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DESIGNING AN INNOVATIVE MODULAR PLATFORM FOR SPORTS CARS USING THE GENERATIVE DESIGN METHOD

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Abstract

Traditional methods, where chassis components are tailored for each vehicle type, lack flexibility and efficiency. The concept of current modular platforms, allows the reuse of components across different models, reducing production costs and enhancing adaptability. But, in current situation these solutions are not common in sports cars segment. The research delves into the challenges and opportunities posed by modular platforms in the context of sports cars, highlighting their potential impact on driving dynamics, design aesthetics, and future innovations. The project focuses on a modular platform approach, providing diversity while maintaining a standardized design sections, emphasizing interchangeability of components besides flexibility, using cutting-edge design methods. This study addresses to create a modular platform suitable for different drivetrain and powertrain configurations, with iterative sprints targeting lightweight and high-stiffness designs by using generative design method. In addition to improving design outcomes, efforts have been made to enhance creativity by employing the steps of the generative design method within the existing workflow (IDeS), and collaboration with the Agile method variant, Scrum, has been established to filter the results, which is crucial for project development. Moreover, it has been applied to an alternative modular platform created with new parts obtained through the generative design application. The results obtained have been evaluated in terms of the model's mechanical properties. These new parts are not only geometrically more efficient but also capable of yielding the same mechanical results even when different materials are used. Numerical results of simulations are compared for the final assemblies created with generated components (Part 1, Part 3, and Part 4) and with initial components. In particular, it has been demonstrated that, by employing the generative design method, equivalent strength values can be achieved by using aluminium alloy instead of steel alloy for the component of Part 3 (Outcome 7). Torsion and bending stiffness tests on each model have been performed before and after generative design process. The parts defined to generate decided with crash tests on rear-mid and front modular platform layouts separately. The results have been compared and it has found that stress distributions are similar which means the parts that we have generated are sufficient in new design such as shapes, weight, and mechanical properties.

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List of Abbreviations

MQB	Modularer Querbaukasten
EMP2	Efficient Modular Platform
CMF	Common Module Family
UKL	Unter Klasse
BIW	Body-in-white
MP	Modular Platform
NPD	New Product Development
OEM	Original equipment manufacturer
FRAM	Fibre-reinforced additive manufacturing
GD	Generative Design
AM	Additive Manufacturing
CAD	Computer Aided Design
IDeS	Industrial Design Structure
CAGR	Compound Annual Growth Rate
OICA	International Organisation of Motor Vehicle Manufacturers
CAAM	China Association of Automobile Manufacturers
HCV	Heavy Commercial Vehicle
EV	Electric Vehicle
QFD	Quality Function Deployment
HPEV	High Performance Electrified Vehicle
CV	Constant velocity
RAC-E	Cornering Angle Regulator, Electric
MGU-K	Motor Generator Unit, Kinetic
ICE	Internal Combustion Engine
AWD	All-Wheel Drive
FWD	Front-Wheel Drive

RWD	Rear-Wheel Drive
e-SSC	Electronic Side Slip Control
DIN	Deutsches Institut für Normung
DRS	Drag Reduction System
NACA	National Advisory Committee for Aeronautics
PDK	Porsche Doppelkupplung
PASM	Porsche Active Suspension Management
CFRP	Carbon-Fiber-Reinforced Plastic
GPF	Gasoline Particulate Filter
FF	Front Engine – Front Wheel Drive
FR	Front Engine – Rear Wheel Drive
RMR	Rear- Mid Engine – Rear Wheel Drive
PHEV	Plug-in Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicle
SPHEV	Series-parallel Hybrid Electric Vehicle
PG	Planetary Gear
THS	Toyota Hybrid System
AC	Alternating Current
HSD	High Strength and Ductility
AHSS	Advanced High Strength Steel
HSLA	High-Strength Low-Alloy
UHSS	Ultra-High Strength Steel
TRIP	Transformation-Induced Plasticity
RP	Rapid Prototyping
AM	Additive Manufacturing
MPV	Multi-Purpose Vehicle
CMP	Common Modular Platform
MLB	Modular Longitudinal Matrix Platform
TNGA	Toyota New Global Architecture

SGP	Subaru Global Platform
CMF	Common Module Family Platform
CLAR	Cluster Architecture
FEM	Finite Element Method
SDE	Stylistic Design Engineering
URES	Maximum Displacement

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List of Symbols

ϕ	Torsion angle
TW	Track width
T	Torsion
F	Force
K_{body}	Torsional Stiffness
α	Bending angle
WB	Wheelbase
Δz	Displacement

INTRODUCTION

Currently, specific chassis components are tailored for each vehicle type, making manufacturing and assembly processes viable only when producing a large quantity of units for each model. However, this approach lacks flexibility for accommodating diverse configurations. The idea of modular platform design has been presented with the aim of addressing this limitation, reducing production costs, and facilitating the adaptation of various chassis types for multiple body design solutions. The modular platform allows for the utilization of the same components and modules across different vehicles (Florea et al., 2016). In recent years, various automobile manufacturers have adopted numerous new modular platforms capable of assembling models in varied sizes. Leading global automakers have significantly invested in the research and development of these modular platforms, with the resulting techniques becoming crucial selling points for their latest vehicles. Prominent examples include the Volkswagen MQB (Modularer Querbaukasten) platform, the PSA Peugeot-Citroen EMP2 (Efficient Modular Platform) platform, the Renault-Nissan CMF (Common Module Family) platform, and the BMW UKL (Unter Klasse) platform, among others (Lampón et al., 2015)

Modularity, as a prerequisite, allows a high degree of interchangeability among assembly units, making it a central focus in ongoing research on platform methodology. However, achieving full adaptability of modular strategies requires substantial internal changes to the production organization within the sector. Compared to traditional, standard parametric platforms, less is known about successfully implementing and rolling out these modular strategies. In the current automobile manufacturing industry, modules typically refer to components that can be easily produced separately and are not interdependent. Certain structural components, such as the body-in-white (BIW) of a vehicle, are not readily divisible enough into modules and are still produced through integrated manufacturing for a single-car version without considering platform factors – meaning they are not shared. While various research already exists for enhancing the efficiency of product families, such as approaching the platform as a multi-objective optimal design challenge or refining the hierarchical models of product families that have predefined platforms (Fellini et al., 2006; Kokkolaras et al., 2002). Achieving interchangeability between production and manufacturing remains challenging due to a lack of division or information regarding specialized structural components like the BIW (Hou et al., 2017). On the other hand, the need to address climate change has prompted the European Commission to tighten legal CO_2 emission limits for passenger cars (European Parliament and the Council of the European Union, 2019). Achieving competitiveness in the automotive industry now entails developing sustainable strategies to adhere to these environmental policies (Jiang et al., 2018). This shift in strategy has brought about significant alterations in the product architecture of vehicles. The product architecture approach in designing these modular platforms (MP)s integrates the advantages of both modularity and platforms. The scalable design of MPs enables variation in the structural dimensions of this fundamental automobile component. Consequently, a single MP can accommodate several automobile models from different segments (varying sizes). From a production systems perspective, the modularity offered by MPs facilitates the inclusion of flexible production systems and the reorganization of facilities to adapt to changing needs. Furthermore, MPs have enabled efficiency gains in production networks, allowing for production mobility among plants producing automobile models from different segments. This implies that the manufacturing resources within the network can be shared by a large number of automobile models and a larger volume of units. In summary, modular product architecture has significantly impacted performance in terms of product variety, design costs, manufacturing flexibility, and network outputs (Lampón, 2023).

In the ever-evolving landscape of automotive engineering, where precision meets passion and innovation fuels the pursuit of excellence, the advent of modular platform design marks a paradigm shifts in the creation of sports cars. This transformative approach to chassis architecture not only redefines the very essence of performance vehicles but also sets the stage for unparalleled flexibility, efficiency, and adaptability. At the heart of this revolution lies the concept of modular platform design—a structural framework that embraces modularity and scalability in the creation of sports cars. Unlike traditional monocoque designs, modular platforms provide a versatile foundation, allowing manufacturers to adapt and adapt a core set of components for a diverse range of models, from nimble roadsters to high-performance coupes.

Modular platforms empower engineers to conceive sports cars with a level of adaptability that was once considered unattainable. This adaptability extends beyond the physical structure to include drivetrains, suspension systems, and even electrification options. The result is a portfolio of sports cars that share a common DNA but cater to diverse preferences and market demands. This creates a new era of innovation in sports car engineering. Manufacturers can leverage cutting-edge materials, advanced manufacturing processes, and emerging technologies, tailoring each module for maximum performance and efficiency. This not only enhances driving dynamics but also opens avenues for the integration of sustainable practices and future-forward technologies. From a production standpoint, modular platform design streamlines manufacturing processes, leading to increased efficiency and reduced costs. Common components can be shared across different models, optimizing the supply chain, and minimizing waste. This not only benefits manufacturers but also positions modular sports cars as more accessible to a broader spectrum of enthusiasts.

In this thesis, a modular platform has been designed for a sports vehicle, taking into account every detail from every angle. Common features, dimensions, etc., of vehicles with different characteristics will be attempted to be unified a common modular platform. As we delve into the realm of modular platform design in sports cars, we embark on a journey that transcends the traditional boundaries of performance and versatility. This exploration will unravel the engineering marvels that underpin the modular paradigm, highlighting its impact on the driving experience, design aesthetics, and the future trajectory of sports car innovation.

Cutting-edge design methods assist designers in creating innovative and trend-setting designs. The most **efficient** and **groundbreaking** among these new methods is generative design. This method can be used to create an effective modular platform design which is already in use in automotive industry. Additionally, the application of generative design technique can be facilitated through the development of new methods in additive manufacturing. In this way, the variety of parts that can be produced with lighter and different materials increases, and it also helps make the generative design technique more widely applicable in the automotive industry.

LITERATURE REVIEW

This study is part of a research initiative investigating the impact of architectures and platforms on the new product development (NPD) process. Platforms influence various aspects of the NPD process, including development strategy, operational performance, knowledge retention and transfer, and the organization of project teams. The primary focus is to compare different product development organizations to identify essential characteristics crucial for developing products with a platform strategy. It was examined three instances to explore the practical management of platform development. All cases pertain to the electro-mechanical industry, involving the creation and production of relatively intricate products with a substantial number of parts and dimensions, encompassing multiple technologies, and produced in sizable batches. Due to these limitations, the analysis is confined but lends itself to more straightforward generalization. Moreover, this area remains open for further research (Muffatto & Roveda, 2000).

The use of platforms is not a new phenomenon. Mitsubishi took the lead in developing the shared platform, incorporating specific requests from Volvo, and incorporating input from Volvo engineers. Subsequently, both companies independently created distinct products using this common platform in 1998. Fiat has implemented platform teams, which are responsible for constructing groups of related products across the three brands by utilizing the same underlying platform. In the 1990s, Chrysler predominantly adopted a novel design strategy. Nevertheless, its extensive multi-phase initiatives, akin to those of Renault, exhibit characteristics of concurrent technology transfer. This is evident as Chrysler endeavours to swiftly develop multiple products based on a common platform (Cusumano & Nobeoka, 1998). Manufacturers respond to the increasing prevalence of product platforms by opting to share significant components of vehicles, such as the floor pan, engines, transmissions, suspensions, exhaust systems, and more. This approach allows for cost savings in development without sacrificing the diversity offered to customers. Leading the way in this practice, companies like VW share their A04/PQ35 Golf IV/V platforms with various Skoda, Audi, and Seat vehicles, achieving an annual production volume of 2,000,000 units. However, critics have already raised concerns about a potential decline in brand distinctiveness and the internal competition for sales within the group, indicating that there is a limit to the sustainability of extensive sharing. Nevertheless, the most significant transformations in terms of process adaptability and efficiency occurred at the turn of the century. This occurred as platforms were streamlined and standardized to create a unified platform that could accommodate various models within the same market segment (Holweg, 2008). PSA (Peugeot S.A.) Group was engaged in additional initiatives. The management at PSA opted to pursue these objectives through the implementation of the common-platform policy. A common platform serves as a foundation for multiple vehicles. When two vehicles are based on the same platform, they share components such as subframe, engines, gearboxes, front and rear suspension, and several other parts, excluding stylistic and distinctive features. The aim of the common platform policy is to achieve a 60 percent standardization of components across all cars produced on the same platform, irrespective of whether they belong to the Peugeot or Citroen brand. This strategy, designed to reduce costs by leveraging a flexible and cost-effective process, would have a significant impact on the manufacturing system. Consequently, the primary aim of the standardization was to streamline the number of platforms and facilitate the sharing of common components and systems among the models produced on a unified platform (Patchong et al., 2003). Another standardisation strategy was applied to a design process for flexible product platform components, emphasizing the importance of embedding flexibility in design to enable manufacturers to adapt to changing market needs without significant increases in investment costs and complexity. The process involves identifying key product platform criteria and uncertainties, generating flexible design alternatives, optimizing them for cost efficiency while meeting performance constraints, and conducting uncertainty analysis to determine the best design (Suh et al., 2007).

In this study, to initiate the formulation of a framework for developing a multi-branded product platform, this study identifies three uniquely different strategic forces that need to be addressed in such multi-branded platform development. First one is to establish a shared architecture, second one is to achieve product differentiation within an extended and multi-branded product range; and third one is to address corporate responsibility during the transition from single-branded to multi-branded platform development. But there are some limits to achieve the product differentiation. The primary obstacle in achieving architectural commonality is the absence of individuals within any brand possessing the requisite knowledge of multi-branded architecture. Instead, the development of multi-branded architectures must originate from the beginning and be based on a new and expanded brand scope. Architectural commonality also involves elements of unlearning, as past experiences have limited relevance. The second challenge pertains to brand management and involves addressing differentiation issues in portfolio management. Increased diversification leads to differentiation, particularly challenging brands following opposing generic competitive strategies. The third challenge dimension is labelled corporate management challenges and involves the amalgamation of the first two. From a corporate management standpoint, it appears crucial to establish new organizational structures that accommodate and integrate the interests of technology and brand management. Ultimately, the development of multi-branded platforms is a corporate strategy that profoundly impacts both business units and functional units (Sköld & Karlsson, 2007).

Every passenger car is constructed based on platforms or architectures that establish the fundamental engineering of the vehicle. Historically, automotive original equipment manufacturers (OEMs) have commonly utilized this engineering across various products. In the pursuit of achieving economies of scale and streamlining product launches, major original equipment manufacturers (OEMs) in the global automotive industry will increasingly prioritize manufacturing a higher volume of passenger cars on specific global platforms, referred to as core platforms. These core platforms will serve as the basis for designing and manufacturing vehicles across different segments (determined by size and price range) and brands on a global scale. Evalueserve's projection indicates that by 2020, the ten major OEMs, including General Motors, Volkswagen, Toyota, Ford, Nissan, PSA Peugeot Citroen, Honda, Renault, Fiat, and Daimler, are expected to reduce their platforms by approximately one-third from over 175 platforms in 2010. Instead, they will concentrate mass production on a few key core platforms. For instance, General Motors recently announced plans to nearly halve its vehicle platforms from 30 in 2010 to 14 in 2018, anticipating an estimated annual savings of USD 1 billion, primarily attributed to product development projects (Seghal & Gorai, 2012). From a technical perspective, modular platforms are structured with a single scalable design that enables adjustments in structural dimensions, including front and rear overhangs, wheelbase, and track width. The modularization of the automotive platform's structural element facilitates the assembly of not only various models within the same segment (with similar sizes), as seen in traditional standard platforms, but also the assembly of multiple models across different segments (with varying sizes) (Buiga, 2012). This research primarily aims to articulate the platform architecture and furnish essential design guidelines and checklists for product designers. Additionally, it underscores the use of a case company's product as an example to elucidate and validate the proposed product design approach. The study involves the design of a platform architecture, integral to the development of modular or integrated products, that serves to identify critical parts design and implement mechanisms to enhance the value robustness of the platform architecture. This value can be quantified by assessing the fulfillment of pertinent engineering metrics, which serve as key performance indicators for meeting the needs of potential customers and stakeholders (Shamsuzzoha & Helo, 2017). The adoption of modular platform (MP) design methods faces challenges in both industry and academia due to the perceived lack of a cohesive organizational framework within the extensive range of available materials. To address this issue, this paper conducted a systematic literature review and meta-synthesis. This process involved connecting 72 methods for designing MPs and their respective instances into a functional model, along with structured classes of design problems. Together, these entities form a meta-method for organizing research on MP design. Through this approach, the study identified the common underlying structure among methods developed over the past two decades. The primary contributions of this research are to establish a functional model linking design methods for MPs and to propose structured classes of design problems that enhance the functional model by categorizing techniques for each sub-function. Lastly, suggesting a construction heuristic for constructing and evaluating functional models and classes of design problems (Gauss et al., 2021).

The aim of this research is to present evidence establishing a cause-and-effect link between modularity and a decrease in the time required to fulfill received orders. The simplification of product complexity through modularity leads to a decrease in the effort needed for developing new projects and the hours dedicated to order fulfillment. The primary contribution of this study lies in providing empirical proof of the cause-and-effect relationship between modularity and the reduction in time until order completion. In terms of measurable outcomes, modularity was found to contribute to a

43.13% reduction in the time needed to fulfill orders. It can be concluded that there is a causal connection between product modularity and the reduction of time required for completing orders in this manufacturer's operations (Piran et al., 2021).

The introduction of modular platforms in the automotive industry has been characterized by the adoption of a shared production system, uniform distribution of value-added activities across the production network, and the designation of certain plants as strategic production hubs for specific models. The research findings suggest the need for a redesign of the production system to address the dynamic nature of these production networks. This involves directing investments towards versatile facilities that ensure the industrialization of new models using modular design without excessive capital expenditure. It also requires the establishment of a facility configuration enabling the rapid and seamless launch of new models. Simultaneously, flexible process redesign allows for the integration of the production of existing models, which can be shifted from other plants in the network. This necessitates the implementation of initiatives capable of managing the production of a wide variety of models on the same production lines (Lampón & Rivo-López, 2022).

In terms of lightweight of the automobile parts, generative design is one of the most innovative idea. So, this method is crucial to achieve more sustainable and lightweight part. It is also ideal for making complex designs into one part and more efficient. There are some studies that are using this approach.

In the process of creating new vehicles, the growing expectations for customer comfort and the heightened safety standards frequently lead to an augmentation in weight. Despite this, to fulfill the need for decreased fuel consumption, it becomes essential in the product development process to integrate intricate and delicate lightweight structures. This study explored the possibilities of components developed generatively for fibre-reinforced additive manufacturing (FRAM). In the following case study, illustrated through the example of a chassis component, it was demonstrated that the integration of Generative Design (GD) and Additive Manufacturing (AM) leads to a noteworthy reduction in costs and weight. This reduction is evident when compared to both traditional manufacturing methods and standalone Additive Manufacturing processes (Junk & Rothe, 2022).

There is another case study designing mechanical pedal by using generative design method. In this project, the mechanical pedal was designed and generated with CAD tool which is Solid Edge and its Generative Design module. The boundary conditions have been determined taking into account the assembly and operational states of the part. The option of specified mass reduction has been utilized to achieve mass reduction at different rates (30 %, 40 % and 50%). As a result of this, the most optimal part has been selected, and the most suitable production method is being determined (Fenoon et al., 2021). In addition to being applicable in the development of automotive parts, the generative design method should also be compatible with manufacturing processes. In this context, additive manufacturing provides solutions that enable us to push the boundaries. In another study, a wheel knuckle has been designed using the generative design method and optimized for production using the powder bed fusion method. Moreover, the utilization of 3DExperience for component industrialization, while taking into account the differences in software features, could be deemed acceptable. However, a significant drawback arises from the compromised use of solid supports designed in CAD. Design for additive manufacturing was one of the main challenges in this study and it was overcome with a holistic approach which is computer aided integrated tools (Dalpadulo et al., 2020).

INDUSTRIAL DESIGN STRUCTURE (IDeS)

What is Industrial Design?

Industrial design involves the process of designing physical products intended for mass production. This creative process entails determining and specifying the form and features of a product before its actual manufacturing. This process primarily involves repetitive and often automated replication. In contrast, craft-based design is an approach where the form of the product form is largely determined by its designer concurrently with the production process. While all manufactured products undergo a design process, the nature of this process can vary significantly. It may be carried out by an individual or a team with diverse expertise, such as designers, engineers, and business experts. The design process can lean towards intuitive creativity or calculated scientific decision-making, often incorporating a combination of both. Additionally, it can be influenced by various factors, including materials, production methods, business strategy, and prevailing social, commercial, or aesthetic trends.

IDeS (Industrial Design Structure) Method

The IDeS (Industrial Design Engineering) methodology should be applied comprehensively across all its key phases to oversee the process of developing a new product within a company, spanning from industrial applications to the medical-health sector. This becomes particularly crucial in instances where the product is intricate and involves the collaboration of multiple company departments and numerous operators over extended periods (months or years). Unfortunately, many companies approach this process in a crude and unstructured manner, which poses significant dangers and results in inefficiencies. This is especially evident in companies where reliance on prior experience remains a fundamental aspect of product development, leading to time and economic losses due to various factors. These may include the discovery of errors in the design phase, challenges arising from the belated realization of complications in manufacturing, a failure to recognize that the developed product lacks the foundation to be competitive in the market, inadequate communication skills with prospective customers, and so forth (Freddi et al., 2022). IDeS, encompassing all stages of industry, commences with the initiation of the project (project setup), progresses through the phases of product development (project development), and ultimately concludes with the commencement of production (start-up production) (Figure 1.1).

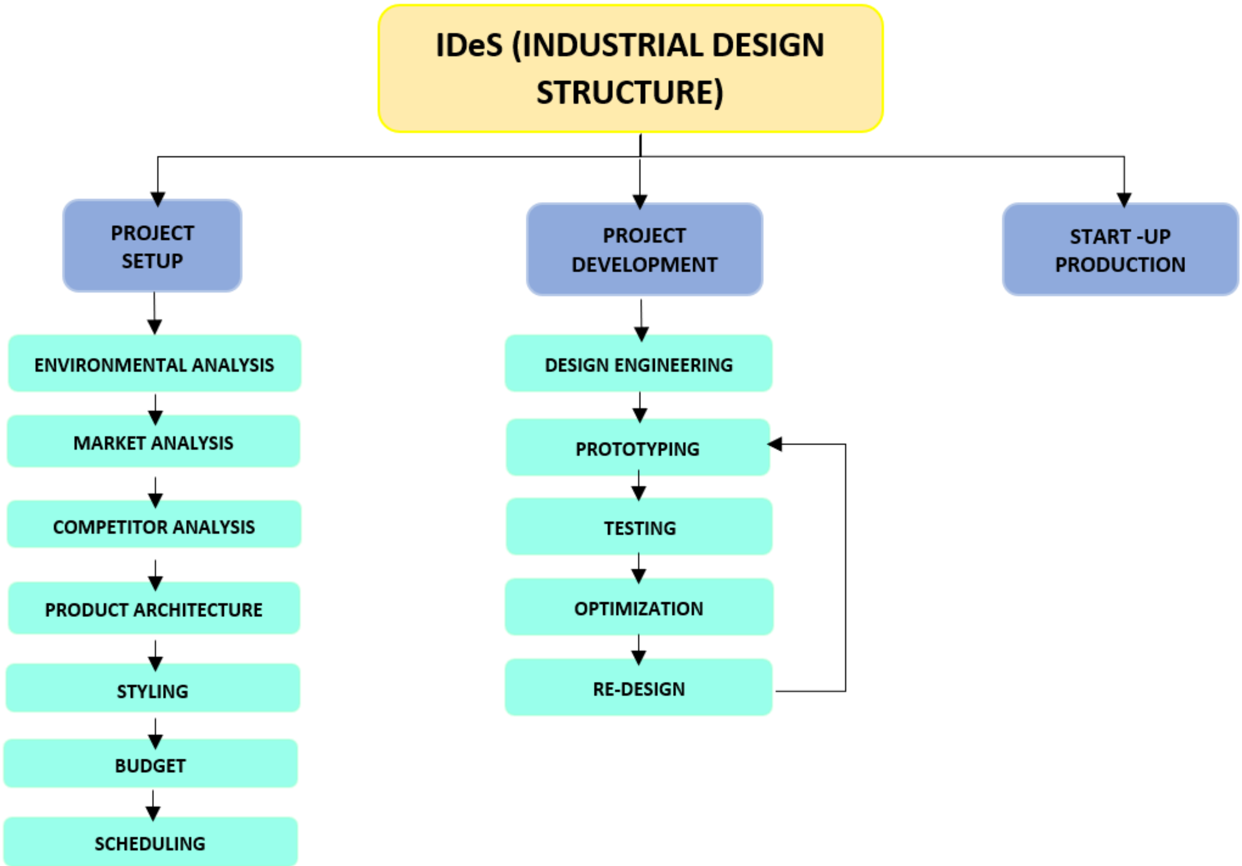

Figure 1.1: Industrial Design Structure

Each heading has its own subheadings. And all of these headings are crucial for detailing and defining the project from every perspective. In the next title, the Project Setup phase will be examined in detail. Later, a new workflow has been created for project development phase (Chapter 3.2).

3.1. PROJECT SETUP

Establishing a project holds paramount importance for any business, encompassing the vital steps of delineating the project's scope, assembling requisite resources, and formulating a comprehensive plan for its execution. This procedural undertaking is indispensable, ensuring that the project reaches fruition within the designated timeframe and budgetary constraints. In official business expression, project set up is formally defined as the detailed process of strategizing, coordinating, and overseeing the resources and activities essential to attain a specific objective. This entails specifying project goals, identifying stakeholders, assembling the project team, and establishing a timeline for accomplishment. Furthermore, project set up entails the formulation of a budget, establishment of communication channels, and identification of necessary resources. Thoroughly undertaking the project set up allows businesses to guarantee the project's success and promotes alignment among all stakeholders involved. In IDeS workflow, project setup involves many steps as follows:

3.1.1. Environmental Analysis

Conducting an environmental analysis is a strategic method employed to identify both internal and external factors that may impact a project's success. Internal elements unveil the strengths and weaknesses of a project, while external factors encompass opportunities and risks that exist beyond the project's boundaries. To understand the general aspect of the head subject of the project, it is necessary to first conduct a general environmental analysis.

3.1.1.1. Automotive Chassis Global Marketing

In the aspect of automotive chassis, in 2017, the global automotive chassis market reached a valuation of USD 50.78 billion and is projected to achieve USD 78.44 billion by 2025, with a Compound Annual Growth Rate (CAGR) of 6.5% during the forecast period from 2017 to 2025. This report assesses and predicts the market's global size in terms of both volume and value. It categorizes the market and forecasts its volume and value based on chassis type, material type, vehicle type, electric vehicle type, and region. The analysis delves into various market forces such as drivers, restraints, opportunities, and challenges. Key players are strategically profiled, and their market shares and core competencies are comprehensively examined. Additionally, the report monitors and analyses competitive developments, including joint ventures, mergers and acquisitions, new product launches, expansions, and other initiatives undertaken by key industry participants.

The research methodology employs diverse secondary sources such as the International Organisation of Motor Vehicle Manufacturers (OICA) and the China Association of Automobile Manufacturers (CAAM). Interviews with experts from relevant industries and suppliers are conducted to recognise future market trends. The bottom-up and top-down approaches are employed to estimate and validate the global market size. Volume estimates are derived by identifying total production volumes and analysing demand trends (Market Research Report, 2018). The provided diagram (Figure 3.1) presents a break-up of the profiles of industry experts who took part in initial discussions. While Tier I and Tier II defines the automotive chassis suppliers, Tier III defines OEMs.

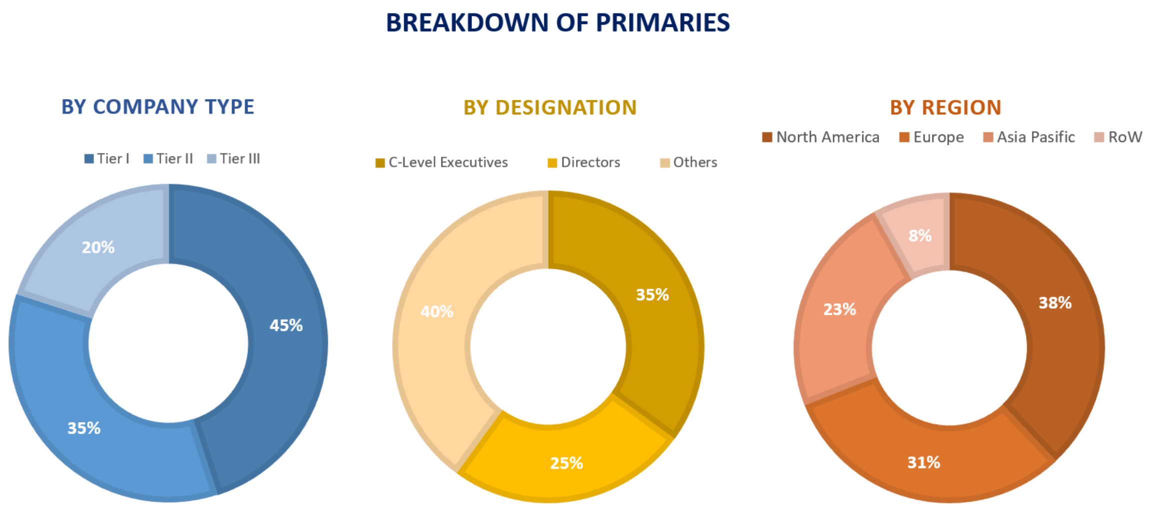

Figure 3.1: Break-up of the profiles of industry experts

The design of automotive chassis systems, including ladder chassis, monocoque chassis, and **modular frame chassis**, has been undergoing continuous development. A notable trend in the automotive industry involves the production of chassis using **lighter materials**, contributing to reduced **vehicle weight without compromising safety**. Monocoque chassis is anticipated to dominate the market, holding the largest share. Mandates for enhanced vehicle safety, improved fuel efficiency, and reduced emissions are expected to drive the growth of monocoque chassis, especially in the passenger car segment, surpassing other chassis types like ladder chassis.

In the Heavy Commercial Vehicle (HCV) segment, modular chassis is projected to witness substantial growth due to its advantages, including enhanced stability and lower weight compared to conventional ladder chassis systems. The market for aluminium alloy as a raw material is predicted to experience significant growth during the forecast period. This surge is attributed to regulations promoting environmentally friendly vehicles and the rapid adoption of electric vehicles, making aluminium alloy-induced chassis systems increasingly attractive to automotive Original Equipment Manufacturers (OEMs). Aluminium is expected to gain a larger market share compared to other raw materials for chassis system manufacturing.

In the electric vehicle category, **skateboard chassis** is poised to capture a substantial market share during the forecast period. This chassis design features a frame capable of accommodating a large battery pack spanning the entire frame area between the four wheels. Additionally, the skateboard chassis supports various body styles for diverse applications.

The Asia Pacific region (Figure 3.2) is expected to lead the market in terms of value in 2017, followed by North America and Europe. The demand for lighter chassis has grown significantly in recent years, with suppliers meeting both domestic and international needs. Furthermore, by 2025, the Asia Pacific region is projected to lead the electric vehicle market in terms of volume, followed by Europe and North America. Key suppliers are making substantial investments to expand their presence in the Asia Pacific region, contributing to this leadership position (Market Research Report, 2018).

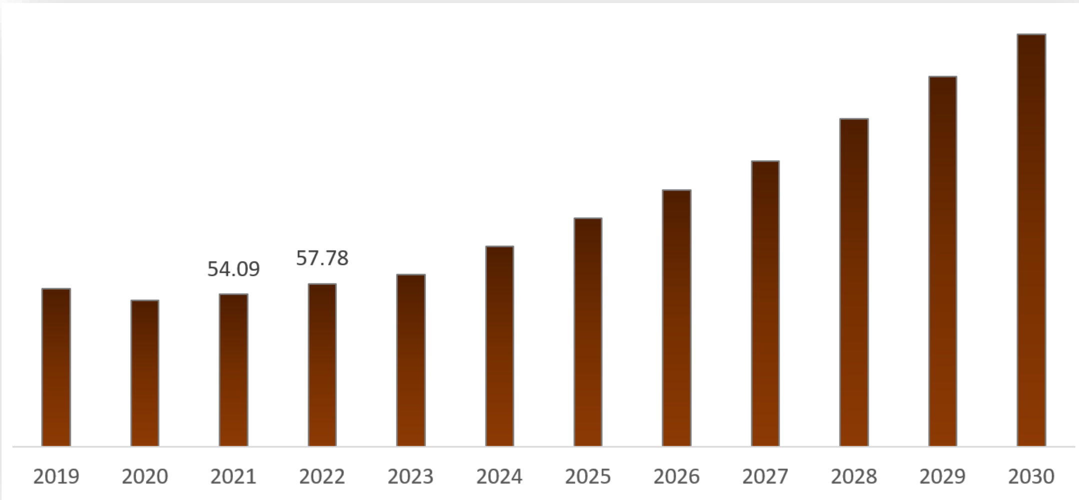

Figure 3.2: The market size of the Automotive Chassis in the Asia Pacific, 2019-2030(USD Billion)

3.1.1.2. Automotive Chassis Marketing by Type

Categorized by chassis type, the market comprises non-conventional, conventional, and modular segments (Figure 3.3). In 2022, the non-conventional sector recorded a value of USD 47.14 billion and is projected to experience a Compound Annual Growth Rate (CAGR) of 11.58% throughout the forecast period. A non-conventional chassis is a type that can accommodate various vehicle components or systems, integrating the body to enhance stiffness and improve handling by adding weight. These chassis are exclusively employed in traditional passenger cars. The absence of frame joints diminishes vibrations and dampens shocks from loosely connected parts. The global demand for non-conventional chassis is rising alongside the growing preference for conventional passenger vehicles equipped with advanced features. Notably, the lightweight nature of this chassis plays a role in reducing fuel consumption in vehicles (Market Research Report, 2023).

