapes. Alloy 6061 has a low density of 2.7 g/cm^3 and excellent corrosion resistance due to the formation of an Al_2O_3 oxide film, which is non-reactive with corrosive elements. Magnesium (Mg) and silicon (Si) are used as the primary alloying elements to provide strength and corrosion stability. Due to its copper content, alloy 6061 is slightly less corrosion-resistant than some other alloys (such as 5052, which is copper-free). However, it resists corrosion from concentrated nitric acid, ammonia, and ammonium hydroxide. The chemical composition of 6061 alloy is: 97.9% Al, 0.6% Si, 1% Mg, 0.2% Cr, and 0.28% Cu. Using standard profiles for frame fabrication simplifies the assembly process. The frame structure consists of simple elements: circular and square section tubes, angles, and plates. This type of construction is cost-effective and easier to maintain and repair. The large gaps between the tubes facilitate the installation and removal of components located inside the frame. The circular shape of the tubes distributes loads effectively. High-load sections of the frame are made of tubes with a 40 mm diameter and 5 mm wall thickness (Ø40 × 5 mm). Lower-load sections use 30 mm diameter tubes with a 3 mm wall thickness (Ø30 × 3 mm). The mounting points for the battery and motors are made of 55 mm square tubing with a 5 mm wall thickness (55 × 5 mm). Suspension arm mounts are made of 8 mm thick plates. To increase strength and rigidity, 6 mm thick gussets are welded at the tube joints. The open ends of the tubes are welded shut using 1.5 mm thick aluminum sheet blanks to prevent water and dirt from entering. Before welding, the tubes are cut according to the drawings and labeled. The cut sections are then positioned on a welding jig table. Aligning the tubes with the drawing dimensions, they are fixed with special fixtures, using magnetic squares to set the required angles. The sections are then secured with tack welds. After verifying all dimensions and angles, final welding of all seams is performed. Seams are welded sequentially from one side to the other to avoid omissions. The strength and integrity of the frame depend strictly on compliance with the drawings and high-quality welding. Special attention is paid to the fit-up of elements to ensure a uniform fit and minimal gaps, which prevents excessive stress and ensures high-quality seams. Aluminum alloy 6061 tubes (square and circular) are joined using pulsed Gas Metal Arc Welding (MIG) in an inert argon gas environment, creating strong, permanent joints (Figure 11). Aluminum and its alloys possess specific properties that make welding more complex than steel, including: a tendency for porosity, high thermal conductivity, high oxygen affinity forming a stable Al_2O_3 oxide film, a high linear expansion coefficient, and a susceptibility to hot and cold cracking. Notably, the melting point of the oxide film (2050 °C) is significantly higher than that of aluminum itself (660 °C). Because of this oxide layer, a high current is needed to break through it with an electric arc, even though the aluminum beneath it melts at a much lower temperature.



1 – nozzle; 2 – contact tip; 3 – torch body; 4 – gas shield; 5 – molten metal; 6 – wire spool; 7 – feed rollers; 8 – welding wire.

Figure 11 – Pulsed gas metal arc welding in an argon environment

Using a constant high current can cause the molten pool to scatter, making the arc difficult to control and increasing the risk of undercuts and burn-throughs. If the current is too low, the oxide film won't break, and the filler metal will sit on the surface without fusing, resulting in a weak joint. Therefore, an MIG welder capable of automatically varying the current—pulsing between high current to break the oxide and low current to weld the base metal—is used. For welding the 6061 alloy, a universal MM215 welder is employed (Figure 12). This welding machine operates with a current range of 20 to 230 A at 240 V and weighs approximately 29 kg. It features technology that simplifies parameter setup and includes a soft-start function. The welding is performed manually with a torch, while the ER4043 aluminum filler wire is fed automatically. Since molten aluminum is highly fluid, welding is performed in the flat (downhand) position. The transfer of the melting electrode wire into the weld pool is the most critical part of the MIG process, influenced by the shielding gas, current, voltage, and wire diameter. AC mode allows for automatic polarity switching during the cycle: the beginning of the cycle breaks the oxide film, and the next part ensures deep penetration.



1 – shielding gas cylinder; 2 – welding wire; 3 – ground cable with clamp;
4 – workpiece; 5 – torch; 6 – MIG welder; 7 – gas hose; 8 – gas pressure/flow regulator.

Figure 12 – Welding setup

Weld quality depends heavily on surface preparation. Each part is cleaned even if it appears free of oil or debris. The oxide film is removed mechanically (using sandpaper or wire brushes) and chemically (using alkaline solvents followed by hot and cold water rinsing and drying). After cleaning, the surface is treated with a solvent (acetone or white spirit) and dried. All welds are of the highest quality with full penetration, completely encircling the tube perimeter.

After welding, weld spatters are removed, sharp edges are rounded, and all surfaces are ground smooth. Since the area near the weld typically retains only about 40% of the base metal's strength, the frame undergoes heat treatment (tempering) to restore strength. Finally, the frame is primed and painted (Figures 13, 14).

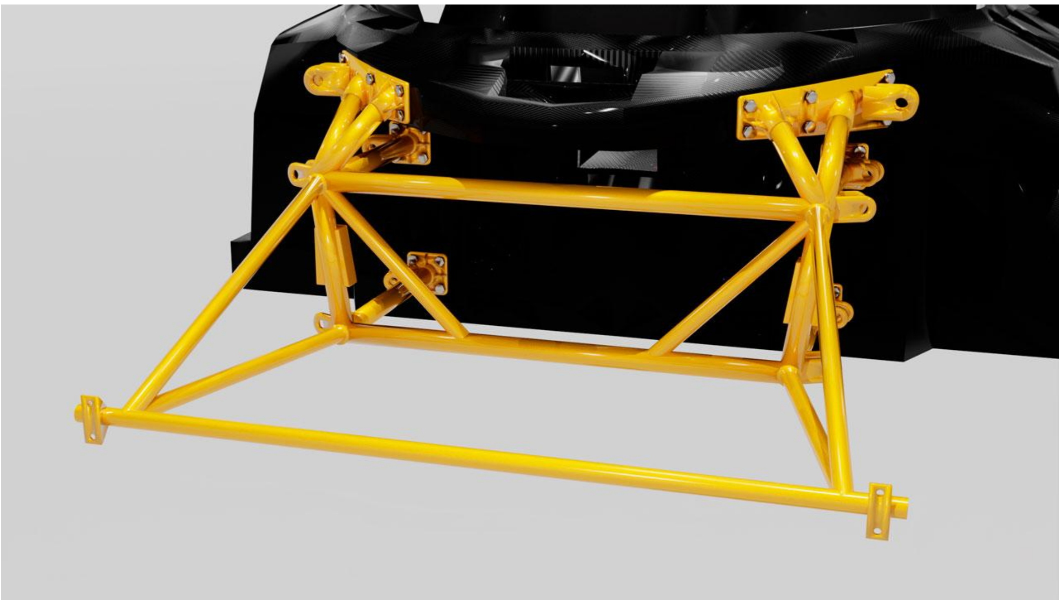


Figure 13 – Front section of the space frame

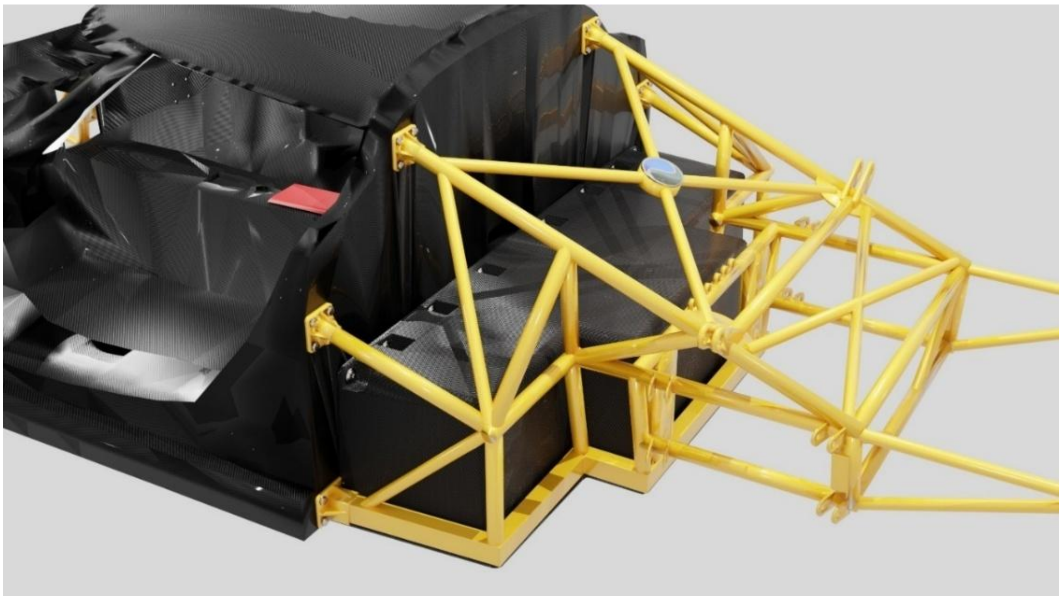


Figure 14 – Rear section of the space frame

1.3.3 Battery pack

An electric accumulator is a device capable of receiving electrical energy from an external source and subsequently releasing it (Figure 15). The process of supplying electrical energy to the accumulator is called charging. The process in which the accumulator delivers electrical energy to an external circuit is called discharging.

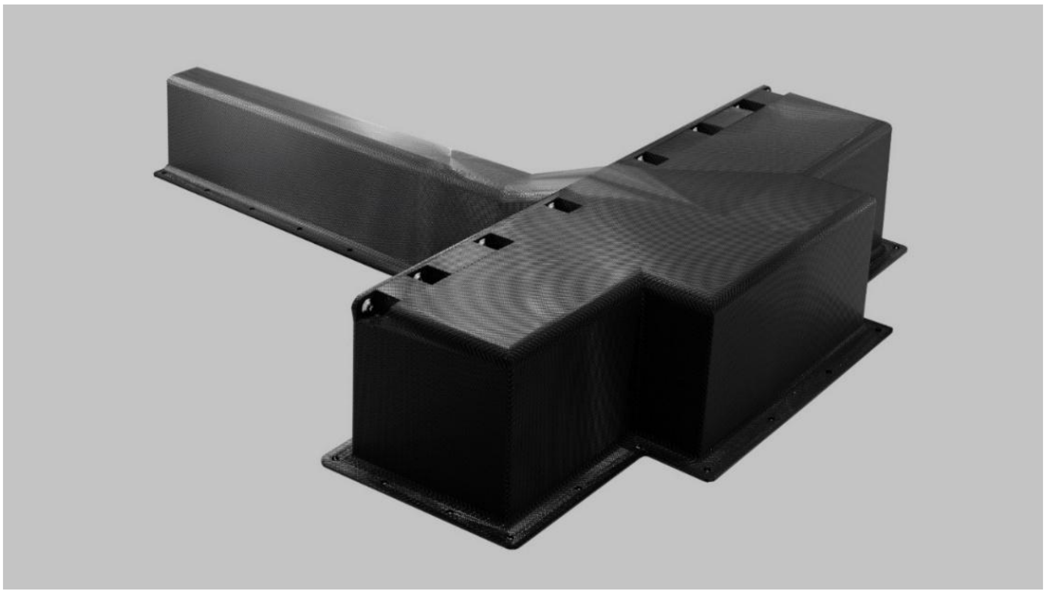


Figure 15 – Battery pack.

During discharge, electrical energy is obtained from the chemical energy of active substances formed during charging; during discharge, the reverse chemical process occurs. During charging, the chemical composition of the accumulator plates changes, accumulating chemical energy. When delivering electrical energy (discharging), the chemical processes run in the opposite direction, and the plates of the discharged accumulator return to their initial state (pre-charge), i.e., the same chemical composition. No destruction of the materials within the accumulator occurs; the chemical reactions are reversible. Thus, the battery pack converts chemical energy into electrical energy. An accumulator consists of an anode (+) and a cathode (-). A battery pack is characterized by its capacity, which is the amount of electrical energy the battery can deliver during discharge from a fully charged state to a maximum allowable discharged state. Battery capacity is measured in ampere-hours and depends on its design, the number of plates, their thickness, the material of the plate separators, and other factors. In operation, the capacity of a battery pack depends on the discharge current strength, electrolyte temperature, discharge mode (intermittent or continuous), state of charge, and battery wear. For instance, as the discharge current increases and the electrolyte temperature decreases, the battery pack's capacity decreases. The capacity C depends on the electrode surface area S, the distance between electrodes d, and the electrical conductivity of the electrolyte. The larger the electrode surface area S, the greater the battery capacity: $C \sim S$. The smaller the distance between electrodes d, the greater the capacity: $C \sim 1 / d$. The higher the electrolyte conductivity, the greater the capacity: $C \sim \varepsilon$. The general formula for battery capacity is: $C = \varepsilon \varepsilon_0 S / d$. Lithium batteries feature high energy density and voltage, long service life, and low self-discharge rates; they are commercially available and widely used. The car utilizes a lithium-ion battery pack with low internal resistance, capable of delivering currents of several hundred amperes for several seconds. The battery pack consists of high-efficiency, high-energy-density cylindrical cells with NMC (Nickel-Manganese-Cobalt) lithium-ion chemistry, featuring a graphite anode and a lithium cobalt cathode (Figure 16). The battery pack is comprised of 16 modules, each with a nominal voltage of 25 V. Sixteen battery modules are connected in series to form a pack with a nominal voltage of 400 V. Each battery module consists of 360 "18650" cells, which closely resemble standard AA batteries (the weight of a single cell is 45 g), connected in a 6s60p configuration—6 cells in series and 60 such groups in parallel. The energy capacity of each battery module using these cells is 5.3 kWh. In total, the battery pack contains 5,760 such cells. For operational convenience, the battery has a voltage of 400 V, achieved through a mixed connection of the cells. Parallel connection of cells is used to obtain higher current at the same voltage. Series connection—where cells are connected sequentially, the positive terminal of one to the negative of another—is used to obtain higher voltage at a constant current. In this case, the total current strength will equal the maximum allowable current for each cell. In a mixed connection, elements are connected in parallel into groups, which are then connected in series. When assembling cells into a battery, it is vital to remember that the battery will function properly only if all constituent cells have identical capacity and voltage. Discrepancies in the parameters of individual cells, especially when connected in parallel, can lead to premature failure of the entire battery and a decrease in its efficiency. The battery is protected from the environment by a carbon fiber enclosure. On the inner side of the carbon fiber lid, there are film-like pads. The lid is secured with screws and rubber gaskets, which are further sealed with silicone sealant. The battery pack is divided into 16 compartments, with a battery module placed in each. Each of the 16 battery modules includes a built-in BMU (Battery Monitoring Unit), which is connected to a central BMS (Battery Management System). The BMS manages operations, monitors parameters, and provides protection for the entire battery pack. The battery has two terminals: positive and negative. The common output terminals are located at the rear of the battery pack. The battery is attached to the monocoque and the rear frame of the car using screws. It powers all the car's devices and motors. Possessing low internal resistance, the battery pack can deliver several hundred amperes for several seconds, creating instantaneous power for the electric motors.

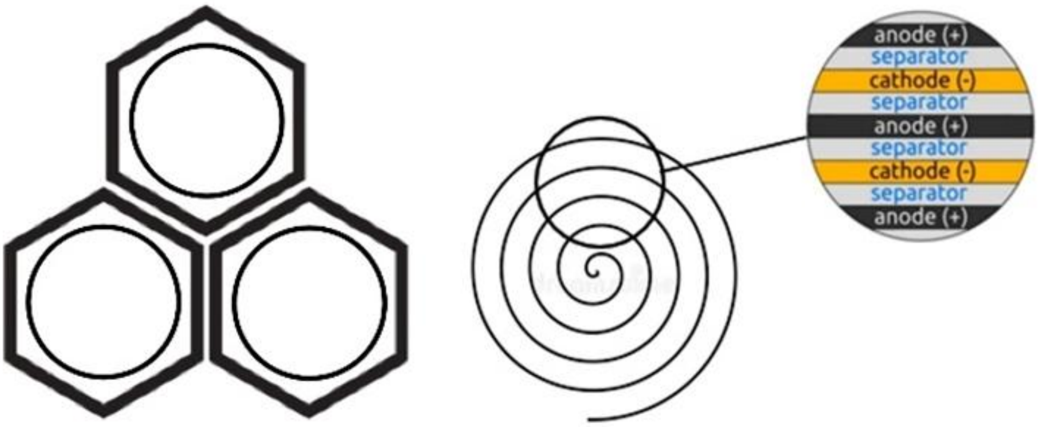


Figure 16 – Construction and arrangement of accumulators in modules.

The electromotive force (EMF) value—the voltage at its terminals in the absence of a load—does not depend on the size or shape of the plates but solely on the accumulator's design. The terminal voltage depends on the load resistance and the internal resistance of the accumulator. The higher the internal resistance and the lower the load resistance, the lower the terminal voltage will be. Internal resistance is composed of the resistance of the electrolyte and the electrodes and is measured in ohms. Capacity is the ability of an accumulator to deliver a certain amount of electricity over a specific time, measured in ampere-hours (Ah). The capacity value depends on the discharge current, electrolyte density, and ambient temperature, and can therefore fluctuate significantly. Efficiency (COP) is the ratio of the energy delivered by the accumulator during discharge to the energy supplied to it during charging; efficiency can never equal one (part of the energy during charging is wasted on heating the plates and electrolyte due to their resistance). An accumulator is characterized by its allowable charging and discharging currents. Exceeding these currents leads to premature battery failure. The battery's charging speed decreases over time due to increasing electron density. The battery pack is charged by a constant current (DC) charger. The charging current does not exceed half of the battery's capacity. Battery charging is non-linear: initially, the battery charges quickly, then more slowly. This occurs due to the increase in charge density within the accumulator. During charging, the number of positively charged LiC_6 molecules at the anode increases, and their density becomes greater. Resistance and voltage within the accumulator increase. To fully charge the battery, more energy is required for the formation of new molecules. The graph of battery charge versus time takes the form of the function *y = x^1/2* (Figure 17).

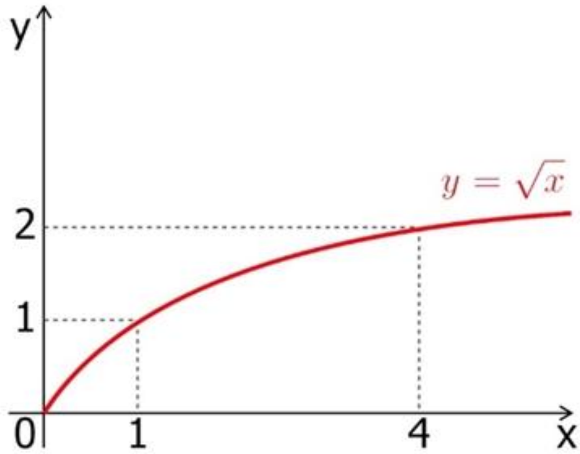


Figure 17 – Graph of charging speed vs. time.

The cathode of the accumulator is made of an aluminum current collector coated with $LiNiMnCoO_2$. Aluminum is used as the cathode current collector because it possesses high electrical conductivity, low weight, and low cost compared to other materials (Figure 18). The cathode slurry consists of $LiNiMnCoO_2$, a binder, a conductive additive, and a solvent. The battery anode is made of graphite foil with a thickness of 100 µm. A separator is placed between the cathode and the anode. A thin insulating film with high ionic permeability and mechanical strength is used as the separator. The separator has a pore diameter of 0.05 µm and a thickness of 10 µm. Non-woven polypropylene is used for the separator. The accumulator's capacity is increased by increasing the surface area of the cathode and anode. To increase capacity with constant plate dimensions, the surface area is expanded by creating grooves on the surface or by filling grid plates. Consequently, the accumulator has a larger capacity than one with smooth plates. Increasing the surface area of the anode, made from graphite foil, is performed via a thermochemical reaction. A similar method is used to increase the surface area of the cathode, which is made from aluminum sheet.

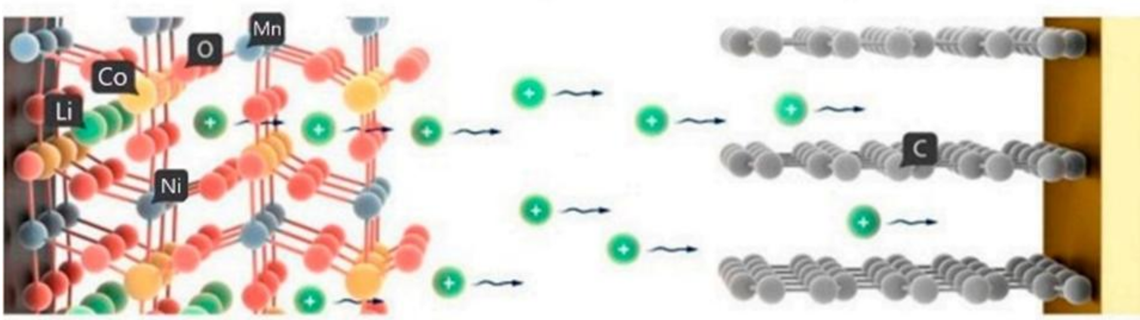


Figure 18 – Diagram of chemical processes in the accumulator

1.3.4 Steering mechanism

Steering refers to the set of devices that enable the turning of the vehicle's steered wheels (Figure 19). The steering system serves to change and maintain the vehicle's direction of movement and significantly ensures driving safety. In this car, direction changes are executed by turning the front wheels via a steering mechanism equipped with an Electric Power Steering (EPS) system. A steering booster (actuator) is a mechanism that creates the additional force on the steering linkage necessary to turn the steered wheels.

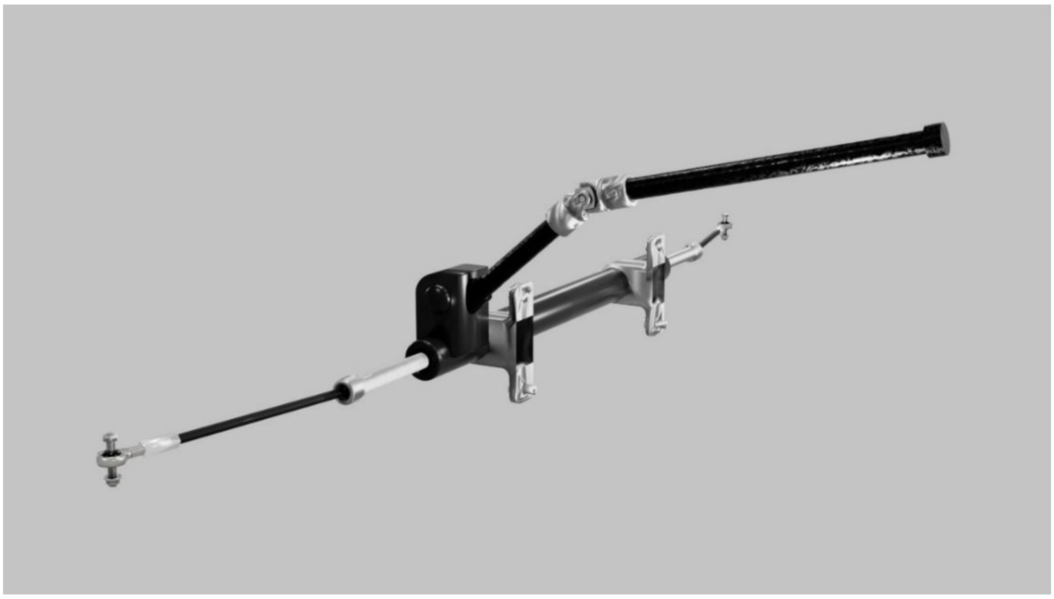


Figure 19 – Steering mechanism of the Dubina Evo electric car

The booster facilitates vehicle control, increasing maneuverability and driving safety. It also dampens shocks and impacts from road irregularities transmitted from the steered wheels to the steering wheel. The booster significantly eases the driver's workload: with its assistance, the driver applies 2–3 times less effort to the steering wheel than without it (for example, when a turn might otherwise require a force of 200 N or more). This is substantial, as up to 50% of the energy expended by a driver in operating a vehicle is attributed to steering. Vehicle maneuverability is enhanced due to the speed and precision of the booster's action. Safety is also improved because, in the event of a sudden drop in tire pressure (puncture or blowout) of a front steered wheel, the booster allows the driver to maintain a grip on the steering wheel and keep the car's direction. However, the presence of a booster adds complexity to the steering design and increases the cost.

Electric Power Steering (EPS) is an electromechanical system designed to reduce the steering effort applied to the steering wheel. EPS consists of the following primary elements: a steering shaft with a torsion bar, an electric motor, an Electronic Control Unit (ECU), a non-contact torque sensor, and a rotor position sensor.

The electric power steering is installed on the steering shaft, the sections of which are connected by a torsion bar equipped with a torque sensor. When the steering wheel is turned, the torsion bar twists, and this movement is registered by the torque sensor. Based on data from the speed sensors and motor RPM, the ECU calculates the required compensation force and sends a command to the power steering motor. The reduction gear is mounted directly on the rack itself, which prevents overloading the steering shaft and its joints. The advantages of EPS compared to Hydraulic Power Steering (HPS) include:

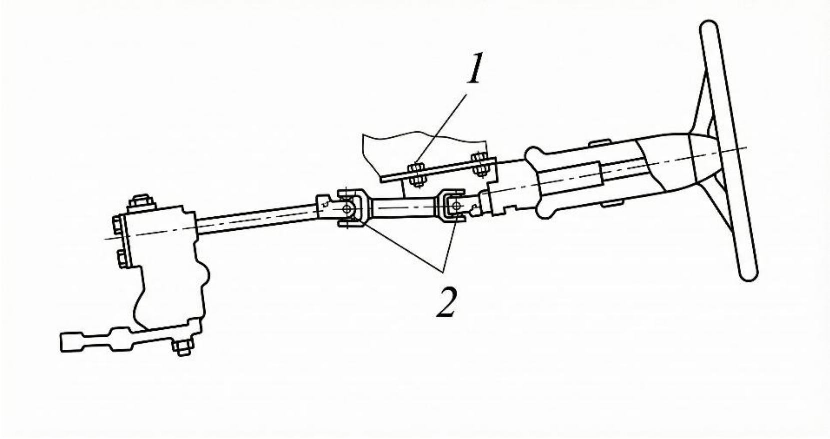
Design Simplicity: EPS lacks a hydraulic system and its associated maintenance issues.

Compactness: The EPS is integrated into the steering mechanism itself.

Efficiency: The EPS motor only activates when the steering wheel is turned, whereas an HPS pump runs constantly, increasing energy consumption.

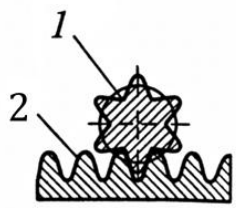
Ease of Tuning: By simply modifying the ECU software, different operating modes can be achieved, such as reducing the compensation force as vehicle speed increases.

The steering is left-handed and designed to be injury-proof (collapsible). This safety feature is provided by the design of the intermediate steering shaft and the specific mounting of the steering shaft to the car's monocoque (Figure 20). The steering system consists of the steering gear and the steering linkage.



1 – bracket; 2 – universal joint
Figure 20 – Injury-proof steering shaft

The car utilizes a rack-and-pinion steering gear (Figure 21) with a steering ratio of 20.4. The steering gear includes the steering wheel, the steering shaft, and the steering pair consisting of a pinion gear and a toothed rack. The steering wheel is mounted on the splines of the upper end of the steering shaft via an intermediate shaft that ensures its safety. The shaft is supported by a radial ball bearing installed in the bracket tube. The steering shaft and its two-piece steering column are attached to the monocoque via a bracket. The lower end of the steering shaft is connected via a flexible coupling with a pinch bolt to the splined shank of the drive pinion. This pinion is mounted in an aluminum steering housing on roller and ball bearings. The pinion meshes with the toothed rack, which is pressed against the pinion by a spring-loaded thrust pad made of sintered materials. This ensures zero-backlash meshing of the pinion and rack across their entire travel. One end of the rack rests on the thrust pad, while the other is set in a split plastic bushing fixed in the housing and sealed with rubber rings. Movement of the rack is limited on one side by a pressed-on ring and on the other by the bushing of the steering rod’s rubber-metal joint, which abuts the steering knuckle arm.



1 – pinion; 2 – rack
Figure 21 – Rack-and-pinion steering gear

The primary component of the steering linkage is the steering trapezoid (the Ackermann steering geometry). This geometry is formed by the tie rods, the steering knuckle arms, and the axis of the steered wheels. The base of the trapezoid is the wheel axis, the top consists of the tie rods, and the sides are the knuckle arms. The steering trapezoid ensures that the steered wheels turn at different angles. The inner wheel (relative to the turn center) turns at a sharper angle than the outer wheel. This is necessary to ensure that the wheels roll without lateral scrubbing and with minimal resistance during a turn. Otherwise, handling would deteriorate, and tire wear and energy consumption would increase. The steering trapezoid can be "front" or "rear" depending on the vehicle layout; this car uses a rear steering trapezoid, located behind the axis of the front steered wheels. Additionally, the linkage can be solid or split. A split steering trapezoid features a multi-link tie rod connecting the steered wheels and is used in conjunction with independent front suspension.

1.3.5 Electric powertrain

The all-wheel-drive Dubina Evo electric car is equipped with two powertrains (Figure 22). Each wheel is driven by an individual motor. The first powertrain is installed at the front of the monocoque, and the second is at the rear. A single powertrain consists of two electric motors and two cylindrical reduction gearboxes. The electric powertrain is the "heart" of the car, converting electrical energy into mechanical energy. The Dubina Evo's motor is a powerful, lightweight, and silent reversible brushless multi-pole electric motor. A brushless motor features a multi-pole neodymium permanent magnet in the rotor and electrically powered magnets in the stator (Figure 23). This design feature structurally distinguishes the brushless motor from other similar devices. It rotates by consuming constant electric current. The primary advantage is the absence of a commutator (brushes), which significantly reduces maintenance costs and time while lowering energy consumption. Previously, wear on the brushes of a commutator motor could lead to increased current consumption without a corresponding increase in power. Additionally, sparks from the brushes during operation create radio interference. The design of a brushless motor makes it simple, compact, economical, and reliable. With the advent of neodymium magnet production technology, the power of brushless motors has increased, while their size has decreased several-fold. However, unlike others, a brushless motor requires a complex and expensive electronic control unit.

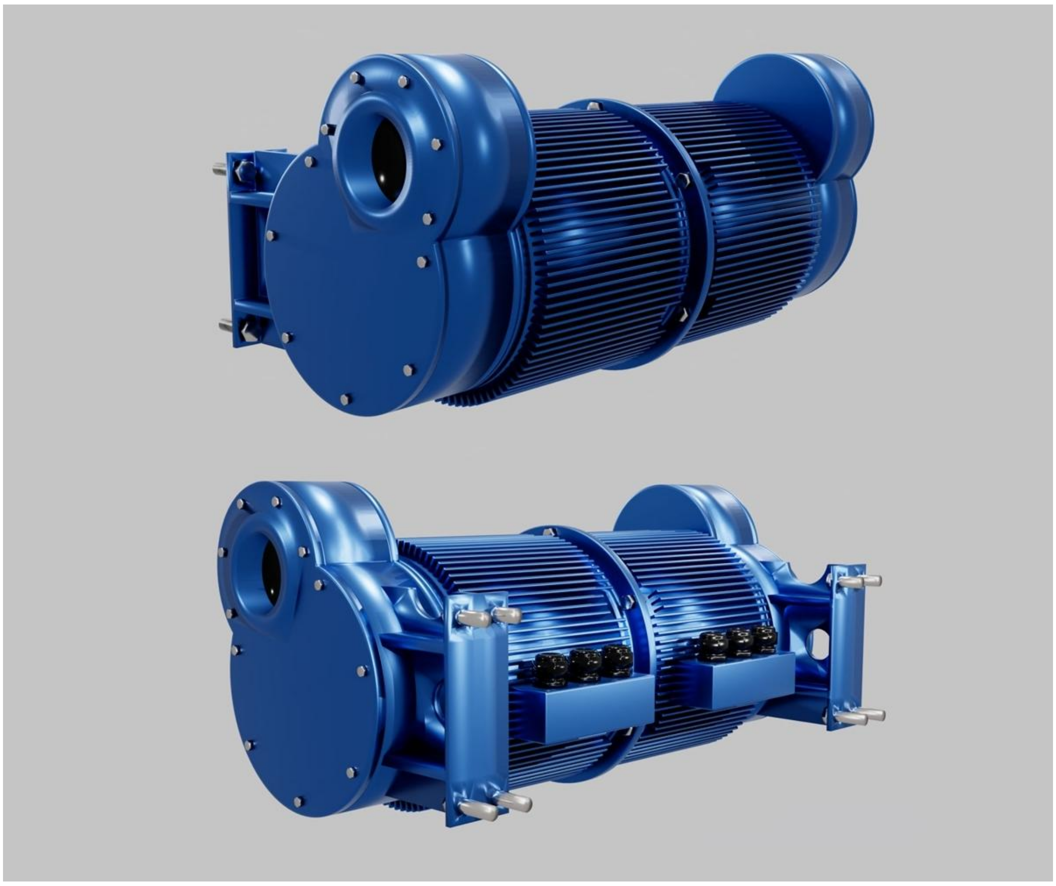


Figure 22 – Electric powertrain

The indisputable advantage of this unit is the ability to vary the RPM of the operating motor. The control unit is responsible for timely switching of the voltage supply to the windings corresponding to the rotor's rotation. This switching is triggered by rotor position sensors (Hall effect sensors, such as the SS41). Thanks to these sensors, the electronic control unit always knows the rotor's position and which windings to energize at any given moment. An electric motor requires rapid changes in both the magnitude and direction of speed. From physics, it is known that the angular acceleration E during the rotational movement of a body (in this case, the motor rotor) is directly proportional to the torque M acting on the body and inversely proportional to its moment of inertia J: $E = M / J$. It follows that to achieve high acceleration or deceleration, the motor must develop significant torque M, while its rotor must have a low moment of inertia J. The expression for the maximum motor torque M_{max} can be written as: $M_{max} = B \cdot I \cdot S = 2B \cdot I \cdot L \cdot R$, where L is the length of the frame conductors (length of the rotor) and R is the distance from the axis of rotation to the conductors (radius of the rotor). The moment of inertia J of a cylindrical body relative to its axis of rotation is calculated as: $J = m \cdot R^2$, where m is the mass of the rotor and R is its radius. Substituting these into the formula results in: $E = 2B \cdot I \cdot L / m \cdot r$. This formula defines the ways to increase motor responsiveness: Increasing the magnetic induction of the motor's field; Designing the rotor with the minimum possible mass and the maximum possible length-to-radius ratio; Increasing the current in the motor windings. Reducing the rotor (armature) mass is achieved by making it hollow (Figure 24). Neodymium permanent magnets are located on the armature, which is designed as a thin-walled cup made of non-magnetic material.