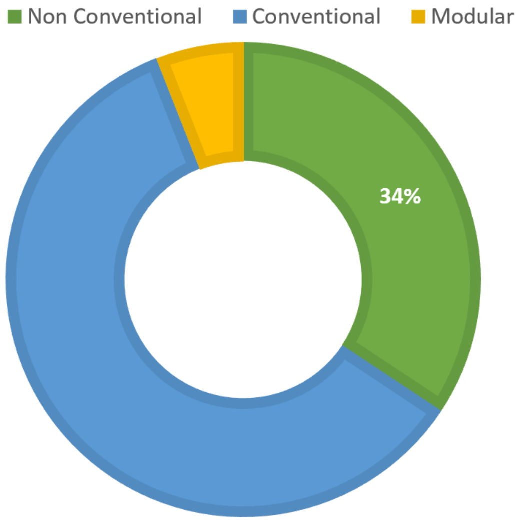

Figure 3.3: Global automotive chassis market share by chassis type, 2022 (Market Research Report, 2023)

3.1.1.3. Modular Platform Marketing

An automotive modular platform involves the modular design and assembly of all car subsystems, the standardized design and production of auto parts in module form, and the final 'assembly' based on model positioning. In contrast to traditional automotive platforms that cater to models at a single level, modular platforms reduce both research and development costs and production expenses while also shortening the timeframe for new model development. Simultaneously, they streamline quality standards, enhancing overall product robustness. Currently, Volkswagen, BMW, and GM (General Motors) have outlined plans for platform integration. Moving forward, their focus will be on prioritizing the development of core platforms over the existing diverse set of platforms. The concept of modular bodies involves utilizing the same chassis with different modular compartments in various scenarios to enhance vehicle utility. Traditional automakers and emerging technology companies like Fiat, Mercedes-Benz, Rinspeed, Rivian, Schaeffler, among others, have introduced concept cars featuring interchangeable bodies. While many current modular cars are still in the conceptual stage, some companies are actively considering mass production as part of their plans.

Typically, automakers provide various modular platforms for different models, with each platform catering to a specific range of models. However, in the future, there is a shift towards **reducing the number of platforms,** emphasizing core platforms, and increasing the production output of these core platforms. This strategic shift aims to further cut costs and enhance the efficiency of both research and development and production processes. Research into automotive modularization focuses on creating electric modular platforms, minimizing the number of platforms, and advancing core platforms. The increasing demand for cost-effective solutions and swift development cycles for new models is driving the evolution of automotive modular platforms.

Currently, the transformation and advancement of the global automotive industry predominantly revolve around new energy vehicles. In 2020, the global sales of new energy vehicles reached 3.125 million, marking a significant year-on-year increase of 41.4%. Projections suggest that this figure is poised to escalate to 15 million by 2026. Against this backdrop, the prevailing trend involves the establishment of dedicated modular platforms designed explicitly for electric vehicles. In comparison to conventional oil-to-electricity platforms, these modular platforms offer distinct advantages such as extended mileage and enhanced safety features. Presently, numerous companies have either launched or outlined plans to introduce exclusive platforms tailored for electric vehicles. Even companies like Volkswagen, Mercedes-Benz, and PSA, which initially adopted the oil-to-electricity approach for manufacturing new energy vehicles, are now delving into the development of their own dedicated electric vehicle platforms.

The concept of electric vehicle modular platforms is primarily championed by traditional automakers adhering to the product structure of conventional fuel vehicle models when transitioning to electric vehicle production. However, their focus leans towards creating a diverse range of electric vehicle product lines to cater to the varied demands of consumers across different market segments. Consequently, modular platforms are extending their reach into the realm of electric vehicles. On the other hand, emerging automakers exemplified by Tesla prioritize short product lines and emphasize the design advantages of individual models along with comprehensive software upgrades for the entire vehicle. For these companies, modular platforms hold little significance in their approach (Research and Markets, 2021).

In 2022, the modular segment achieved a valuation of USD 5.24 billion and is poised for a Compound Annual Growth Rate (CAGR) of 22.80% throughout the projected period, securing the second-largest position in the market. The modular Electric Vehicle (EV) chassis represents a purpose-built architecture designed to enhance long-term efficiency in EV manufacturing. Its ease of assembly and cost-effectiveness distinguish it from other chassis types. The flexibility of modular EV chassis allows manufacturers to easily adjust the production of specific powertrains, enabling the creation of diverse combinations of motors, suspension, steering, brakes, and drives to meet Electric Vehicle performance requirements. Consequently, modular chassis is suitable for a range of vehicles, from small electric cars to large minivans. The increasing demand for electric vehicles, driven by concerns about clean energy and environmental degradation, is expected to significantly boost the demand for modular chassis in the forecast period. Several nations have established targets for reducing vehicle emissions by 2050. To promote the growth of the electric vehicle (EV) market and the corresponding charging infrastructure, they have initiated measures like providing incentives, such as purchase tax reductions, to consumers adopting EVs. For instance, the United States offers incentives of up to USD 7,500 for the acquisition of new electric vehicles. Manufacturers of electric vehicles are prioritizing the development of automotive chassis with advanced design and weight reduction features. This aspect is anticipated to enhance the capacity of EV batteries, potentially leading to increased demand for electric vehicles throughout the forecast period (Market Research Report, 2023).

3.1.2. Market Analysis

Market analysis involves a thorough evaluation of your business's intended market and the competitive environment within a particular industry. This assessment enables you to anticipate the level of success your brand and its products may achieve upon introduction to consumers in the market. The analysis encompasses quantitative data, such as actual size of the market, consumer price preferences, revenue forecasts, as well as qualitative data, including consumer values, preferences, and purchasing motivations.

Performing a market analysis offers various advantages, including the ability to identify trends and opportunities within your industry, distinguish your business from competitors, minimize the risks and costs associated with launching a new business or making changes to an existing one, customize products and services to meet the needs of your target customers, analyze both successes and failures, optimize your marketing strategies, and explore new market segments. Additionally, it enables you to monitor your business's performance and make strategic pivots as needed.

This stage encompasses gathering information related to the requests and requirements of the customer. More precisely, acquiring data is essential to comprehending the necessary product specifications. In this regard, performing Quality Function Deployment (QFD) as a tool to clarify the task proves beneficial (Frizziero et al., 2019). This approach is adaptable for planning various phases and can be applied at different levels. The method initiates with accurately identifying product needs, which is an achievable goal facilitated by interviewing a limited number of individuals.

3.1.2.1. Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a systematic approach for planning products and services. It starts by capturing customer needs, which serves as the foundation for establishing requirements. Subsequently, the organization identifies the essential customer needs, referred to as the "What's." A dedicated team then pinpoints the "How's," focusing on process areas that address each of the identified requirements. However, within Six Sigma, a widely utilized tool in quality function deployment is The House of Quality (Figure 3.4). This tool, in the form of a matrix, efficiently delineates the requirements (both the "What's" and the "How's"). It establishes a connection between these elements, facilitating the breakdown and prioritization of aspects in the process that will have the most significant impact on meeting the customer's requirements.

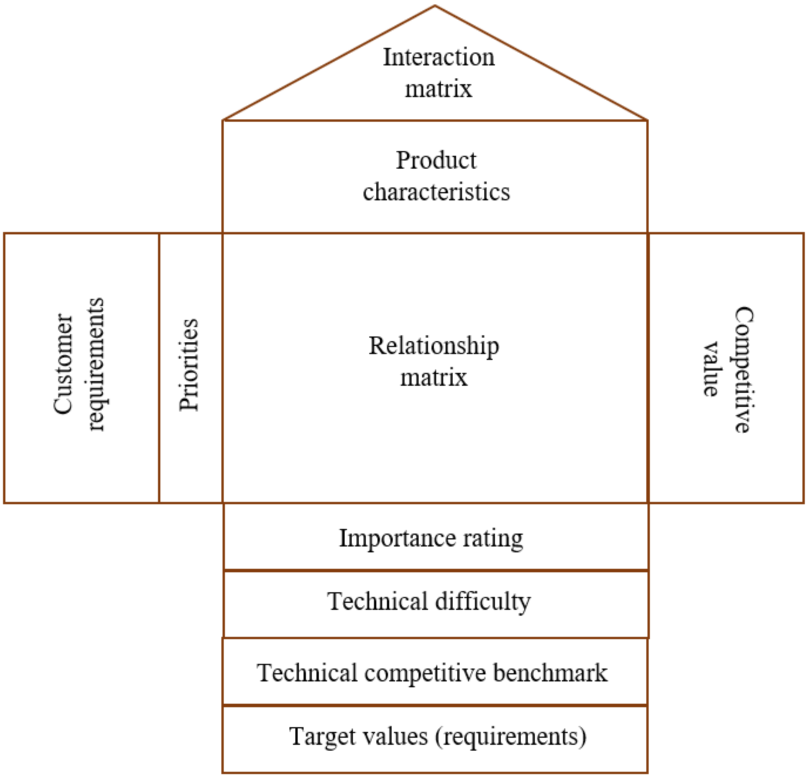

Figure 3.4: House of quality template

The House of Quality serves as a tool for planning requirements and promoting graphic, integrated thinking. Additionally, it functions as a means to capture and retain the engineering thought process, facilitating communication of this process to new members of the Quality Function Deployment (QFD) team. Crucially, it plays a significant role in informing management about any inconsistencies that may arise between customer requirements, risks, and needs.

3.1.2.1.1. Six Questions

In this study in this phase **Six Questions** will be used to define customer requirements:

Six Questions (Figure 3.5) stands out as one of the broadest yet most impactful analytical techniques, alternatively recognized as Five “W” s and one H, Six “W” s, or Six Servants.

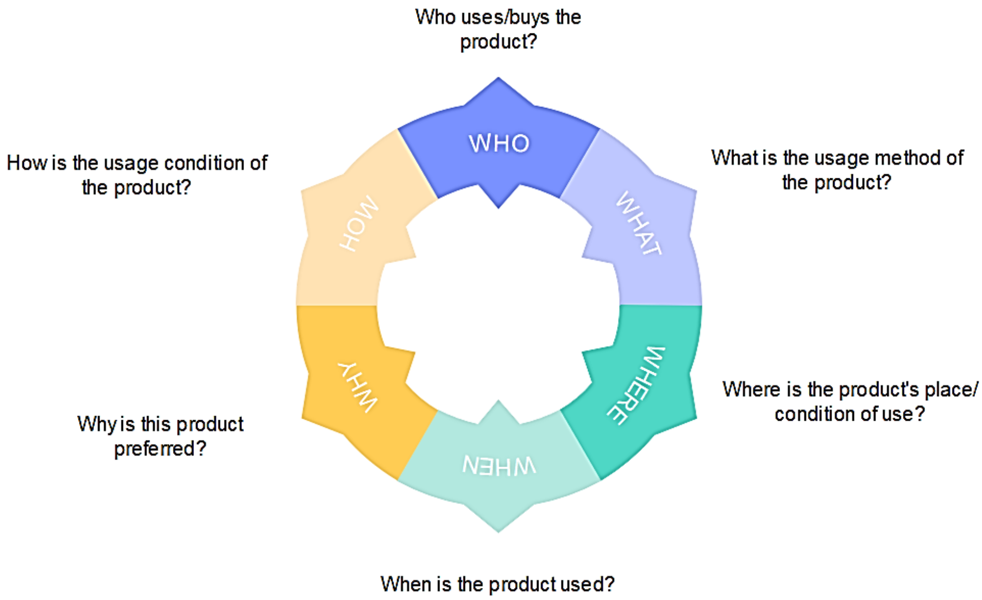

Figure 3.5: QFD- Six Questions

This diagram has been prepared for the sports car for better understanding the customer needs in the aspect of modular platform design. The questions belong to each section refer to the customer requirements for a sports car.

Table 3.1: Responses of six questions for the sports car

WHO?	WHAT?	WHERE?	WHEN?	WHY?	HOW?
Young adults who are economically well off or rich	*short distance journey, high-speed*	*Urban street, day on track, racetrack (optional)*	*Frequently daily usage, variable times*	*High performance, elegant and stylistic appearance*	*Full system performance, Short distance-high speed*

Table 3.1 illustrates the outcomes of the six questions applied in this study, addressing customer requirements related to a sports car. Each answer represents details about the customer purposes for the car. This approach enhances our comprehension of how the product is utilized. The subsequent phase involves constructing matrices to rank customer requirements. To formulate a matrix, it is imperative to specify each customer requirement extracted from the six questions, with each response containing a parameter for customer needs.

Aesthetic design: This requirement parameter can be the response for the "WHO" which addresses the customers who is economically well off and rich. Because potential customers in this definition are closely related to the initial visual appeal of the vehicle. The aesthetic aspects of vehicle technology should be a deliberate consideration in the design and specification process. The customer's perception of the system is significantly influenced by the styling, color, and aesthetic features of the vehicle. As the most tangible and noticeable components of the system, the vehicle's appearance, branding, interior design, and maintenance play a crucial role in shaping the customer's experience and the overall visual identity of the system.

The overall shape and external appearance of a sports car are influenced by aesthetic considerations. Sleek, aerodynamic designs are often favored for sports cars not only for performance reasons but also for their visual appeal. The chassis design must accommodate these external styling choices. Aesthetic considerations affect how body panels are integrated into the chassis. The design should provide a seamless and visually pleasing exterior, with smooth lines and curves that contribute to the car's overall aesthetic appeal. Aesthetic preferences may influence the choice of materials for the chassis. For example, manufacturers might use materials like carbon fiber, not only for their lightweight and strong properties but also for the premium and high-tech appearance they add to the vehicle. On the other hand, some sports cars showcase specific chassis components as part of their aesthetic appeal such as **Lamborghini**. For example, a manufacturer might design the chassis in a way that certain components, such as the suspension system or engine bay, are visible through the bodywork for a more aggressive or high-performance look. Furthermore, the aesthetics of the chassis extend to the interior of the vehicle. The layout and design of the chassis influence the interior space, including seating arrangements, dashboard design, and the overall driver and passenger experience.

Performance: This requirement parameter can be the response for the "WHAT" which helps to provide high speed to the car. Understanding the impact of chassis design on a sports car performance is crucial when it comes to comprehending how modular design influences its performance. There are several ways in which the chassis affects the performance of a car. For example, structural integrity is one of the parameters that needs to be focused on. The chassis provides the structural framework for the entire vehicle. A rigid and well-designed chassis contributes to the overall structural integrity of the car, enhancing safety and stability. Also, handling performance and suspension are another crucial parameter need to be examined. A well-engineered chassis can contribute to better handling, responsiveness, and stability, especially during cornering and maneuvering. Moreover, weight distribution which gives sensitiveness of a sports car is another issue. The design of the chassis affects the distribution of weight throughout the car. Proper weight distribution is essential for balanced handling and optimal performance. It can impact traction, stability, and the overall driving experience. Rigidity, which is one of the most critical aspects of mechanical design, is another factor that affects performance. It is crucial for maintaining the structural integrity of the vehicle and preventing flexing or twisting. A more rigid chassis can enhance stability of the car and responsiveness, particularly in high-performance driving conditions. Also, well-designed chassis can help dampen vibrations and reduce noise from the road, contributing to a smoother and more comfortable ride.

In vehicle designs where speed is crucial, collision performance will certainly gain prominence. In the unfortunate event of a collision, the chassis plays a critical role in absorbing and dissipating impact forces. A well-engineered chassis can enhance crashworthiness and protect occupants. A carefully engineered chassis can contribute to a more enjoyable and high-performing driving experience.

Handling: This factor can compromise for the responses of "WHERE", "WHY" and "HOW" which plays a crucial role in controlling of the sports car. Sports cars are designed to deliver high-performance driving experiences. Superior handling allows these vehicles to navigate corners, curves, and various road conditions with precision and agility. Handling is particularly important during cornering. Sports cars are expected to handle corners at higher speeds with confidence and stability. Effective handling allows the car to maintain traction, minimize body roll, and provide a sense of control.

A rigid chassis is crucial for precise handling. It helps prevent excessive flexing or twisting during dynamic maneuvers, ensuring that the car's suspension and steering systems can work optimally. Manufacturers often use lightweight yet strong materials like aluminum or carbon fiber to enhance structural rigidity without adding unnecessary weight. Also, the distribution of weight across the chassis is a critical factor in handling. Sports cars typically aim for a balanced weight distribution between the front and rear axles to improve stability and responsiveness during cornering. Well-distributed weight helps prevent understeer (front-wheel losing traction) or oversteer (rear-wheel losing traction) tendencies**. The mounting points** for the suspension components are strategically placed on the chassis to optimize handling. Proper placement allows for precise control over the car's movement, responsiveness to steering inputs, and effective weight transfer during acceleration, braking, and cornering. On the other hand, chassis design is closely linked to a car's aerodynamics. Sports cars often feature aerodynamic elements integrated into the chassis to enhance stability at high speeds and provide downforce during cornering. These features contribute to improved handling by keeping the car planted to the road.

The chassis design impacts how the car responds to changes in road surfaces and driving conditions. A well-engineered chassis allows for effective communication between the tires and the driver, providing feedback on the road's characteristics and the car's behaviour. Torsional stiffness refers to a chassis' resistance to twisting forces. Higher torsional stiffness enhances overall stability and responsiveness, particularly during aggressive driving manoeuvres.

Superior handling is not only about performance but also about safety. A sports car with good handling characteristics is more likely to respond predictably to sudden maneuvers or emergency situations. However, Sports car enthusiasts often value the connection between the driver and the car. Responsive and precise handling contributes to a more engaging driving experience.

Engine type: This requirement parameter becomes particularly significant when considering the "WHEN." It is crucial to ensure consistent performance and comfort in a sports car, even when used under varying times and conditions. The engine type directly influences the performance of a sports car. High-performance engines, whether they are turbocharged, supercharged, or naturally aspirated, contribute to faster acceleration, higher top speeds, and better overall power delivery.

The type of engine and its placement affect the weight distribution of the sports car and accordingly distribution of weight across the chassis. Different engine types, such as front-engine, mid-engine, or rear-engine configurations, impact how the weight is distributed between the front and rear axles. This, in turn, affects the car's balance and handling characteristics. The location of the engine within the chassis determines the car's center of gravity. A lower center of gravity is generally favorable for improved stability and handling. The choice of engine type and its placement influences whether the center of gravity is lower or higher, impacting the car's overall dynamics. The characteristics of the engine, including power delivery, torque curve, and responsiveness, play a crucial role in shaping the car's handling dynamics. Chassis design needs to complement the specific traits of the chosen engine type to achieve the desired balance between agility, stability, and responsiveness.

The structural integrity and rigidity of the chassis are influenced by the chosen engine type. Manufacturers design chassis structures that provide adequate support and stiffness to handle the loads and forces generated by different engine configurations. Also, the suspension system is closely tied to both the engine type and chassis design. Mounting points for suspension components must be strategically placed to accommodate the engine layout and optimize handling characteristics. Suspension tuning often takes into account the weight distribution resulting from the engine placement. Furthermore, the cooling needs of various engine types vary, and the chassis design must accommodate the placement of radiators and other cooling components. This affects the overall layout of the chassis, especially in terms of air intake and heat dissipation.

Emission: This factor is important in general. Sports cars, like all vehicles, must adhere to emission standards set by regulatory bodies in different countries. These standards are designed to limit the amount of pollutants released into the atmosphere, promoting environmental sustainability and public health. Besides, sports cars are often associated with high-performance engines that can generate significant power and speed. Achieving high performance while meeting stringent emission standards can be challenging. Manufacturers use various technologies, such as advanced fuel injection systems, catalytic converters, and engine management systems, to optimize the balance between performance and emissions. While sports cars are primarily designed for performance, manufacturers are increasingly focused on improving fuel efficiency to address environmental concerns and meet regulatory requirements. Technologies like direct fuel injection, turbocharging, and hybridization are employed to enhance fuel efficiency and reduce overall emissions. On the other hand, with growing awareness of environmental issues, consumer preferences are also influencing the design and marketing of sports cars. There is increasing demand for eco-friendly technologies and a desire for sports cars that offer a balance between performance and environmental responsibility.

While chassis design does not directly determine the emissions produced by the engine, it plays a critical role in optimizing the overall efficiency and performance of the sports car, which, in turn, can influence emissions. Manufacturers aim to strike a balance between performance, aerodynamics, structural integrity, and emissions compliance when designing the chassis of sports cars. Advances in **materials and design practices** contribute to creating vehicles that meet both performance and environmental objectives. Chassis design impacts the overall weight of the sports car. Lightweight materials and structures are often used to enhance performance and handling. A lighter chassis can contribute to improved fuel efficiency and reduced emissions by requiring less power to move the vehicle. Chassis design must accommodate various emission control systems, such as catalytic converters and exhaust aftertreatment components. The placement and integration of these systems within the chassis are critical for meeting emission standards while ensuring optimal performance and weight distribution. Emission control systems, especially those associated with reducing pollutants in exhaust gases, generate heat. Chassis design must include provisions for effective cooling systems to manage the temperatures of components like catalytic converters. Efficient cooling contributes to better emission control system performance. A well-designed chassis contributes to the overall efficiency of the vehicle. An efficiently structured chassis can enhance fuel efficiency by minimizing energy losses through structural flexing or unnecessary weight. This **indirectly** contributes to lower emissions during operation. Chassis materials impact both vehicle weight and emissions. Lightweight materials, such as aluminum or carbon fiber, contribute to weight reduction, potentially leading to improved fuel efficiency and reduced emissions. However, material selection must also consider the environmental impact of production and recycling. As sports cars increasingly adopt hybrid or electric powertrains to reduce emissions, the chassis design must accommodate the unique characteristics and requirements of these alternative propulsion systems. This may involve considerations for battery placement, electric motor integration, and overall structural adaptations to support different powertrain configurations.

Dimension: This factor addresses all six questions. The dimensions of a sports car can significantly impact its performance, handling, and overall driving experience. The size and materials used in construction directly influence the weight of the car. Lighter sports cars often have better acceleration, braking, and handling capabilities. Manufacturers strive to balance the weight distribution for optimal performance. While engine power plays a significant role in a car's top speed, aerodynamics and weight also contribute. Smaller, more aerodynamic sports cars may have an advantage in achieving higher top speeds compared to larger and bulkier counterparts. Compact dimensions and a lower center of gravity contribute to better handling and agility. Sports cars are engineered to navigate corners with precision, and **a well-balanced chassis,** along with the right dimensions, enhances their ability to take turns at high speeds.

In addition, the distance between the front and rear wheels, known as the wheelbase, affects stability and ride quality. A longer wheelbase can contribute to a smoother ride, while a shorter wheelbase may enhance maneuverability. Sports cars typically prioritize driver and passenger experience over cargo space. The interior dimensions affect comfort and the overall feel inside the car. Some sports cars have a more cramped cabin, while others aim to strike a balance between performance and comfort. Ultimately, the ideal dimensions depend on the specific goals and design philosophy of the sports car in question. The dimensions of a car chassis, which includes the frame and structural components supporting the vehicle, can have various effects on the vehicle's performance, handling, and overall characteristics. The length and width of the chassis contribute to the stability of the vehicle. A longer wheelbase can enhance stability at high speeds, while a wider chassis may contribute to better lateral stability during turns. Also, the dimensions of the chassis play a crucial role in the car's handling characteristics. A well-designed chassis can provide the right balance between agility and stability, allowing the vehicle to respond effectively to steering inputs. The length of the chassis can affect the smoothness of the ride. A longer chassis may contribute to a more comfortable ride by providing better isolation from road imperfections. However, the suspension system also plays a significant role in ride comfort. The dimensions of the chassis influence how weight is distributed across the vehicle. Proper weight distribution is essential for optimal handling and performance. Engineers aim to design chassis with balanced weight distribution to enhance traction and control. Lastly, the shape and dimensions of the chassis influence the aerodynamics of the vehicle. A well-designed chassis can contribute to reduced drag, improving fuel efficiency and overall performance.

Fuel consumption: This factor is involved in as a response of the “WHY” and “HOW” questions. Because fuel consumption in high-performance and high-speed conditions should be taken into account. Sports cars often have powerful engines designed to deliver high performance. While these engines provide exhilarating acceleration and speed, they tend to consume more fuel, especially during aggressive driving. Lightweight construction is a common feature in sports cars to improve agility and handling. One of the primary strategies to improve fuel efficiency is to reduce the overall weight of the vehicle. Lightweight materials, such as high-strength alloys, carbon fiber, and aluminum, are often used in chassis design to decrease the vehicle's mass. However, the trade-off is that some high-performance materials used in sports cars can be less fuel-efficient to manufacture. Nevertheless, a lighter chassis requires less energy to accelerate and decelerate, contributing to improved fuel economy. In the case of hybrid and electric vehicles, the chassis design may need to accommodate additional components like batteries and electric motors. Optimizing the chassis to efficiently house these components without compromising structural integrity is crucial for achieving fuel efficiency in these types of vehicles.

Safety: This factor is related with "WHERE", "WHY" and "HOW". The safety of a sports car can be influenced by various factors, including its design, construction, and the presence of safety features. Alterations to the car's structure, such as extensive body modifications or chassis changes, can affect its crashworthiness. Structural integrity is crucial for the absorption and distribution of impact forces in the event of a collision. Moreover, upgrading the brakes and suspension for better performance is common in sports car customization. However, it's crucial to maintain a balance between improved handling and retaining the vehicle's ability to react predictably in emergency situations. Performance enhancements like engine tuning, turbocharging, or supercharging can significantly increase a sports car's power. While these modifications can enhance performance, they may also affect the overall balance and handling. Additionally, high-performance modifications may require adjustments to braking systems for adequate stopping power. Upgrading the exhaust system for a sportier sound may not directly impact safety, but modifications that affect emissions control systems can lead to legal and environmental concerns. It's important to ensure that any changes comply with local regulations. In the aspect of chassis design, along with other safety features like crumple zones, airbags, and seatbelt systems, contributes to the overall crash protection of a sports car. Modern sports cars are engineered to deform in specific ways during a collision, absorbing energy to protect the occupants. Sports cars typically have a more rigid and stiff chassis, which can contribute to better handling and responsiveness. However, an excessively stiff chassis may transmit more impact forces to the occupants in the event of a crash. Engineers aim to strike a balance between rigidity for performance and flexibility for crash safety. Some sports cars feature reinforced chassis components or additional roll bars to provide protection in the event of a roll-over. This is particularly important for convertible sports cars, where the roof structure may not provide the same level of protection as in hardtop models. On the other hand, the choice of materials in the chassis construction affects both weight and strength. High-strength materials, such as advanced alloys or carbon fiber, are often used to achieve a lightweight yet robust chassis. These materials can contribute to safety by improving crash performance without compromising structural integrity. Sports cars, like all vehicles, undergo rigorous crash testing to ensure they meet safety standards. Chassis design plays a significant role in achieving and maintaining safety certifications. Compliance with safety regulations is crucial for manufacturers to sell their vehicles in various markets.

Lightweightness: This requirement parameter can compensate for “WHY” and “HOW”. The concept of lightweightness is crucial in the design and performance of sports cars. Lightweight cars generally have better acceleration, handling, and braking performance. With less mass to move, the engine doesn't have to work as hard, and the car can respond more quickly to driver inputs. The power-to-weight ratio, which is the ratio of the vehicle's power output to its weight, is a critical factor in a car's performance. A lower weight combined with sufficient power results in a higher power-to-weight ratio, leading to better acceleration and speed. Lighter cars often have better fuel efficiency because they require less energy to move. This is particularly important for sports cars, where fuel efficiency may not be the primary concern but is still a consideration. Achieving the right balance between the front and rear weight distribution is crucial for optimal handling. Lightweight materials and design considerations help engineers fine-tune the balance, contributing to better stability and control. To achieve lightweightness, manufacturers often use materials like carbon fiber, aluminum, and other advanced composites in the construction of sports cars. Additionally, engineering techniques such as weight distribution optimization, aerodynamics, and advanced chassis design play key roles in creating a lightweight yet structurally sound sports car. Lightweight chassis components, such as suspension parts and wheels, contribute to reduced unsprung mass. This can lead to improved ride comfort, better traction, and enhanced handling characteristics. To achieve lightweightness, manufacturers often use materials like carbon fiber, aluminum, and other advanced composites in the construction of sports cars. While lightweight design is essential, maintaining structural integrity and safety is paramount. Especially, chassis engineers must carefully balance weight reduction with the need for a robust and rigid structure to ensure the safety of occupants and the durability of the vehicle.

Versatility: This factor can be the response for “WHAT”, “WHERE”, “WHEN”, “WHY” and “HOW”. Versatility especially addresses for the sports car usage in different conditions and in variable times. Versatility in the context of sports cars refers to the car's ability to perform well across a range of driving conditions and scenarios. While sports cars are primarily designed for high-performance driving, a certain level of versatility can enhance their appeal and practicality. A versatile sports car should offer a reasonable level of comfort for daily driving. While sports cars are often associated with smooth roads and tight corners, a versatile sports car should be able to handle a variety of road conditions. This includes the ability to navigate through uneven surfaces, handle wet or slippery roads, and provide a level of stability in diverse driving environments. Although sports cars are not known for their cargo capacity, some level of practicality can be achieved through clever design and utilization of available space. A versatile sports car may have features like a usable trunk, foldable rear seats, or additional storage compartments to accommodate daily needs or weekend getaways. Also, a versatile sports car should have user-friendly infotainment systems, navigation options, and connectivity features that enhance the overall driving experience. While high-performance sports cars may not be expected to have the fuel efficiency of economy cars, a certain level of efficiency can contribute to versatility.

In the context of sports car chassis design, versatility refers to the ability of the chassis to adapt and perform well across a range of driving conditions and scenarios. While sports cars are primarily designed for high-performance driving, adding a level of versatility can enhance their appeal and usability. Versatile sports car chassis designs often incorporate adaptive suspension systems. These systems can dynamically adjust the suspension settings to provide a comfortable ride during daily commuting and tighten up for improved handling and performance during aggressive driving or track use. Many modern vehicles, including sports cars, come with adjustable driving modes. These modes can modify various parameters, such as throttle response, steering feel, and suspension settings. A versatile chassis allows for these adjustments, enabling the driver to tailor the car's behaviour to different driving scenarios, from comfortable cruising to aggressive performance driving. A versatile sports car chassis maintains a balanced weight distribution, contributing to stable handling and responsiveness across various driving scenarios. Balanced weight distribution is crucial for optimal performance during acceleration, braking, and cornering. Versatile sports car chassis designs maintain structural rigidity while incorporating lightweight materials like aluminium, carbon fibre, or high-strength alloys. This balance enhances performance, handling, and fuel efficiency without compromising safety or durability. Lastly, while primarily associated with comfort and safety, certain advanced driver assistance systems, such as adaptive cruise control, lane-keeping assist, and automatic emergency braking, can contribute to the versatility of a sports car, making it more suitable for varied driving conditions.

3.1.2.1.2. Dependence / Independence Matrix

In the following section, it will be shown dependence / independence matrix using customer requirements concluded from six questions. These are as defined previously**; a)** ***aesthetic design, b) performance, c) handling, d) engine type, e) emission, f) dimension, g) fuel consumption, h) safety, i) lightweightness and j) versatility.***

The characteristics were employed to populate the Relationship Matrices, aiming to determine their relative importance and independence. In the Dependence/Independence Relationship Matrix, it is necessary to input a numerical value into each cell, reflecting the extent to which the requirements in the rows exhibit dependence or independence in comparison to those in the columns.

0 - when the requirement in the row is completely unrelated or not dependent on the one in the column.
1 - when the requirement in the row is moderately independent or not heavily reliant on the one in the column.
3 - when the requirement in the row is highly dependent on the one in the column.
9 - when the requirement in the row is entirely dependent or fully reliant on the one in the column. (Frizziero et al., 2020)

In this instance, by totaling the values in each column, a categorization of the most autonomous characteristics was unveiled (Figure 3.6).

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	AESTHETIC DESIGN	PERFORMANCE	HANDLING	ENGINE TYPE	EMISSION	DIMENSION	FUEL CONSUMPTION	SAFETY	LIGHTWEIGHTNESS	VERSATILITY	TOTAL DEP.
AESTHETIC DESIGN		3	1	1	1	3	1	0	1	1	12
PERFORMANCE	1		9	9	3	3	9	9	9	3	55
HANDLING	1	9		9	0	3	0	3	9	3	37
ENGINE TYPE	1	9	3		9	3	9	9	9	9	61
EMISSION	1	3	0	9		1	9	1	3	9	36
DIMENSION	0	3	3	9	1		3	3	9	3	34
FUEL CONSUMPTION	0	9	0	9	9	3		1	3	9	43
SAFETY	0	9	3	3	9	1	3		1	3	32
LIGHTWEIGHTNESS	1	9	9	9	3	3	9	3		9	55
VERSATILITY	1	9	3	9	3	3	9	3	9		49
TOTAL INDEP.	6	63	31	67	38	23	52	32	53	49	

Figure 3.6: Dependence / Independence matrix

According to the evaluation of the customer requirements by Dependence / Independence Matrix, the most dependent variables are:

- ✓ *Performance*
- ✓ *Engine Type*
- ✓ *Lightweightness*
- ✓ *Versatility*
- ✓ *Fuel Consumption*

The requirement parameters taken from the six questions were also used for building Relative Importance Matrix. In the Relationship Matrix of Relative Importance, each cell needs to be assigned a numerical value, indicating the degree to which the requirements in the rows are either more or less crucial than those in the columns (Figure 3.7).

0 – when the importance of the requirement in the row less than that of the column.
1 - when the importance of the requirement in the row is equal to that of the column.
2 - when the importance of the requirement in the row is more than that of the column.

After calculating the sum of all the values in each column, there was obtained a ranking of all the features. These ones were considered as the most important features that should be well designed.

	AESTHETIC DESIGN	PERFORMANCE	HANDLING	ENGINE TYPE	EMISSION	DIMENSION	FUEL CONSUMPTION	SAFETY	LIGHTWEIGHTNESS	VERSATILITY	TOTAL
AESTHETIC DESIGN		1	2	1	2	2	1	0	2	1	12
PERFORMANCE	1		2	1	2	2	2	1	2	2	15
HANDLING	0	0		1	1	2	1	0	1	1	7
ENGINE TYPE	1	1	1		1	2	1	0	1	1	9
EMISSION	0	0	1	1		2	1	1	1	0	7
DIMENSION	0	0	0	0	0		0	0	0	0	0
FUEL CONSUMPTION	1	0	1	1	1	2		1	2	1	10
SAFETY	2	1	2	2	1	2	1		2	1	14
LIGHTWEIGHTNESS	0	0	1	1	1	2	0	0		1	6
VERSATILITY	1	0	1	1	2	2	1	1	1		10

Figure 3.7: Relative importance matrix

According to the relative importance matrix, the ones with the highest ranks are;

- ✓ *Aesthetic design,*
- ✓ *Performance*
- ✓ *Safety*

All market analysis applications managed us to see the best requirements as a result. The best requirements are equal to the sum of the *most important requirements* and the *most independent requirements.*

- ✓ *Performance*
- ✓ *Engine Type*
- ✓ *Lightweightness*
- ✓ *Versatility*
- ✓ *Fuel Consumption*
- ✓ *Aesthetic Design*
- ✓ *Safety*

3.1.3. Competitors Analysis

Conducting a competitor analysis, also referred to as competitive analysis or competition analysis, involves the systematic examination of similar brands within your industry. This examination aims to provide insights into various aspects such as their products, branding strategies, sales techniques, and marketing approaches. Awareness of your competitors is particularly crucial in business analysis, serving as valuable information for business owners, marketers, start-up founders, and product developers alike. A competitor analysis provides numerous advantages, such as grasping industry norms to meet and surpass them, identifying undiscovered niche markets, setting apart products and services. In addition, addressing customer needs and problem-solving more effectively than rivals, establishing a distinctive brand identity, standing out in your marketing efforts, and evaluating and quantifying your growth.

Competitor analysis is a stage in the design process where designers examine products developed by competitors (utilizing ***benchmarking***) that are potentially available in the market. This phase may also involve a quantitative assessment of the technical features of rival products to establish the maximum boundaries for innovation in the new product (including an Innovation Column and Top-Flop Analysis). Understanding what your competitors are producing is essential for designing a product that is distinct and more innovative.

3.1.3.1. Benchmarking

Benchmarking is the systematic evaluation of products, services, and procedures in comparison to those employed by organizations acknowledged for their excellence in specific operational facets. This method offers valuable insights, allowing you to gauge your organization's performance relative to similar entities, even those in disparate industries or with distinct customer bases. Furthermore, benchmarking serves as a tool for pinpointing areas, systems, or processes that warrant enhancement, whether through gradual (continuous) refinements or substantial (business process re-engineering) transformations.

To create an ideal modular platform, a benchmarking among sports car models by different brands will be created. This process is important for identifying the differences and similarities among existing sports vehicle features, especially in terms of providing suitable parameters and dimensions for the modular platform to be designed.

3.1.3.1.1. Brand and Model Benchmarking

Lamborghini Revuelto: Lamborghini introduced Revuelto which is the first HPEV (High Performance Electrified Vehicle) hybrid super sports car. With the Revuelto, Lamborghini has set a new standard in performance, on-board technology, and driving enjoyment. The ultimate excitement offered by the Revuelto is achieved through a powertrain that produces a total of 1015 cv (constant velocity), combining the force of a state-of-the-art 12-cylinder internal combustion engine with three high-density electric motors and an innovative transversal dual clutch e-gearbox. The potential of hybridization is harnessed to elevate performance and driving sensations to an unprecedented level. Two electric motors are situated on the front axle, enabling torque vectoring during both power delivery and regenerative braking. A third motor is integrated into the eight-speed dual-clutch transmission, now positioned behind the combustion engine. The 3.8-kWh battery pack, located between the seats, has a peak current flow of 187 horsepower, distributable among the three 147-horsepower electric motors as needed. Unlike the Ferrari SF90 Stradale, the Revuelto has the capability to send power to both ends while operating as an electric vehicle. Charging the battery can be done through a port inside the front luggage compartment, but its inconvenient placement suggests it is intended for occasional use. A more exhilarating, albeit less environmentally friendly option, is to recharge it using the V-12, transforming the rear electric motor into a generator. This method takes just six minutes to fully replenish the battery pack.

The Revuelto stands out with its unique design, as the Italians have opted for a configuration with only two seats, dedicating the space where backseats typically exist to house 12 cylinders. This car goes beyond the ordinary, featuring a cockpit reminiscent of a space race rather than a traditional automobile. The steering wheel boasts four rotors that govern different drive modes, and additional buttons not only activate turn signals but also initiate launch control. Lamborghini asserts that the Revuelto offers more headroom and legroom compared to the Aventador, a task that isn't challenging. The area behind the seats can accommodate a single golf bag, and there's additional frunk space capable of easily fitting two carry-on luggage bags.

Ferrari SF90 Stradale: The SF90 STRADALE stands as the inaugural Ferrari to showcase the Plug-in Hybrid Electric Vehicle (PHEV) architecture. This design incorporates the internal combustion engine with three electric motors, with two forming a subsystem named RAC-E (Cornering Angle Regulator, Electric) on the front axle, while the third, referred to as MGU-K (Motor Generator Unit, Kinetic), is positioned at the rear. The MGU-K system is derived from and shares its primary functions with the Formula 1 system. Opting for the Plug-in Hybrid Electric Vehicle (PHEV) architecture enables the SF90 STRADALE to achieve performance levels previously unprecedented in its class. It boasts a groundbreaking 1.57 kg/cv weight-power ratio, setting a new standard, along with a maximum power output of 1,000 cv. Out of this, 780 cv is generated by a 90° V8 turbo engine, marking the highest power output ever seen in an 8-cylinder Ferrari. The remaining 220 cv is provided by three electric motors: one at the rear connected to the Internal Combustion Engine (ICE) and two on the front axle.

The SF90 STRADALE marks Ferrari's debut in equipping a sports car with 4WD, a crucial move to fully harness the incredible power of its hybrid powertrain. This innovation not only allows the car to set a new standard for standing starts with impressive acceleration figures—0-100 km/h in 2.5 seconds and 0-200 km/h in just 6.7 seconds—but also employs a sophisticated control logic to distribute power between the electric front axle and the ICE-electric hybrid rear axle, adapting to driving conditions. Moreover, the hybrid architecture facilitated an expansion of the car's dynamic controls, integrated into the new e-SSC control system. The e-SSC, monitoring dynamic conditions in real-time and ensuring stability, now features two electric motors capable of independently controlling torque to the outer and inner wheels during a corner (Torque Vectoring). This enhancement significantly improves traction when exiting a corner, simplifying, and enhancing the safety of driving at the vehicle's limits with confidence.

An additional 30 kg reduction in weight is achieved when compared to the already lightweight standard version, owing to the utilization of high-performance materials like carbon-fiber for door panels and underbody, as well as titanium for springs and the entire exhaust line. The initial crucial step in devising an effective car layout, particularly in this context, involves the implementation of intelligent cooling flow management. This ensures the efficient and uncompromised release of 1,000 cv under diverse driving conditions, without negatively impacting aerodynamic drag and downforce coefficients. The cooling requirements extend to the internal combustion engine, gearbox, turbocharged air, battery pack, electric motors, inverters, charging systems, and, of course, the brakes (refer to Figure 8). The design of the engine bay received meticulous attention, accommodating both the conventional internal combustion engine systems, which generate temperatures nearing 900°C, and the highly temperature-sensitive electronic components.

The SF90's interior is sedate, by hypercar standards, with the yellow prancing-horse logo adding a splash of color at the center of the steering wheel. This two-seat coupe is home to a sculpted dashboard with fluid lines that mimic the flowing design of the car's exterior. With high-performance exotics, cargo space is typically in short supply. This is certainly the case with the SF90, which provides roughly 85 litre of room for your stuff. The SF90 XX models feature a more stripped-down interior. To save weight, Ferrari removed unnecessary materials such as carpeted floor mats. The SF90 XX's door panels and centre console have been redesigned in carbon fibre, too. But that model's most obvious interior difference is a set of monocoque bucket seats that replaces the standard model's chairs.

McLaren Artura: The Artura was introduced in 2023 as McLaren's entry-level supercar, representing a notable shift in the British automaker's approach. Featuring a mid-mounted twin-turbo 3.0-liter V-6 engine, it marks McLaren's debut in the realm of six-cylinder powertrains. Paired with an electric motor and a small lithium-ion battery, the hybrid system generates an impressive 671 horsepower and 719.4 Newton-meters (Nm) of torque. This propels the sleek two-door to accelerate from 0 to 100 kmh in just 2.6 seconds, reaching a top speed of 330 kmh. In addition to the conventional gasoline engine, an electric motor is integrated into the eight-speed dual-clutch automatic transmission housing. This electric motor is powered by a 7.4-kWh lithium-ion battery pack located beneath the rear of the cabin. McLaren's initial foray into plug-in hybrids also allows the Artura to travel up to 17.7 km solely on electric power, providing a relatively gentle city-driving experience.

Positioned below the new 750S in McLaren's lineup, the Artura is priced approximately $100,000 less but closely rivals its higher-tier counterpart in terms of performance. Additionally, it offers a more comfortable and livable cabin along with a more understated exterior design. Measuring 4544.98 mm in length, the McLaren Artura closely mirrors the dimensions of the 720S. When the doors are open, its width and height are 191.77 mm and 1193.8 mm, respectively.

McLaren, renowned for its lightweight supercars, took significant measures to minimize the Artura's mass. The use of a lightweight carbon fiber architecture plays a pivotal role, and every component, including the forged wheels and carbon ceramic brakes, contributes to shedding valuable kilograms. The McLaren Artura's DIN curb weight, inclusive of fluids and 90% fuel, is approximately 1499.67 kg, making it only about 74.39 kg heavier than the 720S. The car's lightest dry weight is approximately 1395.05 kg.

The Artura prominently reflects McLaren's prioritization of functionality over style. Nevertheless, the interior is enhanced with more sophisticated materials like leather and microsuede. In contrast to other models, there is less visible carbon fiber, aligning with McLaren's reputation for minimalist cabin designs that minimize physical switchgear. The steering wheel remains button-free, consistent with the company's aesthetic. The Artura comes equipped with power-adjustable seats, and its design emphasizes excellent outward visibility, aiding drivers in precise placement on the road or track. Although not as spacious as the McLaren GT, the Artura offers 6 cubic feet of front trunk space for luggage.

Mercedes Benz AMG One: The realization of transferring Formula 1 technology directly to road vehicles has materialized with the introduction of the premium-class E PERFORMANCE plug-in hybrid. This advanced system integrates a 1.6-liter V6 turbo petrol engine and four electric motors dedicated to the turbocharger, crankshaft, and front axle, synergistically delivering an impressive system performance of 1063 horsepower. The synergy is further enhanced by the inclusion of a potent, directly cooled 800-volt battery, exclusively developed by High Performance Powertrains, the engine builder for Mercedes-AMG Petronas F1. This combination establishes the groundwork for an agile, high-precision, and intense driving experience, both on the track and the road.

With a production limit of 275 units, the Mercedes-AMG ONE does not offer multiple trims or configurations, ensuring identical mechanical specifications for every model. The 1.6-liter turbocharged V6, combined with four electric motors, generates a combined output of approximately 782.2 kilowatts. Due to the distinctive nature of the powertrain, determining peak torque is not feasible. The powertrain complexity is rounded out by an automated seven-speed manual transmission and the 4Matic AWD system, featuring an electrically driven front axle, torque vectoring, and a hybrid-drive rear axle. While not the fastest hypercar in a straight line, with a 0-100 km/h time of 2.9 seconds, its exceptional track agility is nearly unparalleled.

The exterior showcases approximately 48.26 cm forged aluminum wheels in the front and 50.8 cm wheels at the back, enveloped in Michelin Pilot Sport Cup 2R M01 tires, specially designed for this car. Advanced aerodynamics include a Race DRS (Drag Reduction System) with both Highway and Track settings, along with NACA air inlets and a vertical shark fin. Inside, notable features include an F1-style steering wheel, dual ten-inch displays, and AMG Motorsport seat pans.

Providing a near-F1 encounter for the average individual, the interior of the Mercedes-AMG ONE features a decidedly sporty design. Though the dual digital displays are somewhat standard, the F1-inspired square steering wheel stands out. This unique wheel incorporates controls for driving modes and suspension settings. The seats are seamlessly integrated into the monocoque with limited adjustments, featuring materials like microfiber and carbon fiber. Notably, the central compartment between the seats includes a fire extinguisher, signaling that this AMG model is anything but ordinary.

Chevrolet Corvette C8 Coupe (E-Ray): LT2 V8 Engine, generating approximately 495 horsepower of power and 637 Newton-meters of torque, this 6.2L small block engine is engineered to deliver an exhilarating experience on every journey, whether on the road or track, contributing to an impressive total output of 655 horsepower. It incorporates eight intake runners of equal length, each measuring 210 mm, to optimize torque and airflow. A dry-sump oil scavenge system, utilizing three pumps, guarantees the maintenance of oil quality and efficient flow to critical areas during high g-force cornering and acceleration.

E-Ray incorporates numerous functional design elements, including broader fenders, quarter panels, and fascia, resulting in a streamlined and sculpted appearance with various aerodynamic and performance advantages. The inclusion of standard ground effects and a spoiler enhances its aerodynamic capabilities, while coordinated body-color accents contribute to an elegant aesthetic. At the core of the E-Ray lies a compact electric motor weighing approximately 36.29 kilograms, propelling the front axle. This exclusive motor, unique to the E-Ray and not shared with any other GM (General Motors) vehicle, remains active across speeds ranging from zero to 241.4 km/h. It is rated at approximately 169.47 Newton-meters of torque, channeled through an 8.16:1 final drive ratio, resulting in a maximum torque output of approximately 1384.63 Newton-meters at the front wheels.

The 1.9-kilowatt-hour (kWh) battery consists of 80 flat-pouch lithium-ion cells sourced from LG. This battery unit, along with all its control circuitry, is integrated into a single structure that fits into the structural backbone tunnel present in every C8's floor. In traditional Corvettes, this tunnel is sealed with a metal plate; assembling the E-Ray involves simply inserting the battery box into the channel, replacing the conventional closeout plate. Unlike the vast majority of hybrids, the E-Ray's electric motor is not connected to the combustion engine in any way. That means the engine is never charging the battery, nor is the front-axle motor ever influencing the output of the small-block V8. Instead, think of them as two completely independent drivetrains crammed into one car.

The primary structural modification to the E-Ray involves the front suspension. To accommodate the front-axle half-shafts, engineers had to elevate the front spring and shock assembly by slightly over an inch. The coilover shocks maintain the same shape and size as those on the Stingray, with identical suspension travel. However, the shock towers are positioned slightly higher, and engineers introduced a tower-to-tower brace to enhance rigidity. Apart from the adjusted mounting of the front coilovers, the front suspension geometry mirrors that of non-hybrid Corvettes, and the rear suspension remains unaltered.

Porsche 918 Spyder: Parallel full hybrid system comprising a 4.6-liter V8 mid-engine with dry-sump lubrication, a hybrid module incorporating an electric motor and decoupler, an electric motor with decoupler and transmission on the front axle, an auto Start-Stop function, electrical system recuperation, and four cooling circuits catering to motors, transmission, and the battery, all integrated with a comprehensive thermal management system. A combustion engine integrated with a hybrid module and transmission, forming a unified drive unit; equipped with a seven-speed Porsche Doppelkupplung (PDK) system; operates as rear-wheel drive; features a front electric motor with transmission for driving the front wheels (decoupled from speeds exceeding 235 km/h); offers five pre-selectable operating modes to ensure optimal coordination among all drive units.

According to Porsche, the weight of the engine is 135 kg, and it produces 599 horsepower at 8700 RPM, along with a maximum torque of 540 Nm at 6700 RPM. Additionally, there are two electric motors contributing an extra 282 hp. One electric motor, with a power of 154 hp, operates in parallel with the engine to drive the rear wheels and serves as the primary generator. The power from this motor and the engine is transmitted to the rear axle through a 7-speed gearbox connected to Porsche's PDK double-clutch system. The second electric motor, with a power of 127 hp, directly propels the front axle, and an electric clutch disengages the motor when not in use. In total, the entire system delivers 875 horsepower and 1280 Nm of torque. Regarding the chassis, there is a double-wishbone front axle, and an optional electro-pneumatic lift system is available for the front axle. The vehicle is equipped with electro-mechanical power steering. The rear axle features a multi-link design with an adaptive electro-mechanical system for individual rear-wheel steering. Both the front and rear are equipped with electronically controlled twin-tube gas-filled shock absorbers, integrated with the Porsche Active Suspension Management (PASM) system. Two-seat Spyder body include a carbon-fiber-reinforced plastic (CFRP) monocoque interlocked with a CFRP unit carrier, a two-piece Targa roof, and a fixed roll-over protection system.

Aston Martin Valhalla: In terms of design, it diverges significantly from its expected closest competitor, the Ferrari SF90. However, it's worth noting that the latest Aston Martin draws its mechanical inspiration from the Italian machine beneath its surface. The vehicle is equipped with three motors: the well-known 4.0-liter V8 located behind the seats, powering the rear wheels, along with two electric motors. One is situated on the front axle, primarily for short-distance electric-only operation, and the other is on the rear axle to enhance overall performance. The combined power of the entire system reaches a maximum of 950 PS (699 kW).

As expected for a vehicle delivering the distinctive luxury associated with Aston Martin, the weight is higher than that of the Valkyrie. However, with a targeted dry weight of 1550 kg, it remains commendable. Aston Martin claims that the Valhalla boasts an unbeaten power-to-weight ratio in its class, supported by performance goals such as a top speed of 217 mph and a Nürburgring lap time of under 6 minutes and 30 seconds. While the twin-turbo V8 is a recognizable Aston Martin adaptation of the Mercedes AMG unit, it takes a flat-plane crank form in the Valhalla, according to Aston Martin. This configuration is intended to enhance responsiveness, accompanied by a higher 7200 rpm rev limit. Managing this power is a new eight-speed dual-clutch transmission with paddle shift and an electronic limited-slip differential. Similar to Ferrari, the Valhalla doesn't have a reverse gear; instead, reversing is achieved by the front electric motor spinning in the opposite direction.

The vehicle's structure primarily comprises carbon-fiber, featuring a brand-new central tub entirely composed of carbon, following a McLaren-style design. With the integration of its Formula 1 team, Aston Martin emphasizes various Formula 1 influences in the Valhalla, notably the pushrod front suspension with inboard mounted springs and dampers. This design choice is aimed at minimizing unsprung mass and optimizing space efficiency. The rear suspension utilizes a multilink system, and the springs and dampers are engineered to provide adaptable ride settings suitable for both road and track conditions. The ride height is adjustable, ranging from a low setting for track mode to a higher setting capable of navigating steep ramps and speed bumps, facilitated by a front axle lift system. The vehicle incorporates electrically assisted steering, carbon ceramic brakes, and 20-inch front wheels and 21-inch rear wheels fitted with Michelin tires.

Producing 600 kilograms of downforce at a speed of 150 miles per hour, the Valhalla incorporates active aerodynamic features, such as a rear wing, while venturi tunnels manage the underbody airflow. The vehicle features forward-hung dihedral doors, and details about the interior are currently undisclosed. Aston Martin has revealed that the cabin will have fixed seat bases, with adjustments for varying sizes achieved by moving the steering wheel and pedals. The driving position is designed to position the feet higher than the seating area, with the assurance of more interior space compared to the similarly configured Valkyrie.

BMW i8: The BMW i8, introduced in 2014, stands out as a pioneering plug-in hybrid, mid-engine supercar that was ahead of its time. Although it may not have been the fastest or most capable in its price category, it presents a distinctive and compelling perspective on the supercar concept. With its striking aesthetics and a notable electric range, the BMW i8 has secured its place as the most successful performance vehicle globally. Representing a significant technological achievement for the BMW Group, both the i8 Coupe and i8 Roadster seamlessly combine futuristic design with cutting-edge engineering. Beyond its immediate success, the BMW i8 holds paramount importance for BMW, as it serves as a cornerstone for the brand's future electrification endeavors across its entire model range.

A distinctive feature of the BMW i8 is its innovative powertrain. The vehicle is equipped with two distinct powertrains: a 1.5-liter turbocharged three-cylinder engine coupled with an electric motor propelling the rear wheels, and a separate electric motor driving the front wheels. The combined system produces approximately 369 hp and 570 Newton-meters (Nm) of torque, enabling an impressive 0-100 kilometers per hour (km/h) acceleration in around 4.4 seconds. Notably, the BMW i8 holds the distinction of being the pioneering hybrid/EV to incorporate a two-speed transmission for its front electric motor. The main goal in creating the BMW i8 as a hybrid was to integrate outstanding fuel efficiency with supercar-level performance and styling. Despite falling short of the expected fuel economy, the i8 still exceeds the efficiency of most supercars, achieving an impressive 35 kilometers per liter equivalent (km/L). With the assistance of its front electric motor, the latest iteration of the BMW i8 can travel up to 35 kilometers solely on electric power.

Unlike most mid-engine supercars that feature both front and rear trunks, the BMW i8 deviates from this norm. The absence of a front trunk, or "frunk," is due to the space occupied by the front electric motor and transmission. Furthermore, the rear trunk has limited capacity, with an average-sized briefcase occupying most of the available space. Interior cargo space is also notably scarce. The interior of the BMW i8 has consistently faced criticism. While the exterior design is striking, the interior design is considered somewhat bland and lacking in premium quality given its price point. It adopts a sustainable approach with unique materials, but the overall design is criticized for being too simplistic and not aligning with the expected level of luxury.

Audi R8: Scarcely do supercars find themselves utilized for daily driving, but the 2023 Audi R8 appears tailor-made for such a purpose. It provides a relatively smooth ride alongside it's exhilarating acceleration. Sharing its foundation and powertrain—a potent V-10 engine paired with a seven-speed automatic transmission—with the formidable Lamborghini Huracán, the R8 adopts a less extreme demeanour, particularly on winding roads or race circuits. Instead, the R8 focuses on delivering a refined experience more in harmony with the overall Audi lineup.

Its compact, two-seat interior boasts premium materials and a minimalist design, eschewing the conventional centre-mounted infotainment display in favour of a dual-purpose digital gauge display. Both driver and passenger enjoy comfort within the snug cabin, making the R8 a compelling option for touring, were it not for its limited cargo space accommodating only one carry-on suitcase. The V-10 engine of the R8 comes in two variants, each powerful enough to resonate with otherworldly exhaust notes. However, the R8's seven-speed dual-clutch automatic transmission lacks seamless operation. Periodic abrupt downshifts lead to sudden accelerations, followed by immediate upshifts. The base R8 is equipped with an adaptive suspension, while Performance models feature a more aggressive fixed-damper setup. Both suspensions effectively absorb bumps, ensuring a comfortable ride conducive to extended journeys without inducing fatigue.

Audi adopts a refreshingly uncomplicated approach in the R8 by integrating the instrument cluster as the infotainment screen. This design choice allows the impeccably crafted sport seats and the high-resolution digital gauge display to command attention within the cockpit. Audi offers extensive customization options for interior colours and textures, presenting choices of black, grey, brown, and red leather available in flat or quilted patterns, with corresponding or contrasting stitching. The overall result is a meticulously designed cockpit featuring easily accessible controls, including the ignition button conveniently positioned on the steering wheel.

Ferrari 812 Competizione: The 812 Competizione represents the epitome of Ferrari's vision for an exceptionally high-performance front-engined berlinetta, elevating the features of the highly praised 812 Superfast to an unprecedented level. The renowned Ferrari engine sound, celebrated globally on both streets and tracks, has been preserved despite the inclusion of a Gasoline Particulate Filter (GPF). Ferrari engineers achieved this by developing a new exhaust tailpipe, resulting in a distinctive medium-high frequency sound that accentuates the capabilities of the 6.5L V12 engine.

The incorporation of independent steering on all four wheels enhances agility and cornering precision, offering unparalleled responsiveness. The extensive integration of carbon fiber not only lightens the 812 Competizione's load but also provides an enhanced sense of control, ensuring a keen response to even the slightest adjustments. With independent rear-wheel steering and a novel electronic management system, individual control over the right and left actuators is granted, leading to a substantial enhancement in performance. This emphasizes the front axle's response to steering commands and ensures optimal grip for the rear axle.

Extensive and advanced aerodynamic research has yielded solutions characterized by extremely unique forms, showcasing profiles that have not been previously witnessed in road-legal vehicles. These innovations encompass new air ducts, an unconventional tail and exhaust configuration, and distinctive patented designs for both the rear screen and front bumper. The interior design closely mirrors that of the 812 Superfast, preserving the primary dashboard layout, door panel interfaces, and volumes, including the distinctive diapason motif. To enhance weight reduction, the new door panel has undergone a redesign. Additionally, the incorporation of the H-gate theme on the tunnel imparts a sportier and more contemporary touch to the cockpit, aligning with the car's racing essence.

Mercedes AMG GT: From the SLS AMG to the initial generation of the AMG GT and now its second iteration, a notable shift in philosophy is evident. The SLS served as a front-engine supercar, showcasing distinctive gullwing doors, an all-aluminum chassis, and a weight distribution of 47:53. This balance was achieved by placing the 6.2-liter V8 engine entirely behind the front axle, coupled with a double-clutch transaxle at the opposite end. Many of these features were retained in the first

AMG GT, albeit with the substitution of the naturally aspirated engine for a twin-turbo 4-liter V8. The car was also made slightly more compact and significantly more affordable, strategically repositioned to compete with the Porsche 911.

The second-generation AMG GT marks a departure from its previous philosophy. It has transformed into a more conventional grand tourer, featuring increased dimensions, added weight, the inclusion of a pair of (quite small) rear seats, standard all-wheel drive, and an overall softer character. In a cost-saving move, it shares the majority of its underpinnings with the new Mercedes SL, a model now under the AMG division and produced on the same assembly line. While the GT is not precisely a coupe version of the SL, it shares all mechanical aspects with the roadster, encompassing powertrains, suspension, chassis, as well as interior and electronic technology. It adopts the roadster's 2700 mm wheelbase, with only a slight increase in overall length to 4730 mm. This larger size, evident in the scale, contributes to a curb weight of 1895 kg, an increase of 325 kg compared to its predecessor.

However, transitioning into a more traditional GT configuration does enhance its visual appeal. The previous AMG GT featured a cab-rearward profile and an exceptionally long hood, necessitated by the need to position the engine entirely behind the front axle. This design choice rendered its profile somewhat unconventional. In contrast, the new GT maintains a long-hood, cab-rearward proportion, although not as pronounced as its predecessor. With the engine shifted beyond the front axle, the driver's seat is moved 200 mm forward, allowing for the A-pillars to be pulled forward as well. This results in a more streamlined windshield angle that seamlessly converges with the curvaceous roofline. The 70 mm extension of the wheelbase to accommodate rear seats contributes to a more balanced proportion. The roofline now smoothly transitions to a faster-angle hatchback, resulting in a sleeker, albeit slightly taller, profile. Additionally, Mercedes' designers have shaped the rear to closely resemble a 911 when viewed from behind, further enhancing the overall appeal of the car.

3.1.3.1.2. Benchmarking Table

After collecting comprehensive information about the sportscar or supercar models, the actual Top/Flop analysis commences. In this phase, you opt to assess the different car models using specific parameters that offer an overview of their essential characteristics, relevant to this project involving a similar parameter. Especially, models of super or sports cars have been compiled to gain a broader understanding with their diversities. Data obtained from details regarding engine position, powertrain layout placement, electric motor capacity and its position, and overall dimensions will form the basis of the modular platform we are planning to design.

For each parameter, the optimal and suboptimal values among the compared cars are identified, coloring the corresponding boxes in green or orange, respectively. The aim of this analysis is to determine the innovative aspects and those that are not available on each compared object. This tool proves highly beneficial because, by considering the best values from each compared car, you can derive a set of initial values for developing an innovative vehicle.

The comparison of the sports/super car models involved assessing them based on the following parameters:

- Values related with Performance: Gasoline Engine Capacity, Displacement, Power, Torque, Acceleration, Fuel Tank Capacity, Electric Motor Capacity, Battery Capacity
- Values related with Engine Type: Powertrain, Gasoline Engine Layout, Electric Motor
- Values related with Lightweightness: Length, Width, Height, Kerb Weight, Wheelbase
- Values related with Versatility: Gasoline Engine Layout, Electric Motor Location, Suspension System, Battery Location
- Values related with Fuel Consumption: CO_2 Emission
- Values related with Aesthetic Design: Seats
- Values related with Safety: Battery Location, Gasoline Engine Layout

Each car model will be evaluated according to these values. The highest and lowest values will be highlighted with different colors to create an innovation table that represents the necessary limits to be achieved. **Because our goal is not to design a vehicle with the most excellent values, but to create a platform that serves vehicles with various features.** By selecting the highest and lowest values from these parameters, the boundary limits of the platform we are going to design will be determined, that is, the values to be met in the design will be identified. Consequently, results will show us the scale of the values for our case (Table 3.2).

Table 3.2. Benchmarking table

Brand	Lamborghini	Ferrari	McLaren	Mercedes-Benz	Chevrolet	Porsche	Aston Martin	BMW	Audi	Ferrari	Mercedes
Model	Revuelto	SF90	Artura	AMG ONE	Corvette C8 Coupe E-Ray	918 Spyder	Valhalla	i8	R8	812 Competizione	AMG GT (C192)
Powertrain	PHEV (Plug-in Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	FHEV (Full Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	PHEV (Plug-in Hybrid Electric Vehicle)	Internal Combustion Engine	Internal Combustion Engine	Internal Combustion Engine
Engine	6.5 V12	4.0 V8	3.0 V6	1.6 V6	6.2 V8	4.6 V8	4.0 V8	3 cylinder	5.2 V10	6.5 V12	4.0 V8
Length (mm)	4947	4710	4539	4756	4699	4643	4565	4689	4496	4696	4728
Width (mm)	2033	1972	1913	2010	2025	1940	1950	1942	1964	1971	1984
Height (mm)	1160	1186	1193	1261	1235	1167	1260	1291	1225	1276	1354
Kerb Weight (kg)	1772	1570	1498	1695	1712	1674	< 1550	1535	1570	1487	1895
Seats	2	2	2	2	2	2	2	4	2	2	4
Wheelbase (mm)	2779	2560	2640	2720	2722	2730	2665	2800	2650	2720	2700
Co2 emission (g/km)	320	154-160	104	198	277	72	< 200	42	339-341	385	319
Displacement (cm3)	6498	3990	2993	1599	6162	4593		1499	5204	6496	3982
Power (hp)	825	780	671	574	495	608	998	231	620	830	585
Torque (Nm)	725	800	720	1063	637	540	1000	320	565	692	800
Gasoline Engine Layout	Middle, Longitudinal	Middle, longitudinal	Middle, Longitudinal	Middle, Longitudinal	Middle, Longitudinal	Middle, Longitudinal	Middle, Longitudinal	Rear, Transverse	Middle, Longitudinal	Front, Longitudinal	Front, Longitudinal
Fuel Tank (l)	90	74	66	55	70	7	78	30	73	92	70
Fuel consumption (l/100 km)	10.3	6.0	4.6	8.7	15.1	3.1	13.1	1.8	13.1	16.9	14.1
Suspension System	Double Wishbone(front and rear)	Double Wishbone (Front), Independent Multi-Link Rear	Double wishbone (front), Independent Multi-link (rear)	Independent Multi-link (front and rear)	Double Wishbone (front and rear)	Doublewishbone (front),Independent Multi-link (rear)	Independent multi-link suspension (front and rear)	Double Wishbone (front), Independent multi-link (rear)	Double Wishbone (front and rear)	Independent Double Wishbones. (front and rear)	Double Wishbone (front and rear)
Acceleration 0-100 km/h (sec)	2.5	2.5	3.0	2.9	2.5	2.6	2.5	4.4	3.4	2.85	3.2
Electric Motor Power	3 X 150 Hp	2 x 135 , 1x 220	1 x 95 Hp	1x 122 Hp , 3 x 163 Hp	1 x 160 Hp	1x 129 Hp , 1 x 156 Hp	2 x permanent magnet synchronous	1 x 143	N / A	N / A	N / A
Gross Battery Capacity (kWh)	3.8	7.9	9.2	8.4	1.9	6.8	150 kW/ 400V	11.6	N / A	N / A	N / A
Battery Location	In the central tunnel	Behind the back wall of the passenger cabin	Below the floor	Below the floor	In the central tunnel	Behind the back wall of the passenger cabin	Front axle and rear axle	In the central tunnel	N / A	N / A	N / A
Electric Motor Location	Between the ICE and transmission 2 x Front Axle, Transverse	2 x Front axle, Transverse Integrated into the transmission	Integrated into the transmission	2x Middle, Longitudinal 2 x Front axle, Transverse	Front axle, Transverse	Front axle, Transverse Rear axle, Transverse	Front axle , rear axle	Front axle, transverse	N / A	N / A	N / A

After constructing the initial table, an additional table which is TOP-FLOP analysis has to be inserted beneath it. But, in this project we need to see all the best and worst values taken from models of the brands. This will provide an opportunity to create an innovation table (Table 3.3). Once the maximum and minimum values are identified, the "highest and lowest values" or TOP – FLOP values for each parameter are extracted individually and placed in a separate column next to the table, referred to as the innovation column. The new design has to refer all those inside the limit values.