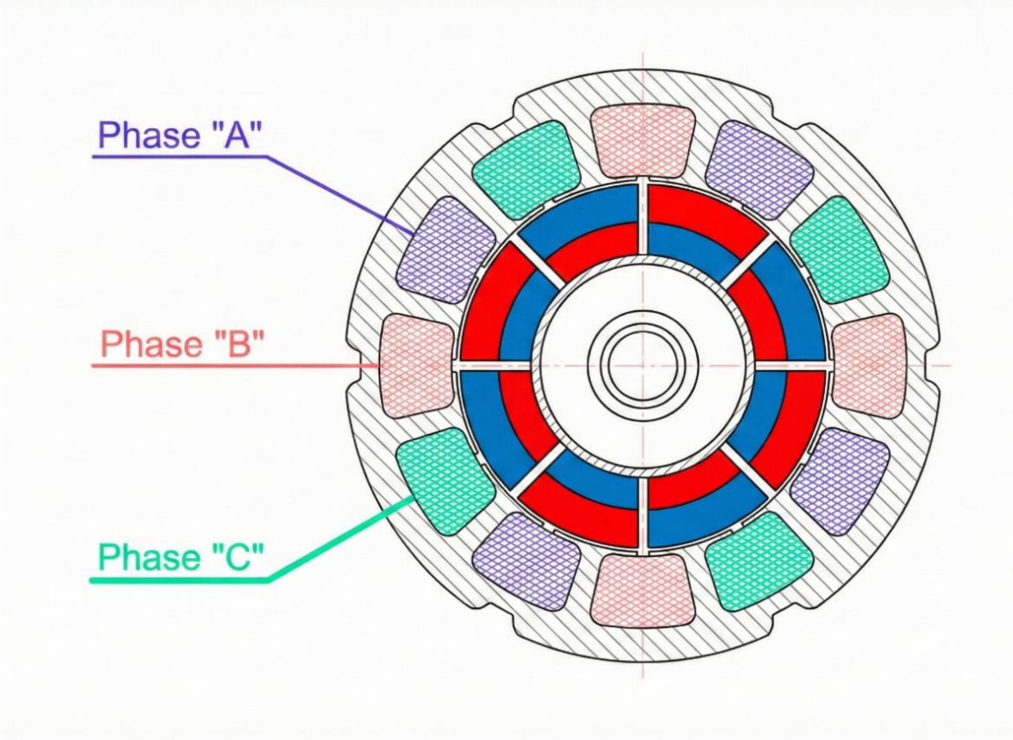
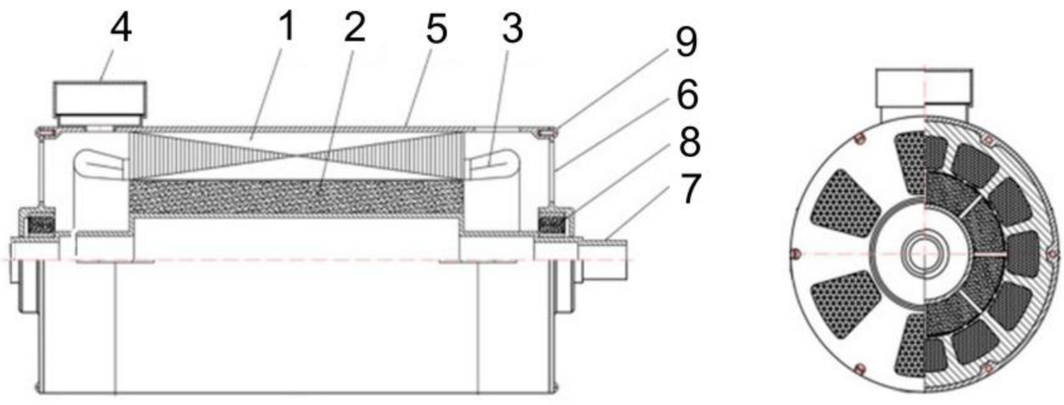


Figure 23 – Three-phase motor winding



1 – stator core; 2 – neodymium rotor magnet; 3 – rotor winding; 4 – terminal box; 5 – motor housing; 6 – bearing cap; 7 – shaft; 8 – bearing.

Figure 24 – Electric motor construction

The torque M_{tr} is a measure of this force, which changes the angular velocity: $\omega = 2\pi \cdot n / 60$, where n is the rotation frequency of the motor in RPM (rev/min). Between the motor power P (W), the angular velocity ω (rad/s), the force F (N), the pulley radius r (m), and the torque M_{tr} (N·m), the following dependency exists: $M_{tr} = P / \omega = F \cdot r$. By substituting the value of the angular velocity ω, we obtain: $M_{tr} = P / \omega = P / 2\pi \cdot n / 60 = 60P / 2\pi \cdot n = 9{,}554P / n$. The rotation frequency of the electric motor and the torque vary depending on the current without changing the gear ratio of the transmission; therefore, there is no necessity for a gearbox in the electric car. As a consequence of this, the smoothness of the electric car's movement is increased and its control is simplified (Figure 25).

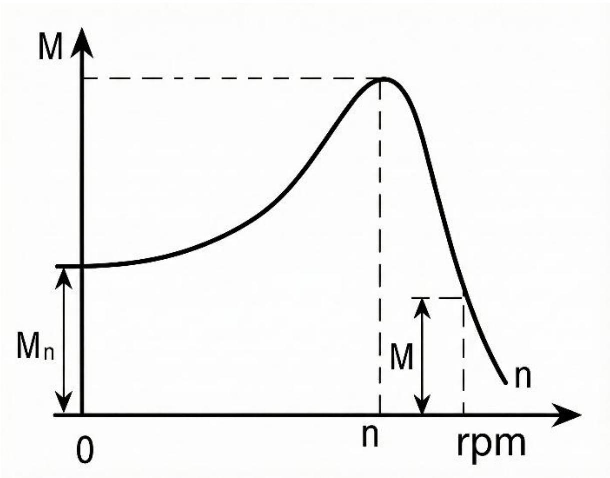


Figure 25 – Dependency of torque on rotation frequency

Motor Braking Technology. A braking system is the car's control system that ensures safety during movement and stops. The braking system serves to reduce the speed of movement, to stop, and to hold the car in place. The Dubina Evo car is equipped with several braking systems having different purposes. The service braking system is intended for reducing the speed of the car's movement down to its complete stop. It is the most effective of all braking systems, acts on all wheels of the car, and is used for service and emergency braking. The service braking system is called the "foot" system, as it is brought into action from the brake pedal by the driver's foot. The parking braking system serves to hold a stationary car in place. It acts on the rear wheels of the car. It is brought into action from a lever by the driver's hand, and therefore it is called "manual." A feature of the electric motor is the ability to instantaneously change the direction of the rotor's rotation. Thanks to such an ability, the possibility appeared in the car to perform braking by the counter-current method. When the brake pedal is pressed, the direction of the current in the car's motors changes, which creates a reverse torque. This technology simplifies the construction of the car. Now there are no heavy mechanical brakes in the car. Braking is performed at the level of software control.

The technology of car movement around an axis. The Dubina Evo car can rotate around an axis (Figure 26). This is because there is one motor for each wheel. Movement around the axis is activated by a button on the steering wheel.

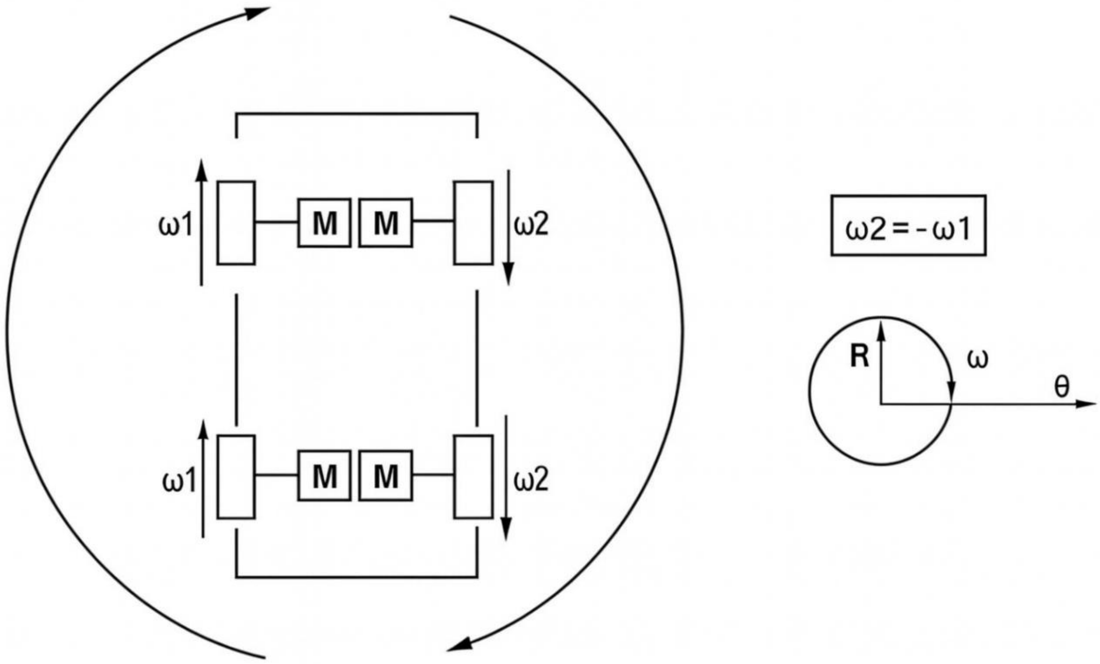
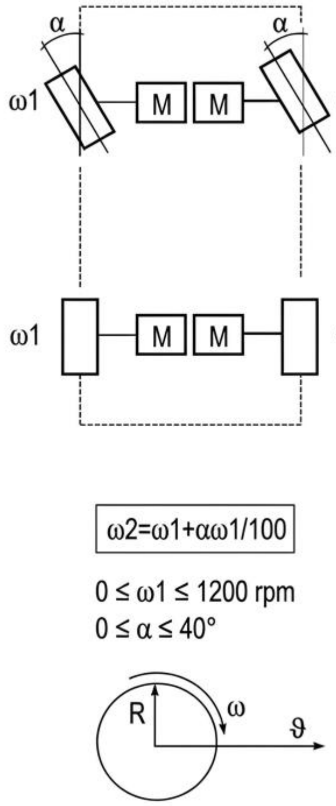


Figure 26 – Scheme of car movement around an axis.

Recuperation technology. While the car rolls along the road without motor traction or when descending a hill, the motor continues to rotate. At this time, the rotor of the rotating motor works as a current generator. The generated current in the stator winding returns to the battery. So that the energy is not dissipated in the motor control circuit, the device engages the motor as a generator. Such a device performs recuperation.

Hyper-speed technology. An electric motor can operate for a small interval of time with peak current. Peak current possesses great strength, which gives enormous power, but only for a short period of time. The peak current function is switched on by a button located on the steering wheel.

Maneuverability enhancement technology. The Dubina Evo has all-wheel drive. There is one motor for each wheel. Such a construction allows for increasing maneuverability with the help of changing the rotation frequency of the wheels depending on the steering angle. The wheel located on a larger radius during a turn rotates with a frequency exceeding the frequency of the other wheel by a percentage equal to the steering angle (Figure 27).



ϑ = 5 km/h

α	ω1	ω2
0	26	26
5	26	27.5
10	26	28.6
20	26	31.2
40	26	36.4

ϑ = 40 km/h

α	ω1	ω2
0	209	209
5	209	220
10	209	230
20	209	251
40	209	293

ϑ = 200 km/h

α	ω1	ω2
0	1045	1045
5	1045	1097
10	1045	1150
20	1045	1254
40	1045	1463

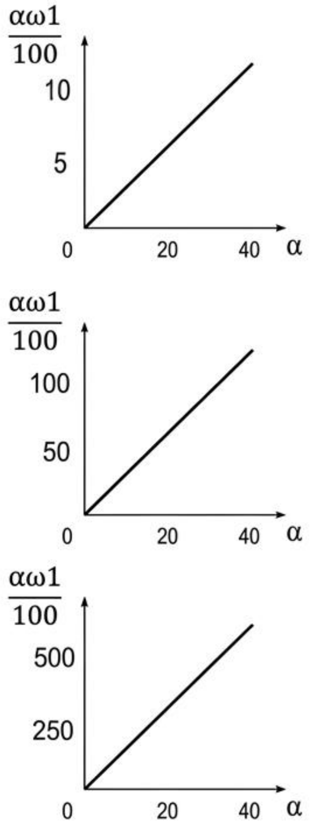


Figure 28 – Maneuverability enhancement scheme

1.3.6 Suspension arms

In the car, an independent, spring-based, double-wishbone suspension with hydraulic shock absorbers and an anti-roll bar is applied for the front and rear wheels (Figure 29). In such a suspension, the movement of one wheel does not cause the movement of the other wheel. These suspensions provide a higher smoothness of ride than dependent suspensions. Unlike other types of suspensions, the construction of the double-wishbone suspension offers a more progressive geometry. The more the double-wishbone suspension is compressed, the greater the negative camber will be, which is achieved thanks to the use of arms of different lengths. This has a positive effect on handling at moments when the car travels at high speed in a corner and the car begins to slide off the trajectory. At these moments, the double-wishbone suspension system will maintain better tire contact with the road, which means the car will be more stable. An additional plus of the double-wishbone suspension is considered to be the smaller dimensions of the upper arm relative to the lower one. In connection with this, during the upward movement of the wheel, the camber angle changes, as a result of which the plane of the wheel remains perpendicular to the road surface even during body rolls.

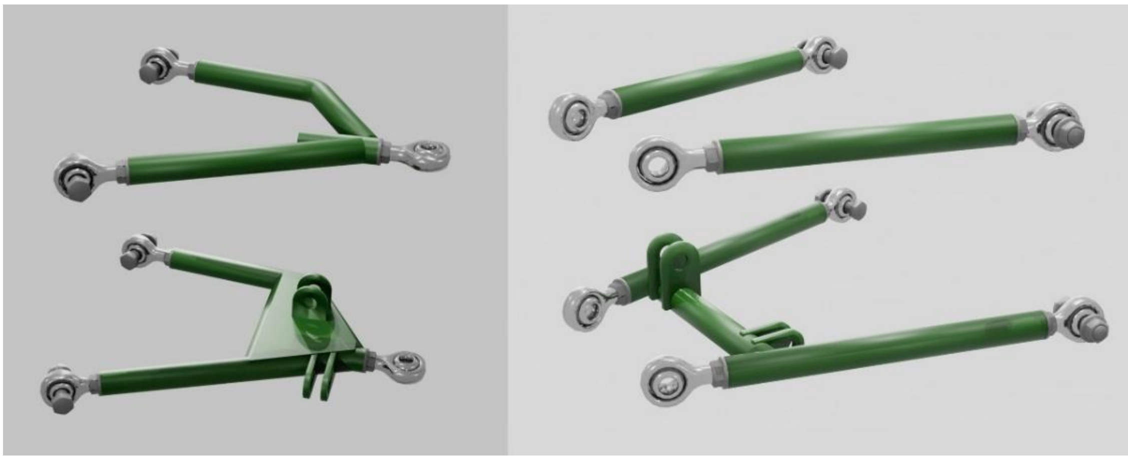


Figure 29 – Front and rear suspension arms

In general, depending on the length and the arrangement of the A-shaped arms themselves, one can adjust the camber and toe angles. The guiding device of the suspension consists of the lower and upper arms, the elastic device consists of coiled cylindrical springs, the damping device consists of double-acting gas-spring shock absorbers, and the anti-roll bar is an elastic U-shaped rod. The upper and lower suspension arms are installed across the car and have longitudinal axes of oscillation. The axis of the lower arm and the upper arm are attached to a bracket on the frame. The inner ends of the upper and lower arms are connected to the axes by ball joints (Figure 30). The outer ends of the upper and lower suspension arms are connected to the steering knuckle by ball joints. The ball joints allow for adjusting the length of the arm. There is a thread on the ball joint; therefore, the length of the arm is easily changed. The ball joints are made non-separable, have an identical design, are interchangeable, and do not require lubrication during operation. The shock absorber is attached by its lower end to the bracket of the lower arm with the help of a rubber-metal joint. The upper end of the shock absorber is attached to a bracket on the car frame with the help of a rubber-metal joint. The suspension ensures a compression stroke of 75 mm and a rebound stroke of 80 mm. The arms are manufactured from structural aluminum alloy. For their manufacture, sections of tubes are welded by arc welding with the help of special equipment.

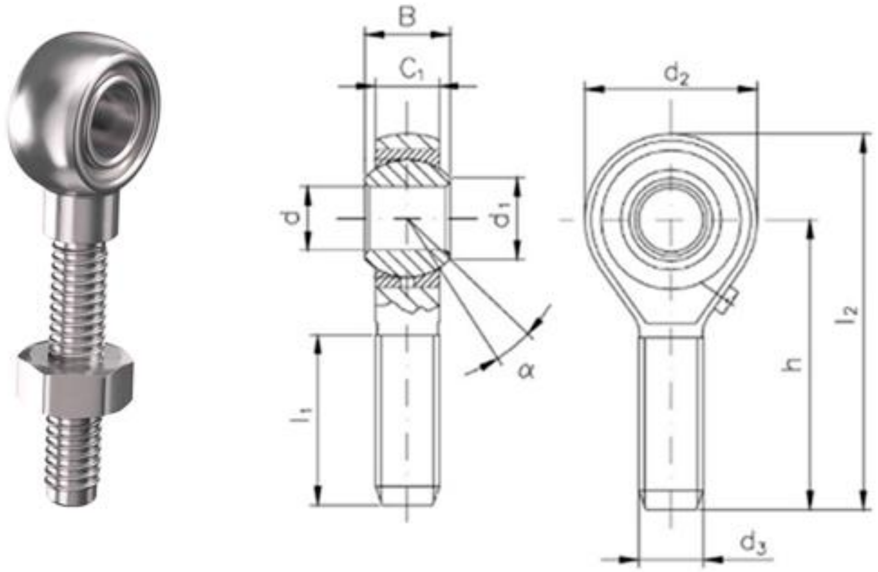


Figure 30 – Ball joint

The rear and front suspensions of the car perform similar functions, but their construction and arrangement differ to ensure optimal characteristics of handling, comfort, and safety. The knuckle of the rear suspension does not rotate around an axis. Therefore, on the rear suspension arms, there are two ends with ball joints. The arms are adjustable due to the use of ball joints; this allows for setting the toe angle on the wheels. The arms are arranged at a certain angle to each other. The lower arm accounts for the major part of the loads, as it acts as the lower support for the shock absorber. The shock absorber in such a suspension is located between the arms; at the bottom, it is attached to the arm, and at the top, to the frame of the car. The rear stabilizer is attached to the lower arm. The rear suspension arms are manufactured from structural aluminum alloy.

1.3.7 Shock absorber

A shock absorber is a device intended for the damping of oscillations and vibrations arising during the movement of the car (Figure 31). A gas-spring shock absorber is used in the car. The shock absorber consists of three main units: a cylinder, a piston with a rod, and a guide bushing with seals. When the car stands on its wheels or moves, pressure is transmitted to the shock absorber rod at that moment. The shock absorber compresses, and the rod, with a piston at the end, moves in a working chamber with oil; the oil presses on a floating piston that divides the chamber into two zones: a zone with the rod in oil and a zone with gas. The piston on the rod has special orifices for the passage of oil.

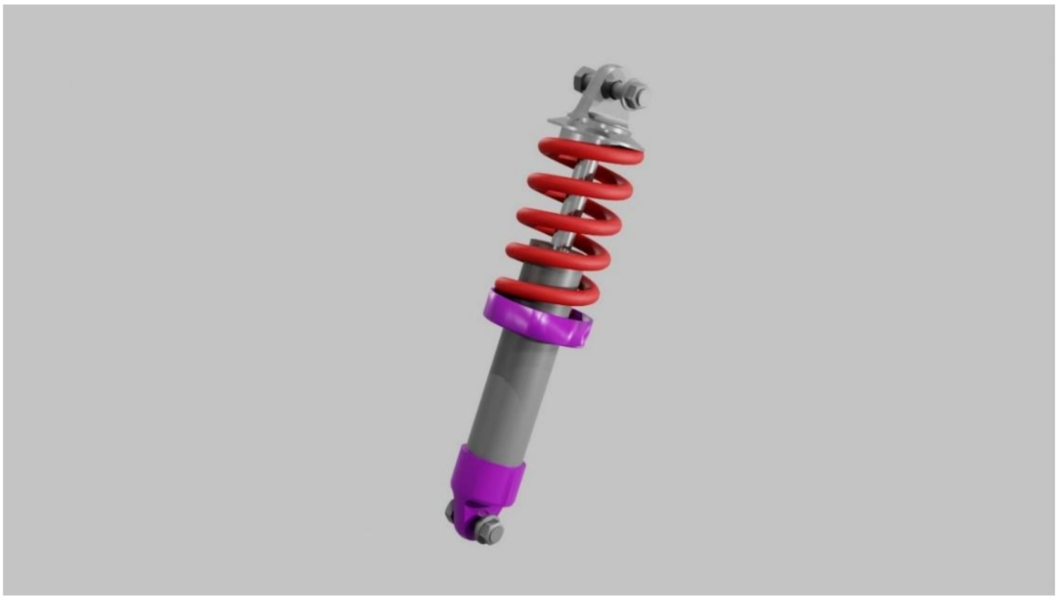


Figure 31 – Shock absorber.

The gas is compressed by the pressure of the floating piston. When the shock absorber decompresses, the rod exits the working chamber, reducing the oil pressure on the gas, which leads to the return stroke of the floating piston. The elastic properties of the shock absorber increase with the increase of the stroke, as the piston travel decreases with the increase of gas pressure. A helical spring installed on the housing has a constant stiffness; a specific pressure is required for its compression and extension. There is a thread on the struts, with the help of which—like a nut on a screw—the height of the washer, against which the spring in turn abuts, is adjusted. From the turning of the washer, the compression of the spring changes, and as a consequence, its preload. The suspension spring is installed between the lower spring seat and the upper spring seat; vibration and noise insulating gaskets are installed between the ends of the spring and the spring seats. The shock absorber is attached by its lower end to the bracket of the suspension arm, and by its upper end to the frame of the car with the help of a rubber-metal joint (Figures 32, 33). The wheel tire must have constant contact with the road; therefore, during extension, the shock absorber extends under the action of the spring. The upward travel of the wheel is limited by a compression buffer, which is fixed on a support installed inside the suspension spring. Under static load, the compression buffer touches the lower spring seat, which ensures its constant operation. A stop limits the compression of the buffer. The shock absorber has a spring preload adjustment and the possibility of changing the shock absorber length, which allows for adjusting the height of the car without changing the ratio of the rebound and compression strokes. There is also an adjustment for the damping forces. Mono-tube gas-filled shock absorbers, compared to twin-tube ones, are cooled better, have lower operating pressure, are simpler in design, lighter in mass, more reliable in operation, and can be installed on the car in any position from horizontal to vertical. Nitrogen (N_2) is used in the shock absorber. This is due to a number of its advantages: Inertness and stability. Nitrogen does not enter into chemical reactions with the oil or the materials of the shock absorber, which prevents corrosion and degradation of components. Stability at high temperatures. Nitrogen retains its properties well even with significant heating arising during the operation of the shock absorber under racing load conditions. Minimal compression. Nitrogen is less prone to compression compared to regular air, which ensures more stable damping characteristics. Absence of moisture. There is no moisture in nitrogen, which prevents the formation of condensate and reduces the risk of corrosion inside the shock absorber.

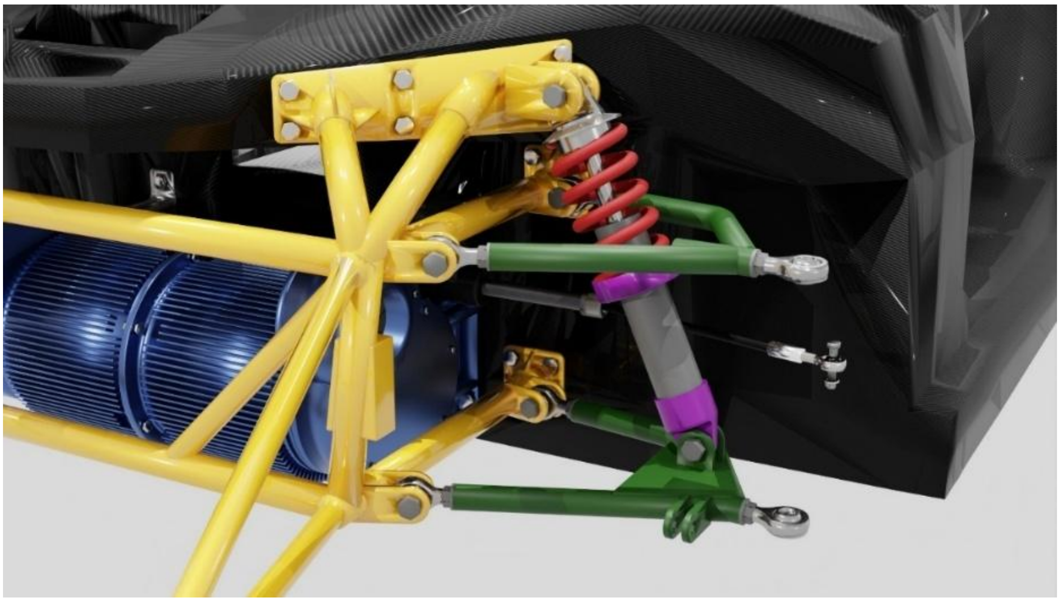


Figure 32 – Shock absorber on the front suspension

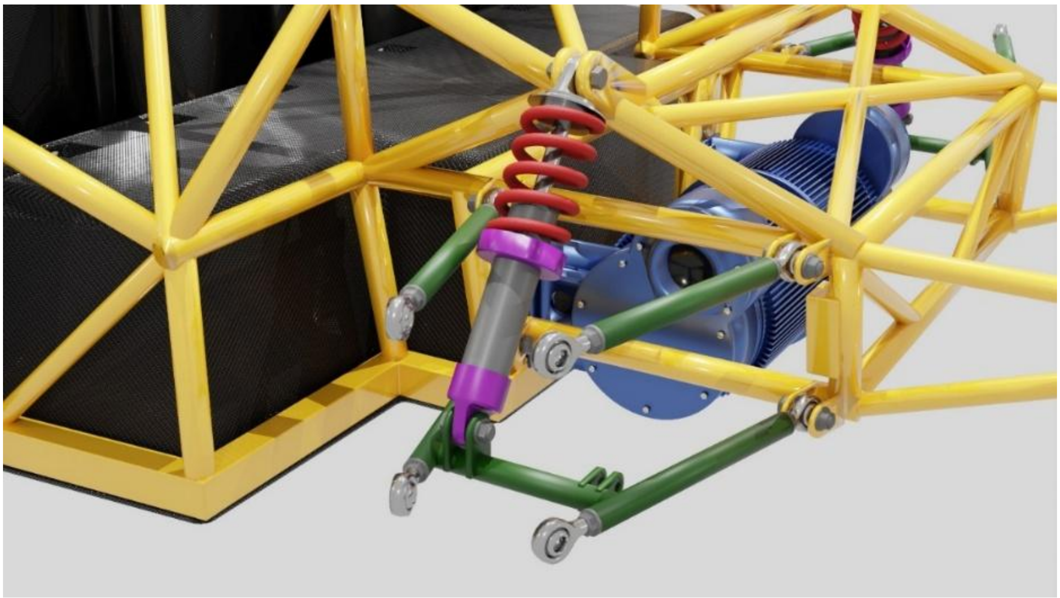


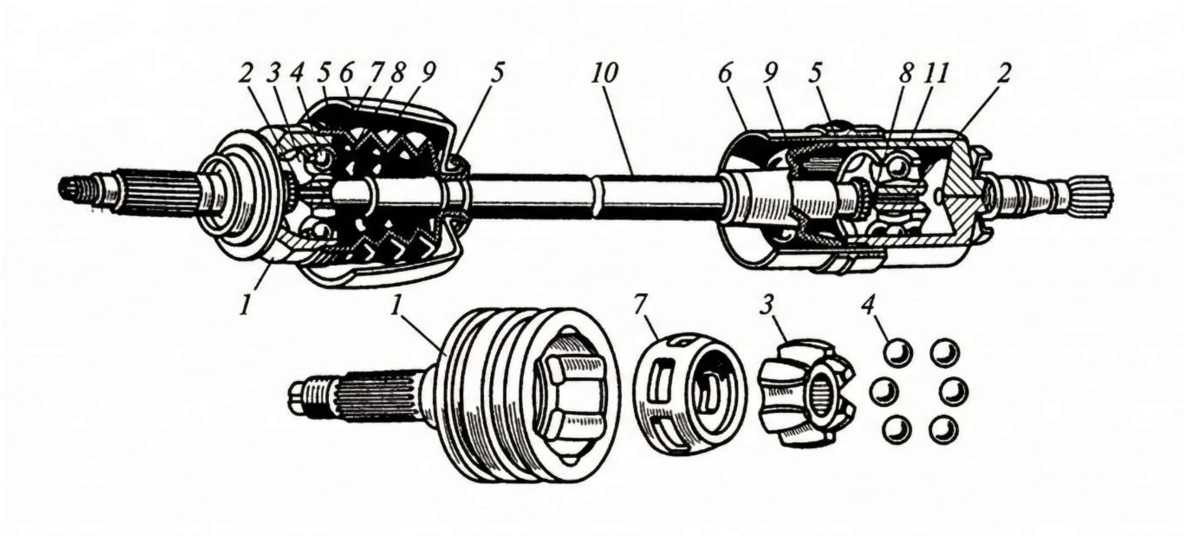
Figure 33 – Shock absorber on the rear suspension

1.3.8 Drive shafts

A drive shaft of a car is a mechanical device that transmits torque from the motor to the wheels of the car (Figure 34). The drive shaft plays a key role in the system of motion transmission from the motor to the wheels, thereby ensuring the movement of the car. The car has all-wheel, non-permanent drive. The drive shafts of the front drive transmit torque from the motor to the front wheels. The drive shafts of the rear drive transmit torque to the rear wheels.