Table 3.3: Innovation table

PARAMETERS	INNOVATION COLUMN
Powertrain	PHEV (Plug-in Hybrid Electric Vehicle), Internal Combustion Engine
Engine	V12 ≥ x > ≥ V6
Displacement	6.5 ≥ x ≥ 1.6
Length (mm)	4947 ≥ x ≥ 4496
Width (mm)	2033 ≥ x ≥ 1913
Height (mm)	1354 ≥ x ≥ 1160
Kerb Weight (kg)	1895 ≥ x ≥ 1487
Seats	4 ≥ x ≥ 2
Wheelbase (mm)	2800 ≥ x ≥ 2560
Co2 emission (g/km)	385 ≥ x ≥ 42
Power (hp)	998 ≥ x ≥ 231
Torque (Nm)	1063 ≥ x ≥ 320
Gasoline Engine Layout	Middle, Longitudinal, Front Longitudinal, Rear Transverse
Fuel Tank (l)	92 ≥ x ≥ 30
Combined Fuel Consumption (l/ 100 km)	16.9 ≥ x ≥ 1.8
Suspension System	Double Wishbone, Independent Multi-Linlk
Acceleration 0-100 km/h (sec)	4.4 ≥ x ≥ 2.5
Electric Motor Power	95 ≥ x ≥ 220
Electric Motor Quantity	0 ≥ x ≥ 4
Gross Battery Capacity (kWh)	0 ≥ x ≥ 11.6
Battery Location	In the central tunnel Behind the back wall of the passenger cabin Below the floor Front axle and rear axle

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The information gathered above will provide all the necessary data for the final analysis we need to conduct in order to identify the parameters that will fully meet customer needs: What-How Matrix. What-How matrix is created where the requirements to be fulfilled are represented in rows, and the methods enabling the realization of those requirements are represented in columns. The customer needs are then inserted in the rows, and the parameters utilized for conducting the Innovation Table are placed in the columns. By making modifications to these parameters, it becomes feasible to address the customer's requests.

3.1.3.2. What-How Matrix

The What-How Matrix (Figure 3.8) is crucial for identifying the specific technical characteristics or performance that need enhancement to achieve an innovative product. The numbering of this matrix is from 1 to 10, and it is ranked based on the answer to the question "How performance values (column) used in the Benchmarking analysis meet customer needs (row)?"

	Powertrain	Dimension	Weight	CO2 Emission	Combined Fuel Consumption	Gasoline Engine Capacity	Power	Torque	Engine Layout	Fuel Tank Capacity	Suspension System	Acceleration	Battery Capacity and Location	Electric Motor	Price	TOTAL
Performance	10	4	8	2	8	10	10	10	4	4	8	10	8	10	8	114
Engine Type	10	6	10	10	10	8	10	10	10	8	0	10	8	10	10	130
Lightweightness	8	8	10	6	6	8	8	8	0	10	2	4	6	6	10	100
Versatility	10	4	4	4	4	6	8	8	10	4	8	0	6	8	10	94
Fuel Consumption	10	4	8	8	10	10	10	10	0	4	2	4	4	10	6	100
Aesthetic Design	0	4	6	0	0	4	0	0	8	0	2	0	6	0	10	40
Safety	6	0	6	10	4	2	0	0	8	2	4	0	6	8	10	66
Total	54	30	52	40	42	48	46	46	40	32	26	28	44	52	64	

Figure 3.8: What-How matrix

After gathering all information about sports car requirements, it is time to decide what kind of design solution will be offered to compensate all these needs. According to the findings after what – how matrix, which is;

- *Powertrain*
- *Electric Motor*
- *Weight*
- *Price*

These parameters will be the main points while designing a lightweight modular platform which is our design solution to attain an innovative sports car. Upon examining the customer requirements scoring, it is observed that *Engine Type*, *Performance, Lightweightness* and *Fuel Consumption* are the requirements most affected by the performance parameters. Thus, when the findings in What-How matrix compensates by the new design, this means that it will provide the most valuable customer requirements. Interpreting these results, key points and goals in our platform design can be easily identified. The *Powertrain* emerges as a detail of the *Engine Type* parameter. In other words, the *Powertrain* layout, and the types of engines to be used – which is demonstrated by the significant role of the *Electric Motor* as a performance parameter – are among the crucial details that need to be addressed in our modular platform design. Also, *Powertrain* layout, *Electric Motor*, and *Weight* of the car are the parameters addresses the *Performance* of the car. Other one of the most important customer requirements is *Fuel Consumption* which can be optimized with a *Lightweight* platform design and using *Electric Motor* in the car. Lastly, considering all these situations, the type of engine used, the system layout, and the use of different materials for lightweight design emerge as the most crucial factors influencing the *Price* of the vehicle.

3.1.3.2.1. Powertrain Layout

The powertrain layout refers to the arrangement and configuration of the main components involved in generating and transmitting power in a vehicle. The powertrain is a combination of the engine, transmission, and other essential components responsible for delivering power to the wheels. The layout determines how these components are positioned and connected within the vehicle. Engine Placement involves the positioning of the engine within the vehicle. Engines can be located in various places, such as the front, rear, or middle of the vehicle. The placement affects factors like weight distribution, handling, and available space. The type and placement of the transmission system, whether it's manual, automatic, dual-clutch, or continuously variable, are critical aspects of the powertrain layout. The transmission is responsible for controlling the power flow from the engine to the wheels. Drivetrain Configuration includes the arrangement of components that deliver power to the wheels, such as front-wheel drive (FWD), rear-wheel drive (RWD), all-wheel drive (AWD), or four-wheel drive (4WD). The drivetrain configuration influences a vehicle's traction, stability, and performance in different driving conditions (Crolla & Mashadi, 2011).

In the realm of automotive design, the front-engine, front-wheel-drive (FWD) layout, also known as the FF layout, positions both the internal combustion engine and the driven roadwheels at the front of the vehicle. Historically, this classification was applied irrespective of whether the entire engine was positioned behind the front axle line. In contemporary times, some car manufacturers have expanded on this designation by incorporating the term "front-mid," referring to a car in which the engine is located in front of the passenger compartment but behind the front axle. This layout represents the most conventional and widely adopted design, known for its popularity and practicality. The engine, a component occupying a considerable amount of space, is situated in an area typically unused by passengers and luggage. The primary drawback lies in weight distribution, as the heaviest component is concentrated at one end of the vehicle. While car handling may not be optimal, it is generally predictable. In Figure 3.9, the arrangements of a front engine with various drivetrain configurations are depicted. There is another combination which is a front-mid-engine, front-wheel-drive layout involves the propulsion of the front road wheels by an internal combustion engine positioned immediately behind them and in front of the passenger compartment.

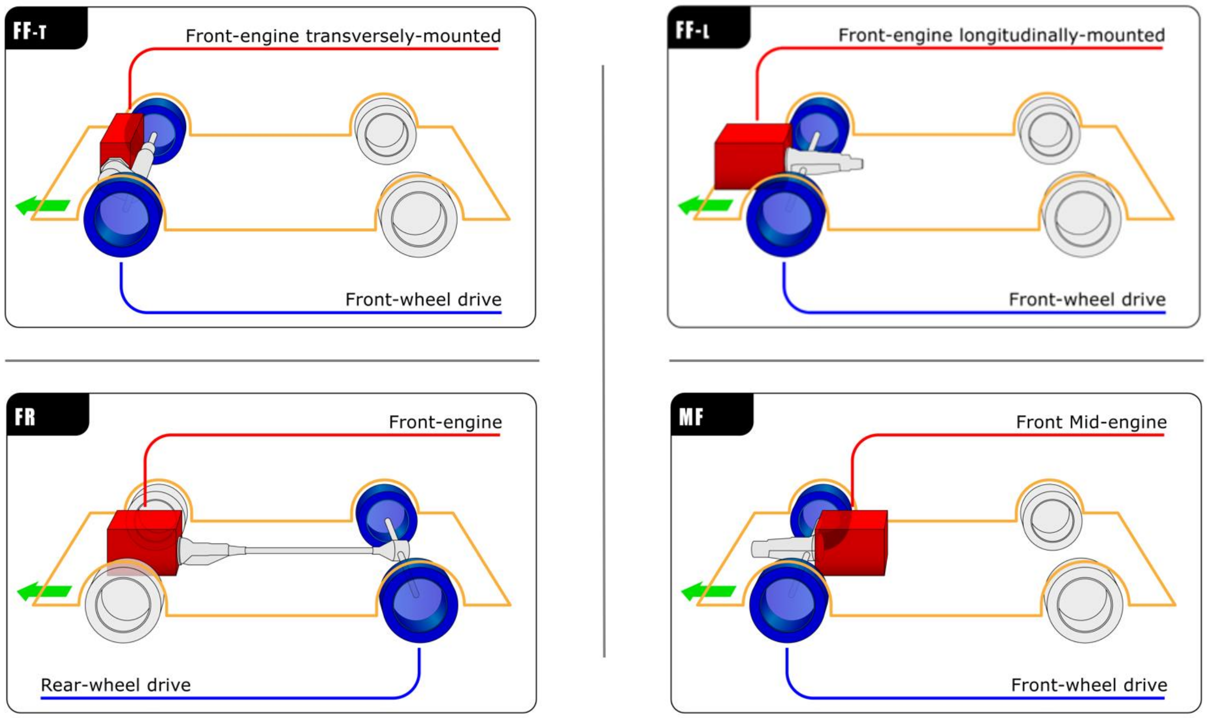


Figure 3.9: Front Engine layouts with different drivetrain configurations

An automotive configuration known as front-engine, rear-wheel drive (FR) features an engine positioned at the front and rear-wheel drive, connected through a drive shaft. This traditional layout, where the engine is situated between the front axle, was predominant in automobiles for the majority of the 20th century. However, in the later part of the 20th century, the FR layout saw diminished usage, giving way to the front-engine, front-wheel-drive (FF), and all-wheel-drive (AWD) configurations (Figure 3.10).

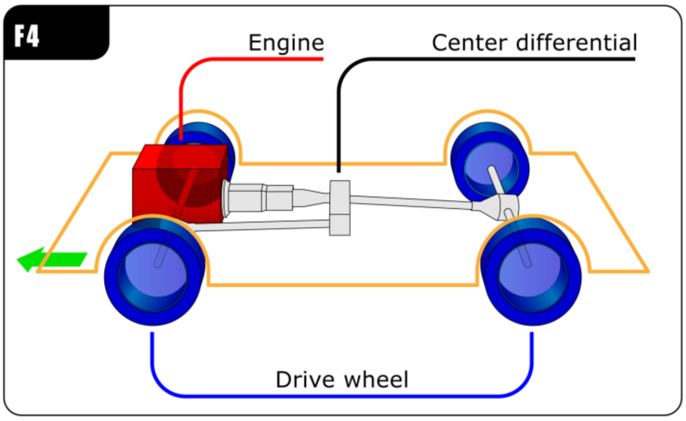


Figure 3.10: Front Engine layout with all wheel drive configuration

Rear mid-engine (RMR), rear-wheel-drive layout, is characterized by the placement of the engine behind the passenger compartment, with its center of gravity positioned in front of the rear axle. The term 'RMR' is now more commonly used to recognize that certain sporty or performance-oriented front-engine cars can also be considered "mid-engine" by having the primary engine mass situated behind the front axle.

In contrast to the fully rear-engine, rear-wheel-drive configuration, the engine's center of mass is positioned ahead of the rear axle. This design is commonly selected due to its advantageous weight distribution. Placing the vehicle's heaviest component within the wheelbase reduces its rotational inertia around the vertical axis, facilitating smoother turn-ins or yaw angles. Additionally, achieving a nearly 50/50% weight distribution, with a slight bias toward the rear, results in a highly favorable balance. This configuration ensures substantial weight on the driven rear axle during acceleration and evenly distributes the weight during braking, effectively utilizing all four wheels for rapid deceleration. Rear engine configurations are shown in Figure 3.11. The RMR layout typically exhibits a reduced inclination for understeer. Nonetheless, as there is less weight exerted on the front wheels, during acceleration, there is a potential for the front of the car to lift, leading to a continued tendency for understeer.

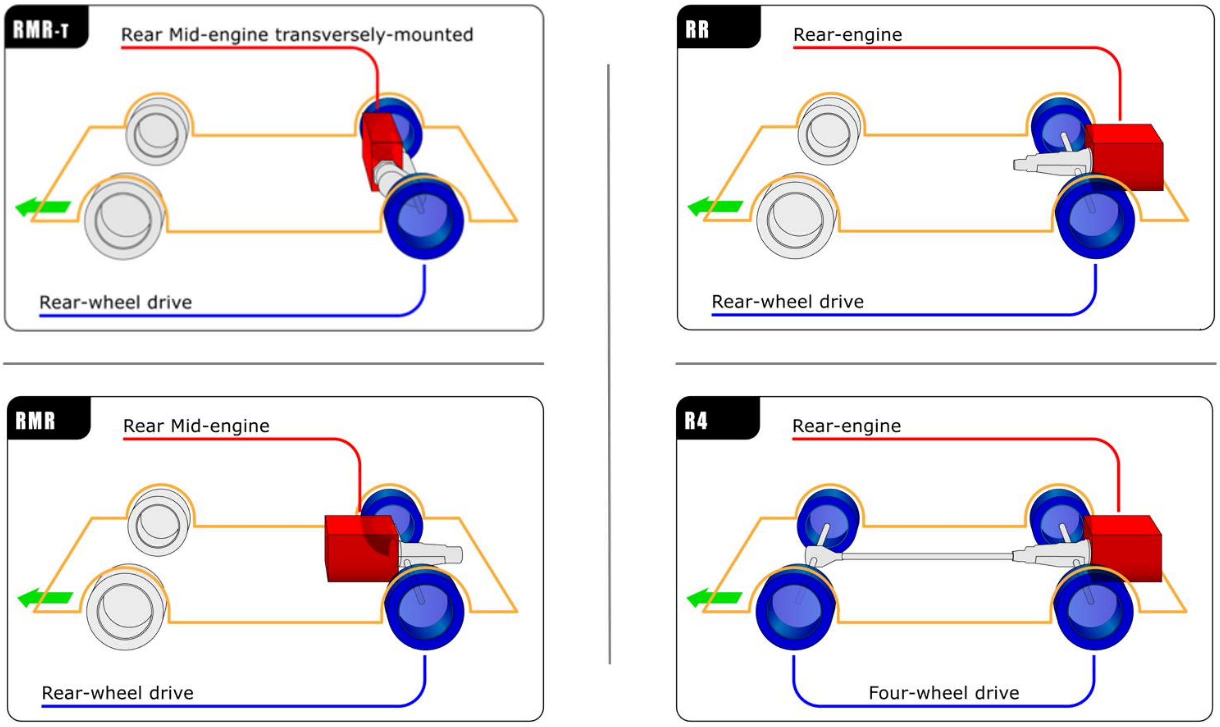


Figure 3.11: Rear Engine layouts with different drivetrain configurations

In contemporary racing cars, the RMR configuration is widely adopted and is often interchangeable with the term "mid-engine." This layout is extensively utilized in open-wheel Formula racing cars (such as Formula One and IndyCar) and the majority of purpose-built sports racing cars, primarily because of its advantageous weight distribution and resulting favorable vehicle dynamics. Despite the inherent challenges in design, maintenance, and limited cargo space, the success of the RMR platform in motorsport has led to its common use in many commercially available sports cars. A similar mid-engine, four-wheel-drive layout provides comparable advantages and is employed when enhanced traction is desired, seen in certain supercars.

On the other hand, in hybrid and electric vehicles, the powertrain layout includes the arrangement of electric motors, batteries, and other components. The placement of these elements impacts factors like range, efficiency, and overall vehicle performance. In the next section, various powertrain layout types in hybrid vehicles are illustrated. These configurations will be needed more complex system.

3.1.3.2.2. Hybrid Electric Vehicle (HEV) Powertrain Configurations

From the perspective of vehicle architecture, hybrid electric vehicle (HEV) powertrains can be divided into three primary categories: series, parallel, and series-parallel split. These classifications are determined based on how power flows and the torque path within the vehicle are structured.

a) Full Hybrid Vehicle Types

- *Series Hybrid Powertrain*

In the series HEV powertrain, the engine does not contribute propulsive torque to propel the vehicle. Its main function is to convert potential energy from fuel into mechanical energy, subsequently transformed into electrical energy through a generator. The generated electrical energy drives the motor via an inverter. This configuration allows for the independent control of the engine speed. As there is no mechanical connection between the internal combustion engine (ICE) and the vehicle's drive axle, the ICE can operate at its optimal efficiency irrespective of the vehicle speed or the power demanded by the driver. Electrical motor can be positioned on both the front and rear axles, enabling the implementation of electric all-wheel-drive capability. Moreover, in series hybrid electric vehicles (HEVs), a transmission, which is an essential component in conventional vehicles, may not be required. The electric motor responsible for propelling the vehicle receives power from either the engine or the battery pack, as depicted in Figure 3.12.

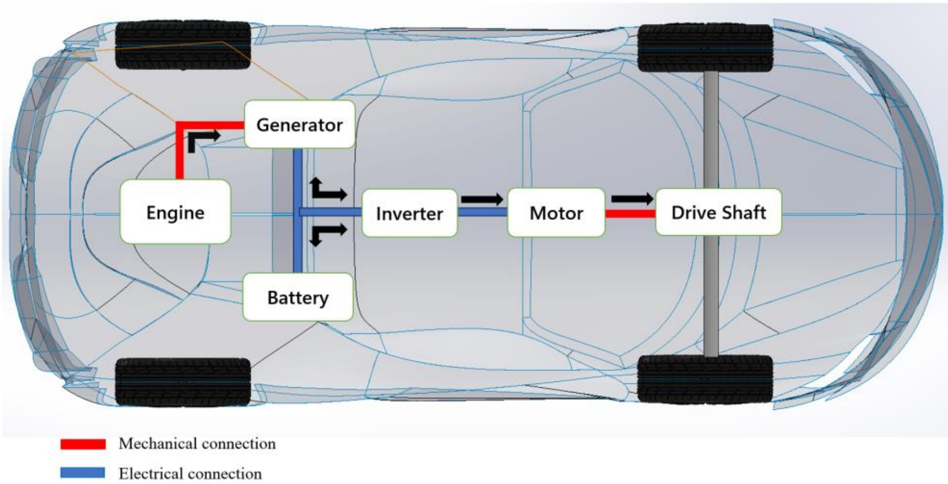


Figure 3.12: Series HEV configuration

- *Parallel Hybrid Powertrain*

In parallel hybrid electric vehicles (HEVs), both the internal combustion engine (ICE) and the motor/ generator (M/G) are mechanically linked to the output shaft (Figure 3.13), enabling them to concurrently contribute power for vehicle operation. The M/G is utilized to adjust the engine operating points, particularly shifting them to a region of higher efficiency. It functions as a generator during periods of low power demand and as a motor during high power demand. This approach allows the engine to operate with greater efficiency compared to a traditional vehicle. The torque of the engine and the motor can be independently regulated, but the speed of both the engine and the motor is consistently proportional to the overall vehicle speed. Additionally, parallel hybrids necessitate the inclusion of a transmission to align the high engine speed with the low vehicle speed.

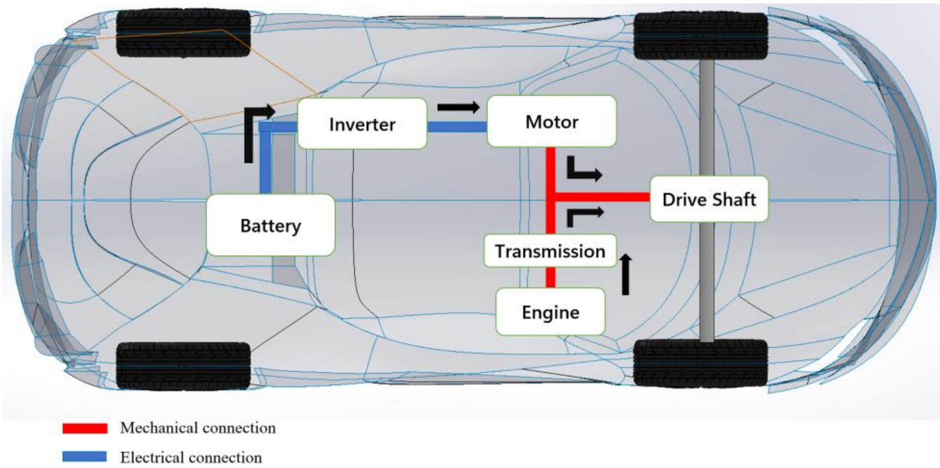


Figure 3.13: Parallel hybrid powertrain configuration

- *Series – Parallel Hybrid Powertrain*

Power-split hybrid or series-parallel hybrid (Figure 3.14) systems are a type of parallel hybrid that integrates power-split devices, enabling power paths from the internal combustion engine (ICE) to the wheels that can be either mechanical or electrical. The primary principle is to separate the power provided by the main source from the power requested by the driver. At lower RPMs, ICE torque output is minimal, leading traditional vehicles to increase engine size to meet market demands for satisfactory initial acceleration. These larger engines often have more power than necessary for cruising. Electric motors, on the other hand, generate full torque at a standstill, making them well-suited to compensate for the ICE's torque deficiency at low RPMs. In a power-split hybrid, a smaller, more efficient, and less flexible engine can be employed.

Series-parallel architectures (SPHEV) leverage the benefits of both series and parallel configurations, but they come with a relatively more costly design and intricate control system. The prevalent powertrain in SPHEVs is the power-split SPHEV, incorporating a Planetary Gear (PG) as the power-split unit. The Toyota Prius was the pioneer in adopting this architecture within the Toyota Hybrid

System (THS). Additionally, the power-split architecture has been adopted by Chevrolet Volt and Opel Ampera (Hannan et al., 2014; Tran et al., 2020; Zhuang et al., 2020).

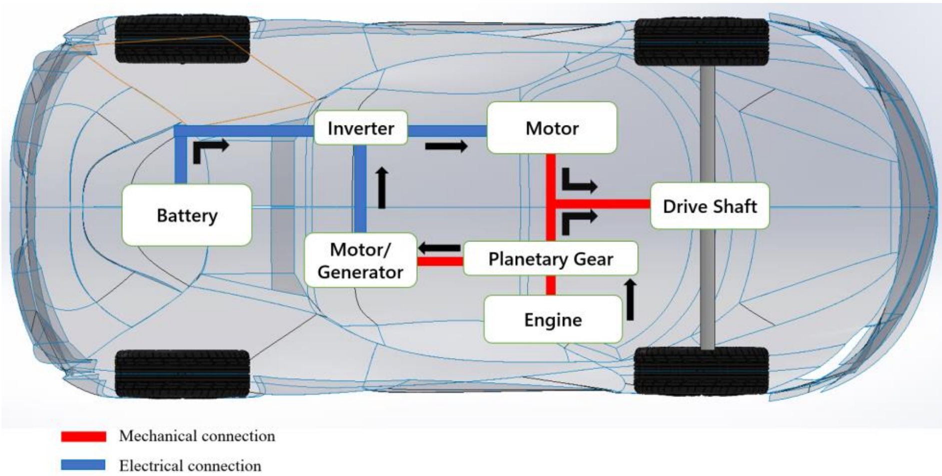


Figure 3.14. Series-Parallel split hybrid powertrain configuration

There are different kinds of hybrid vehicles which uses those powertrain configurations above with their technology. The most common ones are Full, Plug-in and Mild Hybrid Vehicles.

b) Plug-in Hybrid Vehicle Types

A plug-in hybrid electric vehicle (PHEV) is a type of hybrid electric vehicle with a rechargeable battery pack that can be charged by connecting a charging cable to an external electric power source. This is in addition to the internal charging capacity provided by its on-board internal combustion engine-powered generator. Consequently, they can operate solely on electric power for a longer range compared to traditional hybrid electric vehicles (HEVs). The battery pack can be replenished using a nearby alternating current (AC) outlet charger or in one's own garage. PHEVs contribute to more efficient use of utility power as the battery charging primarily occurs during nighttime. Figure 3.15 illustrates plug-in series hybrid vehicle configuration, while Figure 3.16 illustrates plug-in parallel hybrid vehicle configuration. Lastly, plug-in series parallel hybrid configuration is represented in Figure 3.17 vehicle configuration.

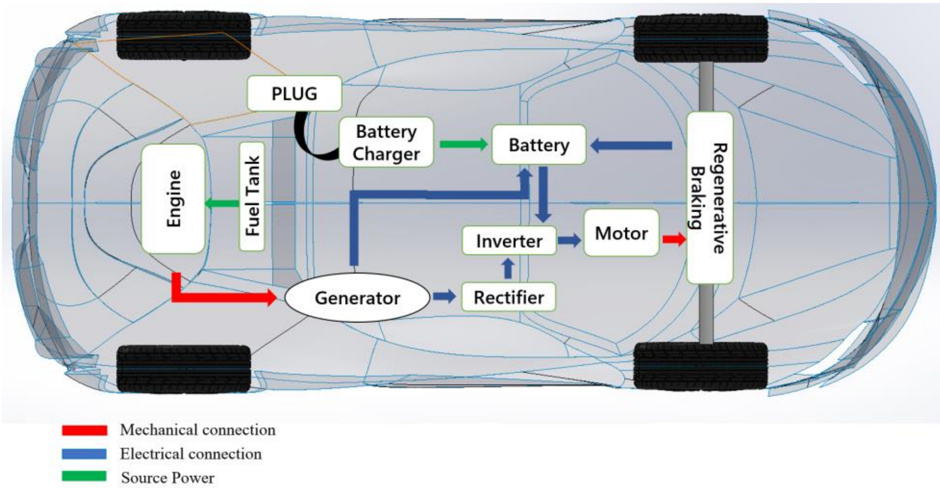


Figure 3.15: Plug-in series hybrid electric vehicle configuration

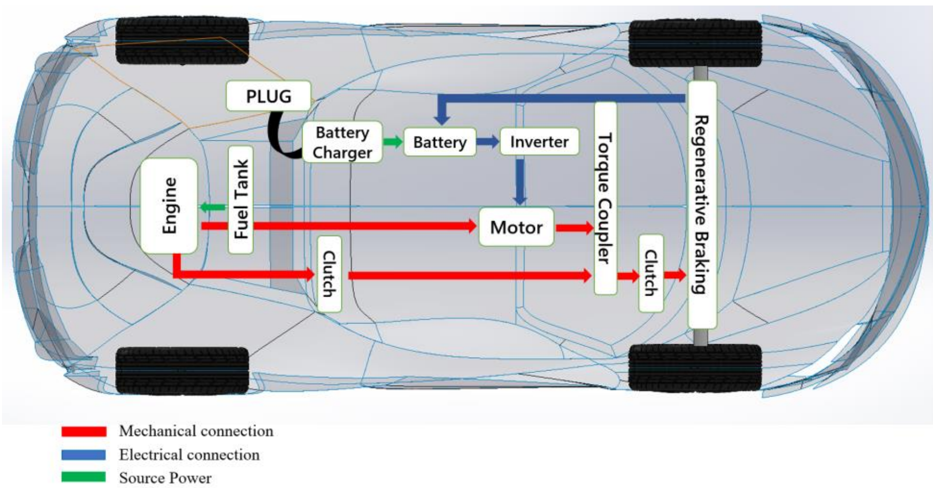


Figure 3.16: Plug-in parallel hybrid electric vehicle configuration

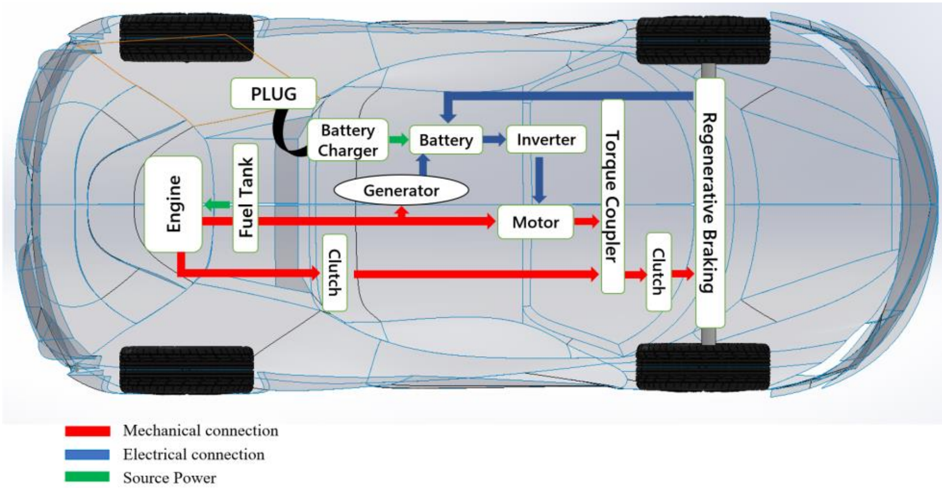


Figure 3.17: Plug-in series / Parallel hybrid electric vehicle configuration (Emadi et al., 2008; Turker et al., 2010)

c) Mild Hybrid Vehicle

Mild hybrid electric can be found in several commercial vehicles due to the small changes and investment needed to modify the conventional vehicle. This hybrid technology incorporates a small electric motor to assist the ICE in start-stop, idle and high load conditions. Also, this small electric motor can operate as electrical generator and convert part of the braking energy into electric energy. In addition, it does not need a high-power energy storage due to the small power rating of the electric motor. A 48 V electrical system may be able to meet the requirements (Benajes et al., 2019).

Providing a modular platform that can accommodate all these configurations is challenging. The aim of this project is to design a shared platform for sports cars with different powertrain configurations. Therefore, layouts used in sports cars will be designed to be the main target of our modular platform which is basically rear-mid engine. Besides, convenience of the platform for rear or front engine layouts are crucial. Following the engine position, the most crucial point is to make design to be compatible with hybrid configurations. Hybrid car configurations will be the main challenge in this project. Because the placement of the electric motor or motors and the battery to be used is of utmost importance.

3.1.3.2.3. Lightweightness

The lightweightness of a modular platform is a critical consideration in modern automotive design, offering a range of benefits from improved fuel efficiency and performance to reduced emissions and material efficiency. Achieving a weight reduction of 100 kg results in a fuel economy of 0.35 liters per 100 kilometers and a reduction of 8.4 grams of CO_2 emissions per kilometer in gasoline engines. This calculation considers adjustments to gear shifting without altering elasticity and acceleration values, attributing the savings to the reduced overall weight. The most practical solution is to opt for lightweight vehicles, as there exists a natural correlation between the mass of a vehicle and its fuel consumption (Khademian & Peimaei, 2020; Refiadi et al., 2019). Manufacturers strive to strike a balance between structural strength and weight reduction to create vehicles that are both efficient and high performing. The pursuit of lightweight constructions can be categorized into three main types:

- Material Replacement Approach,
- Structural Lightweight Construction,
- Production Process Optimization.

These three factors can be achieved through one specific method which is *GENERATIVE DESIGN* method.

a) Generative Design Method

The generative design has recently emerged within the design terminology and is accepted by different kinds of design communities with its variable meaning (Leary, 2020). As a general definition, generative design is a modern design exploration approach that synthesizes design alternatives or progresses a current design using current computing and manufacturing capabilities according to criteria designated by the user (Krish, 2011; Marinov et al., 2019). A methodical explanation of generative design is the iteration of the process with given constraints and boundary conditions for potential results, while the designer can regulate the given values in terms of choosing the best result (Ntintakis & Stavroulakis, 2020). This process produces partially parametrically constrained innovative and feasible designs while using parametric CAD (Computer-Aided Design) systems. This means that user needs and constraints can be achieved with automatically created designs by computer-aided applications (Briard et al., 2020; Kallioras & Lagaros, 2020). Thus, this design space gives an opportunity to compensate for structural requirements, material specifications, and manufacturing applications with only an individual design process using different kinds of design approaches.

History of GD generation: Generative design research began around the 1980s, but as seen from a literature review, mimics of nature in design algorithms in the 70s were the first reference to generative design. The evolutionary hypothesis of nature started from one or several designs in the design space, then improved over time to more proper forms of the proposed design. At this level, conditionally incompatible designs were excluded, and evolution kept generating in other directions. However, the vast majority of publications were mostly theoretical, not including any content of application. Computer technology development gave researchers an opportunity to investigate potential solutions and improve their research in the analysis field. The maximum interest was represented in the architectural field in preliminary stages (Caldas, 2001; Shea et al., 2005). They explored animation tools to make a comparative exploration as a generative design (Muehlbauer et al., 2017). The idea of animation gives architects an opportunity to investigate their design approach according to given parameters in terms of responding to dynamic, material, and variable forces in the long term by large design spaces (Attar et al., 2009; Buonamici et al., 2020). But over time, other fields started to search for development opportunities using computing processes offered by the evolution theory. Recently, generative Design (GD) has become more prominent. In general, GD is stimulated by mimicking nature, thereby using algorithms. The formal logic of this system is to make material additions where requirements exist and discard them where they are not needed. The evolution of this method has made this process available for mechanical design, architecture and civil engineering, microstructural design, and others (Ntintakis & Stavroulakis, 2020).

Furthermore, contrary to aiming for only one optimum design, generative design focuses on providing numerous design alternatives in multiple design fields, making this method more variational for compensating the requests of designers that are challenging to describe numerically while increasing designer creativity (Sun & Ma, 2020). From a practical perspective, GD tools work on the solution of mathematically formulated problems via using an iterative optimization (Figure 3.18) method to minimize an aimed function.

Figure 3.18: Generative design iterative process example

So, it applies to implementing artificial intelligence methods and algorithms applied to solve design problems. However, currently, some applications in engineering design are not constrained to parametric models like topology optimization, and these applications outperform the use of standard CAD programs (Chen et al., 2018; Kazi et al., 2017). Correlatively, generative design fundamentals are not the same as parametric modeling. A new parametric model has similar geometrical qualities but is different in some cases, such as in terms of aesthetic quality due to analytical constraints as a design solution. This information concludes that generative design usage for developing and innovating a new product has more advantages than a geometric model by offering systematic information about a new product in terms of deterministic and heuristic nature (Gulanova & Vereš, 2014). Moving the boundaries rather than sectional density variable makes generative design mesh independent (Tyflopoulos et al., 2018). Apart from topology optimization, which works with the form-finding principle, generative design aims not to create an optimal shape but to have numerous initial values defined by user constraints. In this manner, it has different needs for design construction than topology optimization, thus having different requirements for design setup than topology optimization. Generative design changes the parameters of the problem description, while parametric design changes parameters of the geometry straightforwardly (Oh et al., 2019).

On the other hand, even if generative design tools have been presented as independent modules in some commercial CAD software for engineering design (Figure 3.19), this tool is initially based on algorithms used in topology optimization (Cui & MingXi, 2011). Basically, the main correlation between these two design processes is that topology optimization is the precursor of generative design. Generative design aims to analyze the design alternatives to accomplish structural efficiency and proper designs for designer requirements, whereas conventional topology optimization aims to achieve an optimum design. Even though they have different aspects of the designing method, recent research on generative design showed that it utilizes topology optimization as a design developer instead of design parameterization and develops methods to generate various designs related to cloud computing. Additionally, even though topology optimization focuses on design performance in the engineering field, its results can be undesirable in terms of an aesthetic point, which is an important factor especially for customers. Generative design typically considers designing an object as an optimization process that searches a space of design configurations to find one that best meets an objective function (Chen et al., 2018). This approach focuses on optimizing the design of load-bearing elements and external attachments to minimize weight without compromising rigidity or functionality.

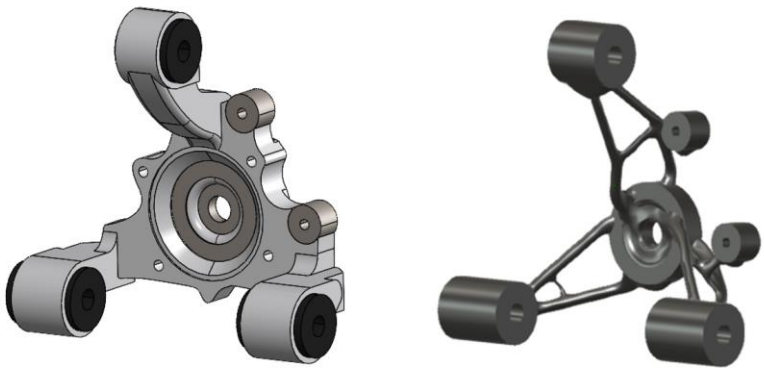


Figure 3.19: Example of CAD and generated module used model

In conclusion, Generative Design is a method that generates lightweight structures for design components and can also be employed to create additional structures to reinforce these components (Chen et al., 2018). These features will be utilized in the execution of this project. Another avenue for achieving lightweight constructions involves optimizing the manufacturing process. This includes reducing spot welds, subsequently lowering body weight, and adopting new joining techniques such as laser welding or manufacturing processes like hydroforming (Saidpour Shsaidpour, 2004). Generative design modules in software provides multiple manufacturing process solutions.

b) Material Choice

Reducing weight is achievable through the application of the Generative Design approach, which entails extraction of the mass. Additionally, it is possible to generate designs using various materials. Thus, it is crucial to examine all current and possible innovative alternative materials for use. Furthermore, the selection of the optimal lightweight material needs to be determined based on the design specifications and the range of loads applied to the structure. Additionally, selecting the right materials will contribute to identifying optimal solutions throughout the design generation process.

Material choice for car design is still a growing competition. To comprehend how generative design techniques affect components, we will employ the most commonly used materials in our designs. Analyzing the current materials utilized in automotive components is crucial. The comparison of the latest automotive materials used will be made in the upcoming Table 3.4.

Table 3.4: Material distribution in automobile design

Material	*Model Year 1995 (%)*	*Model Year 2014 (%)*	*Typical Application Examples*
Steel	55.52	53.4	(Structural parts requiring strength and formability needed) Closure panels, floor pans, front ends, engine components, bumper beams, and roof rails
Cast Irons	12.9	6.78	Brakes and Engine components
Aluminium Alloys	6.21	10	Sub-frames, hood, bumper beam, and closure panels
Magnesium Alloys	0.11	0.28	Instrument panel beam and seat frame
Copper and Brass	1.35	1.78	Electrical wiring
Polymers and Polymer Matrix Composites	6.5	8.35	Intake manifold, instrument panel, fuel tank, lift gate, and door inner panel
Elastomers	4.03	4.93	Tires, trims, and gaskets
Glass	2.62	2.4	Glazing and windows
Other Materials	10.76	12.08	Carpets, fluids, lubricants, etc.

The primary chance to reduce the weight of vehicle components lies in the body and chassis, constituting 60% of the total weight. Over the past three decades, numerous advancements in materials and manufacturing techniques have emerged to lighten the body structure, body panels, and suspension components. The powertrain, encompassing the engine and transmission, contributes to 25-30% of the overall vehicle weight, and there have been notable developments in materials and manufacturing processes to lessen its weight as well ("Lightweight Heavy Impact," 2012; Mallick, 2020). This section examines the common materials currently employed to reduce vehicle weight, even a requirement for enhancing fuel efficiency. For this study, it is focused on *Steel* and *Aluminium Alloys* which are the most common materials in use.

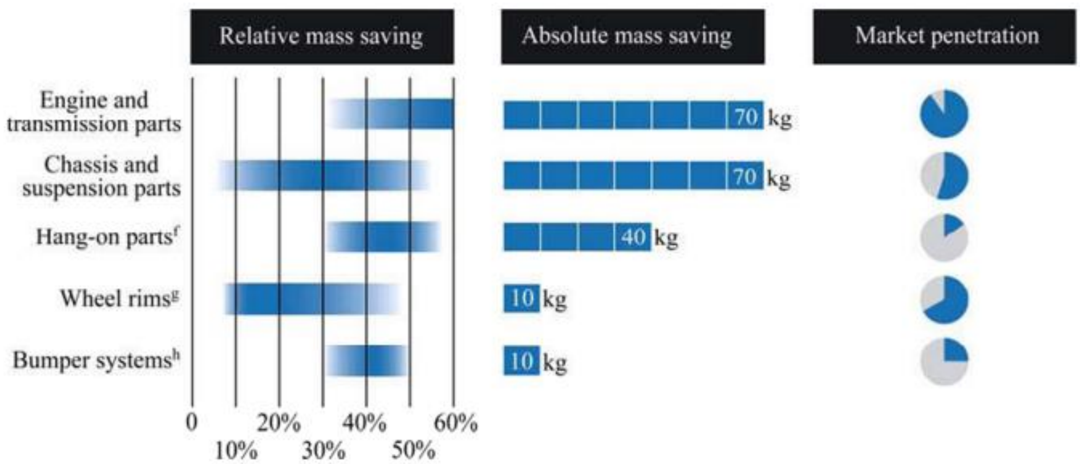
- Aluminium Alloys

Aluminum has been a well-established material in the automotive industry for numerous years. Its key properties, including low density, high specific energy absorption performance, and excellent specific strength, contribute to its significance. Additionally, aluminum exhibits corrosion resistance and can be easily recycled in its pure form. Despite having a lower modulus of elasticity than steel, it cannot directly replace steel parts on a one-to-one basis. Therefore, specific engineering is required to achieve equivalent mechanical strength. Nevertheless, the use of aluminum still presents potential for weight reduction. European aluminum industry has innovatively developed and introduced a range of lightweight solutions using refined aluminum alloys and optimized car designs oriented towards aluminum. A significant advantage of aluminum lies in its availability in various semi-finished forms, including shape castings, extrusions, and sheets, all suitable for mass production and innovative applications. Compact and highly integrated parts are designed to meet the rigorous requirements for high performance, quality, and cost-efficient manufacturability.

Aluminum faces strong competition from other materials, such as recently developed high-strength steels that aim to reclaim the potential for lightweight structures by utilizing alloys with increased strength for reducing wall thickness. Other competing materials include magnesium, titanium, and glass or carbon fiber-reinforced plastics. The latter has advanced significantly in the aerospace industry, with ongoing research and development efforts focusing on mass production, particularly for innovative electric cars. Forward-thinking car designs have embraced the concept of multimaterial design, selecting the "best" material for each function. Challenges in this approach primarily revolve around joining and surface treatment issues, but numerous viable solutions have been developed. The application of semi-finished aluminum parts has seen an increase, evident in engine blocks, powertrain components, space frames (e.g., Audi A2, A8, BMW Z8, Lotus Elise), sheet structures (Honda NSX, Jaguar, Rover), and closures and hang-on parts (DC-E-class, Renault, Peugeot), among other structural components. Aluminum finds application in body structures, closures, and external components such as crossbeams, doors, or bonnets. Pure aluminum bodies have been developed and integrated, primarily in luxury cars despite their relatively higher material and production costs (Hirsch, 2014; Saidpour Shsaidpour, 2004).

In 2012, the average total aluminum content per European car was 140 kg. A systematic analysis of its distribution reveals: Powertrain (engine, fuel system, liquid lines); 69 kg (25 components analyzed) in engine blocks, cylinder heads, transmission housings, and radiators. Chassis and suspension (cradle, axle); 37 kg (17 components analyzed) in wheels, suspension arms, and steering systems. Car body (body-in-white (BIW), hoods, doors, wings, bumpers, and interiors); 26 kg (20 components analyzed) in bonnets, doors, front structure, and other elements. Table 3.5 represents the selection of aluminum parts in use.

Table 3.5: Mass savings and market penetration of aluminium car parts



In recent years, there have been introductions of new alloys and processing modifications to address elevated demands. The use of higher-strength alloys has the potential to reduce the thickness of outer panels without compromising dent resistance, as long as stiffness requirements are satisfied. With decreasing paint-bake temperatures, there is a growing need for a considerably stronger age hardening response. However, the primary challenge for certain components continues to be formability. Consequently, European aluminium sheet manufacturers have recently devised special alloy adjustments, focusing on either enhanced formability or strength, which have been adopted as industry standards by the automotive sector (Hirsch, 2014)

The majority of automotive components crafted from aluminum utilize two distinct alloys. First one is non-heat-treatable or work-hardening AlMg(Mn) alloys (5000 series alloys). These alloys, which are solid solution- (and sometimes strain-) hardened, demonstrate a favorable blend of strength and formability. The other one is the heat treatable AlMgSi alloys (6000 series alloys). These alloys achieve their requisite strength through a heat treatment cycle, particularly for sheets during the paint baking process in the car body. They are also the primary choice for extrusions due to their ability to achieve high extrusion speed and surface quality. Additionally, they exhibit optimized age-hardening characteristics when cooled from the extrusion process. While heat-treatable AlZnMg alloys (7000 series alloys) find use in specific high-strength applications, the more robust, easily manageable, and weldable 6000 alloys typically dominate. Recent developments involve tailoring specific properties through sophisticated alloy and process combinations, as detailed below for specific applications. Innovative approaches, such as new material combinations through roll cladding or the 'Fusion' casting technology with a high-strength core and a corrosion-resistant surface, have emerged in European cars, notably applied in the new BMW 7 series. These approaches create an efficient symbiosis, combining different properties like inner strength with superior surface appearance, corrosion resistance, or formability.

Examining the aluminium usage in chassis design is also possible. Achieving weight reduction in the chassis can reach up to 40%, surpassing traditional steel chassis. This not only enhances driving dynamics, ride comfort, and safety but also contributes to reducing unsprung mass. Alloys like AA

5049 (AlMg2Mn0.8) and AA5454 (AlMg3Mn) from the 5000 series are employed, offering excellent formability (including inter-annealing capability) and weldability, high strength post-forming, and remarkable corrosion resistance, even in an uncoated state. For specific chassis applications, special 5000 series alloys, such as alloy AA5042-AlMg3.5Mn, have been developed to avoid sensitization through unique alloy additions and processing steps. These alloys exhibit a favourable combination of static strength and resistance to intergranular corrosion, and they are now being applied in series production for chassis applications (Hirsch, 2011). Alloys from the 6xxx series consist of magnesium and silicon. The existing 6xxx alloys utilized for automotive body sheets include A6016 in Europe, A6111 in America, and the relatively recent addition of A6181A due to recycling considerations. In the United States, A6111 is commonly employed for outer panels with thicknesses ranging from 0.9 to 1.0 mm, offering a balance of high strength and favourable formability. Alloys with medium strength from the 6xxx series and high-strength age-hardening alloys from the 7xxx series are employed, given that the necessary quenching takes place in the extrusion process. Extrusions find application in the design of space frames (Figure 3.20), as well as in bumper beams and crash elements/boxes (Hirsch, 2014). Parts produced by extrusion have shown with green in the figure.

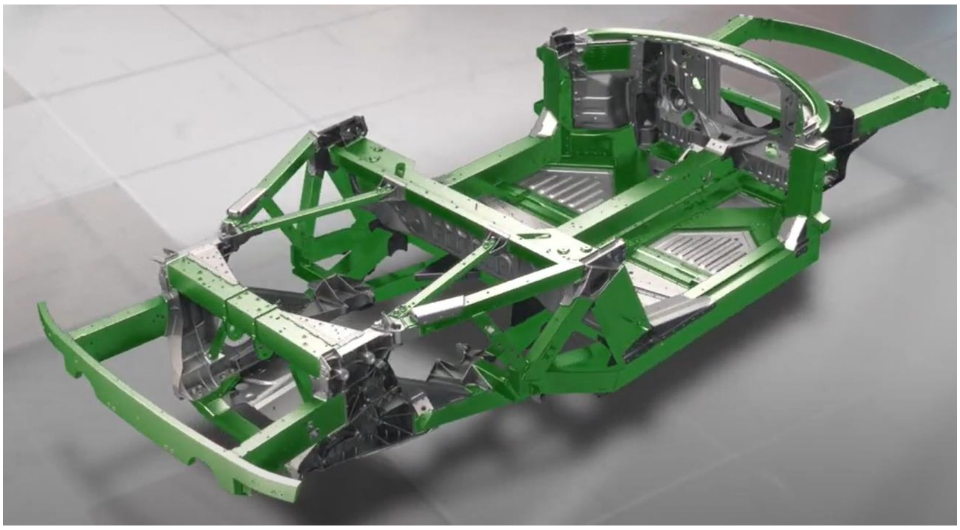


Figure 3.20: Parts produced through extrusion (*Ferrari 488 Spider*, n.d.)

6111 aluminum and 2008 aluminum alloy find widespread use in manufacturing external body panels for automobiles, while 5083 and 5754 are employed for inner body panels. Bonnets are crafted from 2036, 6016, and 6111 alloys. Truck and trailer body panels utilize 5456 aluminium. Automobile frames commonly incorporate 5182 or 5754 aluminum formed sheets, as well as 6061 or 6063 extrusions. Wheels are either cast from A356.0 aluminum or formed from 5xxx sheets. Cylinder blocks and crankcases are often cast using aluminum alloys, with A356, 319, and to a lesser extent, 242 being popular choices for cylinder blocks. The term "aircraft aluminum" or "aerospace aluminum" typically refers to 7075. Die-cast 380 aluminum exhibits higher tensile strength than gray cast iron and weighs approximately half as much in equal volumes. Aluminum's excellent heat conductivity makes it an ideal material for gearbox and motor frames, reducing oil temperature more efficiently than cast iron or steel.

Various alloys, such as 1450, 2119, 2218, 2519, 2020, 2017, 7050, 7055, and 8019, are used in aerospace applications, including rockets (5059), smartphones (6013), and automotive armor (2519, 7034, 7039). An important structural consideration for aluminum alloys is their lower fatigue strength (less than 10^7 stress cycles) compared to steel. For cycling frames and components, alloys like 2014, 6061, 6063, and 7075 are commonly used. The 5000 series alloys are popular choices for fulfilling the growing demand for structural sheets in the automotive industry. Currently, 6000 series extrusions are integral components of automotive structures (Khademian & Peimaei, 2020). A summary table for the aluminium alloys preferences in automotive application parts are shown in Table 3.6.

Table 3.6: Aluminium alloys and their properties

Aluminium Alloys	The application area of the material	Form of the material
2000 Series	External body panels, Automotive armor	
5000 Series	Chassis applications, Inner body panel	Formed sheet
6000 Series	Automotive body sheets, Automotive outer panel	Extrusion
7000 Series	Space frame, Bumper beams, Crash elements, Automotive armor	Extrusion

- Steel Alloys

Currently, the predominant materials utilized in vehicles are various types of steel, providing a diverse range of material characteristics, including thermal, chemical, and mechanical resistance, as well as ease of manufacturing and durability. The ongoing development of steel involves the continuous creation of new materials with improved characteristics for applications in the automotive industry. These high-strength grades are increasingly employed in large-scale production for components such as sheets or profiles, utilizing specialized manufacturing techniques. At present, higher-strength steels make up 80% of the body of European premium-class cars, such as the BMW 7 Series introduced in 2001. As the use of this material has expanded, the yield stress of high-strength steels has seen improvement over the years, ranging from 220 megapascals (MPa) up to 1400 MPa. Furthermore, today, higher-strength steels are being utilized more frequently in smaller vehicle segments (Saidpour Shsaidpour, 2004)

In situations where stiffness is the primary consideration, the utilization of high-strength steel does not confer an advantage over mild steel. Key factors such as material-optimized design, metal fatigue—especially in proximity to joining areas—and considerations such as cost, and recycling have been overlooked. The introduction of the new HSD 700 HD steel grade by ThyssenKrupp subsidiary Hoesch Hohenlimburg (Gruss et al., 2012) presents fresh opportunities for achieving lightweight structures through ultra-high strength micro alloyed steel grades characterized by high ductility (approximately 20% elongation) and low carbon content (maximum 0.06%) (Seyfried et al., 2015).

Ferrous metals, primarily steel, continue to dominate the automotive market, constituting roughly 70% of the average car's weight, including steel sheet metal, forged steel parts, and cast iron. Despite their high density of approximately 7.8 g/cm3, ferrous alloys are not typically categorized as lightweight materials. Nevertheless, there are initiatives aimed at modifying their characteristics to enhance their effectiveness in reducing the weight of transportation vehicles. Increasing strength alone results in a reduction in design weight without altering the specific density of materials.

Meanwhile, the application of high-strength steels leads to the use of thinner sheets, ultimately contributing to a reduction in the overall weight of the vehicle. When coupled with advanced manufacturing techniques and **creative design principles**, steel is regarded as the environmentally friendly and cost-effective material for transportation vehicles. Steel's appealing attributes encompass its affordability, ease of manufacturing, recyclability, and the existence of specialized alloys. From a sustainability perspective, the recycling process for steel is deemed simpler than that of aluminium, partly due to its magnetic properties facilitating sorting in scrapyards. All grades of steel can be melted and blended to create new compositions. The recycling of steel yields environmental advantages and contributes to reductions in CO_2 emissions.

Automotive steels can be categorized in various manners, with common classifications encompassing low-strength steels (such as interstitial-free and mild steels), traditional High Strength Steels (HSS) like carbon-manganese, bake-hardenable, and high-strength low-alloy steels, as well as the innovative Advanced High Strength Steel (AHSS) types, including dual phase, transformation-induced plasticity, twinning-induced plasticity, ferritic-bainitic, complex phase, and martensitic steels [9]. Additionally, there are other steel varieties like hot-formed, post-forming heat-treated steels, and steels specifically engineered for distinct applications.

An alternative method of classification is based on the range of yield strength, given that all steel grades share the same density and elastic modulus. Conventional steel is characterized by a yield strength below 210 MPa. High-Strength Steels (HSS) exhibit yield strengths ranging from 210 to 550 MPa and tensile strengths spanning 270–700 MPa. Ultra/Advanced High Strength Steels (UHSS or AHSS) possess yield strengths surpassing 550 MPa and tensile strengths exceeding 700 MPa. Furthermore, many types of steel comprise a broad spectrum of grades that encompass two or more strength ranges (Feloy et al., 2013; Singh et al., 2016). Advanced High-Strength Steel (AHSS) stands out as one of the most recent and rapidly expanding steel types in the automotive industry. Steels with a UTS surpassing 1000 MPa are termed ultra-high-strength steels. Over the past five decades, three generations of AHSS, an extension of HSLA steels, have been developed to facilitate lightweighting in the automotive industry (Figure 3.21). Depending on the steel generation, certain challenges may arise regarding formability and weldability. The first and second generations of AHSS are specifically designed to meet the functional performance requirements of specific automotive vehicle components. In recent years, new AHSS grades have emerged, including Extra-advanced High-strength Steels (X-AHSS) and Ultra-advanced High-strength Steels (U-AHSS), alongside various types of the so-called third generation AHSS steels (Czerwinski, 2021).

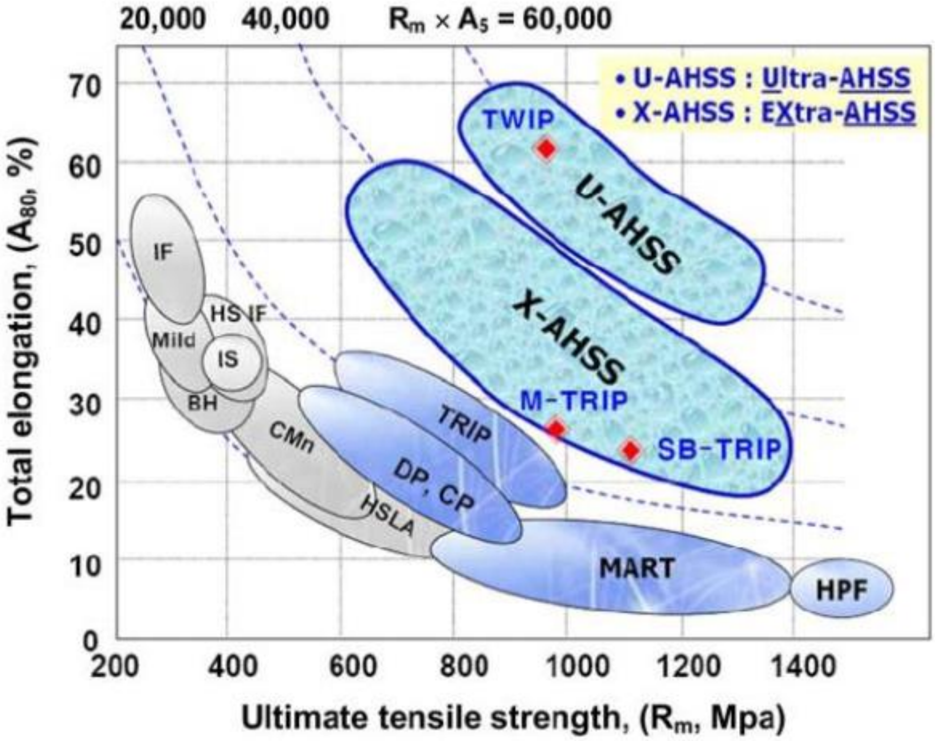


Figure 3.21: The relationship between ultimate tensile strength and total elongation in traditional high-strength steels (Khademian & Peimaei, 2020)

The Advanced High Strength Steels (AHSS) category includes two notable types: the Extra-Advanced High Strength Steels, labeled as X-AHSS, and the Ultra-Advanced High Strength Steels, known as U-AHSS. The evolution and utilization of these steels stem from the growing demand in the automotive industry to manufacture cars that are not only more fuel-efficient with reduced emissions but also exhibit enhanced safety features and greater formability. The Extra-Advanced High Strength Steels (X-AHSS) can be seen as a progression from TRIP (Transformation-Induced

Plasticity) steels, making their debut in car manufacturing within the production domains of major Far-Eastern car manufacturers, particularly in Japan and Korea (Khademian & Peimaei, 2020).

The AHSS category includes specific types like dual phase (DP), transformation-induced plasticity (TRIP), complex phase (CP), and martensitic steels (MART). AHSS can be differentiated based on their strength properties. Unlike conventional high-strength steels where ductility decreases with strength, modern AHSS steels successfully combine high strength with formability and ductility. They are generally classified as follows:

→ High-strength steels with a high energy absorption potential (DP and TRIP steels with UTS < 1000 MPa), designed for dynamic loading during car crashes or collisions.

→ Extremely high-strength steels, typically martensitic steels, boasting very high UTS (>1200 MPa), providing high stiffness, anti-intrusion properties, and acting as load-transferring barriers for automotive passenger protection.

The rationale behind the increased use of AHSS in the automotive industry includes the reduction in car weight achieved by utilizing high-strength, thinner gauge sheet steel, leading to decreased fuel consumption. Additionally, it enhances passenger safety through improved crash resistance. Furthermore, AHSS faces strong competition from lightweight materials such as aluminum and magnesium alloys, as well as plastics (Kuziak et al., 2008).

- Sandwich Composites

A composite with a sandwich structure comprises two slender, high-strength outer layers separated by a dense yet lightweight inner core. Although the core material typically exhibits low strength, its increased thickness imparts notable structural stiffness, strength, and a heightened potential for energy absorption to the sandwich structure, ensuring an overall low density. These sandwich structures represent significant and inventive multifunctional solutions, leveraging the benefits of both low density and high performance (Figure 3.22). The analysis, conducted through a methodology that integrates weight optimization and technical cost modeling with application-specific design costs, indicated that sandwich structures prove to be efficient in terms of both weight and cost in scenarios involving low to intermediate bending stiffness and torsional applications (Czerwinski, 2021).

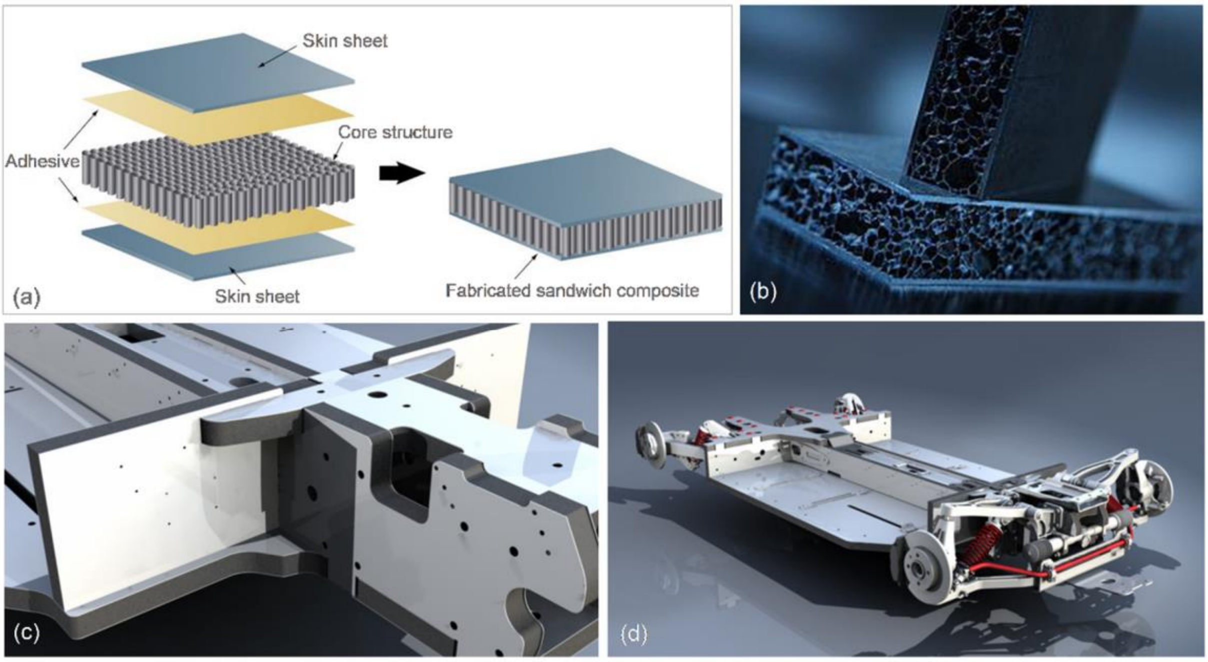


Figure 3.22: Sandwich structured composite application in automotive sub-frame (Czerwinski, 2021)

3.1.3.2.4. Price

Particularly, with the help of GD, it enables the production of lighter parts without the use of costly and lightweight materials. New materials with enhanced performance characteristics are integrated into vehicles for various purposes, primarily aimed at improving crashworthiness, reducing noise and vibration, overall cost, and enhancing fuel economy. Manufacturers of components may be motivated by endeavours to lower piece costs or modify tooling to decrease fixed capital expenses. Typically, suppliers collaborate with material providers and OEM release engineers to address these challenges.

In the past, efforts have been made to standardize certain specifications and testing procedures for steels to reduce costs and enhance availability. Similar initiatives are recommended for new materials to establish standardized specifications. Trade associations and research partnerships can play a crucial role in fostering consensus on standardization.

Changing the material used in a product can enhance its performance, but the associated cost may significantly outweigh the practical benefits. Car manufacturers face cost constraints, compelling them to make pragmatic decisions regarding material choices to avoid an excessive increase in the vehicle's overall cost. For instance, carbon fibre composite materials offer strength to the vehicle's structure while reducing weight by nearly 50% compared to mild steels; however, they are considerably expensive. The cost of carbon fibre for automotive applications is substantially higher than that of steel. For carbon fibre to achieve more widespread adoption, its cost needs to decrease. Presently, carbon fibre composites are limited to usage in high-end luxury and performance vehicles, where customers expect and are willing to pay for cutting-edge technology (Modi, 2016)

There are increasingly stringent environmental regulations regarding harmful emissions, and simultaneously, higher safety standards must be met. Weight reduction plays a crucial role in fulfilling these requirements. Despite the significant growth in the use of aluminium in cars over the past decades, particularly in castings and forgings, progress in the development of body-in-white parts has been somewhat limited. Car manufacturers have introduced all-aluminium vehicles with two competing designs: conventional unibody and spaceframe concepts. However, for a long time, aluminium was not the economically preferred material for auto body panels, closures, or chassis elements. The growing substitution of aluminium for steel is primarily driven by regulatory pressures to meet fuel efficiency and recycling standards. The main challenges still include the high cost of aluminium raw materials, its typically lower formability, and, in many cases, the higher manufacturing costs of aluminium panels. Despite these challenges, both the aluminium and automotive industries have made significant efforts to position aluminium as a cost-effective alternative to steel (Tisza & Czinege, 2018).

Accelerating the introduction of new materials necessitates collaborative endeavours. The presence of global platforms is a crucial factor in the decision-making process. Car manufacturers are increasingly inclined to minimize the number of platforms to share engineering resources and cut costs. A robust international supply chain is a pivotal determinant in the material qualification process for vehicles produced globally. Automakers are striving toward modular platforms, promoting increased sharing of parts between vehicles. Standardizing specifications required for qualifications across the automotive industry can expedite the establishment of supply chains for new materials, reducing both material qualification time and cost. Open innovation challenges initiated by Original Equipment Manufacturers (OEMs) will foster healthy competition among suppliers, potentially leading to innovative and cost-effective products.