Figure 34 – Drive shafts

All-wheel drive ensures a more uniform distribution of torque between the front and rear wheels, which improves handling and stability on the road. The car has the possibility of switching the all-wheel drive on or off. A drive shaft consists of several section-joints to compensate for changes in the angles of the wheels' inclination during the car's movement. It is important to regularly service the drive shaft and lubricate its components to ensure effective operation and prevent wear. The front-wheel drive transmits torque from the reduction gearbox to the front steered wheels. The front-wheel drive represents a cardan transmission, which includes a shaft, and outer and inner joints (Figure 35). The drive shaft *10* is made solid. At the ends of the shaft, there are splines for the installation of the outer and inner drive joints. The outer joint of the front-wheel drive consists of a housing *1*, a race *3*, six balls *4*, and a cage *7*. Inside the joint housing and on the outside of its race, there are special grooves in which the balls are placed. The balls ensure a movable connection between the housing and the race of the joint. The joint race is fixed immovably on the splined end of the shaft by a snap ring *2* and a thrust ring *8*. The joint is protected from dust, dirt, and moisture by a boot *9*, which has a protective cover *6*.



1 – joint housing; 2 – snap ring; 3 – joint race; 4 – joint balls; 5 – clamping ring; 6 – protective cover; 7 – cage; 8 – thrust ring; 9 – boot; 10 – shaft.
Figure 35 – Drive shaft construction

1.3.9 Suspension knuckles

The steering knuckle in a double-wishbone independent suspension is a suspension element that connects the upper and lower suspension arms and allows the front wheel to rotate during turns (Figure 36). This element is also known as a steering upright or a pendulum sleeve. It ensures stability and the support of the wheel in the vertical plane. The construction of the double-wishbone suspension allows for adjusting the inclination angle of the wheel to optimize handling characteristics and road grip. In the body of the knuckle, a groove with holes is made for the installation of the wheel hub. The knuckle of the rear double-wishbone independent suspension is a suspension element that connects the upper and lower arms to the wheel hub, ensuring stability and the support of the wheel in the vertical plane (Figures 37, 38). For the attachment of the suspension arms, there are four lugs on the knuckle. There are no mechanical brakes in the car; the brake in the car is electronic, and the car brakes using the motors. Therefore, there are no mounts for a brake disc on the knuckles. The suspension knuckles are manufactured from structural aluminum alloy.

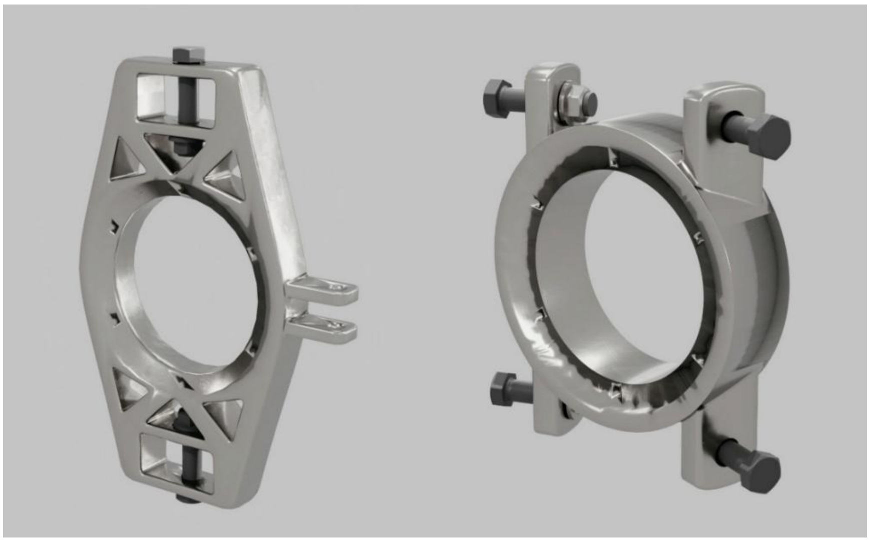


Figure 36 – Front and rear suspension knuckles

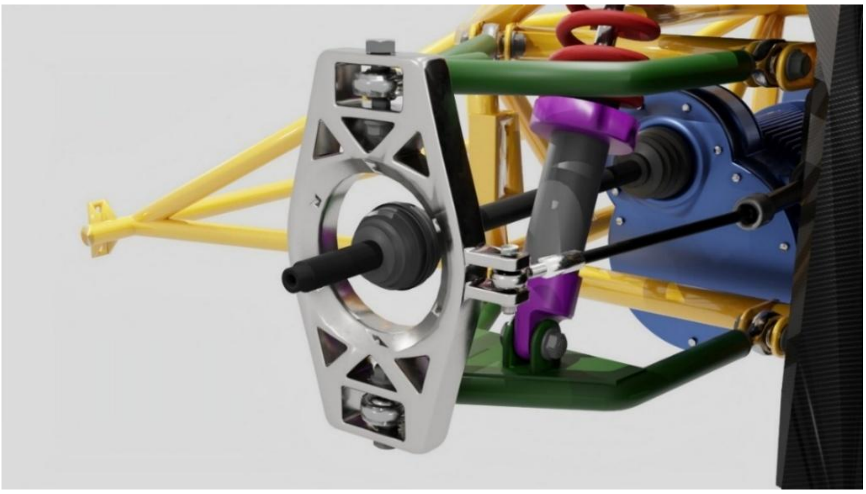


Figure 37 – Front suspension knuckle

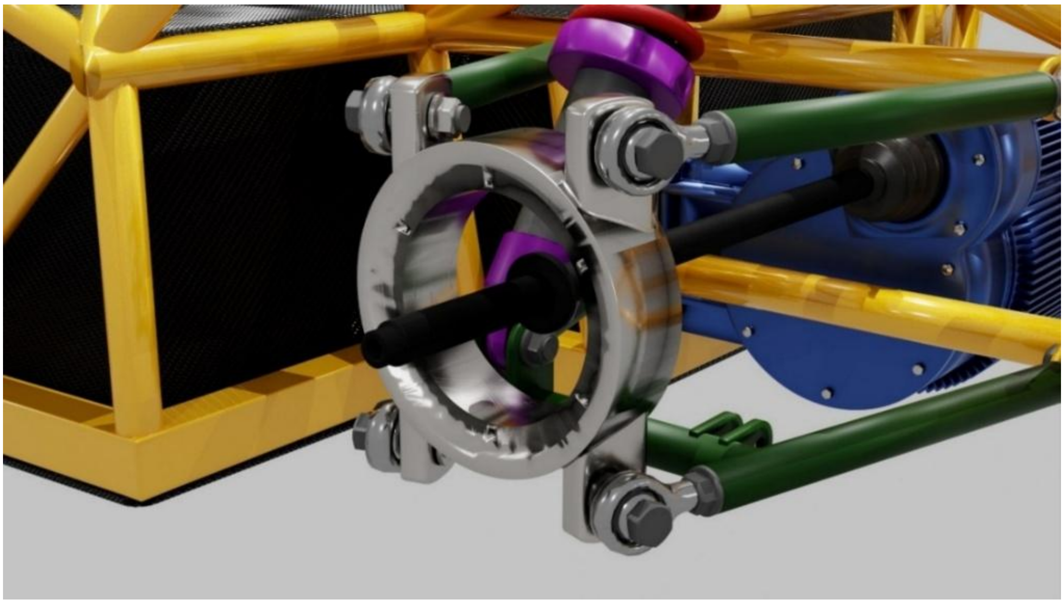


Figure 38 – Rear suspension knuckle

1.3.10 Wheel hub

A hub is a part on which a wheel rotates (Figure 39). The hub ensures the installation of the wheel onto the drive shaft and enables the wheel to rotate. It transmits torque to the wheel from the drive shaft. Hubs are installed in the knuckles of the front and rear suspension. Electronic brakes are used in the car; there are no traditional mechanical brakes in it.

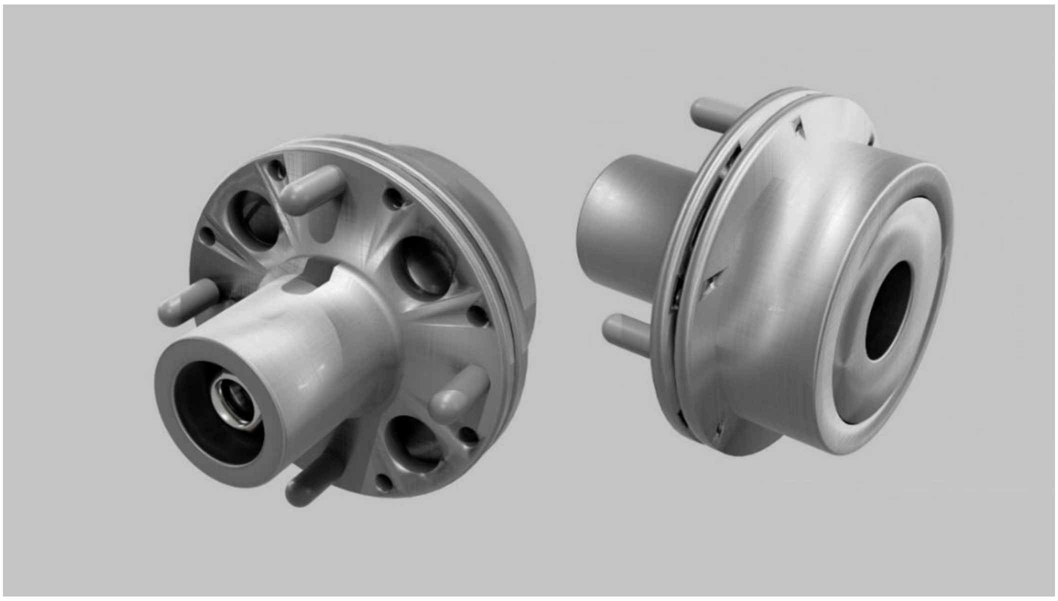


Figure 39 – Wheel hub

Braking is performed by the motor at the software level. Therefore, the hub on the front wheels and on the rear wheels of the car is the identical. A hub consists of an axis and bearings inserted into a special housing. Tapered roller bearings are installed in the hub housing. The outer rings of the bearings are pressed into the knuckle, while the inner rings are installed on the hub shank, which has internal splines and is connected to the shank of the housing of the car's outer wheel drive joint. A tapered sleeve ensures the correct installation of the shank relative to the wheel hub. The position of the bearings on the hub is fixed by a nut. With its help, the axial clearance in the bearings is adjusted, equal to 0.025 ... 0.080 mm. The bearings are lubricated during assembly. To protect the hub bearings from dust, dirt, and moisture, as well as to retain the lubricant in the knuckle, seals and protective rings are installed. The wheel disc is attached to the hub by means of a nut and studs. The hub housing is made of structural aluminum alloy; it is capable of maintaining strength and rigidity under high-temperature conditions.

1.3.11 Anti-roll bar

An anti-roll bar in a car is a device whose purpose is to reduce the body lean of the car during turns and to improve its stability on the road (Figure 40). When the car moves in a turn, lateral forces acting on the suspension tend to cause the body to lean toward the side of the turn. The anti-roll bar, connected to the suspension, transfers part of the lateral forces from one side of the car to the other. This creates an additional force in the direction opposite to the turn, which reduces body lean and maintains a flatter and more stable stance of the car on the road. This component is part of the double-wishbone suspension and is installed on the front and rear axles of the car (Figures 41, 42). The anti-roll bar is connected to the suspension with the help of links. The anti-roll bar links are attached to the bar on one side and to the suspension arms on the other side. The anti-roll bar rod has a U-shape and a circular section. It is manufactured from carbon fiber. The middle part of the anti-roll bar rod is attached to the frame of the car, and its ends are attached in rubber supports by brackets to the frame of the car and to the brackets of the lower arms. Torsional deformation (twisting) is the primary type of deformation for the anti-roll bar, as it is designed specifically for the transmission of torques that reduce the car's roll. If the anti-roll bar construction is subjected to complex loads, for example, during uneven suspension operation or under extreme driving conditions, bending and axial deformations are secondary.

Figure 40 – Anti-roll bar

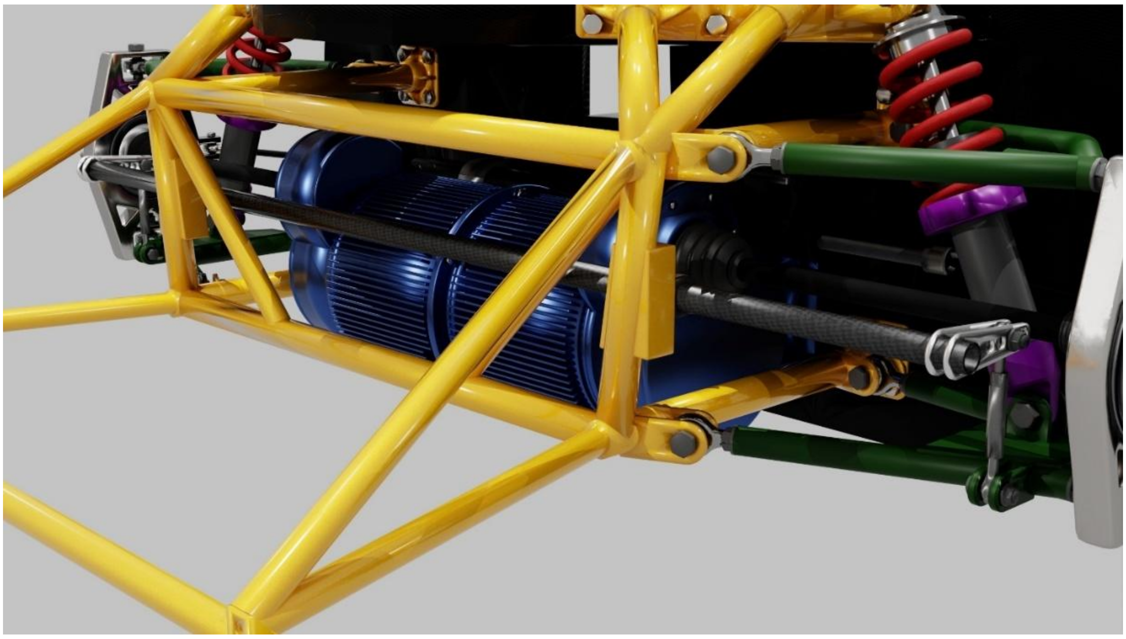


Figure 41 – Anti-roll bar on the front suspension

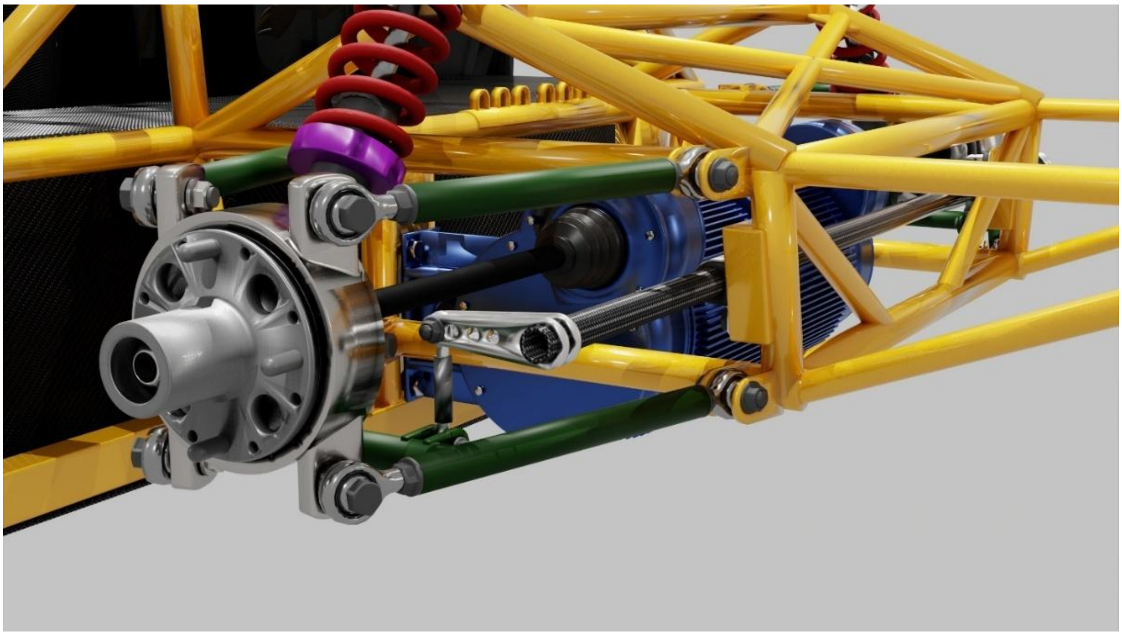


Figure 42 – Anti-roll bar on the rear suspension

1.3.12 Control unit

A control unit is an electronic device responsible for the monitoring and management of various systems and components of the car (Figure 43). It plays a key role in ensuring the correct operation and interaction of the car's various units. The control unit monitors the operation of the motor. It regulates the traction at the wheels to prevent slipping and ensure the stability of the car during movement. It is responsible for preventing wheel lock-up during braking, ensuring the stability and maneuverability of the car in difficult conditions. It manages body functions, such as central locking, lighting systems, rearview mirrors, and others. It regulates the operation of the heating, ventilation, and air conditioning system. It manages the navigation, audio, and multimedia systems. A microcomputer is located in the control unit (Figure 44). It represents a small board slightly larger than a bank card. A specialized distribution is used on the computer. The board is built on the basis of the Broadcom BCM2711 SoC, which contains four 64-bit ARM Cortex-A72 cores with a clock frequency of 1.5 GHz. 8 GB of LPDDR4 SDRAM RAM is available on the computer. The VLI VL805 provides a USB 3.0 Hub via the PCI Express bus. Gigabit Ethernet is provided using the Broadcom BCM54213PE separately from the USB. Wireless communication is ensured by the Cypress CYW43455 chip, providing dual-band wireless networking IEEE 802.11.b/g/n/ac at 2.4 GHz and 5 GHz, as well as Bluetooth 5.0 and Bluetooth LE. The power connector is USB-C; the computer requires up to 3 A. The microcomputer has support for two 4K screens at a rate of 30 frames per second. Next to the two micro-HDMI ports, there is a 4-pole stereo output and a composite video jack. Storage is provided by a Micro-SD card with a slot on the underside of the board. The GPIO connector is the standard 40-pin type.

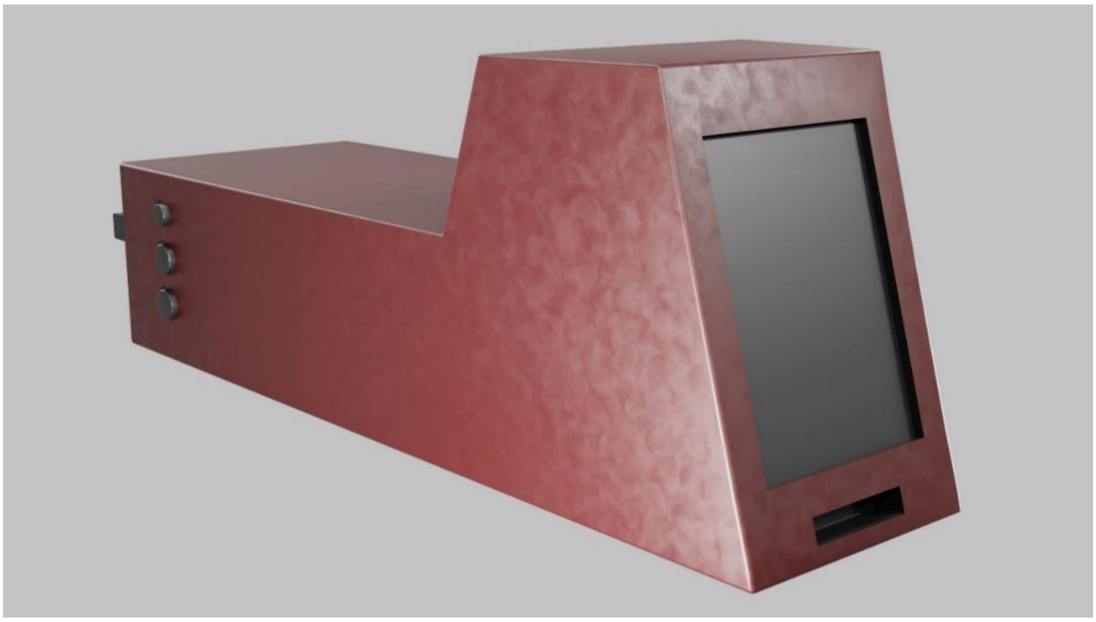


Figure 43 – Control unit

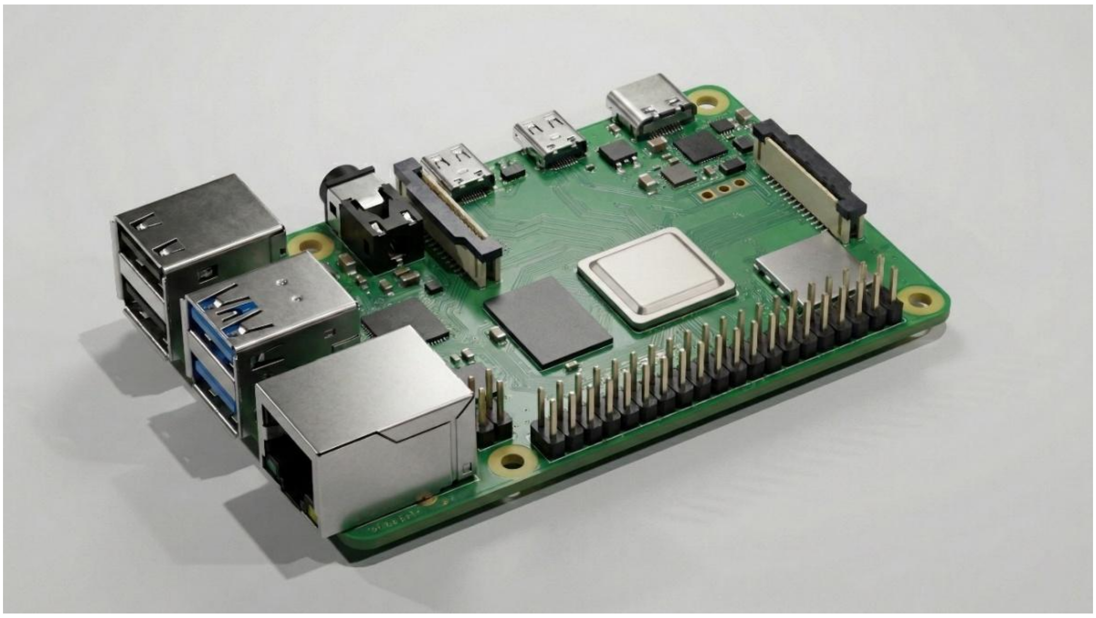


Figure 44 – Microcomputer

1.3.13 Speed controller

Brushless motors with reverse are used in the car. To control them, a speed controller is applied (Figure 45). It participates in starting, speed regulation, braking, and reversing, and also implements the operation of technologies and control systems. Semiconductor devices are used in the controller; there are no moving parts in it. Energy from the semiconductor components is supplied to the motor in pulses, and all adjustments occur by changing the pulse duration. Semiconductor switching elements have high power, fast response, great reliability, small size, and weight.

Figure 45 – Speed controller.

The solid-state equipment in the speed controller is divided into two main parts. The first is the power part, which includes silicon-controlled rectifiers: thyristors, triacs, gate turn-off devices, power transistors, and diodes. The second is the logical part, including integrated circuits and microprocessors. Power electronic equipment is subdivided into four main categories: rectifiers, inverters, choppers, and cycloconverters. A cycloconverter converts the frequency of the current without changing the output voltage. Direct current (DC) comes from the storage battery. The direct current is supplied to the inverter circuit, which creates a three-phase alternating current (AC) with output voltage. A frequency inverter for a three-phase electric motor is a device that regulates the frequency and voltage of the electricity supplied to the electric motor. It allows for changing the rotation speed of the motor, providing precise control;

it changes the motor speed by altering the alternating current on each phase using a pulse-width modulation (PWM) device, thereby changing the effective output signals controlling the three-phase motor from a typical AC wave to a new pulse-width modulation wave. The operating frequency range of the speed controller is from 10 to 400 Hz. The controller operates with high voltage; therefore, an optoisolator is built into it. This is a galvanic isolation of the power circuits from the receiver circuits of the control system. This is done so that powerful pulse interference from the power part of the controller and the motor does not reach the highly sensitive input circuits of the control unit. Therefore, the control unit uses a separate power supply. The speed controller supplies high voltage to the motor winding. The temperature of the conductor is determined by the formula: $Q = I^2 \cdot R \cdot t$. This formula describes the process of converting electrical energy into heat. Therefore, the speed controller changes the characteristics of the current, but not the output voltage. If the voltage on any phase is less than 120 V, the motor will generate excessive heat and quickly burn out. The speed controller not only quickly spins up the motor at the start but also quickly brakes it. The controller performs "soft" braking; the windings are not shunted immediately, but by small pulses. This allows for reducing the heating of the controller and extending the life of the electric motor commutator. The controller performs reversing; it changes the direction of the electric motor's rotation by supplying voltage to it in reverse polarity. The controller has a motor cutoff function; it stops the motor when the voltage in the battery falls below a certain level. After the motor is disconnected, a little energy remains in the battery for the operation of other systems: the speed controller and the control unit.

1.3.14 Pedals

The pedal unit in the car consists of three pedals (Figure 46). The left is the parking brake pedal, in the center is the brake pedal, and the right is the current accelerator pedal. The pedals are manufactured from a structural aluminum alloy. The position of the pedal plates, the inclination angle, and the spring stiffness are adjustable on the pedals. The current and brake pedals are electronic. They perform control through a central microcontroller. When the brake pedal is pressed, the shaft and the magnet move simultaneously. Magnetic sensors on the printed circuit board detect the extent of the magnet's movements and provide output signals for the microcontroller.

Figure 46 – Pedals

The microcontroller processes the signals and performs the control of the motors (Figure 47). Pedals with a magnetic sensor possess high precision and reliability because they lack rubbing parts subjected to wear. The parking brake is mechanical. When the parking brake pedal is pressed, a steel cable pulls out a stopper, which enters a groove of a gear installed on the drive shaft and locks it. The pedals are installed on the cockpit floor for convenience in use. The size of the pedal unit is 43 × 43 × 28 cm.

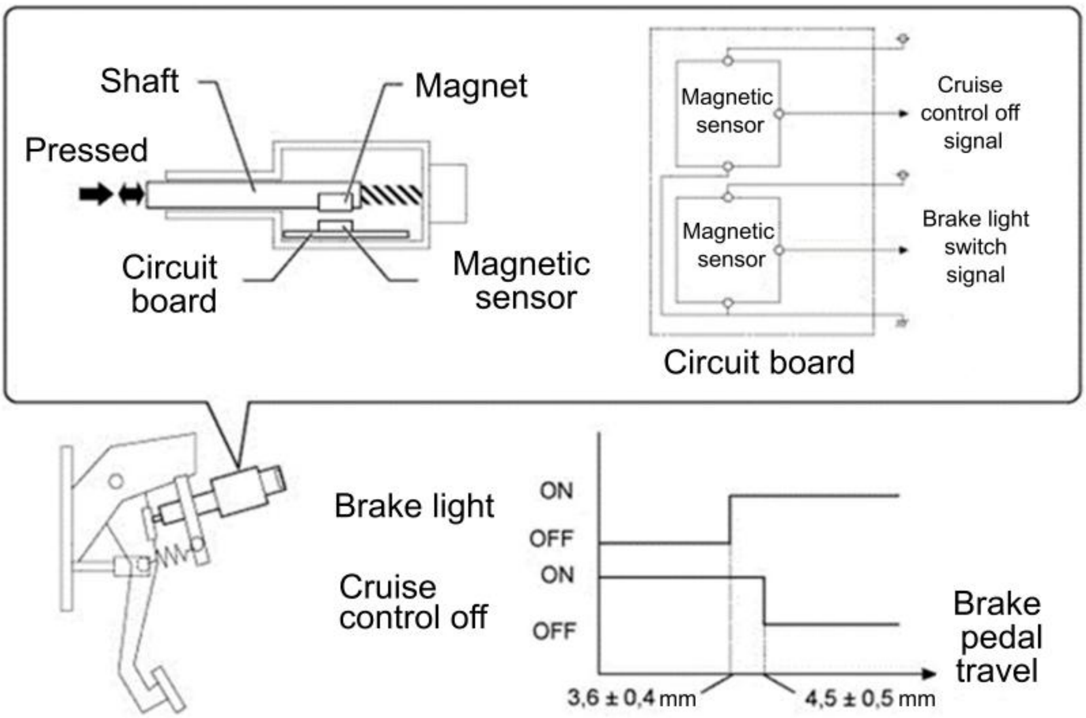


Figure 47 – Control scheme via microcontroller

1.3.15 Split system

The split system is intended for regulating air exchange and air temperature in the car's interior (Figures 48, 49). It performs conditioning, ventilation, and heating of the interior. It also prevents the windshield and side windows from fogging and icing. The split system maintains a set temperature, humidity level, and chemical composition of the air. The split system is located in the front part of the car's monocoque under the instrument panel.

The car has natural, supply, and exhaust ventilation of the interior. Natural ventilation of the interior is performed by lowering the door windows. Supply and exhaust ventilation is carried out through air intake hatches. Air enters through a plastic air supply box, which it reaches from the outside through longitudinal holes in the air intake grille located in the rear part of the motor hood. Inside the box, there is a rainwater reflector that directs water entering with the air along the bottom of the box to a rubber valve. Through the valve, water drains into the environment. The air intake cover allows for regulating the amount of air entering the interior through the heater. At low car speeds and when stationary, when the high-speed air pressure is insufficient or absent, fresh air is forced by an electric fan, which has two rotation speeds: low and high. The temperature of the air entering the body interior is regulated by the amount of heat exchanger supplied to the heater radiator.