On the other hand, one of the primary goals in the automotive industry is to achieve low-cost manufacturing due to the continuously escalating global competition. Although low-cost production is commonly associated with lightweight manufacturing, in numerous instances, lightweight technologies may actually raise production costs due to the requirement for new processes and equipment. Lightweight manufacturing holds a prominent position in research within the vehicle industry for various reasons. The challenging conditions for cost control have intensified the demand for accurate cost estimates more than ever. The constant pressure to cut costs highlights the importance of having comprehensive information about the cost implications. Research indicates that the conceptual design phase can account for up to 80% of the total product life cycle costs, despite representing only 10% of the overall expenses. Cost estimation is a complex task within a company, typically entrusted to experienced engineers and technical cost specialists. There is a necessity for a quantitative modelling approach for manufacturing costs, allowing estimators to base decisions on factual data rather than assumptions or omissions. Unfortunately, currently, there is often limited quantitative information available for cost analysis, leading to a heavy reliance on expert judgment in the cost estimating process (Roy et al., 2011). In the present market, there are compelling motivations to cut costs while simultaneously enhancing speed and precision. Rapid Prototyping (RP) proves to be an excellent approach, particularly when dealing with intricately shaped components, as it significantly shortens the timeline for creating prototypes, patterns, and tooling. Moreover, RP is particularly advantageous in terms of both cost and time. The ability to manufacture freeform surfaces, integrated cores, projections, and supports stands out as the unparalleled strengths of RP processes (Kumar Jauhar et al., 2012). This method stands out as one of the most prevalent applications of additive manufacturing in the automotive sector. However, beyond just prototyping, automotive manufacturers are progressively incorporating this technology into actual production processes. In recent years, the transformative impact of additive manufacturing (AM) technologies has significantly altered our approach to designing, developing, and manufacturing new products. Particularly in the automotive industry, these technologies have proven to be revolutionary, enabling the creation of innovative shapes, resulting in lighter and more intricate structures at an optimal cost (Ganesh Sarvankar & Yewale, 2019).

3.1.4. Product Architecture

A platform is a term that may be used in reference to the lower section of a vehicle, but it is a more ambiguous term compared to frame or chassis. When discussing an automobile platform, it becomes challenging to identify a particular component of the car, as it encompasses a comprehensive array of shared structural, design, and manufacturing features across various brands and models. The primary purpose of developing car platforms is to cut down on manufacturing expenses. Through the standardization of specific vehicle features, costs can be reduced, along with the time required to introduce a finalized product to the market. Some of the current modular platform applications are mentioned in the following section.

PSA Group Modular Platform: A modular vehicle base, known as a platform, forms the foundational element in the design and manufacturing of new models. The platform, when integrated with a powertrain, constitutes 60% of the production cost for a vehicle. It encompasses all functionalities not specific to a particular body style, encompassing the underbody, suspension system, relevant powertrain, and the fundamental electric and electronic architecture. Through the utilization of a single platform, PSA Peugeot Citroën can efficiently create a diverse array of body styles across various market segments, customizing them to suit distinct global markets. This versatility includes the development of four and five-door sedans, station wagons, MPVs, notchbacks, SUVs, cabriolets, and coupés.

Figure 3.23: PSA Common modular platform

Presently, Peugeot and Citroën models predominantly rely on three exclusive platforms developed by PSA Peugeot Citroën (Figure 3.23). There are multiple modular platforms produced by PSA over the years. Noteworthy is the exclusion of shared platforms with Fiat, Toyota, or Mitsubishi, which were created through collaborative agreements. The first platform, *PF1*, currently spans the B1, B2, and C entry segments (exemplified by Peugeot 301 and Citroën C Elysée) and is soon expected to extend to the B-SUV segment (as seen in the Peugeot 2008).

PF1 finds application in various Group manufacturing facilities worldwide, such as Poissy, Mulhouse, Aulnay, Madrid, Vigo, Trnava, Buenos Aires, Porto Real, and Wuhan. Despite its global usage, PF1 maintains strong roots in France and the broader European context. Moving on to Platform

2 (PF2), initially designed for C segment sedans, it has evolved to accommodate diverse body styles, including MPVs, light commercial vehicles like the Citroën Berlingo and Peugeot Partner, and SUVs. Recent expansions have also incorporated the D segment with the Citroën DS5. *PF2* is utilized in manufacturing facilities at Sochaux, Vigo, Mulhouse, Mangualde, Wuhan, and Buenos Aires. It has been implemented at the Kaluga plant in Russia and is slated to commence operations at the Shenzhen plant in China, part of the Group's new joint venture. Platform 3 (*PF3*) is exclusively dedicated to D and E segment executive models. These models are manufactured in Rennes for the European and Overseas markets and in Wuhan for the Chinese market.

The Efficient Modular Platform 2 (EMP2) represents a cutting-edge modular platform that enables the Group to diversify its product offerings globally. The incorporation of advanced modularity and extensive dimensional options opens up possibilities for entirely new configurations. These include four different track widths, five wheelbases, two cockpit and cowl solutions, and two rear suspension architectures (deformable beam and multi-link). The platform also offers various rear-unit modules for different versions, such as short or long variants, five or seven seats, independent or bench seats, and options for internal combustion engines or hybrids.

This heightened modularity enhances manufacturing flexibility, particularly in the body-in-white stage, allowing for the production of up to six rear unit versions on a single line. Introduced in 2013, the EMP2 platform is set to gradually replace PF2 and PF3 by accommodating new launches in the C and D segments. Ultimately, EMP2 is anticipated to account for half of Peugeot and Citroën vehicle sales worldwide, showcasing its significance in the evolution of the automotive landscape.

EMP2 incorporates innovative technological choices, from composite floors to ultra-low rolling resistance tires. These choices enable the Group to offer vehicles equipped with the latest features, including new suspension systems, smooth steering, nimble handling, passenger compartment comfort, and enhanced safety, supporting an upmarket strategy for future Peugeot and Citroën models. EMP2 provides greater flexibility to respond to emerging styling trends, such as large wheels on all four corners, low body styles, and low ride heights, irrespective of the vehicle model (SUV, sedan, etc.). This modular platform is set to diversify the Group's product line-up and is projected to cover 50% of the Group's production volumes worldwide. Initial production of the first two body styles on EMP2 will take place in assembly plants in Vigo (Spain) and Sochaux (France) from early 2013, with global deployment extending to Wuhan, China, a year later (Marsh, 2013)

CMP (The New Modular, Multi-energy Platform for Groupe PSA) represents a novel platform that caters to global markets and diverse customer requirements. This platform is exclusively designed for the production of compact city cars (B segment), entry-level and mid-range sedans (C segment), and compact SUVs under the Peugeot, Citroën, DS, Opel, or Vauxhall brands. It seamlessly complements EMP2, which focuses on developing and manufacturing vehicles in the C, D, and SUV segments.

CMP is characterized by its remarkable modularity, particularly in dimensions, offering two track widths, three wheelbases, three rear modules, and the ability to provide various wheel options to fully express the distinctive identity of each vehicle. Furthermore, it is a multi-energy platform that actively supports the transition to cleaner energy, adhering to the highest emission standards.

CMP offers the flexibility to produce both internal combustion and electric versions on the same production line, allowing customers to choose between petrol, diesel, or electric models. This adaptability enables Groupe PSA to respond promptly to market trends. Starting in 2019, CMP will manufacture the latest generation electric vehicles equipped with a 100kW electric motor, a 50kWh lithium-ion battery pack, and a high-performance heat pump. The platform accommodates advanced internal combustion engines with efficient pollution control systems, such as the award-winning PureTech 3-cylinder petrol engine and the latest 1.5l Blue HDi diesel engine featuring SCR technology for stringent environmental standards in Europe and China. CMP is designed to minimize CO2 emissions by addressing various factors contributing to lower fuel consumption, such as weight reduction, better aerodynamics, lower rolling resistance and optimized powertrains (New CMP Platform, 2018)

Volkswagen Modular Platform: Despite the platform's inception dating back to 2007 with the Audi A5, the Volkswagen Group officially introduced its MLB platform strategy in 2012. This platform, known as MLB, involves a shared modular construction designed for longitudinal, front-engined vehicles. This explains why various cars, such as the Audi A4, Q5, A7, A6, and even the Porsche Macan, are constructed using this platform. Initially used for Audi and Porsche vehicles until 2015, Volkswagen expanded its utilization of the MLB platform in 2016 to produce its first luxury sedan, the Phideon, exclusively targeting the Chinese market. MLB, derived from Modularer Langsbaukasten or 'Modular Longitudinal Matrix' in German, represents a distinct strategy within Volkswagen's comprehensive MB (Modulare Baukasten or modular matrix) program. Unlike MQB, which is tailored for vehicles with a transverse engine orientation, MLB is not a conventional platform but a systematic approach that introduces coherence among diverse platforms sharing the same engine orientation. Importantly, this rationalization is independent of the model, vehicle size, or brand. MLB employs a core matrix of components that allows cars built on this strategy to share a unified engine mounting system, accommodating all drivetrains, including petrol, diesel, hybrid, electric, and natural gas. The MLB platform offers savings across multiple aspects, including engineering costs, car weight, and simplifying the process of adapting the car to other models. This approach provides the company with the flexibility to manufacture cars from different brands at a single plant, establishing a standardized and interchangeable set of components. This standardization enables the construction of a diverse range of cars and contributes to a more efficient car-building process in terms of time. (Naik, 2016)

Figure 3.24: Volkswagen MQB modular platform

Another platform following a similar core principle is the MQB platform (Figure 3.24), which permits Volkswagen to engineer a variety of front-wheel-drive vehicles with front-mounted, transverse engines. The MQB platform by the Volkswagen Group is the company's approach to a shared modular design for constructing its transverse, front-engine, front-wheel-drive (or optional front-engine, four-wheel-drive) layout vehicles. It made its debut with the Volkswagen Golf Mk7 in late 2012 and serves as the foundation for a diverse range of cars, spanning from the supermini class to the midsize SUV class. MQB enables Volkswagen to produce any of its cars based on this platform at any of its MQB-ready factories, providing the group with the flexibility to adjust production across different facilities as needed. Introduced in 2012, the strategy is marketed under the code name MQB, which stands for Modularer Querbaukasten in German, translating to "Modular Transversal Toolkit" or "Modular Transverse Matrix."

MQB doesn't function strictly as a standalone platform; instead, it operates as a system designed to bring coherence to diverse platforms featuring transverse engines, regardless of the eleven vehicle brands offering ten different body configurations. Essentially, MQB serves as a coordinating mechanism for a fundamental "matrix" of components shared across various platforms. This includes a standardized engine-mounting core applicable to all drivetrains (gasoline, diesel, natural gas, hybrid, and purely electric), contributing to weight reduction. This conceptual framework facilitates the production of different models at a single manufacturing plant, leading to additional cost savings.

The Modular Transverse Toolkit (MQB) stands as Volkswagen's most widely employed technological platform currently. It serves as the foundation for various models, spanning from the compact Polo to the expansive US SUV, the Atlas. All MQB models feature transverse engines positioned at the front, and the MQB boasts exceptional space utilization efficiency. Volkswagen is unique among automakers in its ability, facilitated by the MQB, to provide electric powertrain options for all its traditional models. For instance, the Golf is a groundbreaking example as the world's first and only car allowing customers to choose among petrol, diesel, compressed natural gas (CNG), electric, and plug-in hybrid powertrains (*Modular Transverse Matrix*, n.d.).

Toyota Global Flatform: While the Toyota Production System laid the foundation for contemporary manufacturing practices, the Toyota New Global Architecture (TNGA), introduced as an evolution of the Toyota Production System, seeks to transform the development of Toyota vehicles (Figure 3.25). This transformation involves a heightened emphasis on aligning planning and design to enhance efficiency. In essence, a stronger emphasis on standardized parts and components indicates that Toyota's forthcoming vehicles will boast improved aesthetics and provide a more engaging driving experience. Additionally, this approach makes the development process easier and facilitates quicker and more efficient delivery to customers.

Figure 3.25: Toyota (TNGA) modular platform

Toyota's commendable goal of tailoring cars to meet local demands globally led to the existence of as many as '100 platforms and sub-platforms' within the automaker's product lineup. A platform serves as the foundational structure of a car, influencing the design, engineering, and construction of a vehicle. Additionally, the extensive variety of powertrains, including engines modified to suit the diverse platforms, amounted to as many as 800. Managing such a broad array of components and models also presents challenges in enhancing individual models over their production lifespan. However, Toyota's management did not simply halt at recognizing this issue; they went on to completely rethink and re-engineer the platforms and powertrains that would serve as the foundation for their future models, a comprehensive process carried out between 2009 and 2011.

Toyota, historically adept in production engineering, acknowledges the necessity of balancing pragmatic engineering with a passion for the final product in an increasingly competitive future. To instill this approach, the company encourages its production engineers to envision 'ever-better' vehicles, urging them to 'experiment, think, and feel' and to be hands-on in their work, as per internal instructions. In addition to proposing projects on paper, Toyota's engineers are prompted to 'drive as much as possible, especially outside working hours, and love cars.' The company's engineering leaders commit to learning from automotive competitors, actively benchmarking rival vehicles and studying technologies globally. As a result, engineers affirm that TNGA models will exhibit significantly improved driving dynamics, attributed to the platform's notably low center of gravity compared to its competitors.

Subaru Global Platform (SGP): The Subaru Global Platform, known as SGP (Figure 3.26), serves as the modular unibody automobile platform for nearly all Subaru models, beginning with the fifth-generation Subaru Impreza in 2016. Compared to earlier Subaru platforms, SGP offers enhanced strength, increased rigidity, and a lower center of gravity, resulting in improved dynamic performance. The adoption of a common platform has also increased production flexibility and efficiency, allowing existing production lines to adapt to demand by producing different models without significant reconfiguration, and enabling the reuse of common parts across models.

As of 2021, SGP serves as the foundation for all Subaru vehicles. The WRX, unveiling its second generation on September 10, 2021, for the model year 2022, was the final model to transition to the SGP. Notably, models produced by other manufacturers and rebranded by Subaru, such as the Justy and Kei car models, along with the jointly developed Subaru BRZ/Toyota 86, do not utilize the SGP. However, the platform for the second-generation BRZ/86 has been influenced by the SGP.

Figure 3.26: Subaru (SGP) modular platform

The recently introduced Subaru Global Platform is composed of sheets that constitute the foundation or floor on which the body structures and panels, the bulkhead separating the engine and passenger compartment, the suspensions, and additional components like the air conditioning system are situated. The rationale behind creating and designing this structure includes the aim to minimize the time and investments required for developing new vehicles. Essentially, it is a modular framework that, with minimal adjustments, can serve as the foundation for constructing various models, accommodating differences in size and type (Subaru Global Platform, n.d.).

For over five decades, Subaru has been a leader in automotive safety, consistently prioritizing the well-being of all occupants. Building on its already acclaimed lineup of vehicles known for safety, Subaru is once again setting new standards with the introduction of the Subaru Global Platform.

Initially featured in the 2017 Impreza and 2018 Crosstrek, this advanced architecture is set to play a pivotal role in the upcoming generation of all Subaru vehicles. The Subaru Global Platform has been meticulously designed with three primary objectives: enhancing straight-line stability, minimizing noise and vibration, and elevating ride comfort. This innovative architecture boasts a substantial increase in structural rigidity, ranging from 70% to 100% (depending on the models being compared). It incorporates notable improvements to steering and suspension systems and enables an even lower center of gravity, resulting in more responsive and sportier handling for the driver. Furthermore, the design effectively reduces vibrations felt through the steering wheel, floor, and seats, achieving a level of quietness that surpasses current best-in-class standards. By implementing stiffer suspension mounting, the Subaru Global Platform achieves a remarkable 50% reduction in body roll compared to current models, ensuring a comfortable and controlled ride even on challenging terrains.

Renault – Nissan Common Module Family (CMF): A Common Module Family (CMF) is an engineering framework that spans across Renault/Nissan Alliance vehicles, encompassing one or more vehicle segments. It is established by assembling compatible Big Modules, including the engine bay, cockpit, front underbody, rear underbody, and electrical/electronic architecture. It's important to note that a CMF should not be confused with a platform. While a platform represents a horizontal segmentation, a CMF is a cross-sector concept. In other words, a CMF can extend across multiple platforms rather than being tied to a specific one (Figure 3.27).

CMF serves as an advanced tool that surpasses the practice of carrying over elements within a single platform, aiming to broaden the scope of product offerings. The direction is toward enhancing common modules across multiple platforms to standardize components and augment the number of vehicles per platform. The implementation of CMF is set to progressively extend across the Renault and Nissan product ranges from 2013 to 2020. Initially, CMF will be deployed in the compact and large car segments, with subsequent application to models in other segments. For the compact and large car segments, CMF is set to encompass 1.6 million vehicles annually, spanning across 14 models (11 from the Renault group and 3 from Nissan)

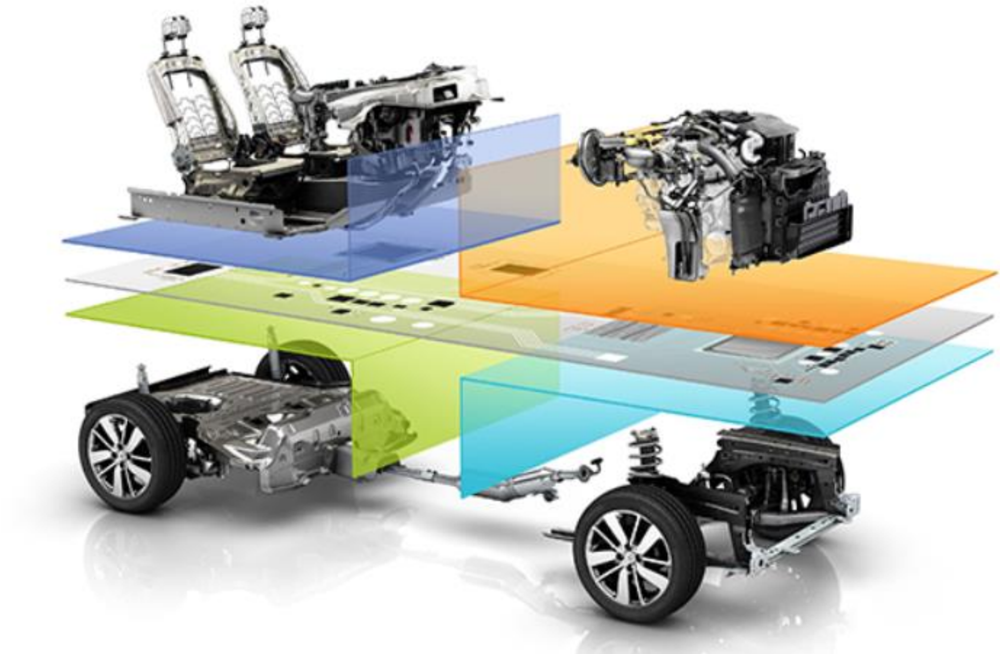


Figure 3.27: Renault-Nissan CMF modular platform

The initial Nissan vehicle releases are scheduled for late 2013 and will include replacements for Rogue, Qashqai, and X-Trail. Subsequently, the first Renault vehicles are expected to debut in late 2014, featuring replacements for Espace, Scénic, and Laguna. CMF is set to establish an "Alliance parts bank" that is precisely tailored to accommodate a diverse product range, aligning closely with customer preferences. The sharing and reuse of components among various models and entities lead to the realization of economies of scale. Implementing this system across the entire volume production of vehicles ensures sustained efficiency over the long term. CMF comprehensively addresses all expenditure aspects through synergies, shared volumes, economies of scale, and risk-sharing within the Alliance, resulting in:

- Component purchasing: The Alliance is poised to achieve a 20%-30% reduction in costs.
- Investment (single entry cost): A substantial 30-40% reduction in costs related to product and process engineering, with variations tailored to the needs of Nissan and Renault.

In comparison to the savings attained through making common on the B platform (originally designed for Modus and Clio for Renault and Micra for Nissan), CMF secures economies of scale by offering unprecedented coverage across the Alliance in terms of the number of vehicles and geographical regions (Nissan Motor Corporation, 2013)

BMW (CLAR) Modular Platform: It is a versatile platform that integrates steel, aluminum, and optionally, carbon fiber. The platform offers both rear-wheel drive and all-wheel drive configurations, making its debut in the G11 7 Series in 2015. Primarily designed for traditional internal combustion engine (ICE) setups, it also features an optional 48-volt electrical system in a mild-hybrid setup. Moreover, it is adaptable to accommodate plug-in hybrid and battery electric drivetrains.

Originally named 35up, the platform was later rebranded as CLAR (Figure 3.28). It spans various car segments, including D-segment, E-segment, F-segment, sports cars, and SUVs. For smaller BMW cars in the B-segment and C-segment, compact MPVs, and smaller SUVs, the front-wheel drive-based BMW UKL platform is utilized instead (Elliott, 2016; Homes, 2016)

Figure 3.28: BMW (CLAR) modular platform

The term "cluster architecture" and its acronym CLAR have been pivotal in BMW's discourse for several years. This highly adaptable architecture has replaced traditional car platforms, allowing for application across a diverse range of model series. Whether it's the compact and dynamic 2 Series Coupe or the luxurious X7 SUV, this architecture provides BMW with the flexibility to streamline production lines and achieve cost savings. During a financial meeting in Munich today, BMW CEO Oliver Zipse unveiled the next generation of cluster architecture, revealing plans to manufacture the new platform for numerous models in Hungary starting from 2025. Unlike some other automakers, the BMW Group continues to steer away from relying on an independent electric platform, choosing instead an architecture equally suitable for all types of drivetrains. While BMW did experiment with an independent electric architecture with the i3 electric hatchback, the endeavour incurred substantial costs, amounting to billions of euros (Boeriu, 2020)

3.1.4.1. Product Design

The first point to be considered in product design is the determination of the overall outline of the design. The specifications of the parts to be used for vehicle design were specified in the Innovation table. General dimensions will be determined first taking into account those constraints. It is important to verify the dimensions of each modular platform parts designed section by section (Figure 3.29). Each part should be designed by considering the dimensions of the components that will be assembled inside such as V8 or V12 engine, battery, or electric motor.

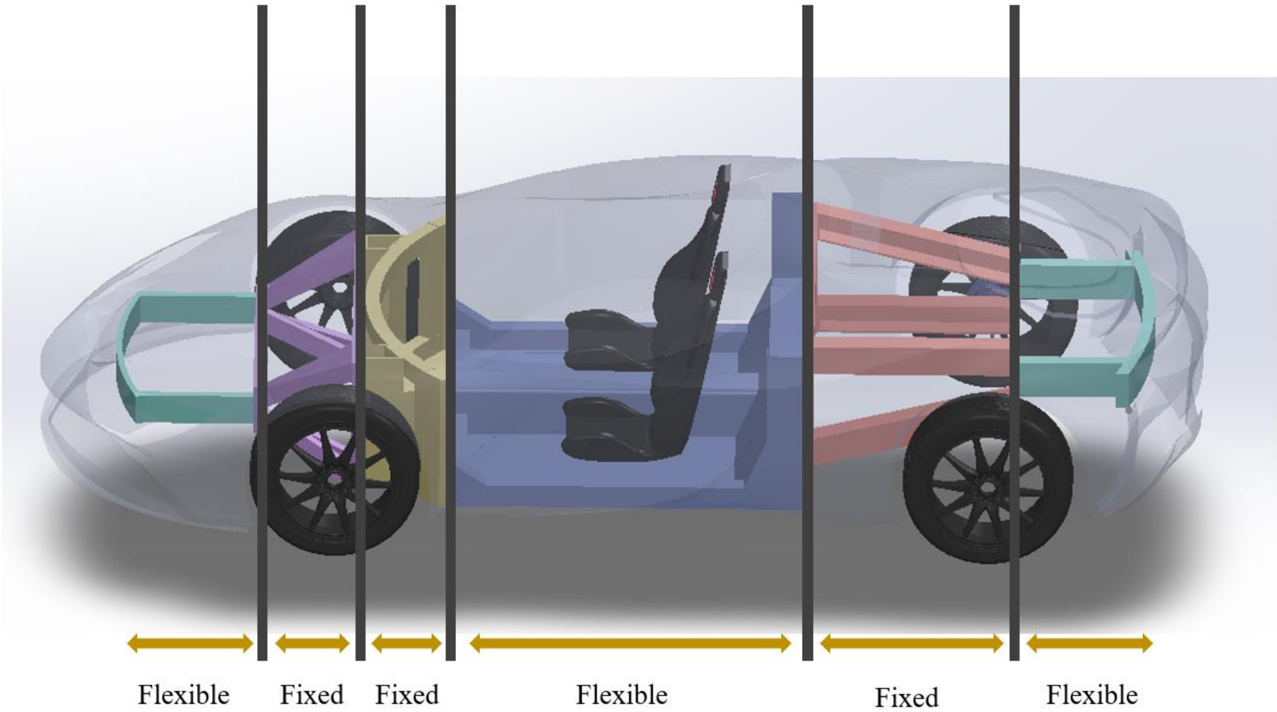


Figure 3.29: Modular vehicle platform

The biggest difference of our design from current systems is that, even though it is a modular platform, not all components are flexible, except for some parts. The aim is to design a standardized platform. Diversity will be achieved through the **interchangeability** of each part with other parts. This will provide us to keep some sections fixed and interchange others. In this thesis, the goal is to develop a platform that corresponds to multiple technologies and design systems, so the platform design will be based on product standards rather than focusing on a specific product.

3.1.4.1.1. Part 1: Engine Compartment

This section describes "Engine compartment" component (Figure 3.30) that can applied at the rear and front, depending on the powertrain layout of the vehicle (see Chapter 3.1.3.2.1. Powertrain Layout). This component is of crucial importance due to its role in incorporating the internal combustion engine, and it is essential for it to cover the dimensions of internal combustion engines suitable for sports cars, particularly in V6, V8, and even V12 sizes. Before deciding final dimensions, Internal combustion engine (ICE) external dimensions have to be taken into account for designing the internal space.

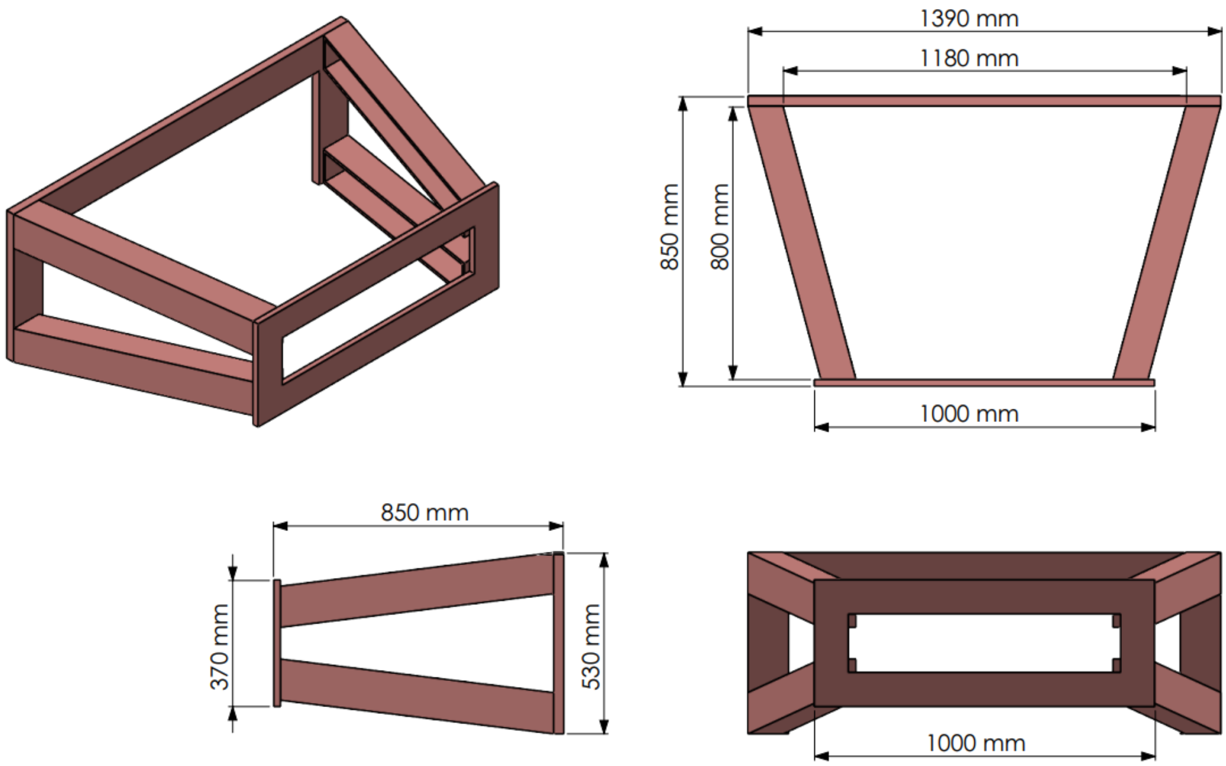


Figure 3.30: Part 1: Engine compartment dimensions

These dimensions have been provided in accordance with the measurement range of a currently manufactured sports vehicle. Subsequently, the suitability of the design will be checked. Existing internal combustion engines, including those with the same number of cylinders, can exhibit slight dimensional variations based on the technology used by the manufacturer. However, when considering a general platform, the standard dimensions you possess should be applicable to all. Therefore, below are images depicting the assembly of the part we designed with engines from different manufacturers, including measurements from companies such as Chevrolet (Figure 3.31), Jaguar (Figure 3.32), General Motors (Figure 3.33 and Figure 3.34), and Ferrari (Figure 3.35 and Figure 3.36) for V6, V8, and V12 engine designs.

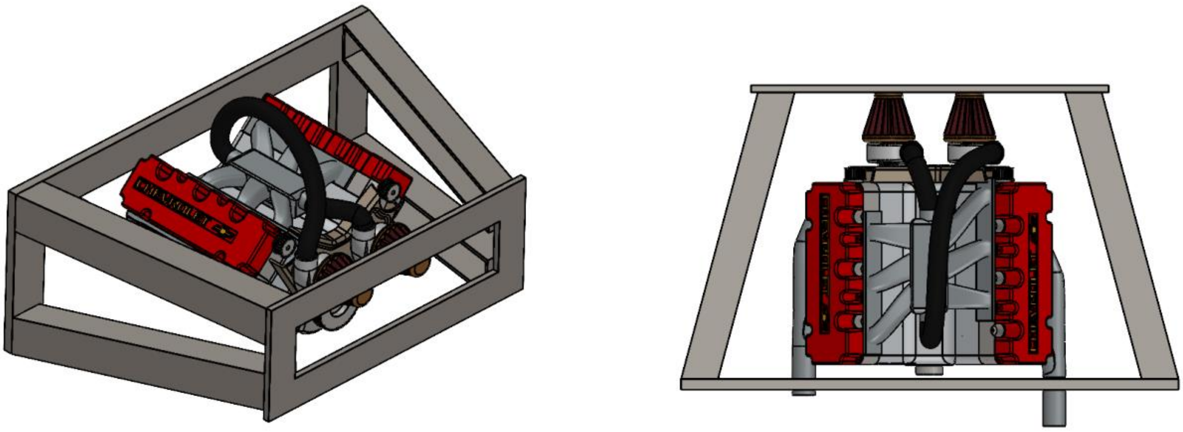


Figure 3.31: V6 Chevrolet engine for longitudinal position

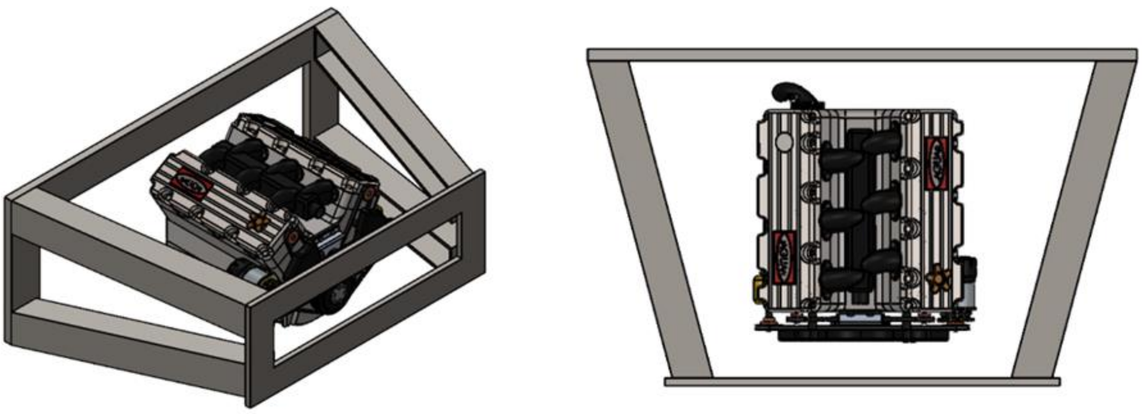


Figure 3.32: V6 Jaguar engine for longitudinal position

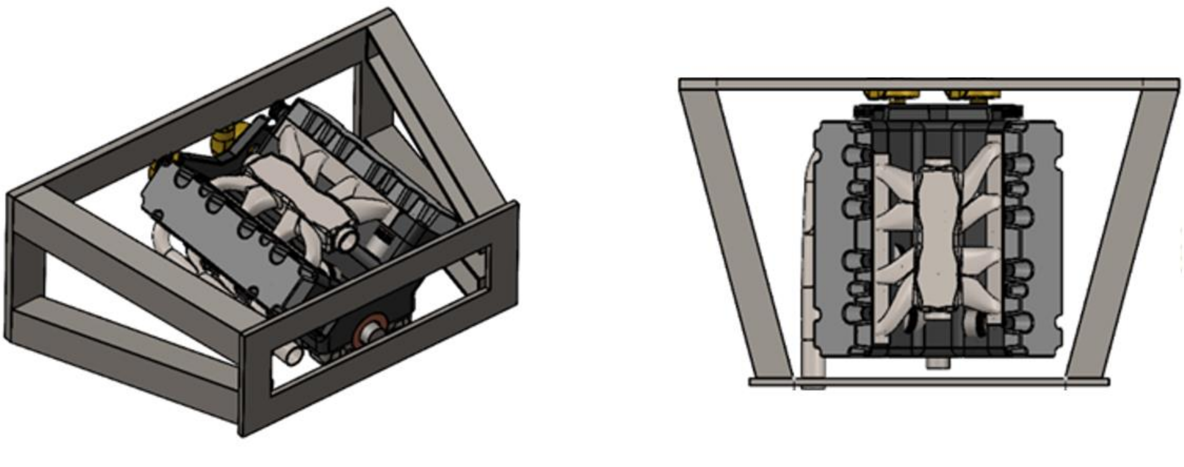


Figure 3.33: V8 Engine for longitudinal position

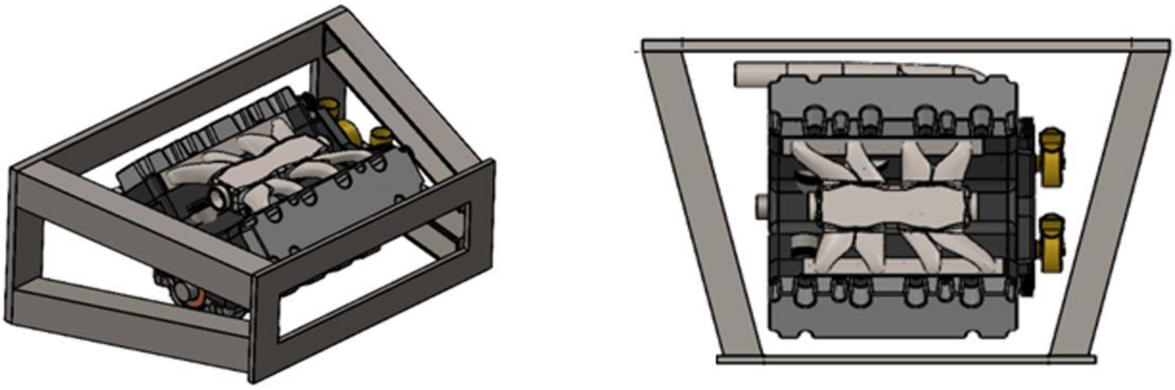


Figure 3.34: V8 Engine for transverse position

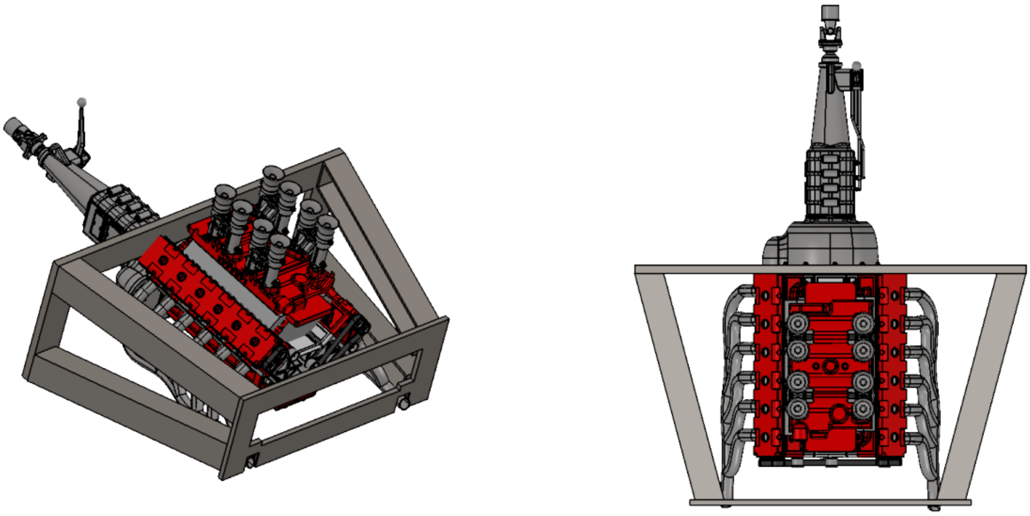


Figure 3.35: V12 Engine for longitudinal positioning with transmission

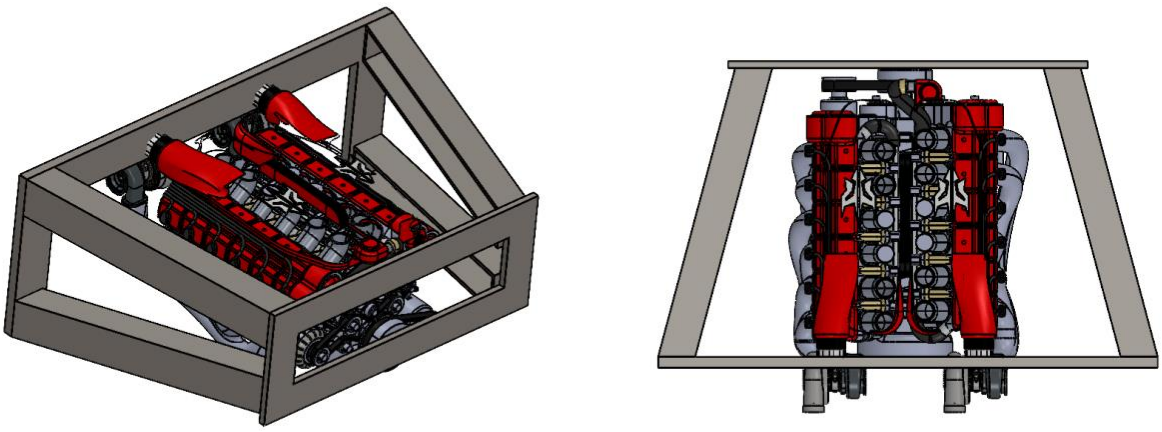


Figure 3.36: V12 Engine for longitudinal position

When assemblies with different engine models are checked, it is observed that the current design has sufficient space for different king of sports car engines.

3.1.4.1.2. Part 2. Passenger Zone

In the lower body design for the passenger area, there are some important issues that has to be taken account:

a) Seat arrangement
b) Battery assembly
c) Compatibility with different materials

a) *Seat arrangement* is one of the most crucial design challenges. Selecting appropriate design parameters will lead to the development of a seat that provides improved comfort and an enhanced driving experience. When trying to define the design features of a comfortable seat, it is crucial to consider a functional definition of comfort in the context of seating.

   Seat design parameters are categorized into three groups: fit parameter, feel parameter and support parameters. In this project, we only focus on fit parameters, because the levels of fit parameters are established based on the anthropometry of the occupant population, encompassing measures like the length of the seat cushion and this is all we need to decide the design dimensions for passenger part of the modular platform. Fit parameters contain cushion width, cushion length, backrest with and backrest height. For an optimal design, some parameters are crucial, such as the heel point (Figure 3.37).

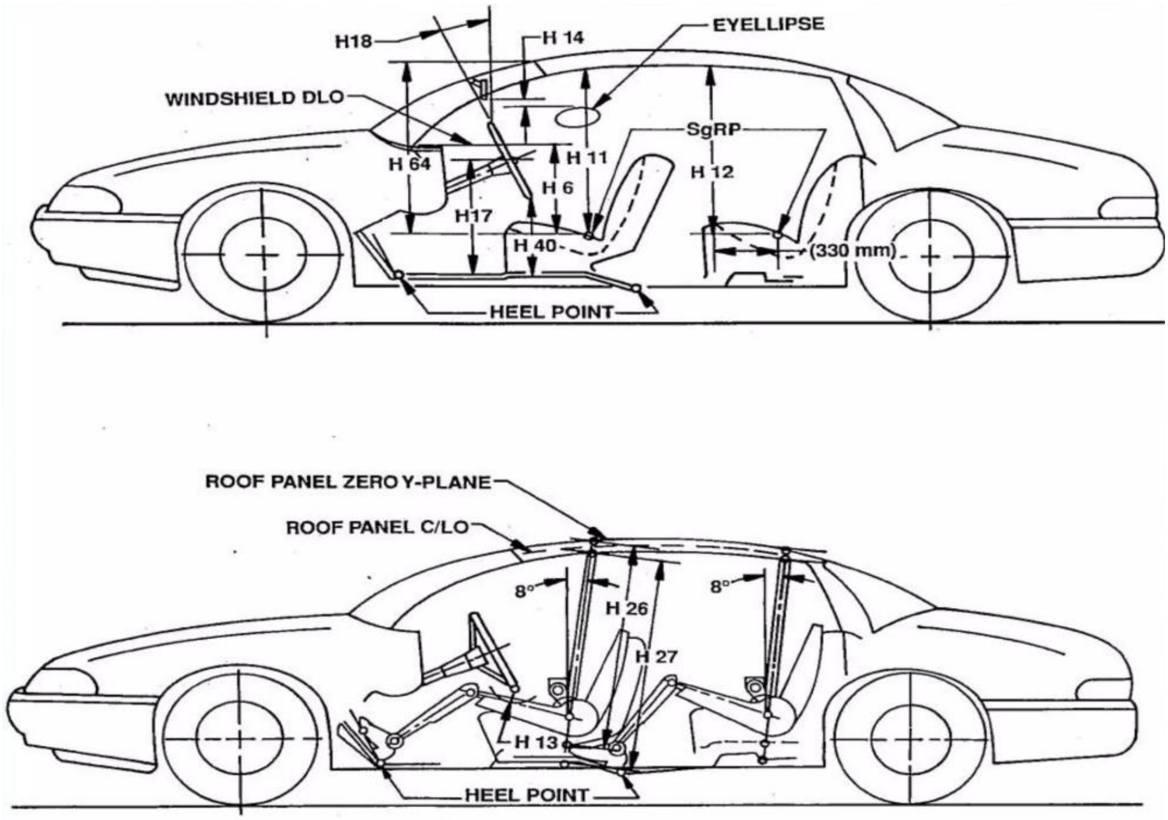


Figure 3.37: Dimensional parameters of seat arrangement illustrated on a car (Society of Automotive Engineers, 2001).

In the automotive industry, where a single seat serves a significant portion of the population, understanding population anthropometry is essential. The limitations on Fit parameter design values typically stem from the goal of accommodating a broad spectrum of the population based on a specific anthropometric measure. A commonly applied criterion in design is ensuring that the seat caters to individuals falling within the 5th-percentile-female to 95th-percentile-male range on a relevant anthropometric measure.

Seat back is the part of the vertical or slightly inclined section of the seat designed to provide support to the driver's lumbar, shoulder, and head regions. Typically, a head restraint system is positioned at the upper part of the seat back. The angle of the seat back is adjustable through a back reclining mechanism. Seat adjustments encompass height, forward and backward, and back reclining systems employed to modify the seat's height, front-to-back positioning, and backrest angle, respectively. A head restraint is positioned at the upper part of the seat back, serving the primary purpose of supporting the head and limiting backward displacement to safeguard the cervical vertebrae. Head restraints come in four types: integrated, detachable, separate, and proactive, with the latter being an advanced version of head restraint (Kale & Dhamejani, 2015)

It is advisable for the distance between the seat back and the waterfall line of cushion to be within the range of 440-550 mm. A recommended cushion width of at the range of min 480-500 mm is advised to cater to both clothing and leg splay. For the seat back height, a recommendation of between 495-640 mm, taking into account the sitting shoulder height of a petite female. (Bire, 2014; Daruis et al., 2011). The seat back breadth can be divided into lower and upper regions, with the lower region accommodating a tapered shape from 574 to 760 mm. Overall, a seat back breadth of 450 mm is suggested for the sports car. And the distance between seat back and front is 470 mm. For this modular platform a sports car seat designed for the assembly illustrated in Figure 3.38 with all measurement details.

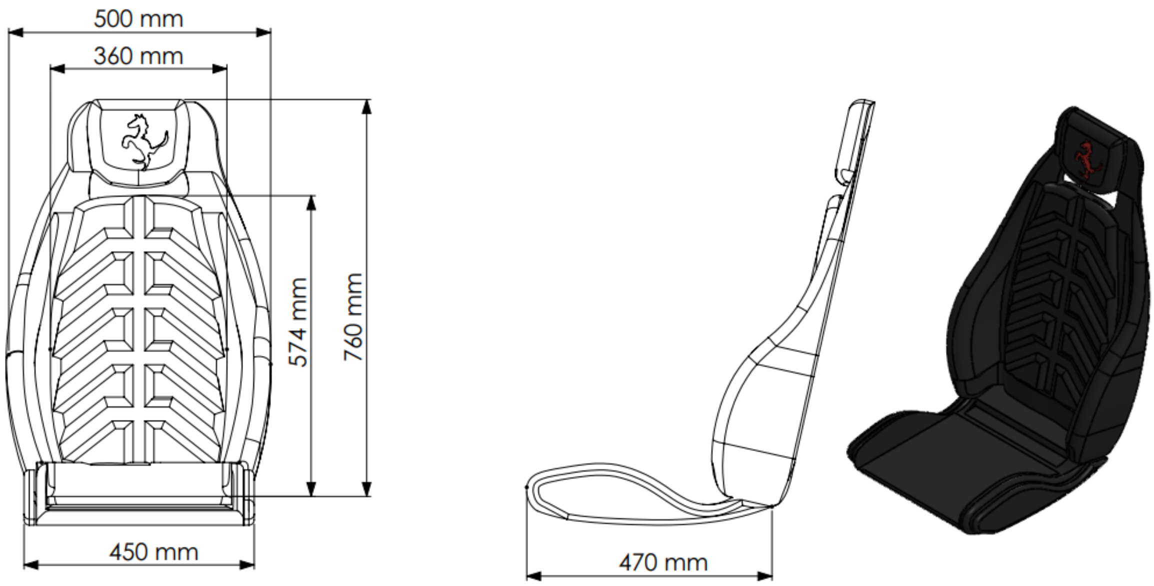


Figure 3.38: Sports car seat dimensions of fit parameters

b) *Battery assembly* has been specifically crafted for compatibility with the hybrid sports car. So, depending on the electric motor capacity and the amount of battery is needed will be assembled on this section. Main idea is to use behind the back wall of the passenger cabin for the battery location. However, if there is a need to expand the battery mounting area, a rearrangement can be made in the battery area based on the change in the fuel tank capacity used by the vehicle, depending on the space allocated for the fuel tank (Figure 3.39).

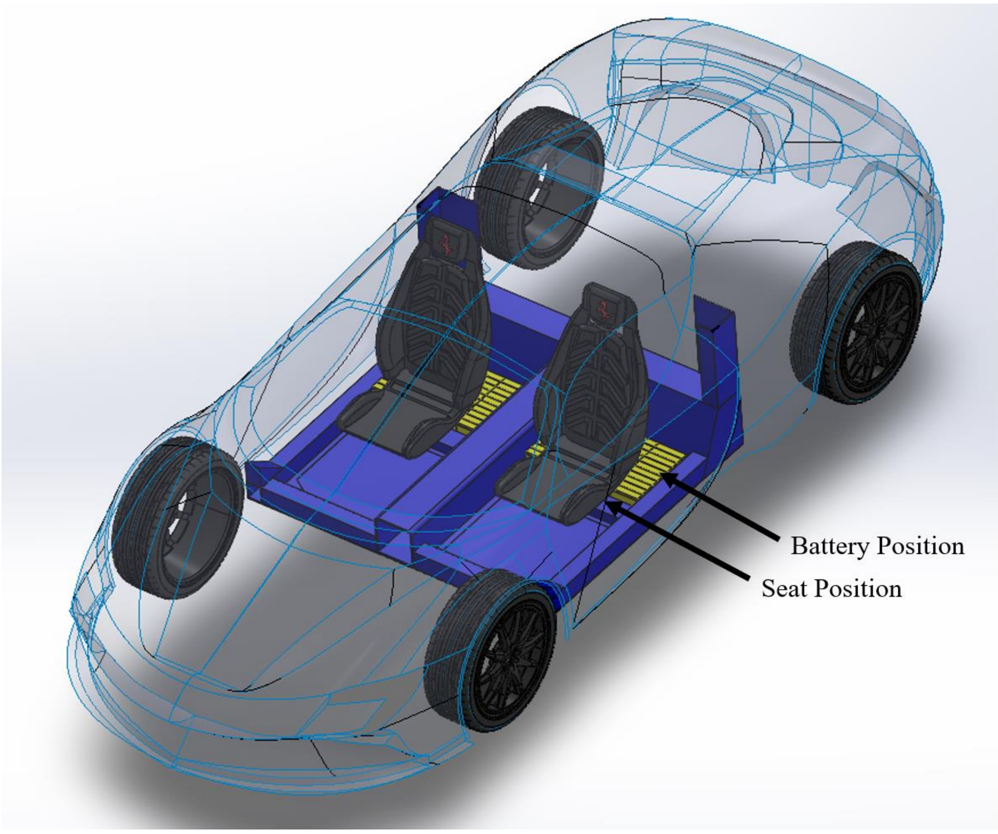


Figure 3.39: Battery positioning on modular platform

Since the volume to be used in the rear axle varies in front and mid-rear vehicles, this space can be utilized for extra batteries, and it varies according to the powertrain layout of the vehicle. The final measurements are shown in Figure 3.40.

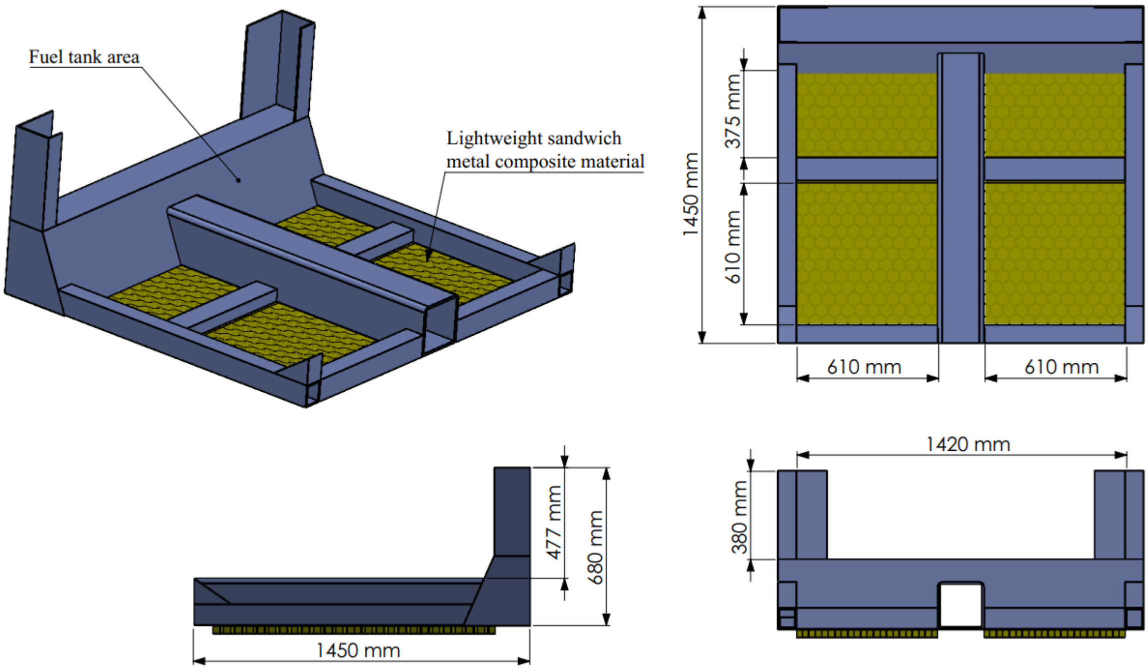


Figure 3.40: Part 2: Passenger zone dimensions

c) *Compatibility with different materials.* Especially, passenger lower body is suitable for the use of different materials due to its function during vehicle motion. In other words, in terms of yaw, roll, and pitch movements, the impact of this lower part is less compared to others. Bu still, it has to be resistant to the torsion. In particular, the inherent thickness of sandwich composites can provide a design advantage against torsional moments. Unlike steel structures, which have the tasks of holding the structure together and providing rigidity, lightweight metal sandwich materials are suitable for use in passenger compartments, especially due to their thickness and compact structure. Therefore, **lightweight metal sandwich composites** can be used for the bottom part of this component.

3.1.4.1.3. Part 3: Cockpit Underbody

This section, as understood from its name, covers the cockpit part of the vehicle, which is one of the fixed areas used in the modular platform design. In this design, the cockpit dimensions are verified using Ferrari SF90 Stradale for rear-mid engine and Ferrari 812 Competizione dimensions to define measurement which is inside the limits in the innovation table (Figure 3.41). These two car models have dimensions inside the limits defined in Table 3.3.

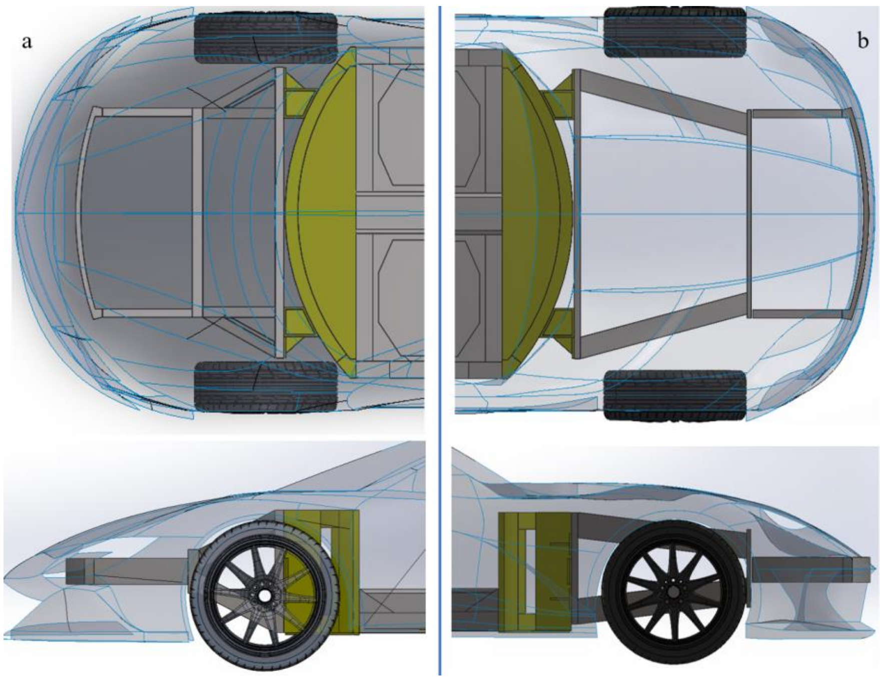


Figure 3.41: Part 3: Assembly with a) Rear-Mid engine configuration b) Front engine configuration

Taking into account these regulations, a cockpit section has been designed. All dimensional details are shown in Figure 3.42.

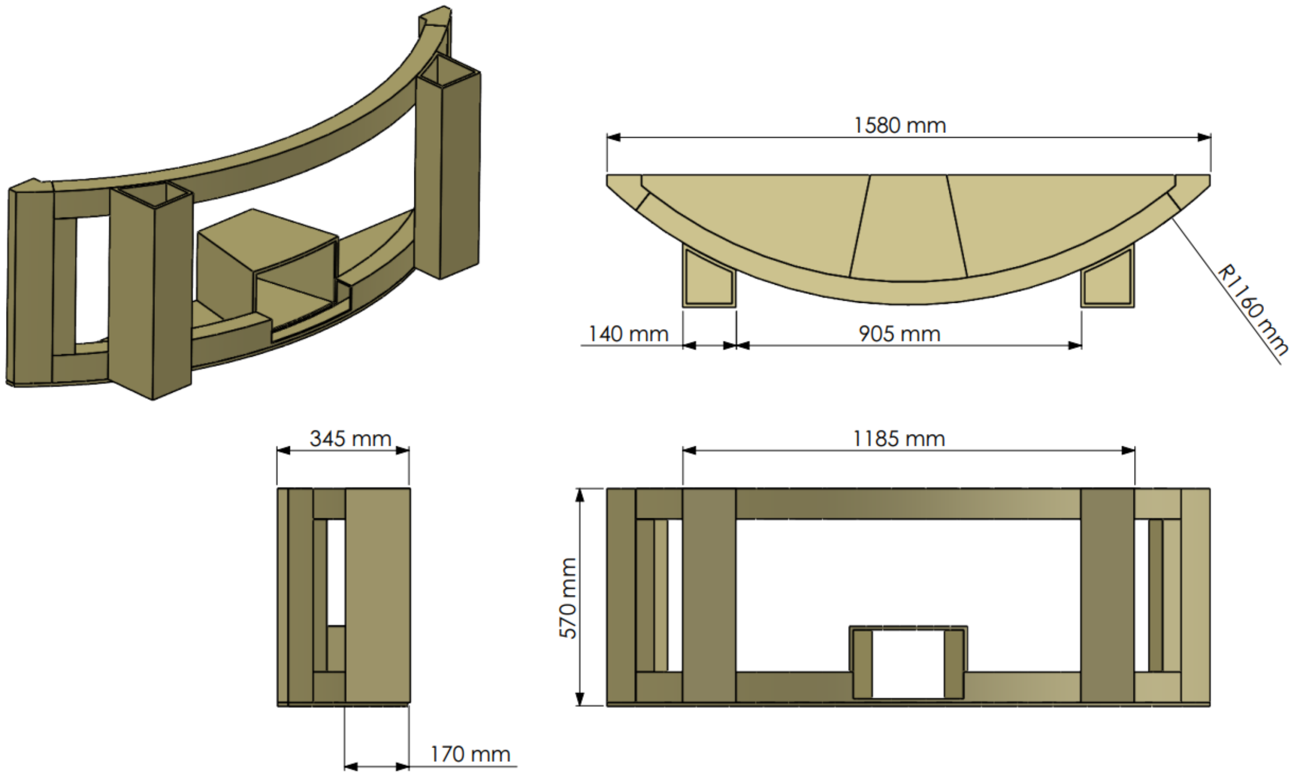


Figure 3.42: Part 3: Cockpit underbody dimensions

This part is drawn in a simplified manner, especially to be able to define the general framework and remain it open for further development. It is crucial issue for this section to be compatible with the lower part in the passenger section. Because the point where the passenger compartment and the cockpit merge is one of the points most affected by loads. Additionally, regardless of the engine position, this component must always join the passenger section at the same points, so they should be designed to be adaptable with each other.

3.1.4.1.4. Part 4: Electric Motor Compartment

This section defines the platform component that can be at the rear or front, depending on the type of the vehicle's powertrain layout. The dimensions of the part have been chosen based on the boundary dimensions have been defined in previous section. This part does not need to have large volume components. Therefore, the only component that we can illustrate inside these dimension limits is electric motor (Figure 3.43). But, as seen in the section 3.1.3.2.1 and 3.1.3.2.2, electric motor can be used in different positions regarding to the layout used.

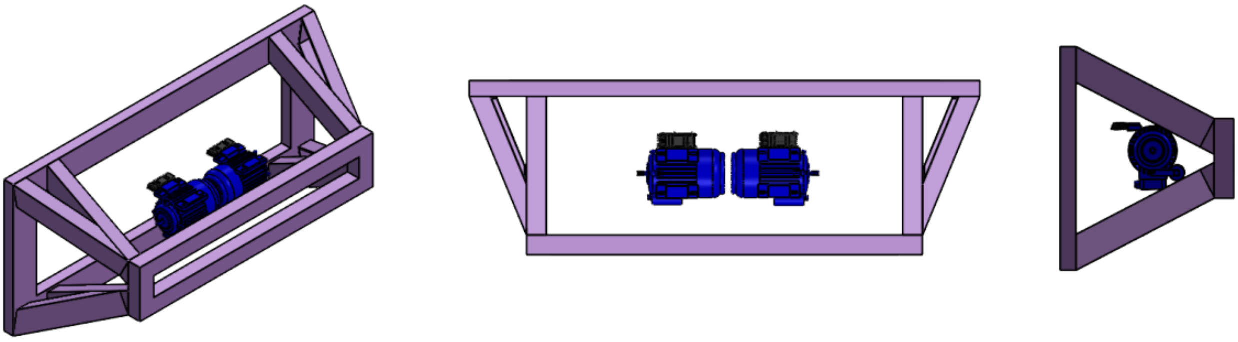


Figure 3.43: Part 4: Assembly with double electric motor

Validated dimensions of the section is seen in the following Figure 3.44.

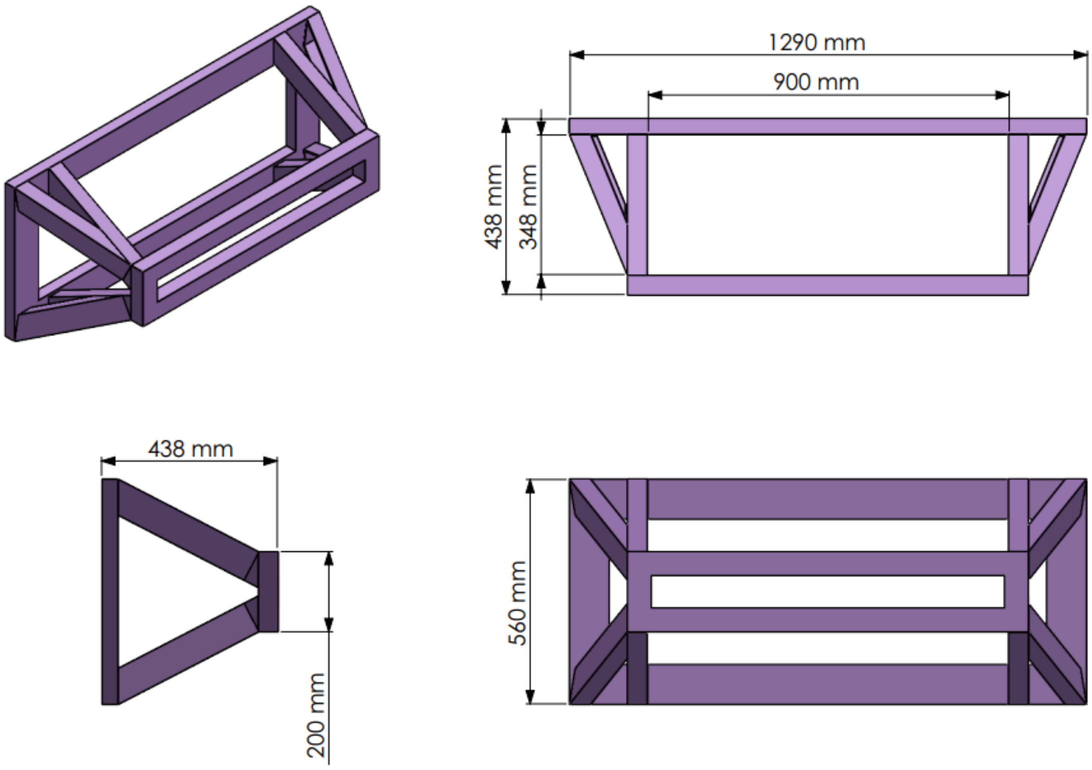


Figure 3.44: Part 4: Electric motor compartment dimensions

3.1.4.1.5. Part 5: Front Beams and Part 6: Rear Beams

There are beams assembly in front and rear to absorb the impact during the crash. There are several research for the material or structure design for the best energy absorption (Ha & Lu, 2020; Mehta et al., 2016; Qureshi et al., 2014; Wesselmecking et al., 2022; Yao et al., 2021). These researches are crucial to apply the proper material for the beams or design the best option for the impact or platform during the collusion.

The front and rear bumper beams in a car are designed to utilize energy-absorbing boxes to collapse and absorb a portion of impact energy. Subsequently, the remaining energy is transferred through both beams to the longitudinal beam and the passenger compartment. This process aims to minimize damage to the car's structure caused by collisions.

Traditionally, bumper beams have been predominantly constructed from high-strength steel, known for its strength and cost-effectiveness, albeit with a drawback of being heavy. However, the demand for lightweight vehicles has prompted a shift towards alternative materials. In recent years, aluminum alloys have gained preference over steel for bumper beams due to their lower density and superior energy absorption characteristics. This shift toward aluminum alloys addresses the challenge of achieving lightweight design in cars while maintaining structural integrity. Furthermore, aluminium alloys 7000 series are used in bumper beams or crash boxes as mentioned before in the Title: 3.1.3.2.3 Lightweightness. Alternatively, composite materials have emerged as a solution, offering a combination of lightweight properties and high strength. Lastly, there are some examples of magnesium used beams on chassis design which is another solution for lightweight and high strength (Du et al., 2023)

3.1.4.2. Dimension Verified Final Design

Each piece obtained as a result of the evaluations has been assembled to create the final model (Figure 3.45). When the measurement values are considered, all of them are within the range of values shown in the innovation table.