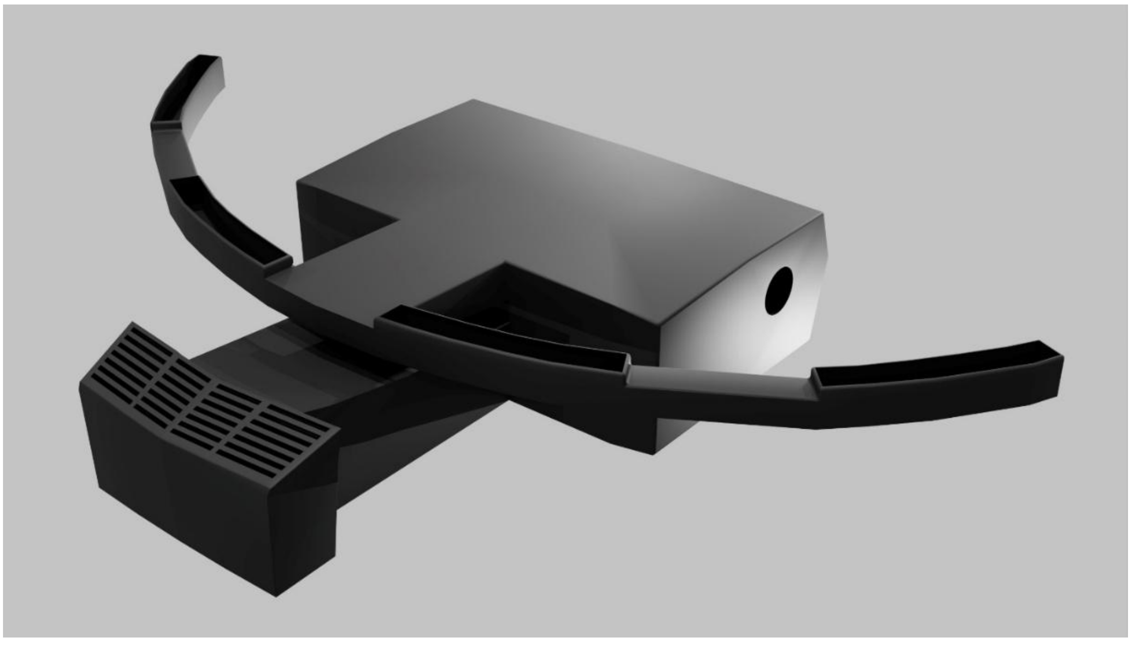
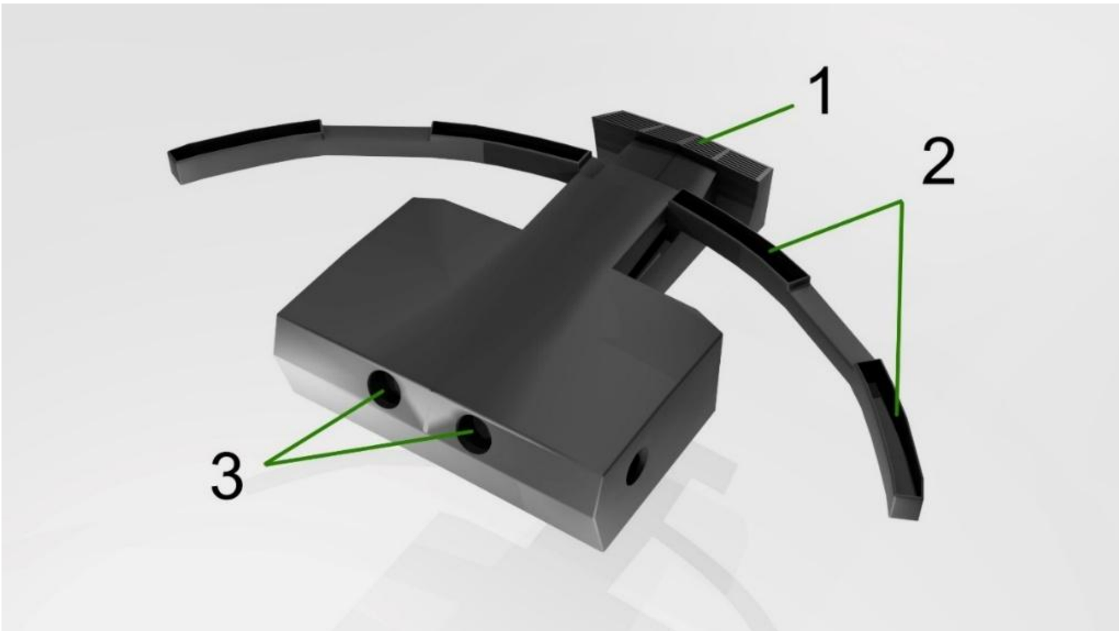


Figure 48 – Split system

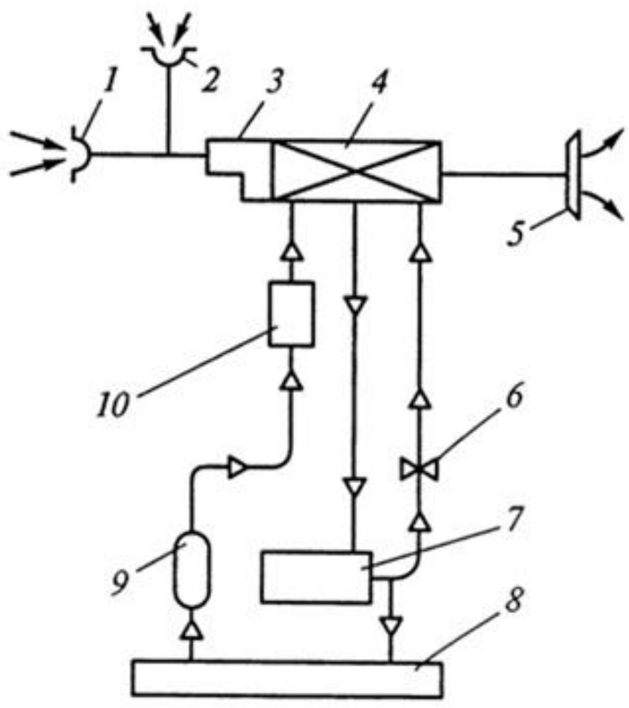
The air entering the interior through the heater is directed along an air duct to the vents. The direction of airflows through the interior is regulated by the vents. An air distribution cover allows for regulating the amount of air directed to the vents and the air duct. When the cover is closed, all air enters the interior through the vents, and when the cover is open, most of it is directed through the air duct into the front part of the interior to the feet of the driver and passenger. The vents have pivoting covers with guide grilles, which allows for regulating the direction of the exiting air flow. When the cover is closed, intensive blowing of the inner surface of the car's windshield is achieved, protecting the glass from fogging and icing.



1 – air intake grille; 2 – air duct; 3 – air distributor
Figure 49 – Split system construction

During forced ventilation with closed windows, outside air is forced into the interior by a fan without being heated. Passing through the radiator housing, the air enters the interior. Forced ventilation is applied during stops and at low movement speeds. At speeds over 50 km/h, the interior is ventilated even with the electric fan switched off, solely due to the high-speed air pressure. Air recirculation in the system is used at low ambient temperatures.

The air conditioning system serves to cool and regulate the humidity of the air in the car interior. In the air conditioning system, fan *3* forces outside air and air from the interior into the cooler *4* through intakes *1* and *2*; from there, the air enters the interior through hatch *5*. In cooler *4*, heat from the air is absorbed by the cooling liquid (freon) as it transitions into a vapor state. Cooling liquid vapors from the cooler enter compressor *7*, in which they are compressed. From the compressor, the compressed and heated vapors are supplied to radiator *8*. In the radiator, the vapors are cooled by the oncoming air flow and turn into a liquid that flows into cylinder *9*. From the cylinder, the liquid returns to cooler *4* again through filter *10*. Bypass valve *6* performs automatic regulation of the air conditioning system, bypassing part of the cooling liquid vapors into the cooler, avoiding the radiator. There are two thermostatic switches in the air conditioning system. One switch manages bypass valve *6* depending on the air temperature in the cooler, and the other disconnects the compressor drive in case of air overcooling in the cooler (Figure 50).



1, 2 – intakes; 3 – fan; 4 – cooler; 5 – hatch; 6 – valve; 7 – compressor; 8 – radiator; 9 – cylinder; 10 – filter.

Figure 50 – Split system scheme

The split system is capable of not only cooling but also heating the interior. When switching the system to heating, the evaporation of the refrigerant occurs in the external unit, and condensation occurs in the internal unit. For this purpose, the direction of the refrigerant pumping by the compressor is changed with the help of a four-way electromagnetic valve. The interior is heated by hot air. Passing through the heated heater radiator, the air warms up and is supplied to the interior. During the intake of outside air, it passes through a grille located between the windshield and the hood, abruptly changes direction, and separates from rainwater, which drains onto the road through a plastic groove located in the under-hood space. Further, the air passes through the air intake box and is supplied to blow over the windshield, door windows, as well as into the footwell of the driver and passengers. The heater consists of a plastic casing in which a radiator, two fans fixed on the electric motor shaft, and upper, central, and lower shutters are installed. When the car is moving, air will enter the interior with the fan switched off. To increase heating efficiency and, especially, to speed up the warming of the cabin during the cold season, recirculation of cabin air through the heater radiator is used. The upper shutter blocks the entry of outside air into the heater and opens a window for air intake from the interior. The constant circulation of "cabin" air through the heater radiator contributes to its intensive warming. In this case, only interior ventilation occurs; the air is supplied to heat the windshield and door windows, plus it additionally enters the footwell of the driver and passenger.

1.3.16 Dashboard

The car's dashboard combines a group of parts and devices into a single construction (Figure 51). The dashboard is manufactured from plastic. It is attached to the monocoque with screws, so that it can be dismantled if necessary. Air ducts of the split system pass inside the dashboard. Most of the car's wiring is hidden under the dashboard. Located on the dashboard are: a display for the driver, a multimedia display, ventilation vents, airbags, and a glove box.

Figure 51 – Dashboard

In the left part of the dashboard, behind the steering wheel in front of the driver, a display is located. The readings of the control and measuring instruments are shown on the display. The control and measuring instruments are intended for monitoring the state and operation of individual systems and mechanisms of the car. These include instruments measuring the charge level in the storage battery, the speed of the car, and the state of the motor, chassis, and transmission. The speedometer displays the speed of the car's movement, the distance traveled per day, and the distance since the start of operation. The tachometer shows the rotation frequency of the motor shaft. In addition, symbols for turn indicators, high-beam headlights, the parking brake, and hazard warning lights are displayed. In the central part of the dashboard, a multimedia display is located. It shows navigation maps, the climate control mode, and a media player.

In the right part of the dashboard, a niche with an airbag for the passenger is located. The airbag is behind a flap, opposite the seat. When the safety system is triggered, the flap opens, and the airbag is filled with air under high pressure. Under the passenger airbag, there is a glove box for storage. The box door is closed with a latch. Vents of the split system air ducts are placed on different sides of the dashboard. The vents change the direction of the air flow and increase the draft in the channel, thus enhancing the efficiency of the ventilation systems.

1.3.17 Steering wheel

The car's steering wheel is designed for sports driving (Figure 52). It is specially developed for managing numerous car parameters while driving. The diameter of the steering wheel is 310 mm. The small diameter of the steering wheel increases the turning speed. This allows the driver to effectively control the car under high-speed conditions. The steering wheel is manufactured from carbon fiber. Carbon fiber possesses great strength, low weight, and low thermal conductivity. The steering assembly consists of four parts: an airbag, a button module, the steering wheel itself, and the steering hub (Figure 53). The button module is attached to the steering wheel. On the module, there are buttons regulating various car settings. Using the menu pad on the module, the display is controlled. The menu pad provides the driver with instantaneous access to various functions without distraction from driving.


Figure 52 – Steering wheel

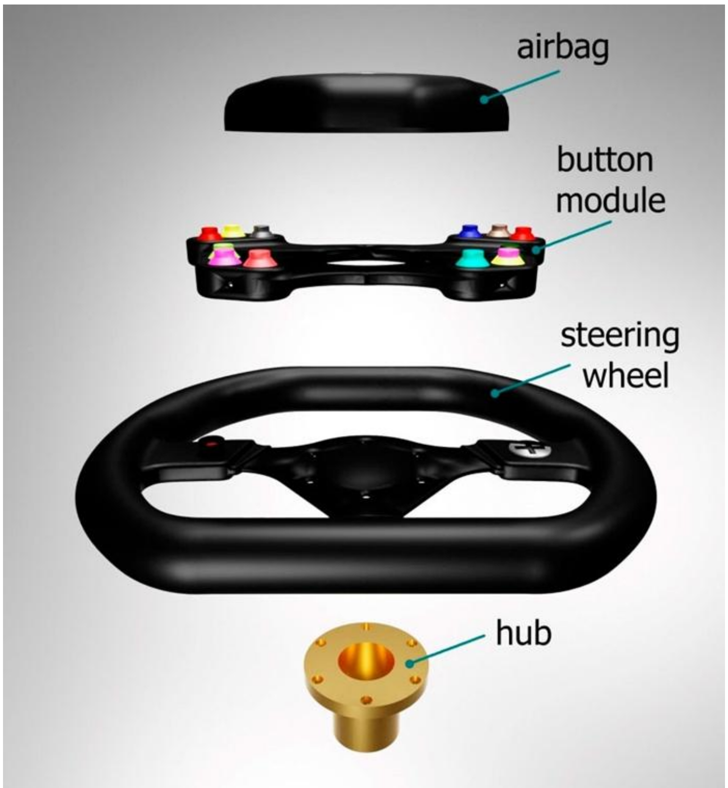


Figure 53 – Steering wheel construction

Located on the module are buttons for turn signals, switching on hyper-speed, reverse gear, movement around an axis, the horn, and wiper control (Figure 54).

1 — horn; 2 — windshield washer; 3 — wipers; 4 — right turn signal;
5 — menu pad; 6 — reverse; 7 — movement around an axis; 8 — voice assistant; 9 — hazard warning lights; 10 — speed limiter; 11 — driving mode; 12 — hyper-speed; 13 — left turn signal; 14 — low/high beam;
15 — windshield defrost.

Figure 54 – Steering wheel with specified button functions

Inside the button module, a printed circuit board with shift registers is installed (Figure 55). Signals from the buttons on the wheel are transmitted through 74HC165 shift registers installed on the PCB within the steering wheel. A shift register is used to increase the number of microcontroller inputs to detect presses among a large number of buttons. The car's computer receives serial digital signals from the 74HC165 shift registers. The 74HC165 chip converts a parallel input signal into a serial output. It allows for increasing the number of digital inputs of the microcontroller. The chip converts the incoming parallel signal on 8 pins (Dx) into an outgoing serial signal on 1 pin (Q7). The transmission is synchronous. An additional pin (CP) is used for the clock pulse. Also, the data register (PL) is controlled by a separate pin, which allows "loading" the parallel signal for serial reading from 8 outputs simultaneously. Thus, from three microcontroller pins, 8 digital inputs are obtained. A cascade is formed from the 74HC165 registers by connecting them one after another, and thus, from the same 3 input lines, 16, 24, 32, etc., digital inputs are obtained (Figure 56).

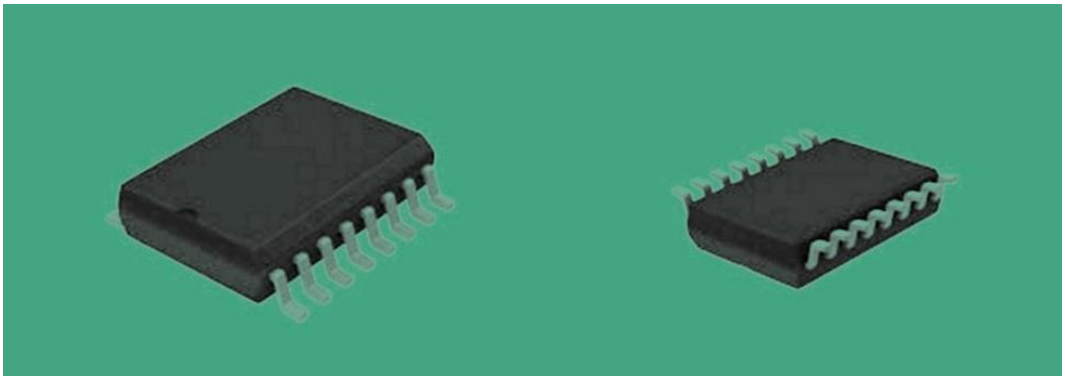


Figure 55 – 74HC165 shift register

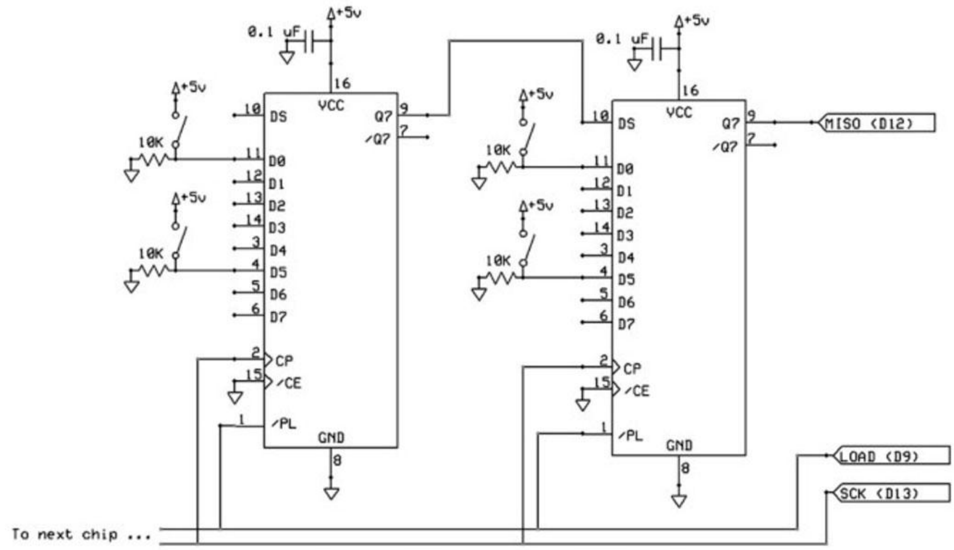


Figure 56 – Scheme of connecting steering wheel buttons to shift registers

A feature of the steering management is that a magnetic sensor is applied in it to determine the steering angle (Figures 57, 58). With the help of this sensor, a signal is supplied to the microcomputer to control the rotation frequency of the electric motors depending on the steering angle. The magnetic sensor, installed in the stationary part of the dashboard housing, determines the steering wheel position with an accuracy of 0.06 degrees. The advantages of using a magnetic sensor are small dimensions, contactless operation, high precision, and a long service life.

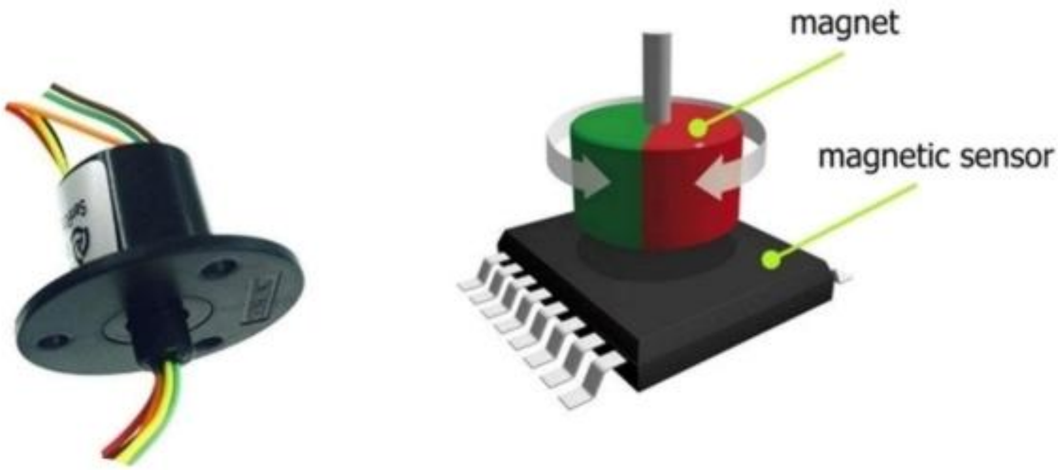


Figure 57 – Rotating connector and magnetic sensor

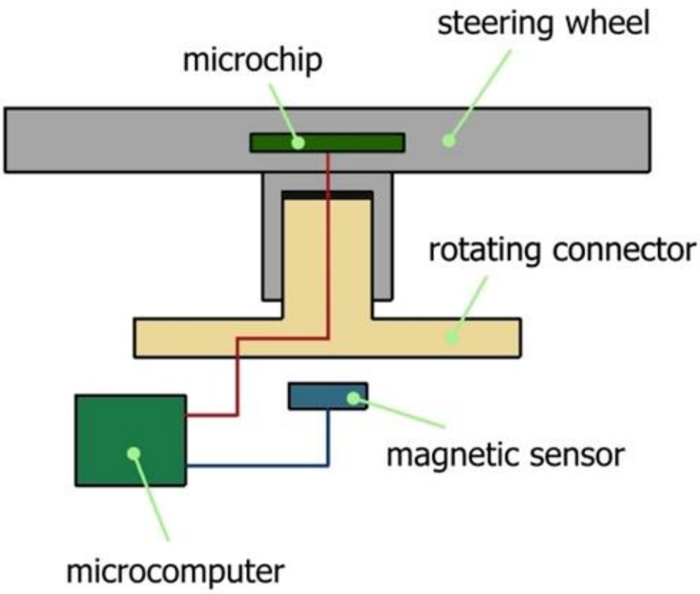


Figure 58 – Magnetic sensor operation scheme

1.3.18 Electrical wiring

The car's electrical wiring is a complex of cable lines, connectors, harnesses, and switching elements intended for the transmission of energy and control signals between all systems of the vehicle (Figure 59). In the car's construction, the electrical wiring is divided into two types: power wiring and low-voltage wiring. To reduce interference, power and signal wires are separated.

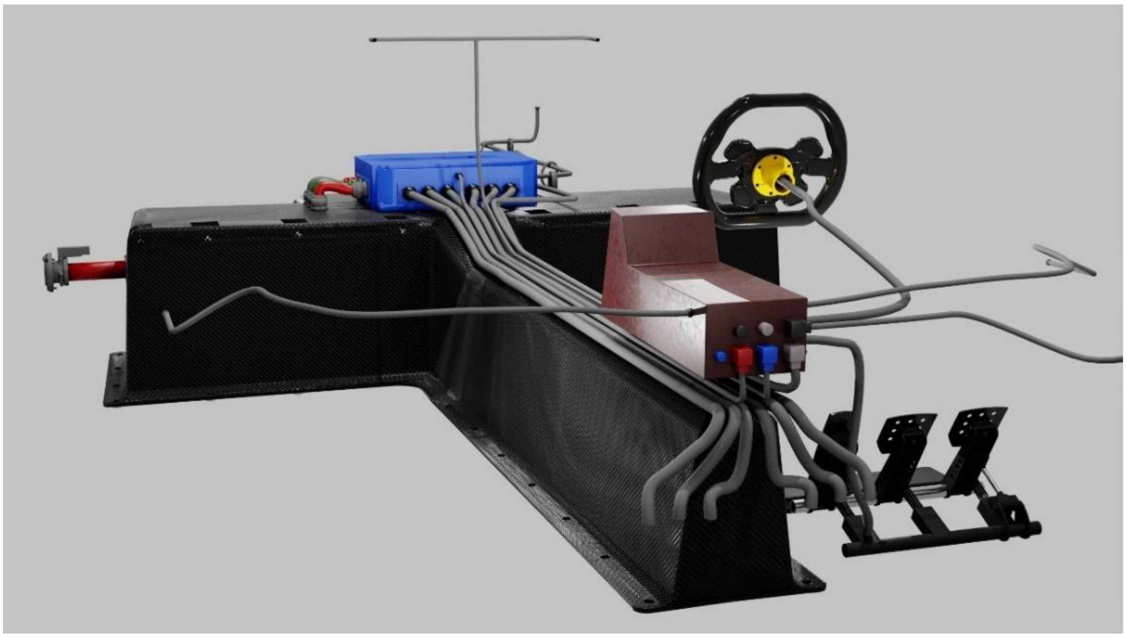


Figure 59 – Car electrical wiring

The power wiring transmits high-power electrical energy from the storage battery to the speed controllers and electric motors. The low-voltage wiring provides power to auxiliary systems and the exchange of control information between electronic units. Both systems function together but are manufactured from different types of cables and possess different protections. A three-phase stranded copper cable of increased flexibility is used between the speed controller and the electric motors. A power cable with a cross-section of 40 mm² is designed for an operating current of 180 – 220 A. The cable is insulated with heat-resistant, oil-and-petrol-resistant protection rated for heating up to + 150 °C. The cable is protected from interference by braiding to reduce electromagnetic induction from the ESC operation. Low-voltage wiring inside the interior (12 – 48 V) performs the functions of control and power supply for the car's electronics. It connects the dashboard and displays, powers the onboard computer and controllers, the ESC control signal lines, lighting systems, the climate control system, and auxiliary modules. For low-voltage wiring, a lightweight stranded wire with a cross-section of 0.5 – 1.5 mm² is used.

1.3.19 Seat

Two "bucket" sports seats are installed in the car (Figure 60). The seat is characterized by a specific shape and design resembling the form of a bucket. The seats have a shape where the bolsters wrap around the body, creating a feeling of sitting inside a "bucket." Sports seats possess high lateral support, which provides additional fixation for the driver's and passengers' bodies during active driving, especially in corners. They are convenient for driving at high speeds and under dynamic driving conditions, which is an important aspect in sports cars. The shape of the seat ensures ideal fixation and the correct position of the spine and joints. The seat is manufactured from durable fiberglass, without separation between the backrest and the cushion, and without backrest tilt adjustment. The weight of the seat is 8.5 kg.

Figure 60 – Seat

The seat upholstery is made of eco-suede. The seat possesses firmer upholstery, which is preferable for drivers who favor a more upright and rigid seating position that improves sensitivity and feedback from the road. There are removable pads for selecting the pilot's optimal position in the seat. The rear part has a glossy black protective coating. Plastic pass-through openings are provided for the use of three-point or six-point safety harnesses. The seat is installed on sliders using brackets. The position of the seat is adjusted by means of the sliders. The sliders ensure the movement of the seat to the required position when the handle of the adjustment mechanism is lifted. The seat is attached to the sliders by brackets stamped from sheet steel. For the installation of the brackets and sliders, M8 threaded mounting holes are provided in the seat. The tilt angle of the seat is adjusted using the brackets.

1.3.20 Powertrain enclosure

During operation, the electric motor heats up. Cooling of the electric motor is important for its normal operation and for increasing its service life. The magnitude of the allowable steady-state motor temperature is determined by the properties of the winding insulation. For the insulation, the temperature rise at individual, most heated points should not exceed 90 °C. Mechanical units and parts of the electric motor are also sensitive to heating. The allowable temperature rise for rolling-element bearings is 95 °C. The electric motor housing is manufactured from aluminum alloy. The thermal conductivity of aluminum is greater than the thermal conductivity of water. Therefore, air cooling of the motor is performed. The motor is located in the lower part of the car. An enclosure is applied for its cooling (Figure 61). During the car's movement, air passes through the ventilation grille of the enclosure and cools the electric motor located within it. The enclosure is manufactured from fiberglass. It is attached to the frame and the monocoque of the car. The enclosure is corrosion-resistant and strong; therefore, it is resistant to the effects of external factors such as moisture, dust, and small particles.

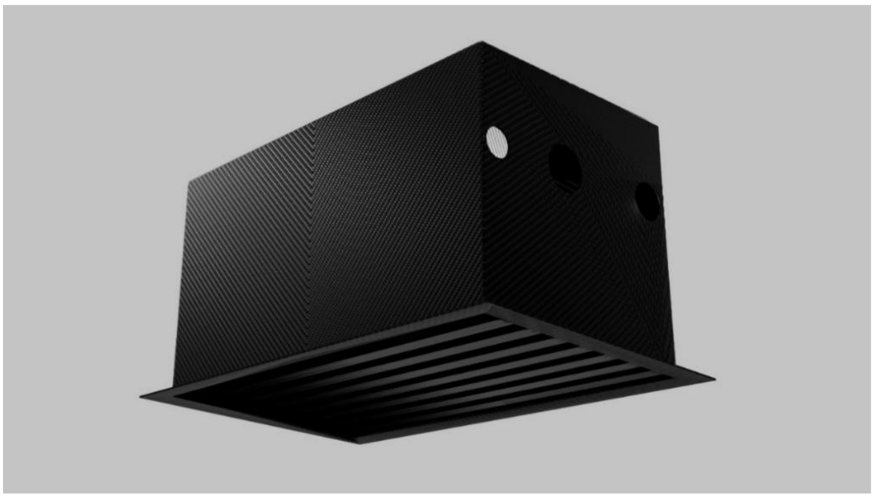


Figure 61 – Enclosure

1.3.21 Front trunk

Despite its sportiness, the car is intended for everyday use. There is free space under the hood of the car. This space is used for a luggage compartment (Figures 62, 63). The front trunk can be used for transporting everyday items, such as groceries, backpacks, sports equipment, and other necessary things.

The luggage compartment is removable. It can be removed on a racing track. It is attached to the car frame and the monocoque with the help of screws. The trunk is manufactured from fiberglass.

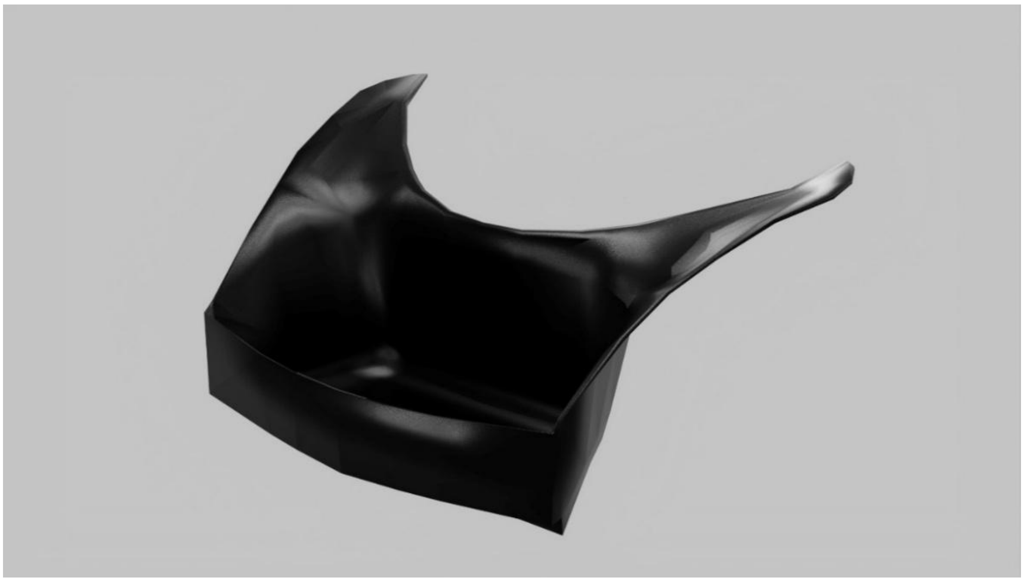


Figure 62 – Front trunk

Figure 63 – Front trunk

1.3.22 Rear trunk

Under the rear hatch of the car, above the powertrain, there is free space. It is used for the rear trunk (Figures 64, 65). Like the front trunk, it can be used for transporting everyday items such as groceries, backpacks, sports equipment, and other necessary things. The luggage compartment is removable. It can be removed on a racing track. It is attached to the car frame and the monocoque with the help of screws. The trunk is manufactured from fiberglass.

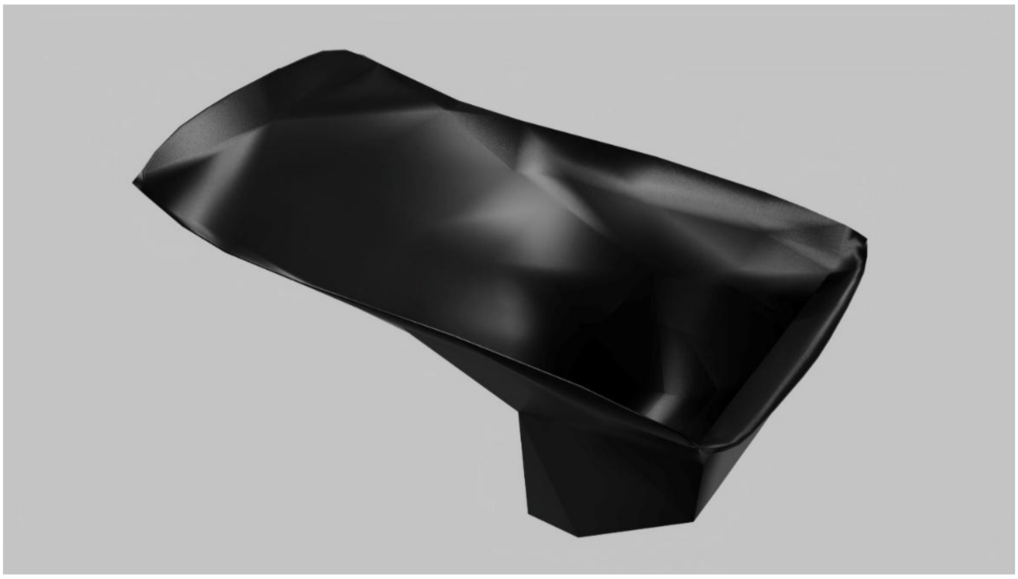


Figure 64 – Rear trunk

Figure 65 – Rear trunk

1.3.23 Wheel arches

The car's wheel arches provide protection against splashes, mud, stones, and other elements of the road surface (Figure 66). They surround the wheel and form a niche, open from the outside, to accommodate the wheel and its associated suspension parts. The wheel arches are manufactured using the thermal vacuum forming method (Figure 67).

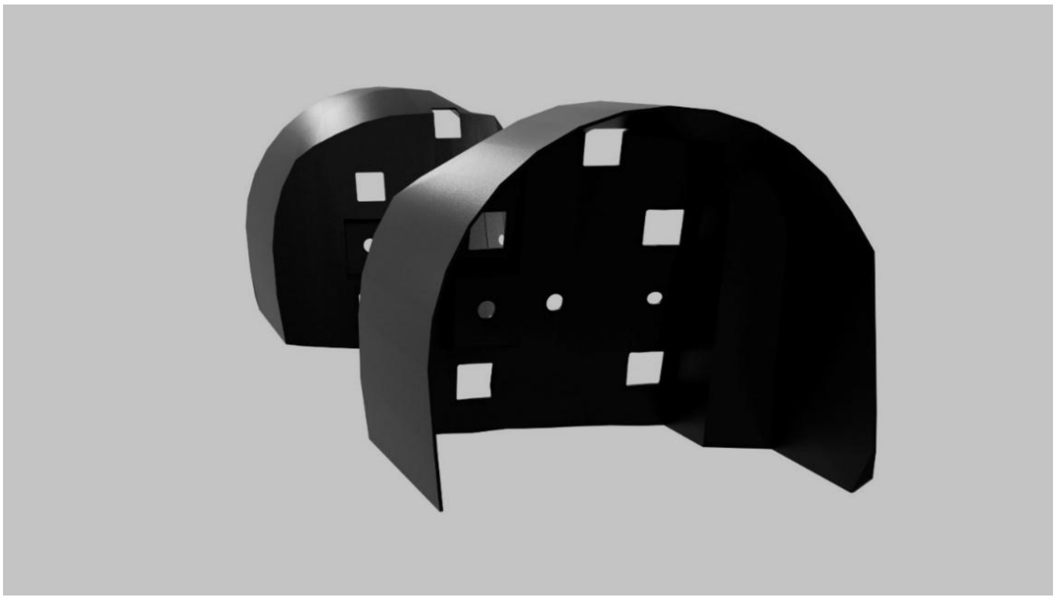
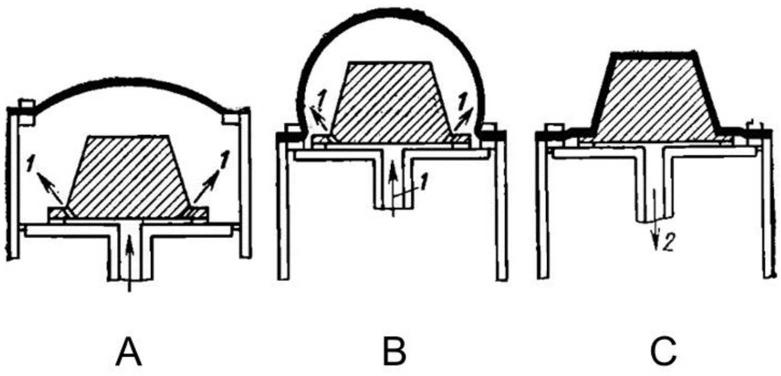


Figure 66 – Wheel arches

A sheet of thermoplastic plastic is used to manufacture the wheel arch. The part has a constant wall thickness. The magnitude of the taper is from 10° to 20°. These characteristics of the part are beneficial for the application of vacuum forming technology. The tolerances for the mold used in vacuum forming wheel arches are less stringent due to the volumetric shrinkage of the formed part after its removal from the mold. Before forming, the plastic sheet is preheated, and using a compressed vacuum, the heated plastic sheet is drawn toward a mold with holes. As a result, the plastic sheet takes the shape of the mold.



1 – compressed air; 2 – vacuum
A – heating the plastic sheet; B – placing the sheet on the mold;
C – air evacuation
Figure 67 – Vacuum forming.

1.3.24 Underbody

The underbody of the car prevents dirt, water, and snow from reaching the car's parts, and it also protects them from mechanical damage (Figure 68). Repairing or replacing the underbody is cheaper than repairing the battery in the event of its damage. The underbody has a smooth surface without protruding parts, which improves aerodynamics.

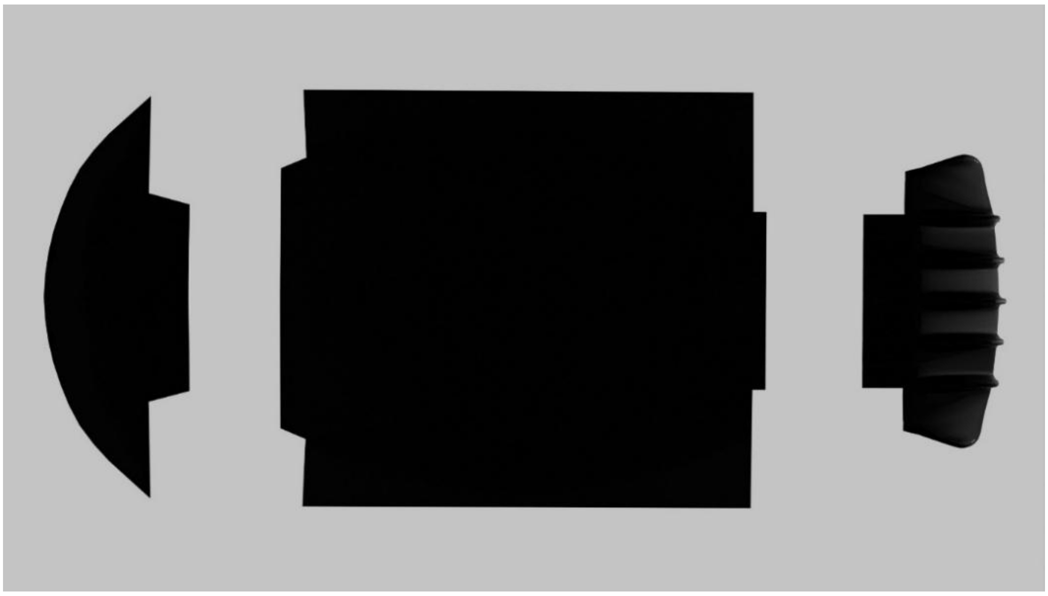


Figure 68 – Car underbody

A diffuser is one of the parts of the underbody. It reduces air turbulence by creating a laminar flow. The underbody is manufactured from carbon fiber and is attached to the monocoque and the frame with the help of screws (Figure 69).

Figure 69 – Underbody on the car

1.3.25 Car door

The car has a vertical lifting door, also known as a "gull-wing" door (Figures 70, 71). It opens vertically upward, forming an angle of about 90 degrees with the car body. This not only adds technological charm to the car but also makes the car convenient for entering. An original mechanism is used to implement the vertical opening of the door. To ensure safety and prevent the accidental lowering of the door, a special locking mechanism is installed in it. This mechanism is activated when the door is in the vertical position. The door is also equipped with an opening limiter. The door hinges on which the door is suspended allow for adjusting their position relative to the monocoque openings. The door is made with a single power-operated lowering window. The door window is safe, polished, and made of three-layer laminated glass. It is installed in the door with rubber seals. The car is subjected to airflow not only from the front but also from the sides. The rounded shape of the window not only promotes the mixing of airflows in the vicinity of the windshield but also allows the airflow washing the sides of the body to move the flow separation point closer to the rear of the car. The exterior door handle is aerodynamic, it is located inside the end face. The door is manufactured from carbon fiber.

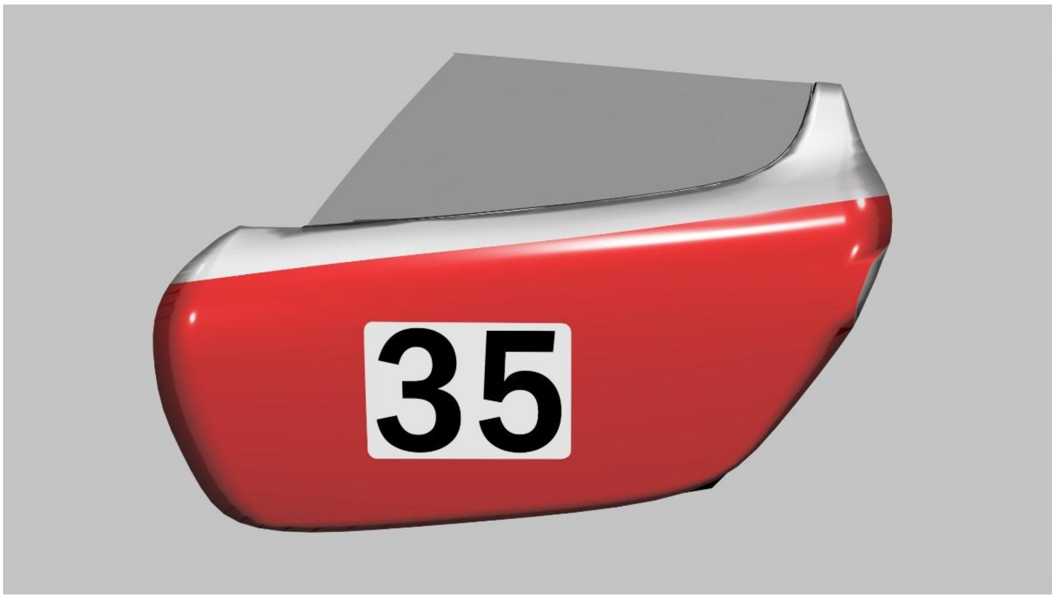


Figure 70 – Car door

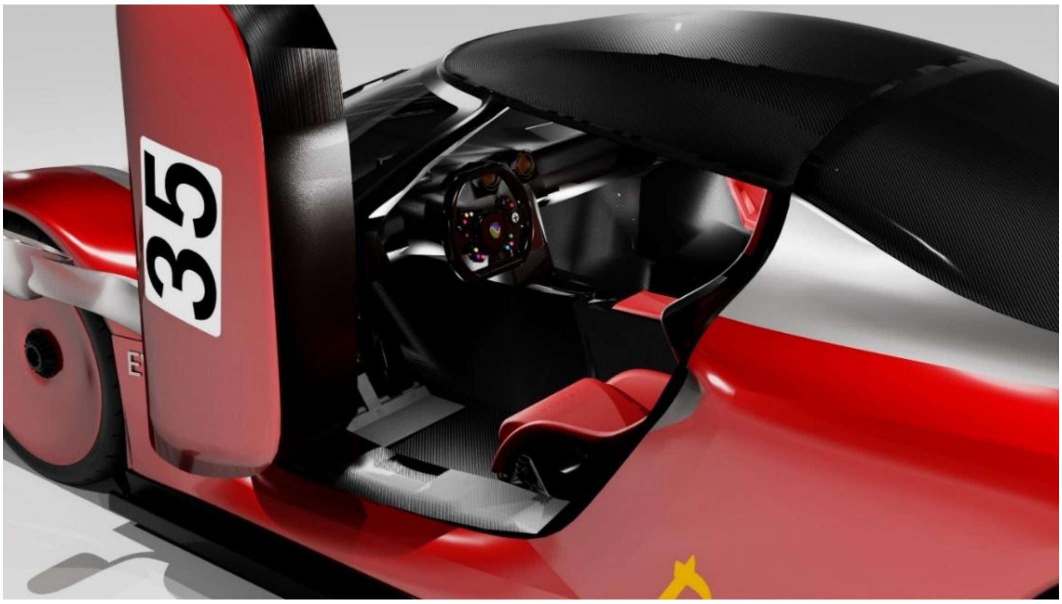


Figure 71 – Door of the Dubina Evo electric car

1.3.26 Windshield

The windshield, also called the windscreen, is installed in the front part of the car, ahead of the driver and passenger (Figure 72). The windshield provides the driver and passenger with a wide view of the road. It serves as a barrier against wind, rain, and snow. The windshield is an important part of the car's monocoque structure. It contributes to the rigidity and strength of the monocoque and also serves as a safety element during accidents. Polycarbonate, a lightweight, high-strength polymer material capable of withstanding high aerodynamic loads, is used for its manufacture. The windshield is equipped with filters that block ultraviolet rays and reduce the intensity of sunlight, which helps prevent the car from overheating and protects against the harmful effects of UV radiation on the skin. The windshield is an important element of the car's design. It influences the overall appearance and style of the vehicle. Its design accounts for high speeds, aerodynamic loads, and safety in the event of an accident. The smooth change in the curvature of the windshield ensures non-separated flow, keeping the boundary layer along the entire length of the body contour up to the rear of the car. Thus, the windshield plays a key role in driving safety and comfort, providing the driver and passengers with the necessary visibility and protection from external influences.

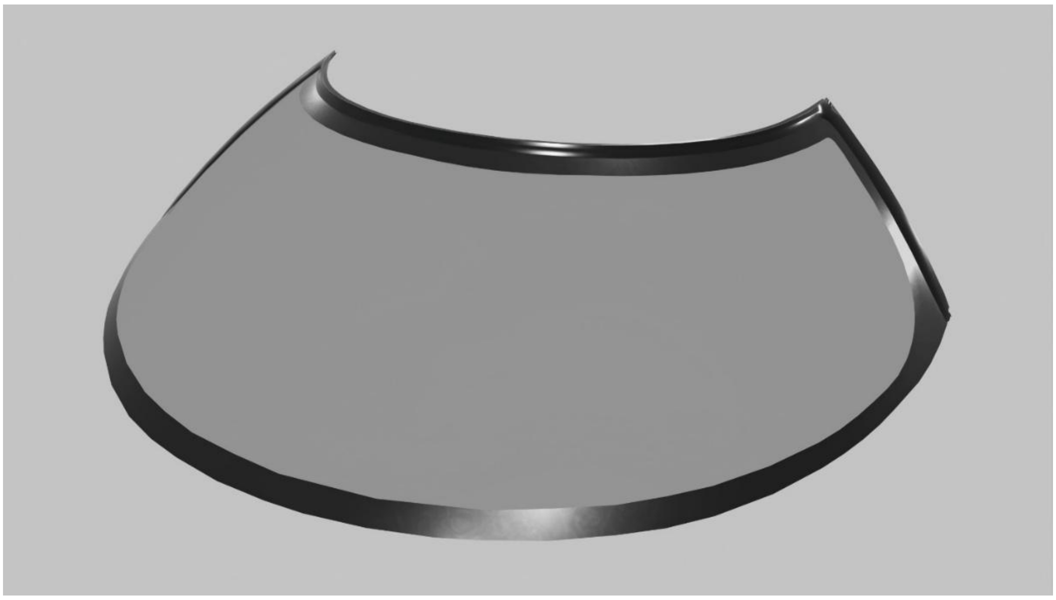


Figure 72 – Windshield

1.3.27 Windshield wiper

The car has a single wiper (Figure 73). It moves across the glass. The wiper is manufactured specifically for the shape of the car's glass, repeating its curve. Due to the curvature of the windshield, the wiper is located on the center line of the glass. In its resting state, the wiper is positioned in the center of the windshield. If the window were flat, it could be hidden under the hood, but since the window is curved, a wiper from under the hood would not cover the entire surface of the window. The wiper has a frameless construction. It represents a plastic housing with a thin metal plate made of spring steel built into it to ensure the normal fit of the wiper blade to the curved surface. The advantages of such a construction are an elegant appearance, the absence of frame loosening, less icing, and, as a consequence, greater mobility. The main cleaning function is performed by blades with a silicone edge, located on the wipers with the help of a special arm (blade holder). The silicone strip is a consumable element, as the strip wears out over time and the cleaning quality deteriorates. The length of the blade is 600 mm, and it is attached to the arm. The wiper drive with a reduction gearbox ensures the movement of the wipers. An electrical-type mechanical drive is used in the wiper. It consists of rods and levers, the task of which is to convert the rotational motion created by the electric drive into reciprocating motion and transfer it to the arm. A linkage (wiper transmission) is located between the drive and the wiper (Figure 74).

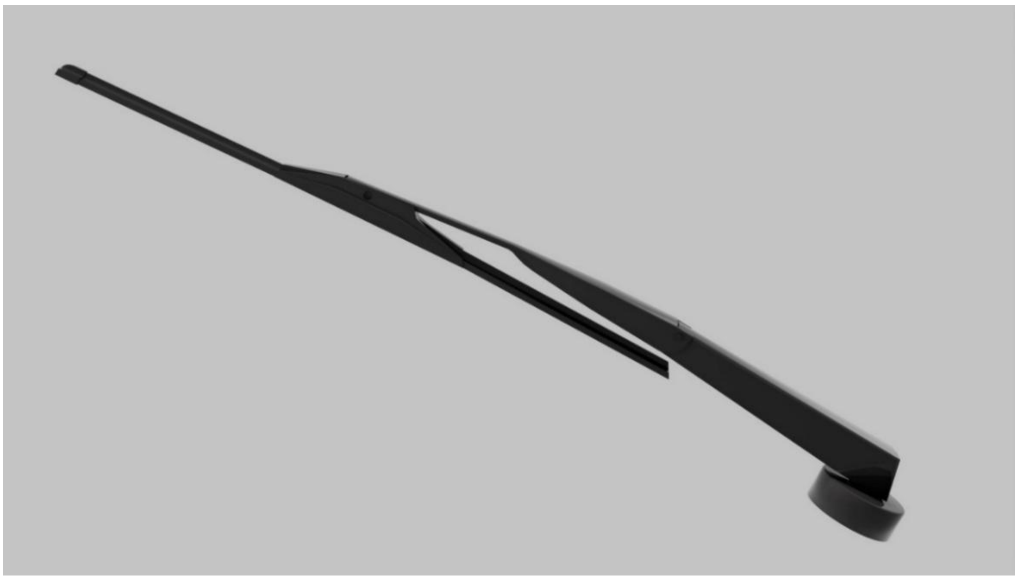


Figure 73 – Wiper

Figure 74 – Wiper on the car window

1.3.28 Body side panel

The side panel is an external part of the car body (Figures 75, 76). It influences the aerodynamic characteristics of the vehicle. Good streamlining of the car body is achieved by using body side panels without abrupt transitions. Such a design reduces aerodynamic losses during movement. The side panel protects the internal parts of the car from mechanical damage. The side panel is manufactured from carbon fiber prepreg, which is resistant to atmospheric conditions, using the manual molding method. It is attached to the monocoque and other body parts with the help of screws.

Figure 75 – Body side panel

Figure 76 – Side panel in assembly

1.3.29 Front fender

The front fender is located above the wheel arches (Figures 77, 79). It is stationary and is attached to the frame and the monocoque with the help of screws. The fender is manufactured from carbon fiber using the manual molding method. There are no sharp corners on the surface of the part. This is because areas with sharp corners have low strength, are difficult to fasten, and are dangerous during assembly (Figure 78).

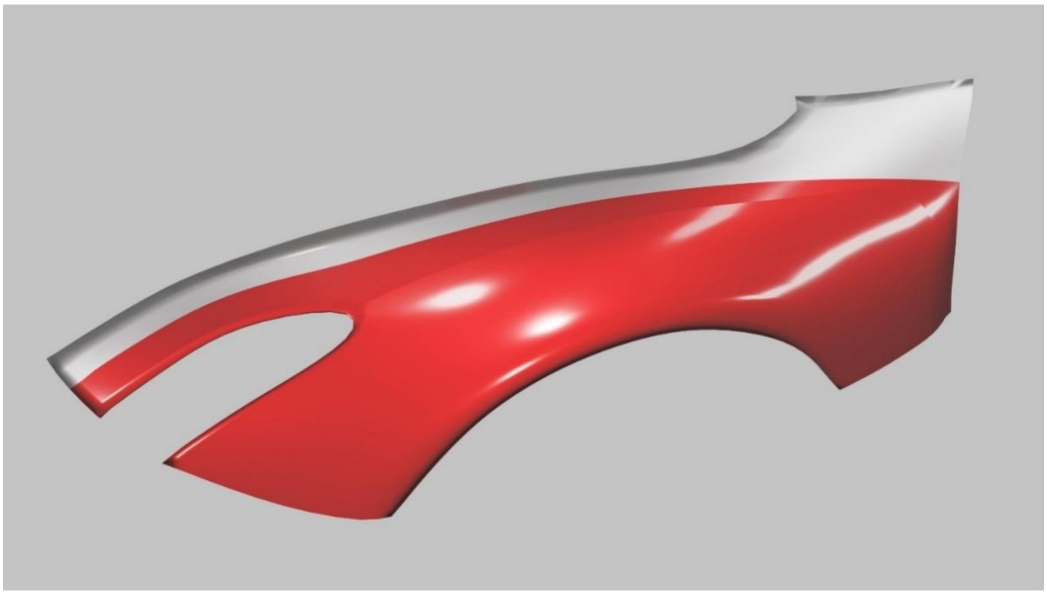


Figure 77 – Front fender

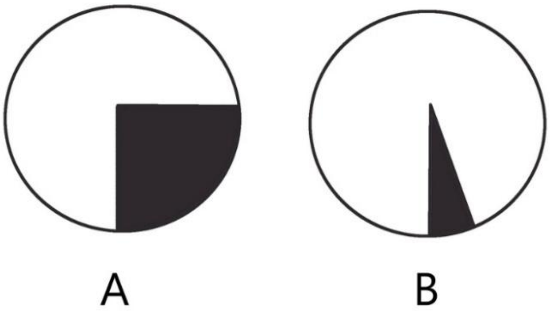


Figure 78 – Straight and sharp surface angles

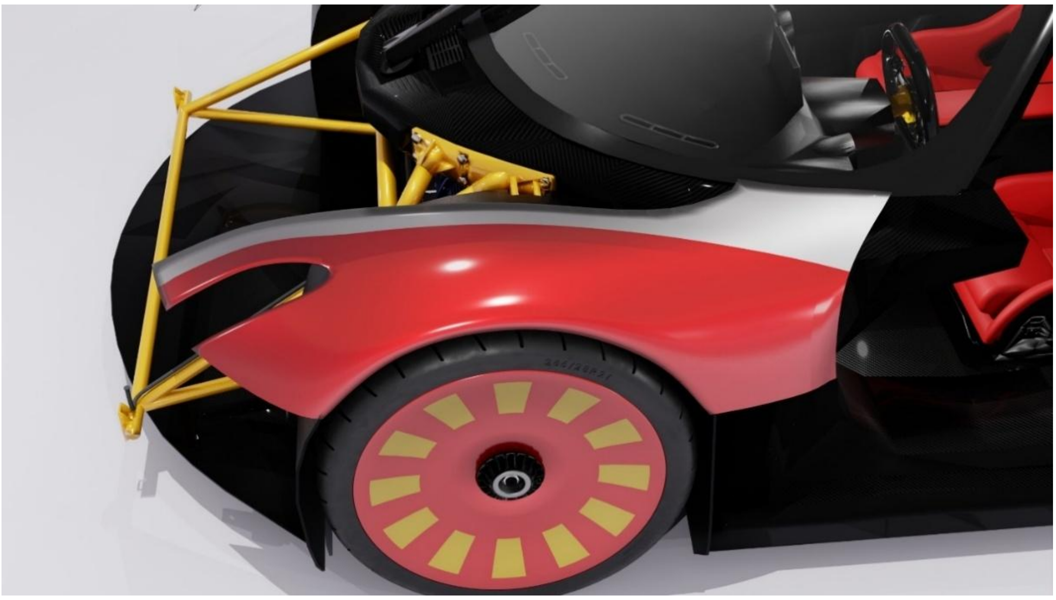


Figure 79 – Front fender on the Dubina Evo

1.3.30 Front bumper

Since the appearance of the first cars, the main function of the front bumper has been to provide protection against impacts and collisions (Figures 80, 81). The bumper absorbs the impact, preventing damage to more critical car parts such as the headlights and the motor. The bumper is a car part that is easy to replace. In addition to protective functions, on a racing car, the bumper improves the aerodynamic characteristics of the vehicle. It enhances aerodynamics and prevents drag caused by air pressure. This may include creating a specific shape to reduce air resistance and increase efficiency. The airflow rounds the bumper at an acute angle and is directed away from the sides of the car. A splitter is installed in the lower part of the bumper. Its trailing edge fits closely against the bumper. The splitter is an aerodynamic plane that serves to limit the flow of air under the underbody and, accordingly, creates a low pressure beneath it. The bumper is manufactured from carbon fiber using the vacuum infusion method.

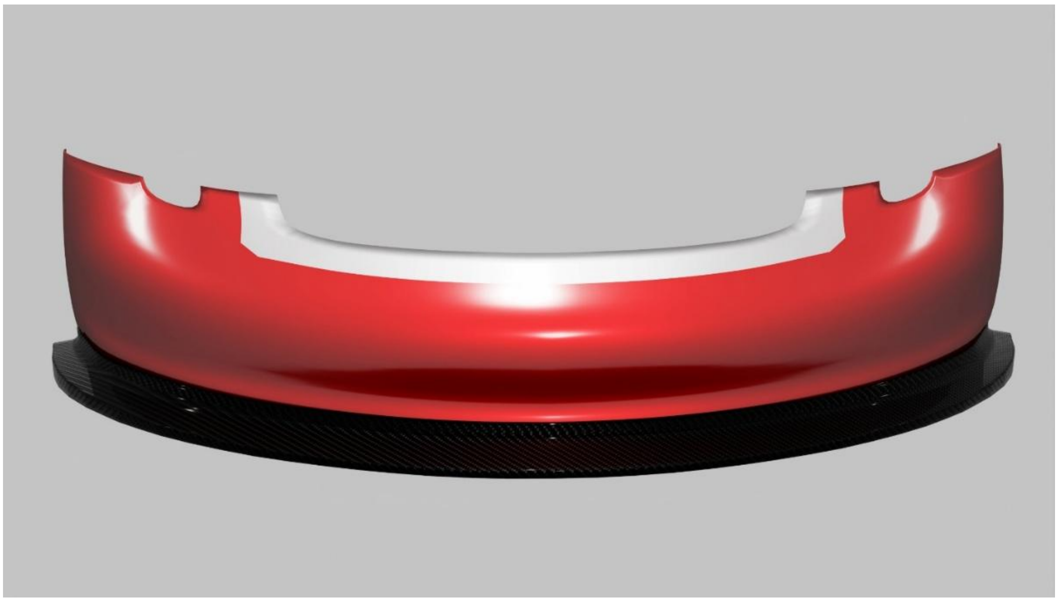


Figure 80 – Front bumper

Figure 81 – Front bumper in assembly

1.3.31 Rear bumper

The rear bumper on the car performs several important functions; it protects the rear part of the vehicle from impacts and collisions (Figures 82, 83). The bumper can absorb the impact and prevent damage to more critical components, such as the rear lights and the motor. The rear bumper is designed for the possibility of quick and inexpensive replacement. The rear bumper influences the aerodynamic properties of the car. It is designed to reduce air resistance and improve overall efficiency. The rear bumper includes splitters that are tuned to improve aerodynamics and stability on the track. To reduce the weight of the racing car and increase performance, the bumper is manufactured from lightweight and durable carbon fiber using the vacuum infusion method.

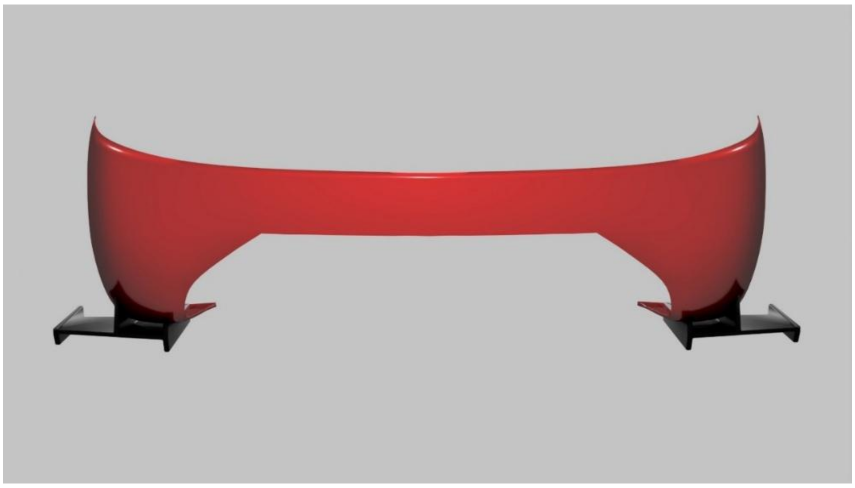


Figure 82 – Car rear bumper

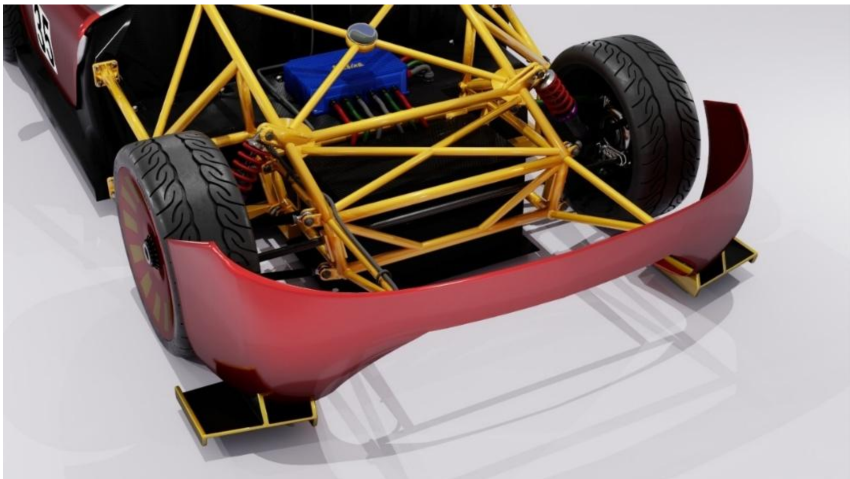


Figure 83 – Rear bumper in assembly

1.3.32 Headlight

The car's headlights provide the driver with good visibility of the road in low-light conditions and also serve to warn other road users of the car's presence on the road (Figures 84, 85). The brightness of a headlight is measured in lumens, 2500 lumens. It determines the intensity of the light emitted by the headlights. The power consumption of a headlight is measured in watts, 30 W. This value shows how much energy is required for the headlight to operate. An LED-type headlight is used in the car. The operating principle of an LED headlight is based on the process of a semiconductor device with a p-n junction creating optical radiation when an electric current is passed through it in the forward direction. LEDs possess a long service life, high efficiency, and low power consumption. In the car's headlights, LEDs with various brightness levels are used for lighting instruments and signaling devices. Headlights are installed in symmetrical pairs on the right and left sides of the car. The headlight is made in a single housing, which integrates: low beam, high beam, sidelight (parking light), turn indicator, and daytime running lights. The low beam is asymmetrical; with right-hand traffic, the right side of the road and the shoulder are better illuminated. The optical system of the headlight directs light in specific directions to ensure good visibility on the road and minimize glare for other road users. The high beam represents a symmetrical light beam of high intensity. Reflectors and lenses are used in the headlight to focus the luminous flux and create a specific light distribution.

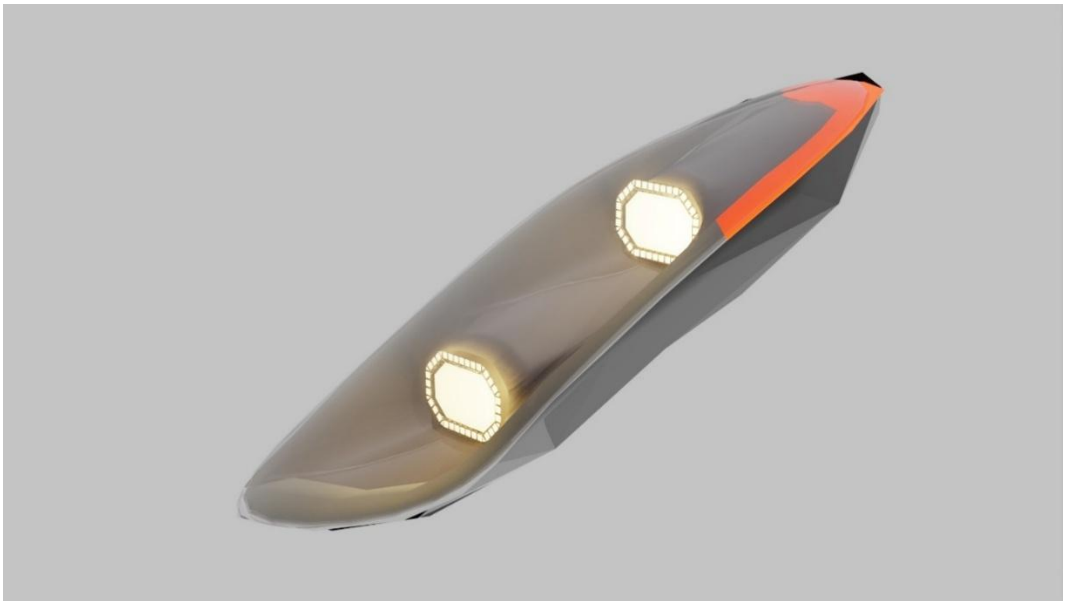


Figure 84 – Car headlight

The sidelight is used to indicate the dimensions of the vehicle. A yellow light source operating in a flashing mode is used as the turn signal. The operating frequency of the indicator is two flashes per second. Turn indicators are also used as a hazard warning signal. Daytime running lights consist of manually controlled low-beam headlights of reduced intensity. LEDs generate heat; therefore, the headlight contains a system for effective heat dissipation to prevent overheating and ensure stable operation.

Figure 85 – Headlight in assembly

1.3.33 Taillight

The taillight serves to indicate the dimensions of the car, provide light signaling when reversing, braking, or turning, and for road illumination (Figures 86, 87). The light uses LEDs, which provide bright light, fast activation, and high efficiency. Similar to the headlights, the taillights have an optical system for directed and uniform light distribution. Reflectors and lenses are used to focus the light. The taillight is designed as three connected units installed in the rear bumper. The light integrates the following lighting devices: rear sidelight (parking light), brake light, rear turn indicator, and reverse light. The brake light is activated automatically when the driver presses the brake pedal. Both the rear sidelight and the brake light are red, but the brake light glows more brightly. The car features a so-called adaptive brake light, in which the light intensity depends on the braking intensity. The reverse light provides illumination when the car is moving backward. It is activated automatically when the reverse mode is engaged. Two symmetrical white reverse lights are installed. Rear fog lights are used to warn following vehicles in conditions of poor visibility. The total power of all the taillight lamps is 50 W. The light housing is covered by a lens (diffuser). The lens is plastic, monolithic, multi-sectional, and three-colored. It is installed in the housing on a rubber gasket. The outer part of the lens is orange and is intended for signaling during vehicle maneuvers. The central part is colorless and serves to signal reverse movement. The remaining sections of the lens are red and are intended for signaling during braking and indicating the car's dimensions.

Figure 86 – Car taillight

Figure 87 – Taillight in assembly.

1.3.34 Hood

The hood is a car body part (Figures 88, 89). It prevents moisture, dust, and dirt from entering the interior of the vehicle. The hood provides easy access to the front trunk, motor, and suspension. It is designed to improve the car's aerodynamics by reducing air resistance. The hood consists of outer and inner panels connected to each other with adhesive. The outer panel is smooth and manufactured from carbon fiber prepreg. The inner panel is also manufactured from carbon fiber prepreg but features reinforcement ribs. The hood is attached to the monocoque on two internal hinges, which allow for the adjustment of its position relative to the luggage compartment opening.

The hood opens backward in the direction of the car's movement. Its front part rests on rubber buffers. In the front part of the hood, there is a lock with a hook that prevents spontaneous opening of the hood during movement. The lock drive is electromechanical. The lock is released from inside the cabin by a button on the multimedia display screen. In the open position, the hood is fixed by a special carbon fiber rod-type prop.

Figure 88 – Car hood

Figure 89 – Car hood in assembly

1.3.35 Trunk lid

A hatch is provided for easy access to the rear trunk, the car's suspension, and the powertrain (Figures 90, 91). The trunk lid with its mechanism opens by lifting upward. This method ensures minimal air resistance during movement and allows instantaneous access to the luggage compartment. The opening of the door is quick and smooth. The trunk lid is manufactured from carbon fiber prepreg. To ensure reliable fixation in the closed position and prevent opening during movement, a special latch is used.

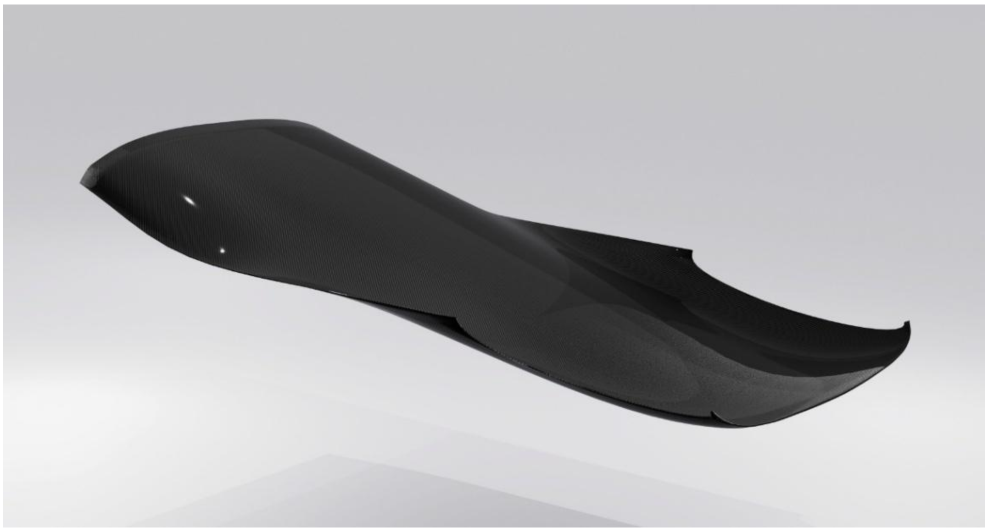


Figure 90 – Rear trunk lid

Figure 91 – Rear trunk lid in assembly

1.3.36 Spoiler

The car possesses aerodynamic stability in roll, pitch, and yaw. Roll stability is ensured by locating the center of pressure close to the longitudinal axis of the vehicle. The value of the longitudinal moment, which leads to changes in wheel loading as speed increases, is determined by the distribution of lift forces acting on the car. A spoiler is used to create the upper contour of the stabilizer, which reduces aerodynamic drag, induces negative lift (downforce) on the rear wheels, and contributes to the increase of the car's longitudinal stability. A spoiler is an aerodynamic device designed to manage the airflow around the vehicle to increase tire-to-road traction. The spoiler is installed on the rear trunk lid. It creates the necessary pressure on the rear suspension shock absorbers. It has minimal air resistance and does not create excessive turbulence (Figures 92, 93). As a result of the pressure from the spoiler on the rear part of the car, the traction of the rear wheels with the road increases. This traction increases braking efficiency. The downforce from the spoiler reduces lift and stabilizes the vehicle. The rear part of the car does not lose traction, preventing the vehicle from skidding. It begins to create effective downforce starting at a speed of 100 km/h. It is rational to use it on a vehicle with an average travel speed exceeding 150 km/h. At low speeds, a negative effect arises from air resistance and the weight of the spoiler. The spoiler is also called an "airfoil" (wing) because of its primary function to create a downward rather than an upward force. The spoiler's angle of attack has a significant impact on its efficiency. The magnitude of the downforce depends on the wing's angle of attack. The larger the angle of attack, the greater the downforce, but there is a limit to this angle. The installation height of the spoiler is important for achieving the optimal balance between stability and road traction. The spoiler is manufactured from carbon fiber. It is attached to the rear trunk lid using mounting screws. The screws are threaded into the bases of the spoiler legs from the inner side of the lid. The working surface area of the spoiler is 0.6 m². The angle of attack is 40°. The downforce at a speed of 200 km/h is 111 kg.

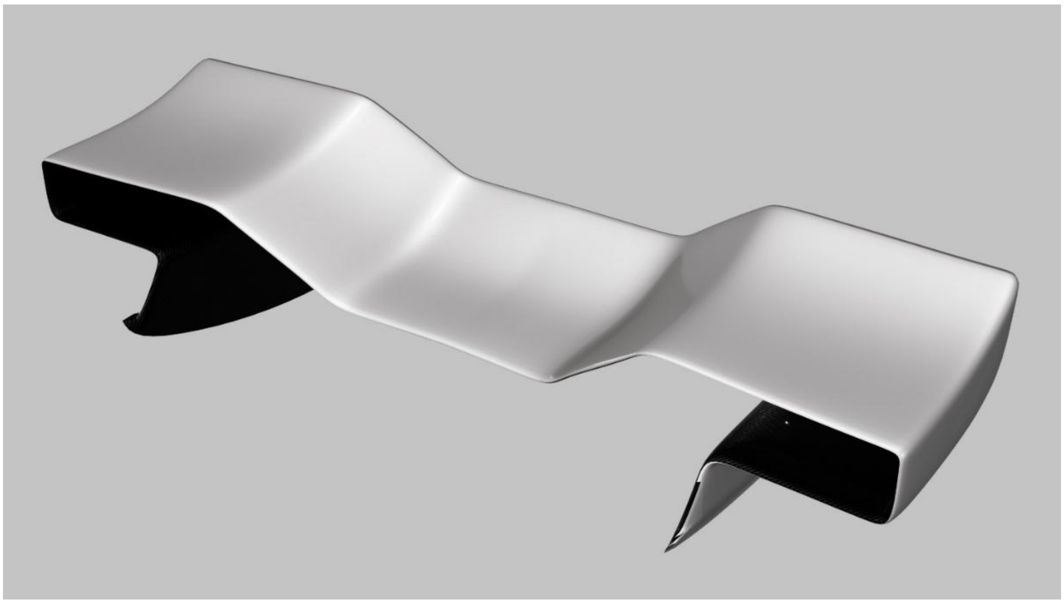


Figure 92 – Car spoiler in assembly

Figure 93 – Car spoiler in assembly

1.3.37 Side mirror

A side mirror is located on both sides of the car (Figures 94, 95). It is designed to provide the driver with a view to the rear and the sides, which is important for track safety and manual steering convenience. The mirror differs from traditional mirrors on road cars and has a specific design aimed at minimizing aerodynamic drag and creating an effective field of vision. The mirror is adjustable, allowing the driver to set it according to individual preferences. The shape of the mirror ensures the widest possible viewing angle for tracking the movement of other race participants. A video camera is integrated into the mirror housing. The image from the camera is transmitted to a screen or the driver's goggles. The mirror is manufactured from lightweight and durable carbon fiber.

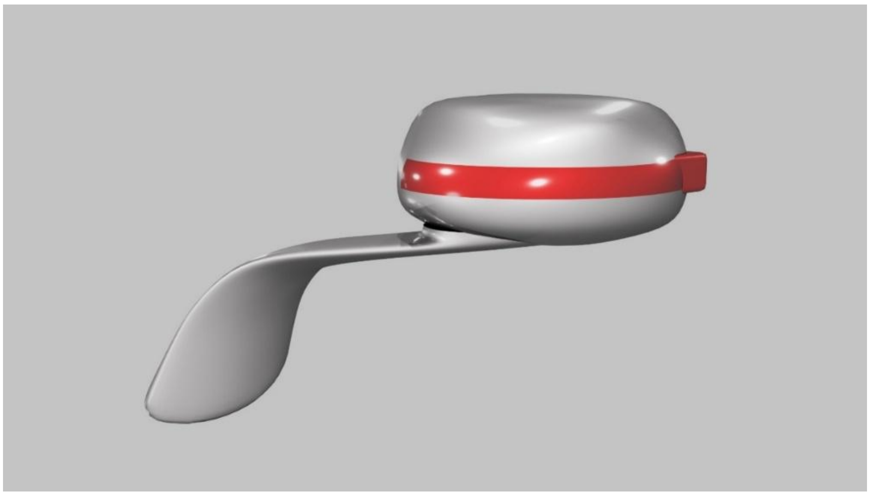


Figure 94 – Car side mirror

Figure 95 – Side mirror in assembly

1.3.38 Wheels

The car wheel converts its rotation into the translational motion of the vehicle, and the torque supplied from the motor through the shaft into tractive force. The wheel reduces friction, facilitating movement through rolling. Kinetic energy is lost due to the contact of the wheel with the road; this is called rolling resistance, which primarily represents energy losses from tire deformation. The wheel provides the connection between the car and the road. It serves to support the vehicle's suspension, enable its movement, and change the direction of travel. A wheel is characterized by its handling, braking distance on wet and dry roads, and stability during straight-line travel and high-speed cornering. The wheel can also provide advantages when moving over uneven surfaces if the wheel radius is sufficiently large compared to the irregularities.

The wheel consists of a pneumatic tire and a rim (Figures 96, 97). A tubeless low-profile tire is installed on the car wheel. The pneumatic tire smooths out road irregularities and, together with the suspension, softens and absorbs jolts and impacts from the road surface, ensuring the smoothness of the car's ride as well as reliable traction between the wheels and the road. A tubeless tire does not have an inner tube. In terms of construction, it is similar to the casing of a tube-type tire and is almost indistinguishable from it in appearance.

A specific feature of the tubeless tire is the presence of a 2 mm thick sealing airtight rubber layer on its inner surface, which holds the compressed air inside the tire. Furthermore, there is a sealing rubber layer on the tire beads that ensures the necessary airtightness at the connection points between the beads and the wheel rim. The carcass material of a tubeless tire is also characterized by high air impermeability, as nylon cord is used for it. The seating diameter of a tubeless tire is reduced, and it is mounted on an airtight rim. The tire valve is hermetically secured directly in the wheel rim by means of a nut with a washer and two rubber sealing washers.

Compared to tube-type tires, tubeless tires increase driving safety, are easy to repair, heat up less during operation, are more durable, have a simpler design, and possess less mass. The increase in driving safety is explained by the lower sensitivity of the tubeless tire to punctures and other damage. When a tube-type tire is damaged, the inner tube does not grip the puncturing object because it is in a stretched state. Air passes through the resulting hole into the casing and exits freely through the gaps between the beads and the wheel rim.

In the event of damage to a tubeless tire, the puncturing object is tightly gripped by the non-stretched sealing rubber layer, and air escapes from the tire very slowly. As a result, it is possible to bring the vehicle to a safe stop. In some cases, when the puncturing object remains in the tire, air does not escape at all. The ease of repairing tubeless tires is explained by the fact that many types of damage can be fixed without removing the tires from the wheels, which is especially important in road conditions. During repair, sealing plugs are inserted into the damaged area using a special needle. The lower heat buildup of tubeless tires is attributed to better heat dissipation through the wheel rim (which is not covered by an inner tube) and the absence of friction between the casing and the tube, which exists in conventional tires. Improved thermal conditions are one of the reasons for the increased durability of tubeless tires, whose service life is 10% to 20% longer than that of tube-type tires. However, the cost of tubeless tires is higher than that of tube-type ones. Such tires require special rims, and their mounting and dismounting are more complex, requiring special tools and devices.

The tire tread pattern has a significant impact on the vehicle's movement. During tire development, special attention is paid to the competent combination of the tread pattern and the overall design that defines the tire's shape. Tires designed for use on hard-surface roads have a "road" tread pattern. It consists of longitudinal zigzag ribs and grooves. This type of pattern provides the tread with high wear resistance and ensures quiet tire operation. It allows for an instantaneous response to steering while creating high vehicle stability during cornering. The tread zone inside the tire allows for an even distribution of pressure across the contact patch when the car enters a turn. In addition, a specific rubber compound is used for the tread, with the primary task of further increasing grip with the road surface.

Treads can be developed for optimal performance on specific tracks, under competitive conditions, and even in various climatic conditions. Tires are selected according to the requirements of a specific track and weather conditions to maximize the performance and safety of the racing car. The specialized composition of a racing tire features a specific rubber compound that provides excellent road grip at high speeds. This rubber can also be designed to operate in various conditions, such as dry or wet roads. The tire compound includes rubber, adhesive, a vulcanizing agent, and additives. The compound is manufactured from synthetic rubber. The rubber is mixed with carbon black; carbon black increases strength and gives the tires their black color.

A racing car tire features a wide profile, which improves road grip and increases stability at high speeds. The low profile of the tire also contributes to improved handling and the aerodynamic characteristics of the vehicle. The tire possesses sidewalls with increased rigidity, which enhances cornering stability and allows the car to better handle driving dynamics. The tire is designed for operation at ambient temperatures ranging from - 45 to 55°C.

The tire consists of a tread and a carcass. The tread provides traction, while the carcass provides support. The tire is a pneumatic inflatable structure consisting of cords and wires in a donut shape, encased in rubber and filled with compressed air to form an inflatable cushion. These racing car tires are also approved for street use. Racing tires are engineered to maximize friction during cornering and acceleration at the expense of durability.

There are also racing slicks; they have no tread, which ensures maximum contact with the road surface, whereas rain tires have channels for water evacuation to avoid aquaplaning. When using ultra-low-pressure tires, additional devices are necessary to mechanically clamp the tire beads, thereby eliminating the possibility of the tire spinning relative to the rim or accidental debeading during movement. Preheating is desirable for all tires. However, the heating of the carcass itself is largely achieved through tire deformation. Deformation occurs, firstly, as a result of the wheel rolling along the track (where the lower part of the tire forms the so-called contact patch) and, secondly, due to the flexing of the tire sidewalls during cornering. Low-profile tires deform much less and heat up less, which requires a completely different compound composition.

Figure 96 – Car wheel

Low-profile tires are less sensitive to pressure. This is explained by two factors: first, a stiffer carcass requires less air support, and second, the air volume itself is smaller, so pressure changes less significantly with temperature fluctuations. Thus, low-profile tires are easier to use without preheating compared to high-profile tires. In the case of low-profile rubber, the extreme stiffness of the sidewalls requires precise tire placement on the track surface and, consequently, a more sophisticated suspension arm design.

Radial tire technology is currently the standard construction for practically all automotive tires. In a radial tire's construction, main layer cords run from the beads and across the tread such that the cords are laid at approximately right angles to the tread centerline and parallel to each other, with stabilizer belts directly under the tread. These are corded belts; the advantages of this construction include longer tread life, better steering control, improved fuel economy, and lower rolling resistance.

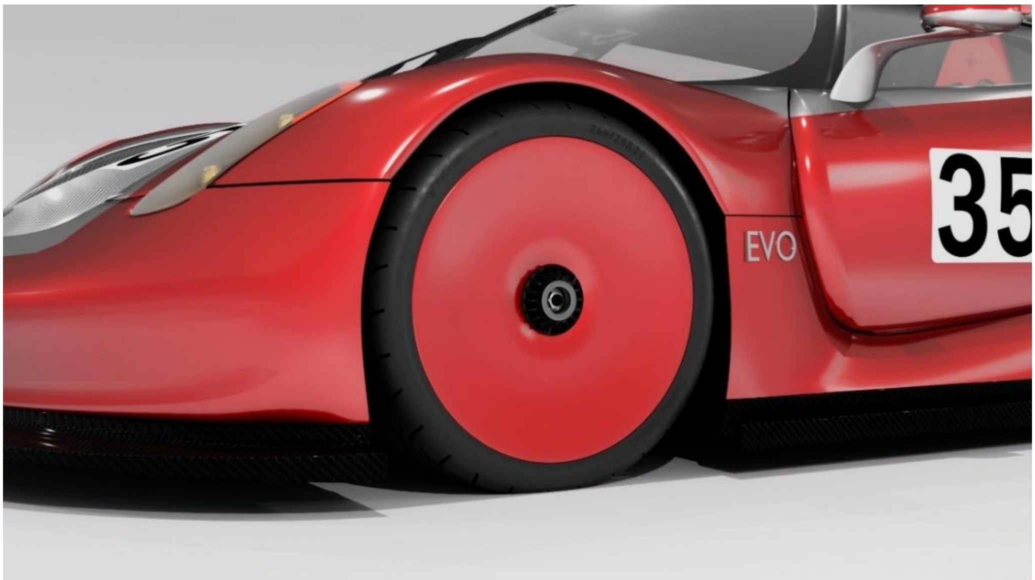


Figure 97 – Wheel on the Evo car

The wheel rim is designed to mount the pneumatic tire and connect it to the hub (Figure 98). The rim is manufactured from carbon fiber to reduce unsprung mass, increase rigidity, and decrease inertia. Technically, reducing the mass of the wheel means lowering the mass of unsprung parts and inertial forces. Due to this, the wheel "handles" road surface irregularities more easily, providing a more precise response from the car's suspension. In turn, the car's contact with the road and its handling are improved. Reducing inertia, accordingly, increases the service life of the vehicle itself, improves braking and acceleration dynamics, and consequently reduces fuel consumption.The car's wheel disc features deep, non-detachable rims with connecting elements in the form of a solid screen. The rim is the outer edge of the wheel that holds the tire. It represents the outer circular structure of the wheel on which the inner edge of the tire is mounted. Rims serve for mounting the pneumatic tire and have a specific profile. A deep-well rim is used, made as a single non-detachable unit. In the middle part of such a rim, a drop-center (well) "B" is made to facilitate the mounting and dismounting of the tire. The well is symmetrical. Tapered bead seats are located on both sides of the well, ending in flanges. The angle of the rim seats is (5+1) °, which improves the tire's seating on the rim. All wheels have standard parameter markings: 266/28 R21 110Y.266 — tire width in mm; 28 — aspect ratio (the ratio of profile height to width); with the same width, the higher this indicator, the taller the tire; R — radial tire type; 21 — rim diameter in inches (internal tire size or external rim size); 110 — load index up to 1060 kg (the maximum allowable load per wheel); Y — speed rating up to 300 km/h. Tire markings and dimensions are placed on the sidewall. The primary dimensions of a tire are the width *B* and height *H* of the profile, the rim diameter *d*, and the outer diameter *D* (Figure 98).

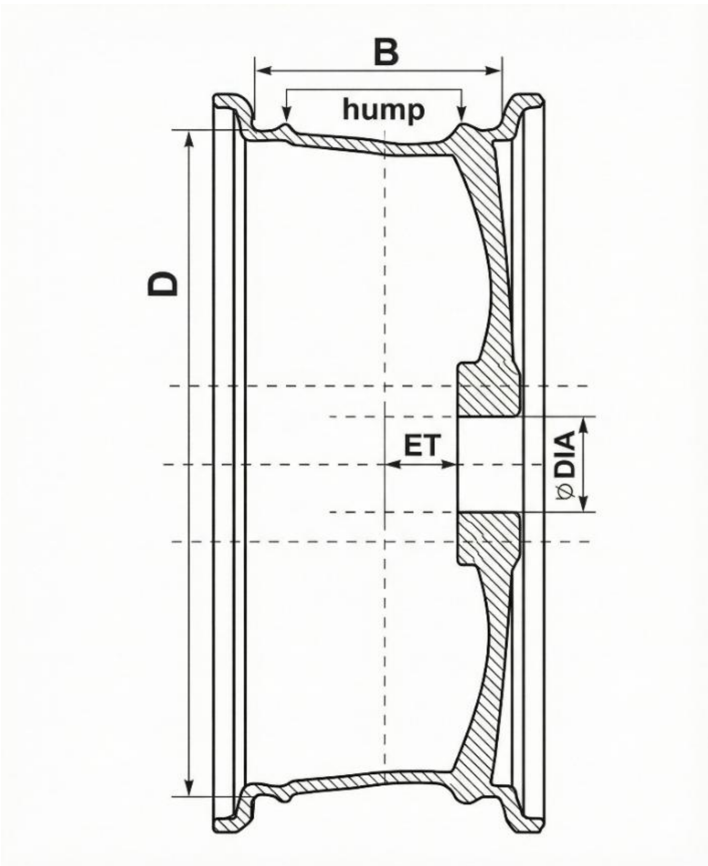


Figure 98 – Wheel drawing with specified dimensions

When installing a wheel, it is important to ensure that the wheel does not catch on any parts of the vehicle. When replacing wheel rims, due attention should be paid to ensuring that the installed rims have the same load capacity, diameter, rim width, and offset. An incorrect choice of rims and tires can adversely affect handling, the service life of the wheel and bearing, brake cooling, the accuracy of speedometer and odometer readings, braking distance, headlight aim, bumper height, ground clearance, and the clearance between the tire and the body.

After assembly and before mounting the wheel, so-called balancing is performed. Balancing is not carried out on a disassembled wheel, as this is ineffective. The mass ratio of the tire and the wheel must be determined only as an assembly, and final balancing is conducted in the assembled state and at the specified nominal pressure.

1.3.39 Central wheel nut

The central wheel nut is used to secure the wheel to the car (Figure 99). This nut is screwed onto the hub and locked to prevent the wheel from unscrewing during movement. The mounting seat has a taper; therefore, the nut seats tightly on the hub and wedges the wheel rim onto the hub. Due to the hub's taper, the wheel is better centered. At the end of the hub, there is a special thread onto which the wheel nut is screwed. The thread itself has a diameter of 75 mm and is carefully machined for better fastening.

The wheel nut is tightened with a torque of 300 N·m to ensure proper fixation and prevent issues with loosening or wheel misalignment. Instead of a hexagonal shape, the wheel nut has a splined (toothed) design; during fastening, these teeth fit into special grooves of the impact wrench. The multiple teeth on the nut are designed so that the socket of the impact wrench easily aligns with the nut's grooves.

On a racing car, a single central nut is used for wheel attachment because it makes it easy to remove and mount the wheel during a race using only one nut. In racing conditions, pit stop time is critically important; using a single central nut to secure the wheel significantly speeds up the wheel change process during the race. This is convenient and efficient, as mechanics only need to focus on a single point for a quick wheel change. Furthermore, the conical shape of the nut allows for easy and accurate centering of the wheel, which is vital for ensuring stability and preventing vibrations during the race. Efficiency and speed of service play a key role in the world of motor racing, and the design of the central wheel nut is one aspect that contributes to the optimization of this process.

Figure 99 – Central wheel nut

1.3.40 Charging unit

The vehicle's storage battery is charged by a charging device (Figures 100, 101). The charging station connects to the city's three-phase AC network with a voltage of 220 V and a frequency of 50 Hz. Using the charging unit, alternating current (AC) is converted into direct current (DC), which is necessary for charging the battery. The AC-to-DC converter is integrated into the charging unit rather than the vehicle to avoid size and weight constraints. The charging unit is mounted on a wall.

Figure 100 – Charging unit.

At a current of 50 A, the charging station delivers 11 kW of power. The maximum power of the charging station is 25 kW. It operates with a voltage from 120 to 400 V and a current of up to 100 A. At 220 V and a current of 30 A, the charging power is 6.6 kW. A battery with a capacity of 90 kWh will charge in 13.5 hours. The charger is made of durable plastic; the housing features a display showing information on current, voltage, and charging time. The housing has an oval shape with a recess for winding the cable. The dimensions of the charging station are 600 × 350 × 250 mm. The cable is wound and secured by plugging the connector into a socket on the housing.

Figure 101 – Charging the car from the station

The socket type is IEC 62196—3 Type 2 (Figure 102). The connector has a circular shape with a flat top edge. The connector diameter is 70 mm, and the height is 63 mm. This is a seven-pin connector consisting of 1 ground, 3 positive [phases], 1 neutral, and 2 signal pins. A feature of the connector is the ability to use both single-phase and three-phase networks, with a maximum voltage of 480 V and a current of 50 A. The connector allows the use of charging stations with Mode 2 and Mode 3 operating modes. In January 2013, the European Commission selected the IEC 62196 Type 2 connector as the official charging connector for the European Union. Since then, it has been adopted as the recommended connector in several countries outside Europe, including New Zealand.

There are many types of charging connectors. Depending on the region and standards, Mennekes (for Europe), SAE J1772 (in North America), or others may be used, and a DC connector may also be present. For standardization and ease of use, it is desirable to use one type of connector on all vehicles.

Figure 102 – Plug and socket

The plug is connected to the cable. To ensure the cable is flexible and can be wound and hung on the charging station, it is made of multi-strand wire. The charging station cable consists of five conductive cores, each with a cross-section of 10 mm². The cable length is 6 m. The outer part of the wire is equipped with protective insulation capable of withstanding mechanical damage, heat, and moisture.

Silicon rectifiers are used in the charging device. Their advantage is that the charging current can be regulated within a wide range during the process; since a voltmeter, ammeter, and fuses are mounted on the rectifier itself, separate charging panels are not required. In this case, charging follows a rectifier-battery scheme. Therefore, the charger possesses high efficiency, increased reliability, good thermal characteristics, small size, and low cost. Silicon carbide (SiC) components play a crucial role in these parameters. They are combined with existing silicon MOSFET switches and SiC switches to ensure maximum efficiency with a relatively small number of components. Air-cooled modules with a capacity of 30 kW and above, utilizing appropriate gate drivers and control electronics, meet international charging standards.

2 Dubina Evo car production

2.1 General information about the mini-factory

The mini-factory was designed for construction in a humid subtropical climate, with an average annual temperature of +12 °C, characterized by long hot summers, short warm springs, and mild but relatively dry winters. The mini-factory is a single-story building with a total area of 960 sq. m., featuring a height of 4.7 m to the bottom of the load-bearing structures and a ridge height of 5.6 m (Figure 103).

Figure 103 – Mini-factory Dubina

The factory building houses a production hall, administrative offices, and a canteen. The production hall includes a production line consisting of five stages. The manufacturing process throughout the factory is monitored by surveillance cameras. The first production stage involves welding. The second stage is the assembly of the battery pack. The third stage of the production line involves the moulding and assembly of composite material parts. After polymerization, the mould with the part proceeds to the fourth stage for demoulding and machining. Following machining, the part arrives at the fifth and final stage of car assembly, which takes place at a single workstation. All body parts are assembled there. Two workers install all vehicle equipment and mount the electrical wiring in a specific sequence. Assemblers equip the body with the powertrain, battery, and instrument panel. Once the parts are installed, workers verify the operation of all vehicle systems. After assembly, the vehicle enters the paint booth. After the paint is applied, hot air is supplied to the booth for drying. Following the painting process, the vehicle undergoes a final quality check (Figure 104). The factory personnel operate like a single sports team. The team is led by the factory director. The entire team consists of sixteen people: Factory Director, Senior Designer, Junior Designer, Senior Technologist, Junior Technologist, Senior Hardware Programmer, Junior Hardware Programmer, Senior Web Programmer, Junior Web Programmer, Assembler, Machine Operator, Electrician, Welder, Moulder, Painter, and Household Worker.

1 – column; 2 – roof purlins; 3 – entrance gate; 4 – wall; 5 – windows;
6 – exit gate; 7 – downspout; 8 – entrance door; 9 – canopy; 10 – paint booth;
11 – stairs; 12 – split system; 13 – air duct.
Figure 104 – Structural elements of the mini-factory

2.2 Factory structure

2.2.1 Framework

The load-bearing framework of the 48 x 20 m mini-factory building consists of variable-section steel frames, comprising columns and beams, as well as a system of wall and roof purlins (Figure 105). Variable-section I-beam steel columns, manufactured by electric welding from 2 cm thick steel plate, are the load-bearing elements of the metal framework, absorbing the primary loads on the clear-span building. Each steel column consists of a shaft, a cap, and a base, with a 12 m spacing, a width of 20 m, a height of 4.7 m to the bottom of the load-bearing structures, a ridge height of 5.6 m, and a roof slope of 4°. Column components are welded at a specialized facility and shipped ready-made to the construction site. All elements of the primary load-bearing framework are coated with an 80 μm thick primer to protect against corrosion during transportation, installation, and operation.

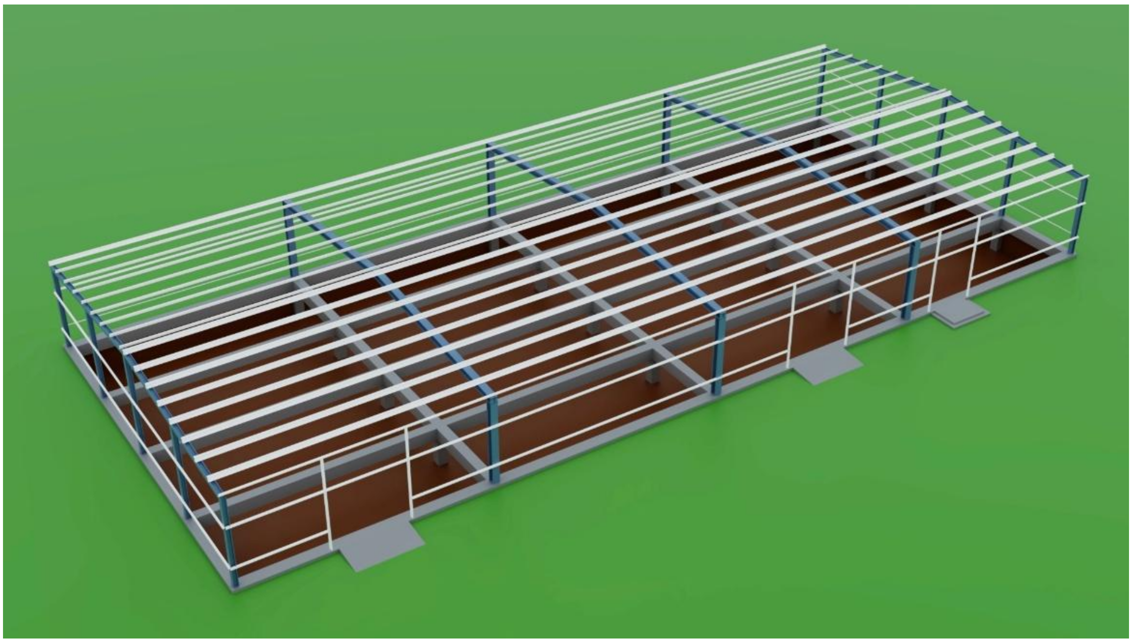
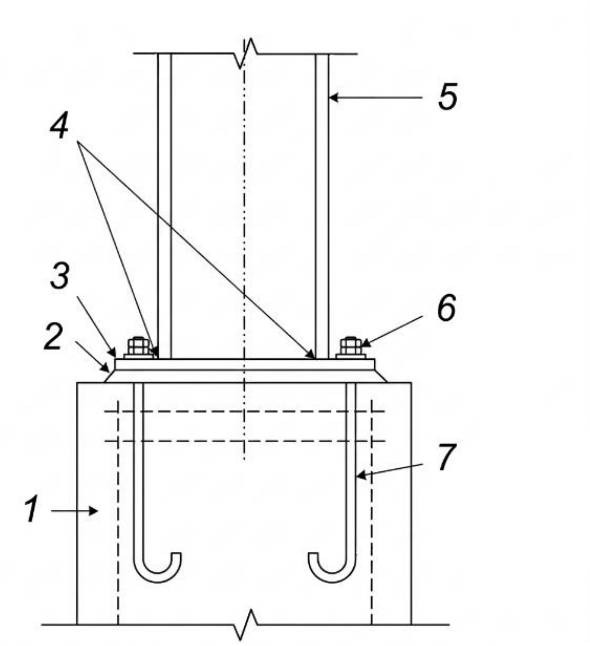


Figure 105 – Mini-factory building framework

The load from the building framework is transferred to the foundation through the base of the frame; the building frame has a rigid connection to the foundation. Rigid column support ensures the transfer of lateral and bending moments, creating a stable structure. The steel column is attached to the foundation using anchor bolts and a base plate, which is made of a 500 × 500 × 20 mm steel plate and welded to the base of the column (Figure 106). The base plate distributes the load from the column over a larger foundation area, preventing point loads. Anchor bolts serve to fix the column's position and transfer tensile forces arising from bending moments into the foundation. The column base is designed for the uniform distribution of concentrated pressure from the column to the foundation surface and guarantees the fixation of the lower end of the column in accordance with the established design scheme.



1 – concrete foundation; 2 – grout; 3 – base plate; 4 – butt weld;
5 – steel column; 6 – double lock nuts and washer;
7 – anchor bolt.
Figure 106 – Column-to-foundation connection.

2.2.2 Roof

A double-layer steel standing seam roofing system with an insulation thickness of 120 mm is used on the roof (Figure 107). The inner panel provides an aesthetic appearance inside the building, acts as a vapor barrier, and enhances the fire resistance of the roofing system. It offers the advantages of a system with an additional framework and is suitable for rooms with high relative humidity.

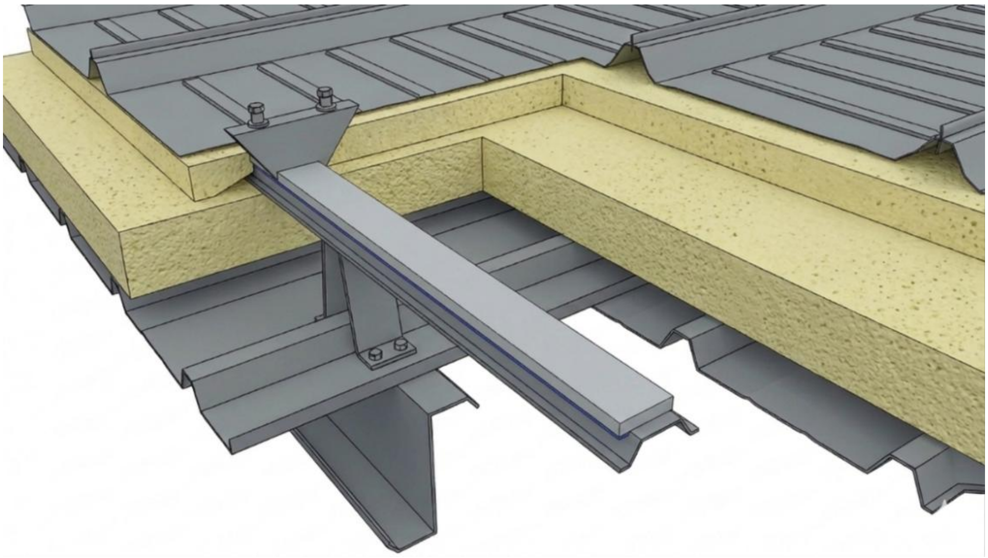
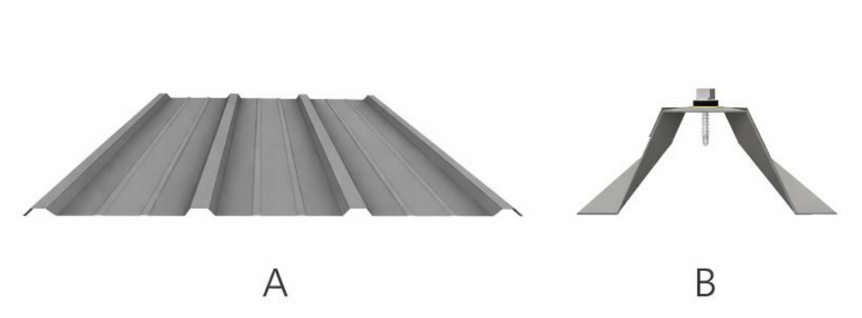


Figure 107 – Double-layer steel standing seam roofing system

The roof utilizes factory-rolled panels with a width of 1 m. The fastening system allows for the longitudinal movement of the panels during seasonal thermal expansion. Transverse ribs provide additional stiffness to the panels. The panel material is 0.75 mm thick galvanized steel with a zinc mass of 275 g/m² (Class 1). This ensures decades of corrosion protection; the coated steel panel does not crack at bends and is UV-resistant. The panels are attached to the roof purlins using stainless steel self-tapping screws with polymer caps matching the color of the panels (Figure 108).



A – roofing panel; B – joining method
Figure 108 – Roofing panel and its joining method

The building's roof purlins are horizontal beams that are part of the roof's metal structure and serve to distribute the load from the roof to the columns. They ensure the strength and stability of the roof and are also used for mounting lighting fixtures and the ventilation duct (Figure 109).

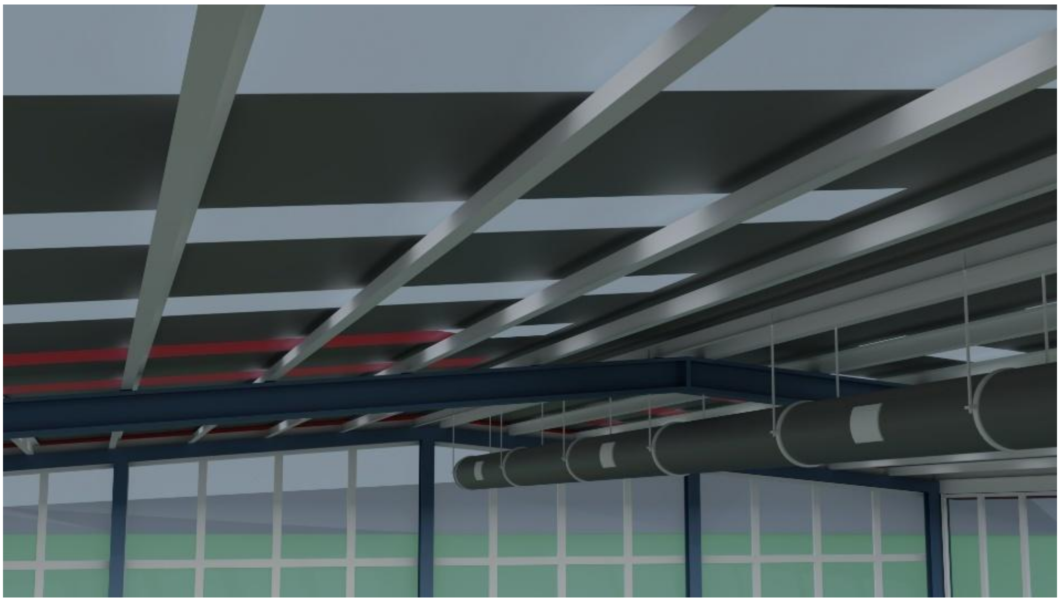


Figure 109 – Roof purlins

Skylights (mansard windows) are installed on the roof directly in the plane of the slope at the same angle as the roof (Figure 110). Special flashings for standing seam roofs are used for their installation, ensuring a watertight connection with the metal panels. For a steel standing seam system, it is critically important to use watertight flashings designed specifically for flat metal coverings to prevent leaks at junction points.

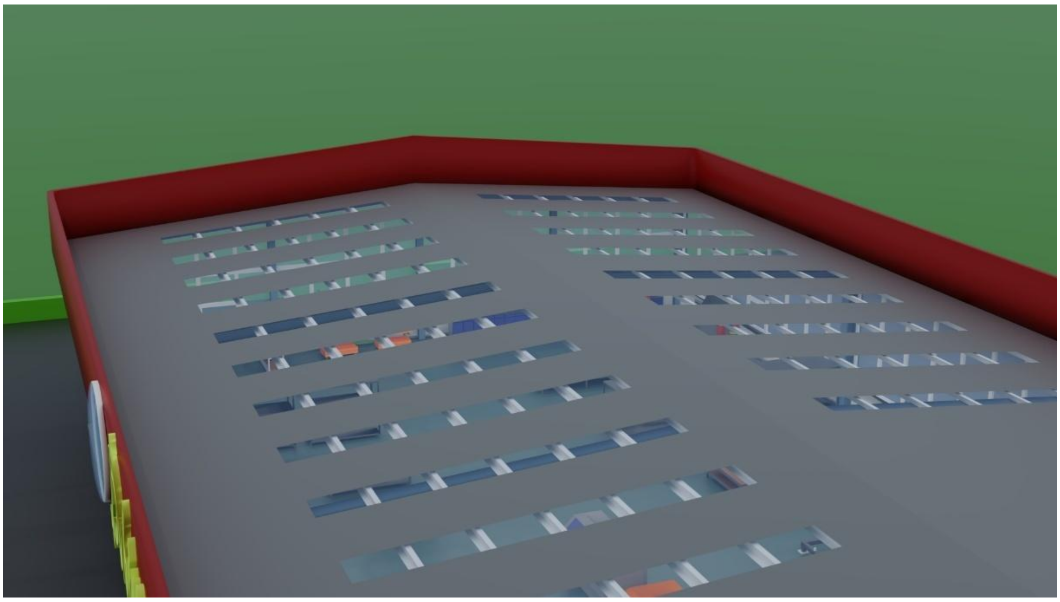


Figure 110 – Skylights on the roof

2.2.3 Walls

The walls are curtain walls; they are loaded only by their own weight and wind loads within the floor level and transfer the load to the building's framework. Wall systems consist of profiled steel panels attached to the secondary framework using self-tapping screws with polymer caps matching the color of the panels (Figure 111). The installation of panels requires less labor, and their cost is lower than that of brick walls.

Figure 111 – Mini-factory wall

Installation of the internal wall panel provides protection for the thermal insulation against possible mechanical damage and improves interior aesthetics. A perforated panel is used, which features increased sound absorption. The internal wall finish conceals the elements of the secondary framework. Ventilation grilles, opening trim elements, and decorative accessories are mounted within the wall panel. Advantages of wall panels include: aesthetic appearance, high-quality coating, simple and rapid installation, easy replacement of damaged panels, a wide range of adapted accessories, a full set of trim details and elements, cost-effectiveness, functionality, and durability.

Wall purlins (girts) are used to support the wall panels, cladding, and windows. Wall purlins (horizontal beams) distribute loads to the building's framework. They are an important element of the building framework and are manufactured from steel. Wall purlins are made of cold-formed galvanized Z-profiles. Installation is carried out using galvanized bolts. Openings are constructed from galvanized cold-formed L, C, U, and Z profiles. All elements of the load-bearing framework are shot-blasted and coated with an 80 μm thick primer to protect against corrosion during transportation and installation.

2.2.4 Heating

To ensure a comfortable temperature at the factory in a humid subtropical climate, a system of sixteen electric convectors with a total capacity of 32 kW is used. Given the mild winters and an average air temperature of +12 °C, such a system is optimal for maintaining the working microclimate. Each convector has a power output of 2 kW. This modern heating device is enclosed in a steel housing shaped like a rectangular parallelepiped with dimensions of 120 × 60 × 6 cm. The convector features a large heat-exchange surface area despite its slim profile. Cold air intake vents are located at the bottom of the housing, while louvers for the heated airflow exit are at the top. An innovative X-shaped monolithic heating element made of aluminum alloy allows the device to reach operating temperature quickly and heat the air silently without over-drying it or burning dust. The control unit includes an electronic thermostat and a power mode switch for precise temperature maintenance, allowing for flexible regulation of the building's temperature and the factory's energy consumption. Internal tip-over and overheat protection sensors provide an immediate electrical circuit break in case of an emergency. The operation of the convector is based on the physical law of natural air convection. Cold air at the bottom of the room enters the device through the lower vents. As it passes through the blades of the heating element, the air warms up. Heated air becomes lighter, expands, and rises through the upper louvers due to natural draft. Rising to the ceiling, the warm air gradually cools, descends, and enters the convector again. This creates a continuous circulation of warm air that effectively heats the building's interior space. Using convectors with an IP24 splash protection rating reliably protects the electronics from condensation. The electronic thermostat and auto-restart function allow the system to resume operation independently with preset settings even after brief power outages, which is vital for an uninterrupted production cycle. Sixteen such units with a total capacity of 32 kW effectively compensate for heat loss through the factory's glazing and gates, creating a stable thermal environment for engineers and technicians. The heating system operates on a temperature schedule with a "night mode." The use of programmable thermostats integrated into a single climate control system makes the enterprise efficient. Climate control for the factory saves energy while constantly monitoring indoor temperatures. Reducing the temperature by just 1 degree saves approximately 7% of electricity. A constant temperature without fluctuations improves health and reduces the risk of colds. Furthermore, a stable temperature extends the service life of equipment and protects electronics from the humidity of the subtropics. Condensation forms on cold surfaces. If the car's metal frame or a machine tool is colder than the air in the workshop, they will become covered in water droplets. Constantly maintaining the temperature above +12...+15 °C at night prevents the equipment from cooling to the critical point where moisture begins to condense on it. According to sanitary standards and technological production requirements, the recommended temperature for offices and administrative areas—where work is sedentary and physical activity is minimal—is between +21 °C and +23 °C during working hours to ensure employees do not get cold. This is the temperature at which the brain functions productively and the body does not overcool. In the assembly hall, where the main production takes place, people are moving, and the equipment generates some of its own heat. During working hours, the temperature there is maintained between +18 °C and +20 °C. This is an ideal temperature at which workers do not overheat while moving, and it is the optimal mode for the precision of CNC machines. At night, the temperature throughout the building is set between +12 °C and +14 °C. This is sufficient to prevent condensation on metal without wasting excess energy. For "by-the-hour" automation, a "smart factory" system with programmable thermal regulators is used: 08:00 — Start of the shift: temperature in the workshop +19 °C, temperature in the engineering hall +22 °C. 17:00 — End of the shift: transition to "night mode," the thermostat switches to maintain an indoor temperature of +13 °C. 06:00 — Automatic activation of convectors at full power to pre-heat the building after the night to +19 °C in the workshop and +22 °C in the engineering hall.

2.2.5 Floor

A structural element recessed below the ground surface that absorbs loads from the building and transfers them to the base is called a foundation. The factory foundation is a pad foundation (column foundation) with a grade beam (rostverk) and a slab-on-grade floor. The soil at the foundation site consists of semi-solid loams and clays. The bearing capacity of the soil beneath the footing of the pad foundation is 200 kPa (1.5–2.0 kg/cm^2). The soil withstands the loads from columns and grade beams, transferring them evenly without excessive settlement. The reinforced concrete grade beam is monolithic, with a height of 700 mm and a width of 500 mm, constructed at the floor level. The floor is independent of the grade beam. The slab-on-grade is not rigidly connected to the grade beam; instead, it is separated by an expansion joint—a 20 mm thick strip of PSB expanded polystyrene. Foundation settlement is not transferred to the floor. The grade beam and pad foundations absorb the loads from the columns and the framework, while the floor absorbs the loads from equipment and loading vehicles. The floor consists of a compacted base of sand and crushed stone with a thickness of 400 mm (Figure 112). Then, a 100 mm thick lean concrete bed (class B7.5) is laid upon it, followed by a waterproofing membrane, and finally, a concrete screed (class B22.5) reinforced with A500C welded wire mesh (Ø10 mm with a 200 × 200 mm pitch). The upper and lower mesh zones are set on chairs (spacers). The thickness of the screed is 150 mm.

1 – soil; 2 – sand; 3 – crushed stone; 4 – lean concrete;
5 – waterproofing; 6 – concrete screed.
Figure 112 – Building floor.

The concrete bed (lean concrete) serves as an intermediate layer between the compacted base and the screed. This preparation layer is designed to protect against groundwater and to provide additional pressure distribution onto the soil. For the concrete bed, B7.5 concrete with a low stiffness class is used, as the strength requirements for this layer are less demanding. In this case, the lean concrete performs the following functions: it prevents the cement paste from leaking into the soil, ensuring the required strength of the monolithic floor screed; it levels the site and provides convenience for the installation of the reinforcement cage and the monolithic screed; it acts as an additional shock absorber during minor soil deformations, thereby protecting the base structure. Next, waterproofing is laid over the lean concrete, and the screed is poured on top of it. A topping is applied to the surface of the floor screed to create an ultra-strong, wear-resistant, and sealed finish layer. The final floor covering is a polyurethane coating, chosen for its strength, chemical resistance, and ease of maintenance. This is a seamless polymer coating based on polyurethane resins. It forms a dense, slightly textured surface with high wear resistance and multi-colored markings. The polyurethane coating offers: high strength and wear resistance; resistance to impacts and abrasive loads; resistance to chemicals (oils, fuels, weak acids, and alkalis); elasticity (it does not crack under vibration or temperature fluctuations, unlike epoxy coatings); seamlessness and airtightness (no crevices where dirt can accumulate); and durability (10–15 years under normal operation). The total thickness of the coating is 3 mm.

2.2.6 Doors

A metal swing door with windows is installed at the main entrance of the mini-factory building (Figure 113). Within the assembly hall, metal doors with small windows are installed. Interior doors are fitted for the engineering hall, the director's office, the meeting room, the restroom, and the cafeteria. Metal doors are installed for the locker room and the paint booth preparation room.

Figure 113 – Main entrance door

2.2.7 Gates

The factory utilizes automatic roller shutter gates (Figure 114). They are used for loading parts and equipment, as well as for unloading finished products. The first gate is located in front of the assembly area, and the second gate is positioned in front of the warehouse. The gate height is 2.5 m, and the width is 3 m. The operating principle of the gates is similar to window shutters. Metal guide channels (C-channels) are located on the walls of the opening, within which the gate curtain moves up and down. A housing box is situated above the channels, where the gate curtain is coiled. The coiling system consists of an octagonal shaft with the edge of the curtain attached to it, along with a mechanism that rotates the shaft in either direction to open or close the gate. This mechanism is controlled by an automatic system via a remote control. The gates are also equipped with a manual override mechanism installed in case of an automatic system failure. The curtain consists of durable aluminum slats, 23 mm thick and 80 mm high, filled with rigid polyurethane foam, which provides the thermal insulation properties of the gate system. The slats are interconnected using factory hinges. Aluminum slats are lightweight and rust-resistant. The service life of aluminum gates exceeds that of plastic and steel structures. Unlike swing gates, these do not require free space for opening. The roll coils vertically upwards and does not require additional space to open. Roller shutter gates are also more convenient compared to sliding gates because no opening/closing mechanism needs to be mounted on the ground. However, the design of such gates has many gaps through which warm air escapes the building; therefore, they are used in relatively warm climates.

Figure 114 – Roller shutter gates

2.2.8 Stairs

A service ladder is provided at the rear of the factory building to provide access to the roof (Figure 115). It is designed for roof maintenance: cleaning gutters and windows, inspecting the condition of the roofing material, and providing access to ventilation equipment and external split-system units. The ladder structure is rigidly attached to the building framework's wall purlins (girts). It is manufactured from steel profiles and painted for corrosion protection. It is engineered for operational loads and equipped with anti-slip steps, ensuring a safe climb during any season. Restricted access prevents the ladder from being used by unauthorized persons. Roof access is organized through a service hatch equipped with a locking mechanism. This allows for controlled access and prevents unauthorized entry. Having a dedicated ladder simplifies the maintenance of engineering systems, reduces work time, and increases the overall operational safety of the factory building. Roof access via the ladder allows for the prompt execution of seasonal tasks, such as clearing snow or foliage, without the need for specialized lifting equipment.

Figure 115 – Service ladder to the mini-factory roof

2.2.9 Cornice

A significant architectural feature of the building is the massive cornice, which serves as a harmonious extension of the roof (Figure 116). On the front side of the factory, it extends forward by 2 meters, forming a kind of canopy over the front facade. This solution not only protects the entrance area and the adjacent part of the foundation from precipitation but also creates a striking visual accent. The structure's finished and modern appearance is enhanced by a 1-meter-high decorative trim (fascia) that runs along the entire perimeter of the cornice. This parapet conceals the structural elements of the roof, engineering utilities, and drainage system, creating a neat and cohesive exterior for the building. The cornice gives the factory a disciplined, monumental look, transforming an industrial building into an aesthetically attractive object of modern architecture.

Figure 116 – Building cornice

2.2.10 Climate control system

The factory's ventilation and air conditioning system is a vital element of the engineering infrastructure, ensuring safe, comfortable, and technologically correct working conditions throughout all areas of the enterprise. Its design and operation account for the specific requirements of small-scale car production, including welding, painting, assembly, and office zones, as well as air quality and thermal regime standards. Supply and exhaust ventilation is utilized in the production hall, providing a constant intake of fresh air and the removal of contaminated air. In welding areas, local exhaust ventilation is installed to remove welding fumes, smoke, and aerosols directly at their source. The paint booth utilizes a separate, specialized ventilation system with filtration, ensuring a directional airflow, removal of paint vapors and solvents, and maintenance of the specified temperature and humidity during painting, drying, and cooling modes (Figure 117). The ventilation control for the paint booth is located in a dedicated equipment room, which enhances safety and reduces the risk of ignition and air contamination.

Figure 117 – Heat exchangers of the climate control system

In the assembly area, ventilation is designed to dissipate heat from equipment and maintain comfortable conditions for personnel. Airflows are organized to prevent drafts and avoid kicking up dust, which is particularly critical during vehicle assembly. In administrative and engineering rooms, an air conditioning system is used to maintain a stable temperature and a comfortable microclimate for employees. Air conditioners and supply units provide air filtration, as well as temperature and humidity regulation. All ventilation and air conditioning systems are integrated into a single control scheme, allowing for the adjustment of operating modes depending on the production process, season, and room occupancy. The reliable operation of these systems ensures personnel safety, technological process stability, and the high quality of the products manufactured by the factory.

2.2.11 Drainage system

The building's drainage system is designed according to an organized scheme and is intended for the effective removal of rainwater and meltwater from the roof surface. Semicircular gutters are installed on the roof slopes and along the cornice line; they collect water evenly across the entire length of the roof and direct it to flow convergence points, where the gutters connect to the funnels of the vertical downspouts (Figure 118). This shape of the gutters ensures a steady flow of water and reduces the risk of overflow during heavy precipitation. On the horizontal edge at the bottom of the cornice slope, the semicircular gutters are installed with a slope towards the corners of the building. In these locations, water from the gutters enters the vertical downspouts. The corner placement of the intake sections allows for a compact drainage organization and keeps the facades clean without disrupting the building's architectural appearance. Through the vertical pipes, water flows by gravity downwards into a drainage ditch located along the building. The drainage ditch ensures the collection and distribution of runoff, preventing soil erosion near the foundation. Additionally, a drainage ditch is located along the perimeter of the parking area; it is situated at a slight 3° angle relative to the building's lowest point to ensure that rainwater does not stagnate in the parking lot or flow toward the mini-factory building. The collected water is diverted into the stormwater drainage system, which eliminates its accumulation on the factory grounds and provides reliable protection for the building and adjacent areas against excessive moisture.

Figure 118 – Roof and site drainage elements

2.2.12 Sewage system

The factory's sewage system is a comprehensive engineering network designed for the disposal of domestic, industrial, and surface wastewater from the enterprise territory. The system is designed considering the functional zoning of the building, technological processes, and environmental and sanitary safety requirements. It is divided into two primary circuits: the domestic (sanitary) sewer and the storm sewer. The internal domestic sewage system serves the restrooms, locker rooms, canteen, and domestic premises. Wastewater from sinks, showers, toilets, and kitchen equipment is directed by gravity through a piping system into a common sewer manifold. Sewage lines are positioned to avoid intersecting with production zones and to provide convenient access for maintenance and repair. Special attention is paid to production areas such as the paint booth and the moulding area. Direct discharge of technological fluids into the common network is prohibited; all chemical waste is disposed of according to safety protocols, ensuring the environmental integrity of the factory's operations. The storm sewage system is designed to collect rainwater and meltwater from the roof and the factory grounds. Water from the downspouts enters the drainage ditches and is then directed into the storm sewer system. This scheme prevents water stagnation, soil erosion, and excessive moisture around the foundation. All elements of the sewage system are integrated into a single network, ensuring the reliable and uninterrupted disposal of effluents. The factory's sewage system contributes to the maintenance of sanitary conditions, environmental protection, and the stable operation of the production complex as a whole.

2.2.13 Lighting

Lighting in the factory is provided by a combination of natural daylight and artificial light. During daylight hours, natural lighting predominates thanks to large windows located around the building's perimeter and in the roof, through which sunlight penetrates all areas of the factory. Windows are present in every room of the facility. In the locker room and restroom, windows are positioned at a height of 2.5 m. This ensures a sufficient level of illumination during the day without the need for constant use of artificial light. Artificial lighting is provided by LED lamps. In the assembly hall, engineering hall, and domestic premises, fifty-seven rectangular LED lamps with a power of 100 watts each are suspended from the metal purlins (Figure 119). These fixtures are 300 cm long and 20 cm wide, with a color temperature of 5000 Kelvin. This corresponds to daylight white light and ensures accurate color rendering during assembly work. Seven lamps are installed in the engineering hall, creating equally bright and uniform illumination for the workstations. The paint booth uses special protected and sealed light fixtures mounted into the walls and ceiling. They are designed to operate in conditions with high concentrations of aerosols and provide uniform illumination of all surfaces for high-quality painting operations. The doors of the paint booth feature windows that allow sunlight or light from the assembly hall lamps to pass through. Above the building entrance and the entrance gates, LED lamps are suspended under the cornice to provide good visibility on the factory grounds during the dark hours.

Figure 119 – Lighting lamps in the workshop

2.2.14 Electrical wiring

The factory's electrical wiring is an extensive engineering system that provides a reliable and safe power supply to all production, engineering, and domestic premises. It is designed considering the high energy intensity of the equipment, the continuity of technological processes, and industrial safety requirements. The main power input is routed through the main switchboard located in the technical zone. From there, power cables branch out into power and lighting circuits. The power wiring is intended to supply production equipment, welding machines, ventilation units, and the heating system. To protect against mechanical damage and environmental factors, and for ease of maintenance, all wiring in the production workshops is routed through special metal cable trays under the ceiling and within protective corrugated conduits along the walls. The assembly hall is equipped with 380 V power connectors for industrial equipment and 220 V outlet groups for handheld power tools. Each group of consumers is protected by individual circuit breakers and residual current devices (RCDs) in local distribution boards, allowing for repairs in one area without de-energizing the entire factory. The lighting wiring is configured in separate groups, ensuring the operation of LED fixtures throughout all factory premises. Lighting control is organized by zones, enabling economical energy use and the adaptation of illumination to current production tasks. In rooms with special operating conditions, protected cables of the appropriate class are utilized. Low-voltage systems include communication lines, internet, video surveillance, security and fire alarms, as well as control networks for engineering equipment. These lines are laid separately from power cables to reduce electromagnetic interference and enhance equipment reliability. Particular attention is paid to the grounding and potential equalization system. All metal structures, equipment, and electrical installation housings are grounded, ensuring personnel protection against electric shock. The electrical wiring is installed in compliance with regulatory requirements, designed for long-term operation, and ensures the stable and safe performance of the factory as a whole.

2.2.15 Equipment and tools

The factory's equipment and tools are selected to accommodate small-scale vehicle production and ensure the execution of all technological operations—from parts manufacturing to final assembly and painting. Their layout is organized to minimize the movement of personnel and workpieces, enhance safety, and ensure ease of maintenance. Pneumatic tools powered by compressed air are widely used in the assembly hall and the paint booth. These include impact wrenches, grinders, and spray guns for applying coatings. Due to the absence of an internal electric motor, the use of pneumatic tools reduces the physical load on workers, increases operational precision, and ensures consistent quality. Compressed air is supplied by compressors located in the paint booth hall and near the car assembly station. This placement reduces pressure losses in the lines and enhances the reliability of the pneumatic system. The machining area features CNC (Computer Numerical Control) machines, including milling and turning centers. They are designed for the production of high-precision suspension and drivetrain components. Additionally, a 3D printer is located in this area, performing the printing of metal parts such as the electric motor housing and suspension knuckles. The 3D printer is indispensable in small-scale production. It allows for the rapid manufacturing of complex geometric shapes, prototypes, and small batches of components—tasks that are often impossible with traditional casting or cutting methods—without the need for lengthy equipment retooling. The welding area is equipped with a semi-automatic electric arc welding machine (MIG/MAG) used for the fabrication and assembly of metal structures, chassis frame elements, and suspension parts. The equipment is complemented by jigs and auxiliary fixtures that ensure geometric precision and the quality of welded joints. Taken together, the factory's equipment and tools form a flexible and functional production environment, allowing for the efficient execution of all car manufacturing stages while maintaining high levels of quality control and occupational safety.

2.3 Mini-factory layout

2.3.1 Assembly area

The assembly area is located in front of the production room entrance, the exit gates, and the paint booth gates (Figure 120). This layout is chosen because the vehicle assembly is performed in a single location after all parts and sub-assemblies have been manufactured. The assembly area does not overlap with other production processes. If necessary, the entire vehicle can be moved into the paint booth for painting, sanding, washing, or drying. The assembly area is marked on the floor in green with a yellow border. This marking facilitates the positioning of the vehicle for assembly, while the yellow border defines a boundary within which no equipment or tools that might obstruct the assembly process should be left.

1 – assembly area; 2 – CNC machining area; 3 – battery assembly area;
4 – warehouse; 5 – welding area; 6 – molding area; 7 – paint booth;
8 – paint booth equipment room; 9 – locker room; 10 – director's office;
11 – meeting room; 12 – engineering hall; 13 – canteen; 14 – restroom;
15 – entrance hall.

Figure 120 – Factory layout

The wall with a window between the assembly area and the engineering hall visually expands the space, and the window allows for the observation of the production process, which enhances the assembly workflow. The distance from the boundary of the designated assembly area to the walls and equipment is sufficient for transport trolleys carrying large parts to pass freely without interfering with the workers performing the assembly (Figure 121).

Figure 121 – Evo vehicle in the assembly area

2.3.2 CNC machine area

The CNC machining area is located near the vehicle assembly zone, which is necessitated by the need for the rapid manufacturing and refinement of parts (Figure 122). This solution aligns with the concept of small-scale production, where flexibility and the ability to quickly adapt to design changes are paramount. The area is equipped with a milling machine, a lathe, a multi-axis machining center, and a 3D printer for metal printing. These machines produce engine and suspension components. Parts are moved from the machines on trolleys directly to the assembly area. Passageways are provided between the machines for the transportation of large components. The area also features a workbench, which serves as a metrology post equipped with inspection tools to ensure the precision of all parts before they reach assembly. If the assembly process reveals a need for part modification, engineers promptly transmit the adjustments to the CNC area, and a new version is delivered to the assemblers shortly thereafter. Unlike a conveyor belt oriented toward mass production, this setup represents flexible manufacturing that additionally allows for process refinement and the ability to modify the design during production. This is particularly vital for hand-built production, where experience is accumulated and technology is perfected.

Figure 122 – CNC machining area

2.3.3 Battery pack assembly area

The battery pack is assembled on a specialized assembly jig located in the center of the area (Figure 123). The jig is fabricated from square tubing and steel angles. There is an access point on one side of the jig to allow a trolley to exit with the completed battery. The carbon fiber battery housing is delivered from the molding area, while the battery cells arrive from the warehouse. The cells are placed into the housing and interconnected. After assembly, testing, and charging, the finished battery pack is transferred to the vehicle assembly area. The battery pack is moved from the battery assembly area to the vehicle assembly area using a hydraulic pallet jack. The pallet jack is positioned under the jig, raised to lift the battery off the stand, and then moves it to the vehicle body for installation.

Figure 123 – Battery pack assembly area

2.3.4 Warehouse

The warehouse is located at the end of the workshop near the building gates (Figure 124). The warehouse serves as the starting point for the entire production process; from here, parts and materials are distributed to various production areas. The racking systems hold boxes of components, tools, containers, canisters, metal profiles, and rolled materials. The warehouse also stores tires, foam boards, and raw workpieces for production. Materials and parts are transported from the warehouse to the production areas using specialized trolleys. The position of storekeeper is filled by a junior process engineer.

Figure 124 – Warehouse

2.3.5 Welding area

The welding area is the most productive zone, where the vehicle chassis, motor mounts, and suspension arms are fabricated (Figure 125). Electric welding is performed in an inert gas environment; therefore, gas cylinders are located within this area. In addition to vehicle parts, the welding area is used to manufacture fixtures, assembly jigs, and racking units. The area is situated adjacent to the warehouse to facilitate the rapid transfer of metal profiles, gas cylinders, and consumables. A dedicated ventilation system is installed above the welding jig to extract fumes. Two welders operate in this area.

Figure 125 – Welding area

2.3.6 Molding area

The manufacturing process in the molding area is the most labor-intensive. A molder takes a part matrix (mold) from the rack and places it on the molding table. The fabrication of a part begins with cutting the prepreg. Prepregs and resins are stored in special airtight refrigerated cabinets. A worker cuts the prepreg according to a pattern and places the cut material into a plastic container, which is then moved to the molding station. The molder lays the material into the matrix, covers it with a lid, and sends it to the curing area. There, the part undergoes polymerization and hardening. Afterward, the matrix is returned to the molding table to remove the finished part. Once removed, the part is sent for machining, and the matrix is returned to the mold warehouse. Since fiberglass, epoxy resin, and dust from machining can contaminate vehicle components, all sanding and finishing operations are performed inside the paint booth to prevent this. Large components requiring pre-assembly, such as the vehicle monocoque, are assembled in the pre-assembly area (Figure 126).

Figure 126 – Vehicle monocoque in the molding area

2.3.7 Paint booth

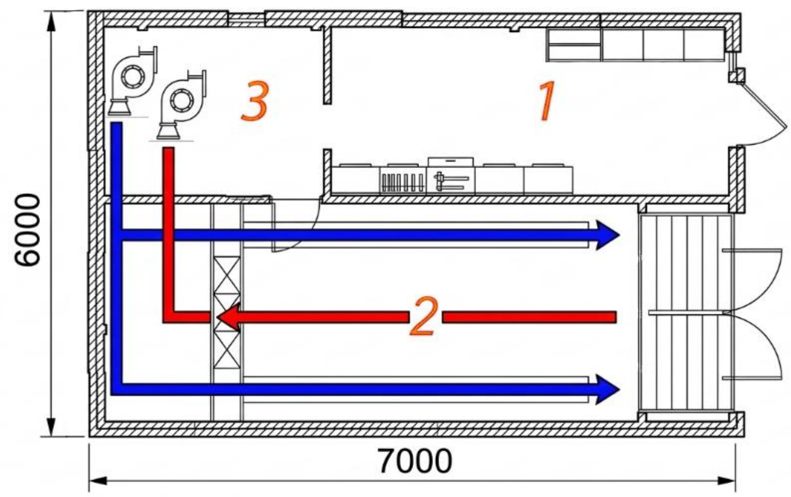
Painting a car body is a long and complex procedure consisting of several stages carried out in a specially designed booth (Figure 127). The body and various parts, such as the hood, trunk lid, side skirts, and bumpers, are painted here. After painting, the vehicle is returned to the assembly area, while the painted parts are placed on the assembly section racks. At the first stage of preparation involving body sanding, the ventilation system plays a crucial role. It must not only remove dust and gases from the paint booth but also filter the air supplied to it. The objective of ventilation during car body painting is to settle suspended paint particles and extract them from the booth. To achieve this, clean dry air is supplied through a dust filter via a ceiling duct, while air exhaust is handled through ducts located under the paint booth floor. This ensures that dust and gases do not rise from the floor but settle onto it. To prevent the air from drawing dust through the booth's crevices, the pressure inside the booth is maintained higher than the external pressure (positive pressure); therefore, the intake fan has a power of 2 kW, while the exhaust fan has a power of 1 kW. At the final stage, during the drying of the painted vehicle, the air in the booth must be dry to prevent condensation on the body. For this reason, the filtered air is heated to 60 °C and remains circulating within the paint booth. The lighting in the booth is uniform and shadow-free. The walls are painted in a matte white color to eliminate glare. For the operator, the clearance between the wall and the vehicle body is 1.5 m.

Figure 127 – Paint booth

The booth includes a preparation area containing tools and materials such as a double-atomization basecoat spray gun, a clearcoat spray gun, a primer gun, rags, and a mask. In the preparation hall, the spray guns are cleaned after painting in a gun washing station connected to the exhaust system. Adjacent to the washing area, there is a separate waste bin for solvent cans, paint and lacquer tins, and measuring cups.

2.3.8 Paint booth equipment room

The paint booth equipment room is located to the right of the booth (Figure 128). It has a separate entrance from the assembly hall. The equipment room is separated from the main booth by an airtight partition with an insulated door, providing convenient access for personnel while preventing solvent vapors and dust from entering the room.



1 – preparation hall; 2 – paint booth; 3 – equipment room.
Figure 128 – Paint booth hall layout

The room provides a changing area for personnel, where coveralls, respirators, safety goggles, and gloves are stored. Clothing and equipment are kept in ventilated metal lockers. Before their shift, workers enter here to change and prepare the equipment for painting. The equipment room houses the control unit for the booth's ventilation and drying systems, a compressor for pneumatic tools—equipped with a compressed air purification and heating device—a rack for spray guns and hoses, a garment rack for specialized workwear, and shelving units for paints, polishes, sealants, sponges, and sealing spatulas. A vacuum cleaner for cleaning the booth is located near the shelves. The control units for ventilation and drying are located closer to the rear wall of the room. Workstations for system maintenance are positioned along the solid walls, ensuring clear access to the control panel. The panels, equipped with indicators and buttons, allow for the monitoring of temperature, humidity, and airflow velocity inside the booth. Air ducts leading to the filtration and exhaust systems also pass through this room.

2.3.9 Changing room

The changing room is located near the workshop entrance, between the assembly hall and the engineering center, making it convenient for both factory workers and engineers. The entrance to the changing room is from the assembly hall. The entrance door is situated in the wall that divides the factory into the assembly hall and the engineering center. Before starting work, employees enter the assembly hall, proceed to the changing room to change, and then go to their workstations. The changing room is designed for the use of both factory workers and plant engineers. It contains lockers for work clothes as well as a utility closet for storing janitorial and cleaning equipment. The dimensions of the changing room are 6.5 × 3.5 m. It houses 17 lockers, each measuring 0.6 × 0.5 × 1.85 m. Two benches, measuring 2 × 0.35 × 0.35 m, are placed along the length of the room between the lockers.

2.3.10 Director's office

The director's office is part of the engineering center. It is separated from the rest of the office area by a wall and is accessed through the engineering hall. The office features a desk with a computer, where the director works with documentation, analyzes reports, and issues orders (Figure 129). A cabinet for personal belongings stands behind the desk, while two chairs are positioned in front for receiving employees, partners, and clients. The office hosts interviews with new staff and partners, as well as meetings with engineers to solve production tasks and establish plans for the coming days. In this office, new projects are born, production schedules are drafted, strategic decisions are made, and the course of development is set. It is not merely a workspace; it is a command center, a captain's bridge. The director is not just a plant manager; he is the captain of a ship upon whom the entire production depends. He issues technical specifications to the engineers and oversees their execution. The well-being of the entire team depends on the director. The director charts the enterprise's development course. Like a ship, a factory can sink due to emergencies. Pirates may attack the ship and steal all the technologies. Other vessels might overtake the ship and deliver goods ahead of it. A ship may find itself caught in government coups or storms and sink. It is the director's duty to ensure this does not happen.

Figure 129 – Director's office

2.3.11 Meeting room

The meeting room is located behind the wall of the director's office. It has a separate entrance from the engineering hall. The room is furnished with a long table and chairs (Figure 130). A large, modern interactive screen is mounted on the wall for displaying blueprints, charts, and presentations. The meeting room is used for briefings, conferences, making operational decisions, and signing contracts.

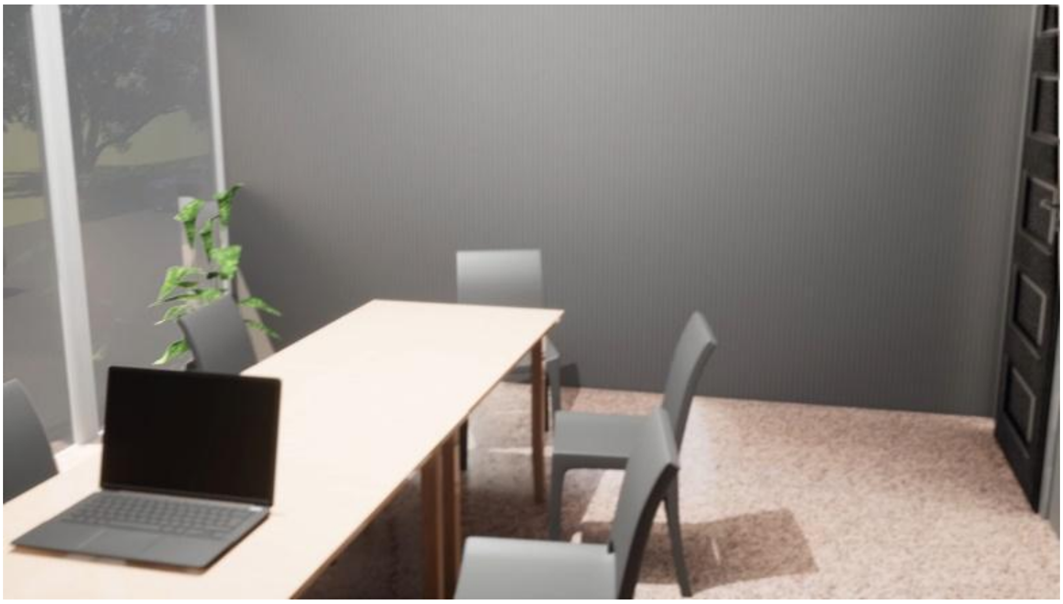


Figure 130 – Meeting room

2.3.12 Engineers' hall

The engineers' hall is a spacious room where design engineers, process engineers, programmers, and designers work. The hall is separated from the production workshop by a wall with windows (Figure 131). These interior windows provide a sense of greater visual space and allow for observation of the activities in both the assembly hall and the engineering hall. The desks of the process engineers are located near the entrance to the engineering hall, behind the windows. The hall contains ten desks, as well as cabinets for literature and documents. Pictures of completed projects hang on the walls. A cloakroom is located near the entrance door to the hall. The engineering hall is divided into several departments: design, electrical engineering, and software. Design engineers develop new parts and design electrical circuits, integrated circuits, and batteries. Process engineers establish the manufacturing technologies for the parts. Programmers handle both hardware programming (programming components to perform specific functions) and web development. Designers create the aesthetics, produce animations of 3D models, and design websites, advertisements, and video edits. A hierarchy of senior and junior engineers exists within the staff; for example, a senior process engineer reviews the technology documentation written by a junior process engineer. The position of deputy director is held by the senior design engineer.

Figure 131 – Engineers' hall

2.3.13 Canteen

The canteen is located on the right side of the factory, with the entrance situated in the front hall. Along the wall near the entrance is a kitchen area equipped with wall-mounted and floor cabinets, as well as a workspace. The kitchen features a refrigerator, microwave ovens, a sink, a two-burner electric stove, and an exhaust hood. There are four square tables with plastic chairs, providing a seating capacity for sixteen people. The furniture is arranged to ensure free movement between rows and to maintain a comfortable atmosphere during meal times (Figure 132). The table surfaces are made of moisture-resistant and durable materials suitable for daily use. The canteen is spacious and well-lit thanks to panoramic windows that offer a view of the factory parking lot and the facility grounds. Natural light creates a sense of comfort and openness. Meals in the factory canteen are provided free of charge. The factory has a scheduled lunch break from 12:00 to 13:00, during which all employees can eat. Additionally, it is a factory tradition to have tea at 15:00. Lunch is prepared by a domestic staff member responsible for household tasks. She prepares daily meals considering typical preferences and the need to provide hearty and cost-effective nutrition for the employees. The menu changes daily to ensure variety. For example, the lunch menu may include: First course: Kharcho soup, borscht, or chicken noodle soup. Main course: Buckwheat porridge, pasta, or mashed potatoes served with meat cutlets, chicken or pork goulash, or fried fish. Salads: Fresh cabbage and carrot salad or Vinegret (beetroot salad). Bakery: Fresh bread. Beverages: Dried fruit compote, tea, fruit morse, or coffee. Sour cream, mayonnaise, and mustard are always available in the refrigerator. For dessert, the staff member prepares apple, pear, or banana sharlotka (sponge cake) sprinkled with ground cinnamon for a pleasant aroma. All prepared meals are portioned into special container plates and stored in the refrigerator.

Figure 132 – Factory canteen

2.3.14 Toilet

The entrance to the restroom is located in the front hall, opposite the main entrance to the factory and between the entrances to the engineering hall and the canteen. The restroom is equipped with a toilet and a washbasin. Although it is a small area, it is a vital part of the factory that is essential for the well-being and comfort of all employees.

2.3.15 Hallway

The entrance hall of the factory is a transitional zone that connects all the main areas of the building. Every employee passes through this hall upon entering the facility. It contains the doors leading to the production workshop, the engineering hall, the canteen, and the restroom. Above each door is a sign indicating the name of the room: Assembly Shop, Engineering Hall, Restroom, and Canteen. The hall is illuminated by an LED lamp and benefits from natural light passing through the glazed wall and entrance door. During the cold season, the entrance hall functions as a thermal vestibule, preventing warm air from escaping the building and reducing heat loss.

2.3.16 Parking

A paved parking lot with a total size of 64 × 16 m is located on the asphalted territory in front of the factory, designed for sixteen vehicle spaces. Each parking space has dimensions of 5.5 × 3 m and is delineated by white horizontal road markings with a line width of 0.1 m. The facility utilizes a perpendicular parking layout, where a 10-meter-wide drive aisle is maintained between the factory building and the parking zone to ensure safe maneuvering.

2.3.17 Barrier gate

Entry to the factory grounds is provided through a driveway equipped with a barrier gate (Figure 133). The electromechanical barrier, featuring a 4.3 m boom, is designed to automate access control to the facility. The automated system opens the passage in 6 seconds. The design of the barrier combines compactness with a sleek aesthetic. The equipment is characterized by an extended service life of 2.5 million cycles, achieved through the absence of friction in the optical sensor unit that monitors end positions. A potentiometer on the control unit is used to adjust the boom's travel limits. This device ensures high precision in setting the end positions and guarantees the correct operation of the barrier. The automation system is connected to the power supply through a circuit breaker. This method protects the device's electrical components from the negative effects of overloads and voltage spikes, while also ensuring safety during equipment maintenance. To de-energize the barrier for servicing, it is sufficient to flip the toggle switch. The barrier is operated via a remote control. A manual override handle inside the cabinet is used to raise the boom manually. Programming of the model's main operating parameters is performed by selecting commands on the control unit using DIP-switches. Special terminals are provided on the control block for connecting electrical peripherals to the barrier.

Figure 133 – Barrier gate

2.3.18 Hedge

A living hedge made of evergreen boxwood (Buxus sempervirens) holds a special place in the landscaping of the surrounding territory. This plant was chosen intentionally; it thrives in the subtropical climate, maintaining a rich emerald color year-round, and possesses a high foliage density that allows for the creation of perfect geometric shapes. The hedge is shaped into a strict rectangular block, 80 cm high and 50 cm wide. These proportions are specifically selected: a height of 80 cm is sufficient to visually demarcate zone boundaries without obstructing the view of the lower part of the factory facade or the parked vehicles. The 50 cm width provides the hedge with a sense of solidity and stability. The dense trimming makes it resemble a solid green wall, inviting to the touch. Despite its decorative appearance, the hedge performs several important practical tasks. It clearly separates the parking lot from the roadway and pedestrian paths. The dense foliage traps road dust and absorbs noise, creating a more comfortable atmosphere on the grounds. During periods of heavy subtropical rainfall, the hedge acts as a natural barrier, slowing surface water runoff. Against the backdrop of the factory’s metal panels, the vibrant green foliage creates a sophisticated contrast, emphasizing the modernity and cleanliness of the enterprise. Regular formative pruning is part of the factory's corporate culture. The domestic staff member is responsible for maintaining its perfect shape.

2.4 Mini-factory personnel

2.4.1 Mini-factory director

The director is the most significant figure of the enterprise; the entire production process largely depends on him. The factory must run like clockwork, and nothing should interfere with its operation. The director organizes an efficient, stable, and safe manufacturing process. On a daily basis, he plans and delegates responsibilities among the engineers. The director determines priority areas, analyzes previously completed work, and introduces modifications to projects. He conducts interviews with prospective employees and meets with clients. Possessing an advanced technical mindset and a deep understanding of all production processes, the director generates ideas, creates cutting-edge technologies, and anticipates potential challenges. He demonstrates stress resilience, accountability, and discipline. He combines strong leadership qualities with the ability to engage in dialogue and find compromises with his employees.

2.4.2 Senior designer engineer

The Senior Designer is the key specialist of the engineering center, serving as the acting plant director when necessary. His workstation is located adjacent to the director's office. The Senior Designer creates new products, develops and verifies engineering documentation, and oversees parts from the development stage through to manufacturing. He is responsible for quality control of manufactured components, introducing adjustments based on test results, and improving the design of existing products. The Senior Designer plans, organizes, and optimizes production processes, implements innovations to increase plant efficiency, and monitors production deadlines and quality standards. He conducts briefings with other engineers, interacts closely with the director, reviews documentation prepared by junior engineers, advises staff, and proposes modernization ideas.

2.4.3 Junior designer engineer

The responsibilities of the junior designer are similar to those of the senior designer. The junior designer creates new products, optimizes production processes, implements innovations, and improves factory efficiency; however, they handle less complex and high-stakes assignments. Unlike the senior designer, the junior designer does not act as a substitute for the director in his absence. The work of the junior designer is reviewed and verified by the senior designer. The junior designer prepares reports and develops engineering documentation for submission to the senior designer.

2.4.4 Senior process engineer

The senior process engineer develops and implements the manufacturing workflows required to produce the parts and structures designed by the engineering team. Upon receiving documentation from the designers, he analyzes the part architecture, determines the optimal manufacturing methods, and adapts the technology to the capabilities of the machine tools, 3D printers, welding equipment, assembly area, and paint booth. He ensures the manufacturability (producibility) of the products and the compatibility of all components. He prepares routing sheets (process maps) for the workers, maintains order at the workstations, and monitors compliance with safety regulations and sanitary standards. The process engineer's workstation is located adjacent to the assembly area. The senior process engineer participates in morning briefings in the meeting room, where production tasks, issues, and solutions are discussed. He proposes changes aimed at increasing efficiency, mitigates technological risks, and ensures the stable operation of the entire production line. Thanks to his work, the factory produces high-quality parts and maintains an uninterrupted production cycle.

2.4.5 Junior process engineer

The responsibilities of the junior process engineer are similar to those of the senior process engineer, whom they substitute for in their absence. Additionally, the junior process engineer performs the duties of a storekeeper: they accept deliveries of parts and materials, oversee their organization and storage in the warehouse, and conduct inventory audits. The junior process engineer inspects manufactured products, conducts tests on new technologies, and prepares reports for the senior process engineer regarding the work performed. They monitor compliance with safety regulations and sanitary standards and explain production technologies to the factory workers.

2.4.6 Senior embedded systems programmer

The senior embedded systems programmer is responsible for the development, configuration, and maintenance of the software and embedded systems used both in the production processes and within the design of the vehicle itself. He works with electronic control units (ECUs), sensors, actuators, and circuits, ensuring their correct integration into the product and the factory equipment. In addition to a desktop computer, his workstation is equipped with electronic components, microcontrollers, and circuit boards. In his daily work, the senior hardware programmer interacts with the director, who sets tasks related to the development of vehicle electronic functions and equipment automation. He collaborates with design engineers during the creation of electronic nodes, coordinating the placement of controllers and sensors. Together with process engineers, he determines the methods for programming and testing electrical equipment on the shop floor, helping to adapt manufacturing processes for electronic components and their calibration. The senior hardware programmer develops firmware for controllers, writes programs for CNC machines and test benches, creates diagnostic systems, and ensures the stable operation of the vehicle's electronics. He works in integrated development environments (IDEs) for microcontrollers, uses low-level languages (C, C++), electronic computer-aided design (ECAD) systems, and debugging tools. Essential skills include deep knowledge of electronics, circuit design, digital and analog systems, communication protocols, proficiency with microcontrollers, and experience with industrial production equipment.

2.4.7 Junior embedded systems programmer

The junior embedded systems programmer, like the senior, is involved in writing code for device operations, flashing microcontrollers, configuring sensors, and preparing software for production equipment; however, their work involves less complex and lower-stakes tasks. The junior programmer develops individual firmware modules, performs code debugging, analyzes simple logical errors in device operation, and conducts testing. He is responsible for executing specific tasks related to the programming and testing of electronic devices used within the factory and the vehicle design. His workstation is equipped with a desktop computer, development boards, microcontrollers, power supplies, and measurement equipment to verify the functionality of the developed code and hardware circuits. The junior programmer actively participates in the testing of vehicle electronic systems, assists in setting up test benches, and monitors equipment performance after modifications are implemented. He possesses foundational knowledge of circuit design, microcontrollers, communication protocols, and the C and C++ programming languages, and is proficient in using measuring instruments and debuggers. The junior embedded systems programmer works under the supervision of the senior hardware programmer. He receives technical specifications from the senior programmer and coordinates his work with design engineers regarding the placement of electronics within the vehicle, as well as with process engineers regarding the sequence for equipment testing and calibration on the production line.

2.4.8 Senior web programmer

The senior web programmer is responsible for developing high-tech networking solutions that provide connectivity between the vehicle and external services. He creates software for interaction between the onboard control unit and cloud platforms, navigation services, remote diagnostic servers, and over-the-air (OTA) firmware update systems. His work includes designing the architecture of network modules, configuring data transmission security systems, developing APIs, and integrating the vehicle's electronic components with internet services. He solves the most complex technical challenges, establishes technical requirements, and oversees the correct implementation of the vehicle’s network functions. The senior web programmer interacts with the director, who defines the functional requirements, as well as with hardware programmers and design engineers to ensure the compatibility of electronics and software.

2.4.9 Junior web programmer

The junior web programmer is responsible for the development and support of the factory's internet resources, including the online store and the official corporate website. He creates web page designs, application interfaces, and visual elements, ensuring a user-friendly experience across the company's services. Additionally, he handles the installation and configuration of web applications running on the vehicle's onboard microcomputer, prepares user control panels, updates UI elements, and conducts testing. The junior web programmer is accountable for the usability and visual quality of digital services, providing employees and customers with seamless access to necessary functions and information. His work involves executing applied tasks under the guidance of the senior specialist, adjusting visual and programmatic functionality, and adapting web applications to meet factory requirements.

2.4.10 Assembly specialist

The assembly specialist performs the vehicle assembly within the dedicated assembly area. This stage represents the final operation of the entire production cycle. At a single station, the assembler attaches the frame to the monocoque, sequentially installing components onto the frame and mounting the suspension, transmission elements, electrical wiring, power units, electronic modules, control systems, and auxiliary equipment. All tasks are performed according to the process sheet developed by the process engineer, strictly adhering to the specified sequence and requirements for tightening torques, clearances, and tolerances. Throughout the process, the assembler constantly monitors the precision of component installation and their mutual compatibility. If misalignments, defects, or non-conformities are identified during assembly, he immediately informs the process engineer or design engineer to resolve the issue promptly. This feedback loop allows for rapid adjustments to the design or manufacturing technology, thereby increasing the quality of the final product. The assembler may propose more efficient, faster, or safer methods for part installation, optimizing the sequence of operations and simplifying the assembly process. Such proposals are reviewed by the process engineer and, if necessary, integrated into the production documentation. The assembler possesses high qualifications, attentiveness, precision, and a strong sense of accountability. The reliability, functionality, and quality of the finished vehicle depend directly on his skill. It is at the assembly station where the vehicle takes its final form and becomes ready for operation, making the assembler one of the key figures in the manufacturing process.

2.4.11 Machine operator

The machine operator is a highly skilled specialist who manufactures parts in the machining area. He possesses deep knowledge of mechanical engineering, is proficient in reading blueprints, and works with CNC (Computer Numerical Control) programs. His professionalism directly determines the precision of components, the reliability of assemblies, and the overall quality of the vehicles produced by the factory. His work focuses on CNC machines, lathes, milling machines, and additive manufacturing equipment. Using digital models in accordance with engineering documentation and process maps, the machinist produces parts from raw workpieces. On CNC machines, he performs precision surface machining, drilling, milling, and turning operations. On lathes, he manufactures hubs, drive shafts, and steering components, while milling machines are used for gears and gear racks. In the additive manufacturing section, the machinist uses a 3D printer to produce suspension knuckles, electric motor housings, and gearbox housings. After processing, the machinist cleans the part surfaces, removes burrs, and performs dimensional inspection—checking sizes and the geometry of mating surfaces using measuring instruments. He transfers finished parts to the assembly area, ensuring the continuity of the production process. The machinist is also responsible for monitoring the technical condition of the equipment. Since machines require constant observation, setup, and timely maintenance, he is capable of detecting malfunctions at an early stage, replacing worn elements, and preventing emergency situations. During the work process, the machinist identifies machining defects and suggests ways to rectify them. If necessary, he may propose changes to the manufacturing technology if it improves part quality or reduces production time.

2.4.12 Welder

The welder performs the welding of metal structures at a specialized welding station. The strength, geometry, and safety of the vehicle's structural elements depend directly on his work. The profession requires high qualifications, precision, physical endurance, and strict adherence to technological standards. The primary task of the welder is the fabrication and assembly of metal units and structures. He performs the welding of the vehicle frame and suspension arms, which are made of aluminum alloy. The welding is carried out using semi-automatic electric arc welding in a shielding gas environment (MIG), which ensures high-quality seams, minimal part distortion, and reliable structural joints. Before starting the process, the welder secures the frame components on a welding jig (fixture), locking them in the design position to maintain precise geometry and prevent warping. Once fixed, he sequentially welds the joints while monitoring welding parameters, depth of penetration, and the visual appearance of the weld bead. The welder’s work involves stringent safety requirements. He wears a specialized protective uniform, a welding helmet, and personal respiratory protection. Since hazardous fumes are released during welding, the station is equipped with auxiliary exhaust ventilation, and the welder uses a mask with a built-in respirator function. Upon completion, the welder cleans the seams, removes spatters or overlaps, and prepares the surface for subsequent operations. Depending on the production route, the finished welded structures are transferred either to the painting section for anti-corrosion protection or directly to the assembly area.

2.4.13 Electrician

The electrician is responsible for the assembly, installation, and testing of all electrical and electronic systems in the vehicle. Their work covers everything from individual electronic nodes to complex electrical circuits that provide power, control, and safety for the vehicle. The electrician performs the installation of electrical circuits, cable routing, and the mounting of connectors, fuses, and switching elements. They assemble control units, motor speed controllers, battery packs, and distribution hubs. When assembling battery packs, the electrician connects individual cells into modules, installs control and protection systems, and verifies proper cell balancing and contact reliability. When working with the motor speed controller, the electrician mounts power and signal circuits, configures operating parameters, and prepares the device for further testing. Special attention is paid to insulation quality, correct wire labeling, and protecting electrical connections from vibrations and external influences. After installation, the electrician conducts a series of tests: measuring resistance, checking for short circuits, and verifying the performance of nodes under load. If a malfunction is detected, they identify the cause, rectify the defect, and, if necessary, report the issue to the process engineer or designer. All operations are carried out in accordance with electrical schematics and technical documentation. The reliability of the vehicle's electronic systems, its operational safety, and the stable performance of all electrical components depend directly on the electrician's expertise.

2.4.14 Molder

The molder manufactures parts and assemblies from composite materials used in the vehicle's construction. Their work involves high-tech molding processes that require precision, meticulousness, and a deep understanding of material properties. The molder prepares the molds, cleans them, and applies mold release agents before laying up layers of prepreg in accordance with the process sheet. He carefully monitors fiber orientation, the number of layers, proper placement, and the uniformity of the mold filling. Additionally, the molder carries out the vacuum bagging process: he places the component into the mold, seals the vacuum bag, connects the vacuum system, and monitors pressure, temperature, and dwell time during the curing cycle. He ensures that the finished product is free of voids (air pockets), wrinkles, fiber displacement, or other defects that could compromise the strength and quality of the part. The molder interacts with the senior process engineer to receive process sheets, instructions, and molding cycle parameters. He coordinates with design engineers to clarify part features, dimensional requirements, and tolerances. After manufacturing, the molder performs a visual quality inspection, prepares the product for further processing, and transfers it to the machining area or the paint booth.

2.4.15 Painter

The painter works in a specially equipped paint booth featuring ventilation, filters, a drying system, explosion-proof lighting, and temperature control. The painter utilizes professional equipment, including spray guns, orbital sanders, pneumatic lines, filters, and specialized respirators. The painter’s workspace includes not only the booth itself but also the paint complex equipment hall, where filters, hoses, protective clothing, and tools are stored. The painter uses specialized coveralls, gloves, masks, and respiratory protection systems.

His tasks include sanding components, removing defects, degreasing surfaces, applying primer, painting, ensuring anti-corrosion protection, and inspecting the final coating. The painter combines professional craftsmanship with an artistic sense and technical precision. He possesses high concentration, meticulousness, and a deep knowledge of coating application technologies. The painter strictly adheres to safety regulations, as his work involves solvents, aerosols, and heated air in proximity to electrical equipment. The vehicle's aesthetics, the evenness of the finish, the absence of defects, and the durability of the paint layer all depend on his expertise. The painter receives components for painting from the assembly or fabrication units and returns the finished, coated parts to the assembly stage. He interacts with the process engineer, who determines the coating application modes, the sequence of operations, and quality requirements—especially when changing colors, selecting new materials, or resolving surface quality issues.

2.4.16 Facilities & domestic assistant

The factory's domestic staff member is responsible for maintaining cleanliness and order throughout the entire enterprise. Her work covers both administrative offices and production areas. Daily, she ensures the conditions in which employees can perform their work safely and effectively. Her range of tasks includes cleaning the offices, the engineering hall, the locker room, the entryway, the dining room, and utility spaces. She is responsible for mopping floors, wiping down surfaces, dusting equipment, and maintaining hygiene in the restrooms. In the kitchen, the domestic worker prepares lunch for the staff, portioning the meals into containers and placing them in the refrigerator; employees then take their lunch and reheat it in the microwave. She also handles the dishwashing and ensures the kitchen remains orderly. In the production shop and the engineering hall, she sweeps the floors, collects small debris, and disposes of waste. A transparent plastic jar is kept in the workshop, where she places any small items found on the floor (bolts, nuts, washers, paperclips). This simple yet highly practical solution allows workers to quickly retrieve misplaced parts and prevents them from being lost or sucked into the machinery. On the factory's surrounding grounds, she trims the living hedge and clears litter. Her meticulousness and attention to detail make her an indispensable part of the team, providing the factory with impeccable domestic maintenance.

Conclusion

This book has consistently described the Evo electric supercar and the mini-factory for its production. At the dawn of electric vehicle development, they inspired further research and development in the field of electric transport. Humanity has entered a new era of electric mobility. Now, there is no need to fear oil depletion or air pollution. The Evo electric vehicle has been a symbol of progress for me—a hope for a bright future where machines move silently and without harm to others. The Evo vehicle demonstrates the superiority of the electric car, where power and environmental friendliness coexist. It personifies a future where electricity replaces liquid fuel while offering unsurpassed characteristics. The Dubina Evo embodied design solutions not used in other vehicles. These solutions improved performance through the use of new technologies. The car applied new technologies for electric motor operation and steering. The combination of these technologies ensured not only magnificent dynamics but also the surprising efficiency of the supercar.

The Evo vehicle and the mini-factory for its production presented proof in several aspects. First, electric vehicles can compete in speed and range with vehicles running on liquid fuel. Second, the mini-factory demonstrated the possibility of producing an electric supercar at a small enterprise with a small group of people.

The mini-factory presented in this book can be viewed as a foundation for the further development of production, the introduction of new technologies, and the refinement of processes. The described principles and solutions can be adapted for other enterprises, educational projects, and engineering developments. In this sense, the book describes a complete facility. It covers all components of the enterprise. Such a presentation allows one to see the factory as a single mechanism in which every part influences the final result. This factory became the first step for the company—a testing ground for refining technologies. Special attention is paid to the logic of the production process, built on a step-by-step principle from parts manufacturing to vehicle assembly at a single assembly station. Such an organization showcases small-scale manufacturing with production flexibility, quality control, and close interaction between workers. The described solutions demonstrate how, even within limited spaces, it is possible to create an efficient, modern, and safe production facility.

A factory is a complex, multifaceted mechanism involving people. The role of the human in the operation of the factory is significant. Sixteen professionals, each an irreplaceable link in a single chain. It is the human contribution that turns a set of drawings and materials into a finished, high-tech vehicle. Despite the high level of technology, automation, and the use of modern equipment, it is the specialists who shape the stability of the enterprise, its culture, and the quality of the products. Their responsibility, professionalism, and interaction determine the success of the entire enterprise. The Dubina mini-factory demonstrates that modern automotive manufacturing does not necessarily require giant conveyor belts and thousands of employees. The Dubina mini-factory represents flexible production and a cohesive team striving for perfection in every detail.

Ultimately, the experience of creating the Evo electric vehicle is of great importance for the further development of electric transport. The technologies developed for this car can be adapted and applied to mass-produced economy-class models, making them more accessible and high-performing. All the technical possibilities of electric-drive vehicles have not yet been revealed. Many years will pass before their properties are fully realized.

To this day, the project of the Evo vehicle and the mini-factory continues to be refined. At the time of writing this book, work is underway to improve the suspension, battery, speed controller, and gearbox. Additionally, drawings, specifications, and estimates for the mini-factory are being created. The Evo electric vehicle is a dream turned into reality, and its story is only beginning.

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