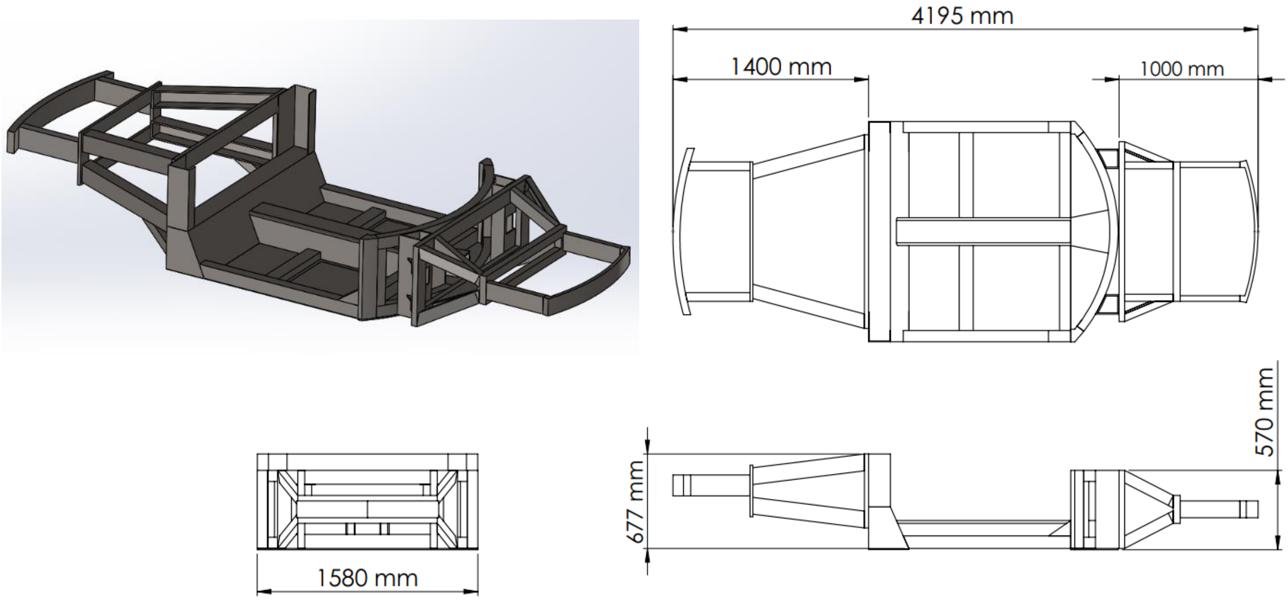


Figure 3.45: Modular platform design final model and dimensions

3.1.4.3. Mechanical Stress Analyses

This chapter defines the loads applied on the design and verification process of the chassis under these loads. The car system experiences external loads originating from road contact, inertia, and aerodynamics, as well as internal loads generated by various moving parts such as the engine, transmission, suspensions, and steering system. These internal loads serve as internal sources of noise and vibrations. By consolidating the resultant of inertia forces and aerodynamic loads at the center of gravity, the set of external loads acting on the vehicle can be simplified to six components applied at the center of gravity and six reaction forces/moments at each of the tires, as depicted in Figure 3.46.

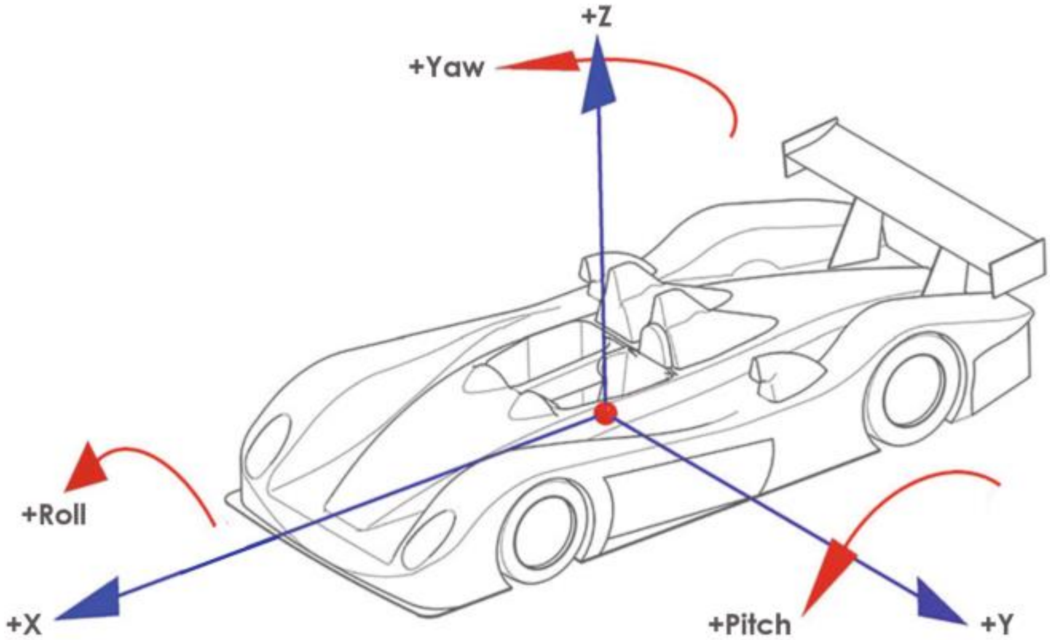


Figure 3.46: Forces during the car motion (Trzesniowski, 2014).

In the examination of vehicle motion within the field of vehicle dynamics, it is a common practice for the user to set specific operating variables. Consequently, values are assigned to parameters like forward velocity and tractive/braking force or longitudinal acceleration/deceleration. The motion of the unsprung mass is then analysed in relation to itself. These disturbances can be induced by a control action or external factors such as a wind gust. When investigating vehicle stability and control, the pertinent perturbation velocities include forward velocity, lateral velocity, yawing velocity, and rolling velocity. Pitch and vertical perturbations are disregarded in stability and control assessments. The lateral-directional equations, for this reason, are expressed in terms of lateral velocity, yawing, and rolling velocities (Milliken & Milliken, 1995)

In this chapter, the loading scenarios will be examined arising from these forces and moments. The car body can be viewed as a unified entity separated from the underpart (chassis) by elastic and damping components (springs, dampers, bushings). These elements serve to insulate occupants from shocks and vibrations. The vehicle is divided into the "sprung mass," comprising the body with interiors and passengers, and the "unsprung mass," consisting of the chassis and powertrain system.

When considering the car body as a system under static loads, deformations resulting from these loads depend solely on the **stiffness** characteristics of the body. Specifically, excluding inertia and aerodynamic forces, the loads acting on the body are those exchanged at the interface with the chassis/suspension system. In steady-state conditions, such as constant velocity cornering in a wide turn, the car experiences primarily static loads. Consequently, the body can be analyzed based on its **static stiffness** properties in such scenarios (Cheli, 2013).

The stiffness characteristics of the body can be assessed using either static or dynamic measurements. The body-in-white of the automobile is placed on a platform, anchored at designated points (like the front and rear dome attachments), and subjected to a predetermined set of loads. In our context, a dedicated vehicle platform will be formulated, and an analysis of the potential deformations the platform might experience will be conducted. The various loads to which the chassis is subjected include:

- Longitudinal Torsion (vertical asymmetric loads)
- Vertical Bending (vertical symmetrical loads)
- Lateral Bending (lateral loads)
- Horizontal Lozenging (longitudinal asymmetric loads)
- Crash Cases

3.1.4.3.1. Longitudinal Torsion (Torsional Stiffness)

Longitudinal torsion endurance is characterized by the ability of torsional rigidity to withstand twist loads, as illustrated in Figure 3.47. To comprehend longitudinal torsion, imagine the scenario where the front tires of a vehicle go upward due to a bump, considering the critical conditions of dynamic loads on the front chassis. This situation significantly influences the equilibrium of handling.

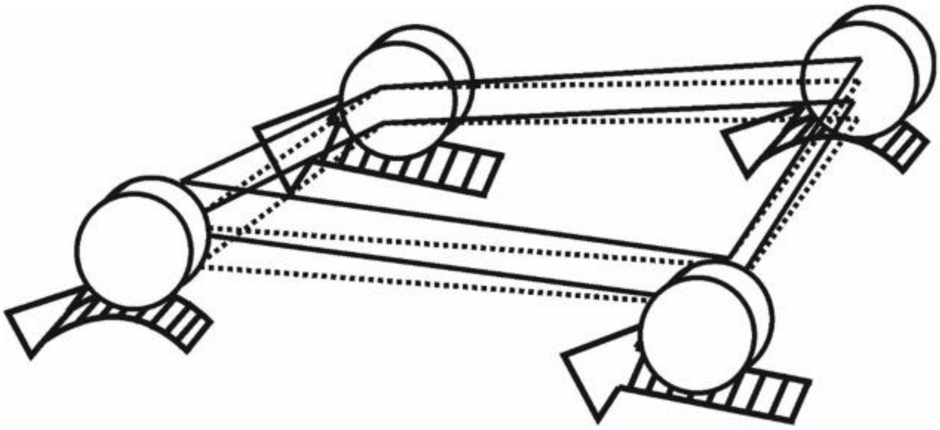


Figure 3.47: Longitudinal torsion

The design of the chassis involves ensuring adequate torsional rigidity; insufficient rigidity can adversely impact suspension performance. Torsional rigidity indicates the amount of torque required to deform a component and is a key factor influencing the frame performance of cars. This can be determined by conducting a static torsional test under longitudinal torsion conditions. An ideal chassis possesses high stiffness with minimal weight and cost. A chassis that flexes is more susceptible to fatigue and subsequent failure; however, if a chassis can effectively handle torsional loads, bending should pose less of a concern (Hazimi et al., 2018; Mendes Costa, 2020).

The importance of body torsional stiffness in car design is well-established. Variations in torsional stiffness can impact suspension kinematics, compliance, and the handling, steering, and ride characteristics of the vehicle. The adjustability of the chassis is influenced by this parameter, determining its capacity for tuning. For example, an overly flexible chassis can pose challenges in adjusting the lateral load transfer distribution alongside roll stiffness distribution (Danielsson, 2015). Figure 3.48 defines a schematic drawing of the torsion load on a car chassis.

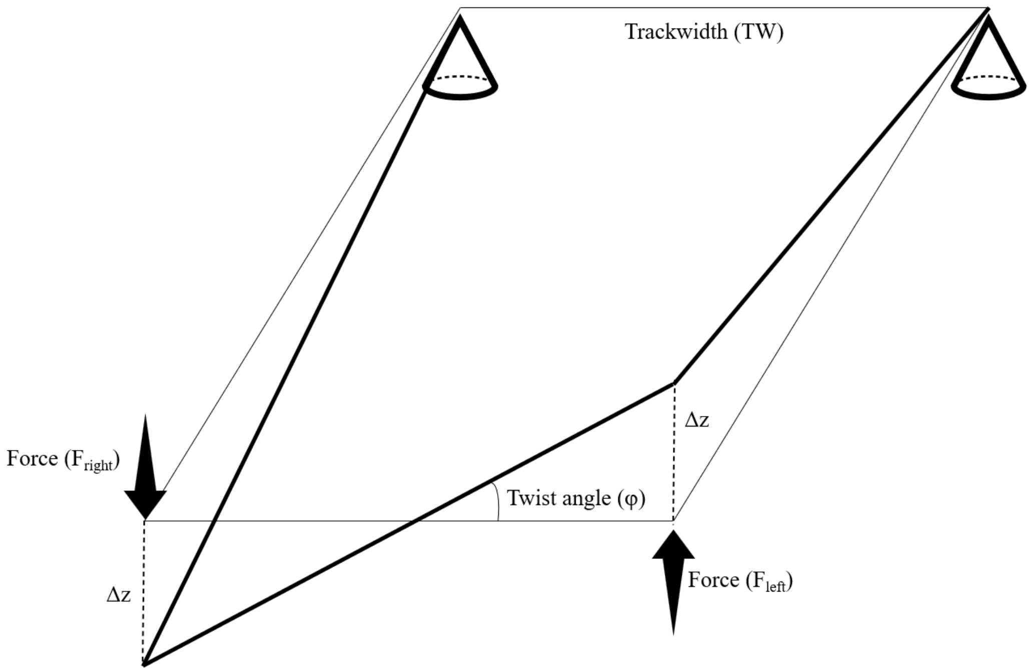


Figure 3.48: Torsional stiffness load case

Torsional stiffness can be computed using Equation (a) for the torsion angle, Equation (b) for the torsion moment, and Equation (c) for the value of torsional stiffness.

$$\phi_{front} = \arctan\left(\frac{\Delta z}{0{,}5.TW_{front}}\right) \quad (a)$$

$$T_{front} = \frac{1}{2}.TW_{front}.\left(F_{left} + F_{right}\right) \quad (b)$$

$$K_{body}\left[\frac{Nm}{deg}\right] = \frac{T_{front}}{\phi} \quad (c)$$

3.1.4.3.2. Vertical Bending (Bending Stiffness)

This loading scenario holds the second-highest significance for the chassis due to its fundamental importance. Vertical bending is relatively more significant compared to other loading types because the chassis is constantly under this influence at all times. This is a type of loading on the chassis due to the weights of all the components carried by the chassis and the driver (Figure 3.49). While vertical bending in the chassis only arises due to the gravitational effect when the vehicle is in a static state, most of the time, there will be a much higher magnitude of vertical bending than the static situation because the vehicle is often under the influence of dynamic loading (Zhen Hui, 2012). (Bonsanto Oliveira et al., 2018; Hazimi et al., 2018)

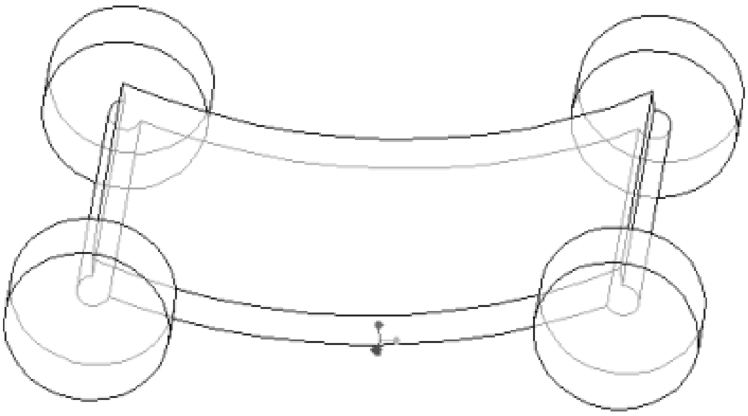


Figure 3.49: Vertical bending

Bending stiffness involves a deviation in **the pitch angle** between the front and rear parts of the vehicle body. The body of the vehicle undergoes bending when subjected to acceleration, leading to load transfer. This phenomenon becomes evident during both acceleration and deceleration, resulting in what is commonly known as dive and squat behaviour. Another instance where bending stiffness comes into play is the recovery of the pitch angle after encountering a speed bump. In the design of vehicle bodies, there is a belief that a higher torsional stiffness value will also contribute to achieving an appropriate level of bending stiffness. Nevertheless, it is intriguing to examine whether enhancing bending stiffness would bring about alterations in the dynamic behaviour of a passenger car (Danielsson, 2015). A prevalent technique for assessing static bending stiffness is the three-point bending test, depicted schematically in Figure 3.50.

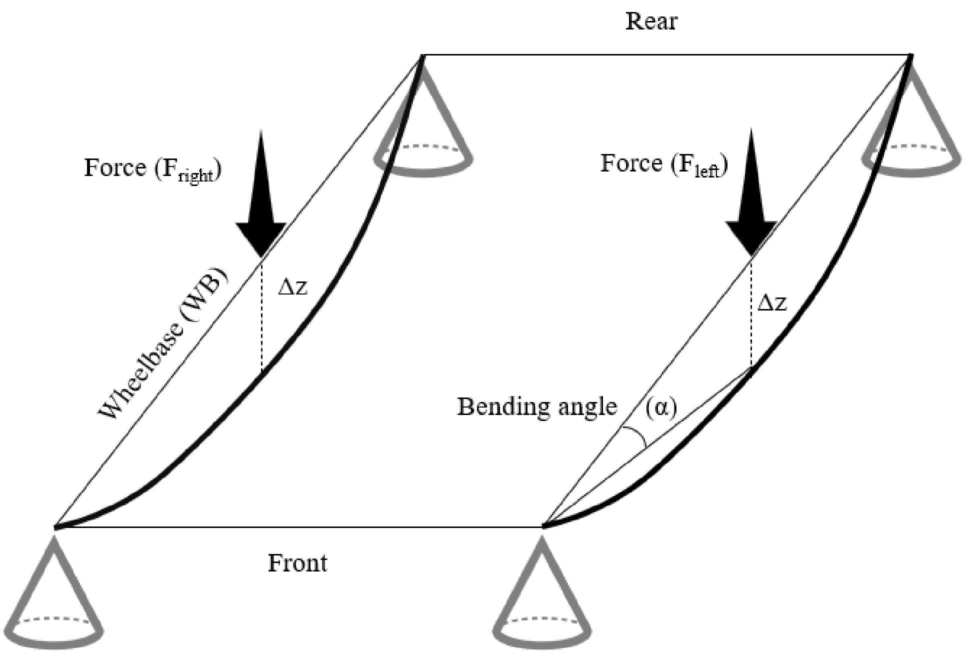


Figure 3.50: Bending stiffness load case

The equations employed in determining the bending characteristics include Equation (d) for the bending angle, Equation (e) for the bending moment, and Equation (f) for bending stiffness.

$$\alpha_{front} = \arctan\left(\frac{\Delta z}{0{,}5.WB}\right) \tag{d}$$

$$T_{left} = \frac{1}{2}.WB_{left}.\left(F_{left}\right) \tag{e}$$

$$K_{body}\left[\frac{Nm}{deg}\right] = \frac{T_{left}}{\alpha} \tag{f}$$

3.1.4.3.3. Lateral Bending (Lateral Stiffness)

This particular loading scenario (Figure 3.51) occurs when the sports car negotiates a high-speed turn, resulting in the transfer of inertial forces to the chassis. The magnitudes of these forces are contingent upon the sports car's speed, the corner's radius, and the degree of road banking. This specific load case holds significance for chassis sections directly linked to the suspension. The chassis members in this region directly bear the load of the suspension, leading to stresses in these members that can be significantly higher compared to those in other sections of the chassis (Oymak & Feyzullahoğlu, 2021).

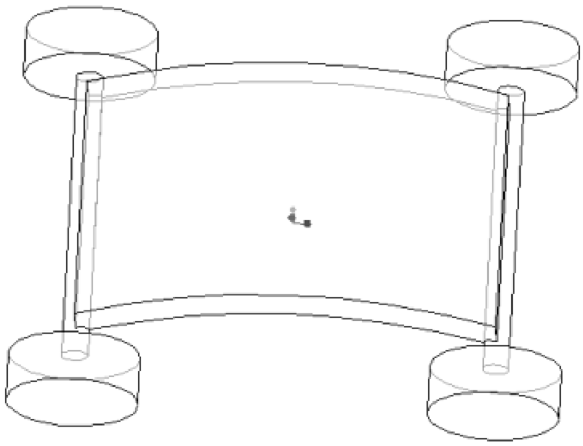


Figure 3.51: Lateral bending

Lateral stiffness pertains to a load case in which a force is exerted in the lateral direction at both the front and rear axles. This situation is analogous to the centrifugal forces experienced during cornering. The distribution of lateral stiffness between the front and rear axles plays a crucial role in influencing the yaw behaviour of the vehicle, ultimately impacting the car's performance in terms of yaw dynamics. Although assessing the lateral stiffness of the Body in White (BIW) is not a commonly performed evaluation in body design, it is important to highlight that its influence in shaping vehicle dynamics should not be ignored or undervalued.

3.1.4.3.4. Horizontal Lozenging

This situation, shown in Figure 3.52, arises when opposing wheels experience uneven loads, resulting in a deformation that takes on a parallelogram shape. This deformation is caused by factors such as variations in the road's vertical profile, differences in traction between one side of the car and the other, and instances of heavy braking where one tire locks up. Similar to the lateral bending load case, this scenario is crucial for sections of the chassis directly linked to the suspension.

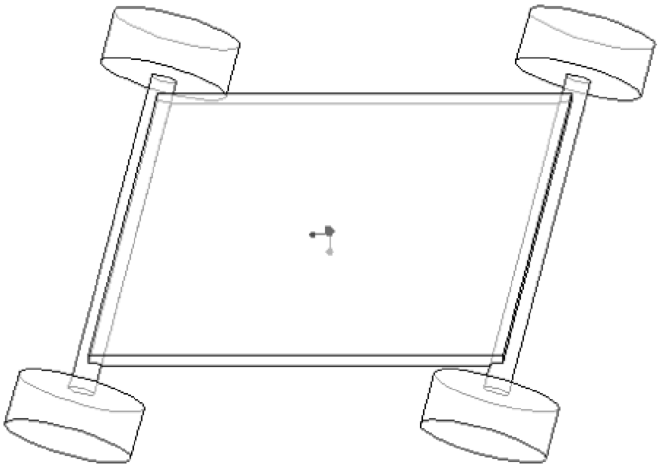


Figure 3.52: Horizontal lozenging

3.1.4.3.5. Crash Cases

Crash cases involve the analysis of forces and impacts that a vehicle may experience during various types of collisions. Chassis design engineers need to consider these scenarios to ensure that the vehicle structure can effectively absorb, distribute, and manage the energy generated during a crash, providing optimal protection for occupants. In the event of a collision, it is essential for the structure to deform in a manner that absorbs the impact energy, ensuring safe deceleration levels and protecting the driver's body. You may have observed that older cars exhibited greater impact resistance compared to modern cars, where even minor collisions can result in significant damage. Enhancing passenger safety involves absorbing a substantial portion of impact energy through the deformation of the car's chassis.

The primary goals of Crash Analysis, commonly referred to as an NCAP test, are to guarantee the overall safety of the occupants in a vehicle, with a particular emphasis on the passenger seating. The energy absorber plays a crucial role in enhancing the overall safety of passengers in a vehicle. In the testing process for crash analysis, a dummy model, designed to replicate the occupant, is utilized while seated in the vehicle. Materials utilized as energy absorbers need to be lightweight, cost-effective, and capable of withstanding significant shock during a crash. The incorporation of lightweight components in a vehicle contributes to an overall reduction in vehicle weight, thereby aiding fuel efficiency. Materials such as Aluminum, Aluminum alloys, Steel, Magnesium alloys, various Polymeric materials, and Composite materials like Carbon Fiber Reinforced Plastic (CFRP) play a significant role in enhancing the efficiency and applicability of the energy absorber. When subjected to testing, CFRP undergoes distortion upon crushing, while aluminum tends to fold under the same conditions (Carroll et al., 2010; Chandak et al., 2021).

In this study, to understand the deformation areas of the modular platform, a crash test can be simulated by using software. Frontal impact scenario has been performed on platform design to understand the maximum deformation areas to define and decide which areas are suitable for development and which parts are most convenient to change. Some those loading scenarios above will be sufficient to validate our modular platform design.

- Torsion stiffness analysis
- Bending stiffness analysis
- Frontal Impact analysis

Those analyses will be performed to understand the platform behaviour. Particularly during torsion stiffness analysis, it will be evident which areas will experience high stress, and crucial parts that require attention will become clear. For the bending test shear stress will be examined in the connection areas. For the crash test, analysing where the deformation will concentrate at the front of the vehicle during a collision will assist us during the product development stage for the part development.

3.1.4.3.6. Torsional Stiffness Analysis

- For Rear-Mid Engine Layout

As mentioned before in load cases section, torsional rigidity is of a design is related with angular deflection of the modular platform. Determining this deflection is possible by conducting a simulation with precise parameters. SolidWorks Simulation was utilized to determine the torsional deformation caused by forces on the designed model. The modular platform design has been simplified for torsional simulation. This can be achieved with “Beam Model Method”. Beams serve as mathematical entities enabling a simplified depiction of the vehicle structure's stress and strain in response to external loads and constraints. These mathematical models are established through structural analysis using the finite element method (FEM). Assuming restricted displacements, the conventional correlation between forces and displacements can be acknowledged (Genta & Morello, 2009). The first step for stiffness analysis is to define the boundary conditions and torsion forces on the platform. Loading areas and fixed areas have been defined in the program as joints as seen Figure 3.53.

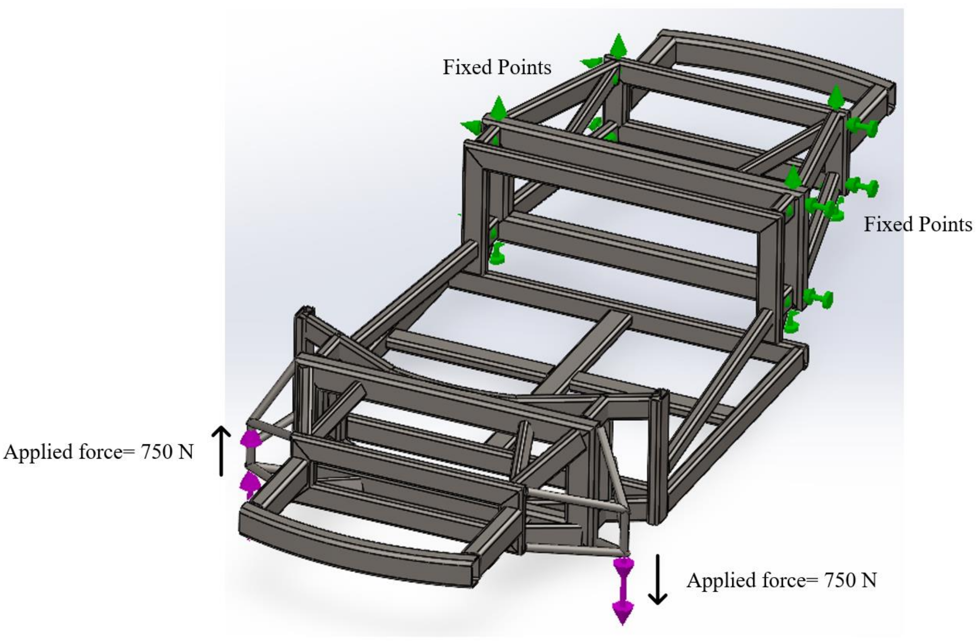


Figure 3.53: Boundary conditions on rear-mid modular platform

While loads applied on chassis shown with purple arrows, fixed points at rear shown with green marks. All parts were configured to be made of AISI 4130 Steel alloy. Because, initially, analysis will be made on a homogeneous design with materials and this alloy is one of the most commonly used ultra strength steel on car chassis design. To enable comparison between the initial and final designs, efforts were made to keep the design as free from complexity as possible. All simulations have been built on a system where all components are defined as beams, and connection points are taken into account while defining fixed geometry and loading areas. At the end of the simulation, the first important parameter that is needed to be examined is the displacement value are shown in Figure 3.54.

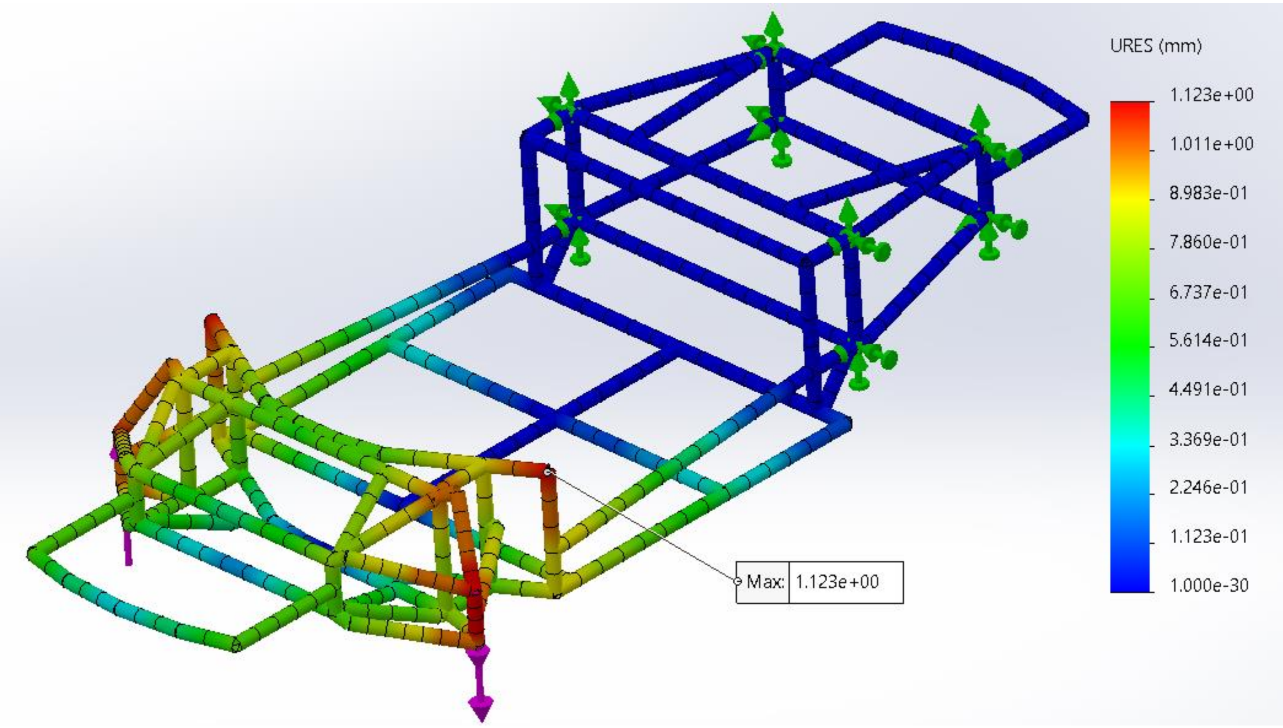


Figure 3.54. Displacement results of torsional test for rear-mid modular platform

Max displacement which is 1.123 mm occurs in the area of cockpit (Part 3). Torsional rigidity equation is given in Equation (c) which is the ratio of the torque load to the angular deflection. Angular deflection (ϕ) is calculated here is 0.09969 (deg). From the Equation (b), torsional stiffness value (K) is found 9705.086 (Nm. /deg).

The most important parameter is to find torsional rigidity which is represented in Figure 3.55.

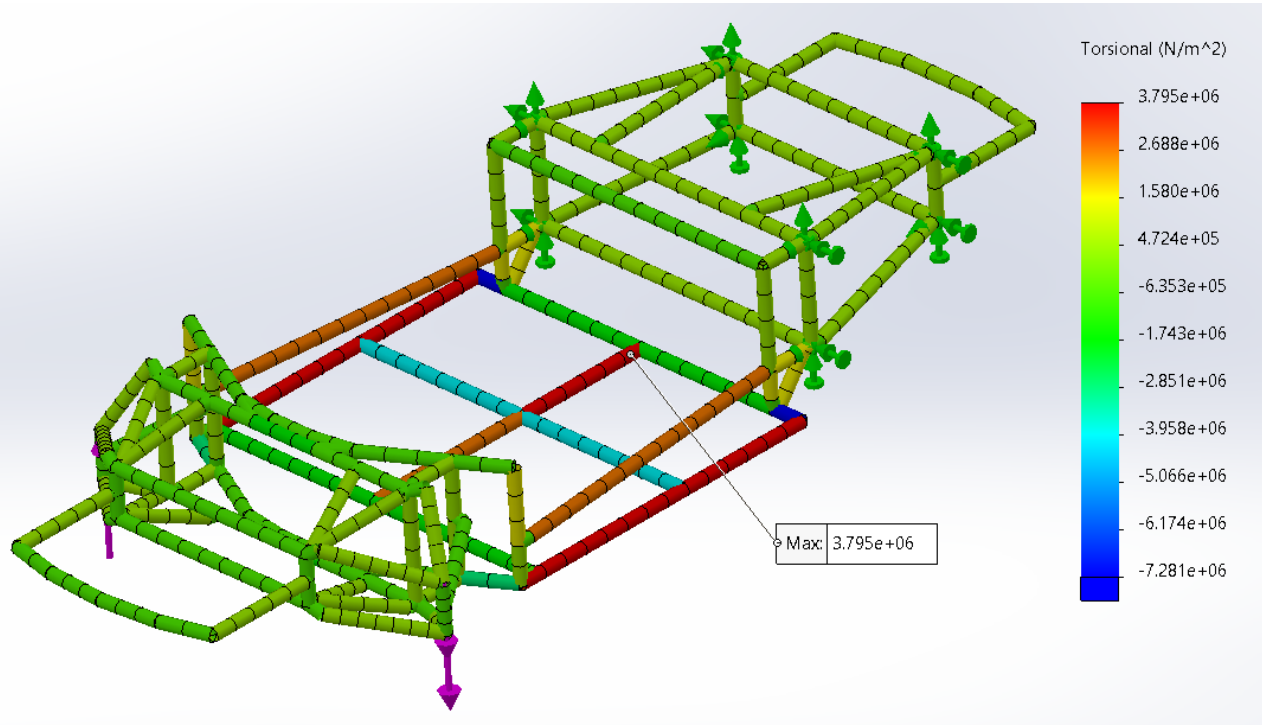


Figure 3.55. Torsional stress distribution of rear-mid modular platform

The maximum torsional stress is 3.795 MPa, occurs in the passenger zone (Part 2). Since this model only includes the lower part of the chassis, it includes higher stresses, especially in the passenger section. However, the main focus here should be on the connection points of Part 2 with the other sections (Part 1 and Part 3).

The support beams in Part 3 and Part 4 bear the stress. Those areas can bear enough stress thanks to the geometry. This means that boundary conditions to be created for generative design can be performed in these areas. It is obvious that the most important joints to examine are the areas where engines and suspension systems are assembled. Having sufficient strength geometry even in this simplified model gives us an opportunity using aluminium alloys, especially in cockpit underbody

(Part 3) and electric motor compartment (Part 4) sections. The compatibility of the aluminium alloy used parts in this design will be analysed in the Generative Design application.

- For Front Engine Layout

The initial model we have is suitable for the rear-mid engine layout, which is most commonly used in sports cars. However, there is an increasing trend in the production of sports cars that can also serve as family vehicles to reach a broader market. The most significant difference is that these vehicles are generally designed with a front-engine layout. This section will include the torsion test of the modular platform designed for the front engine layout.

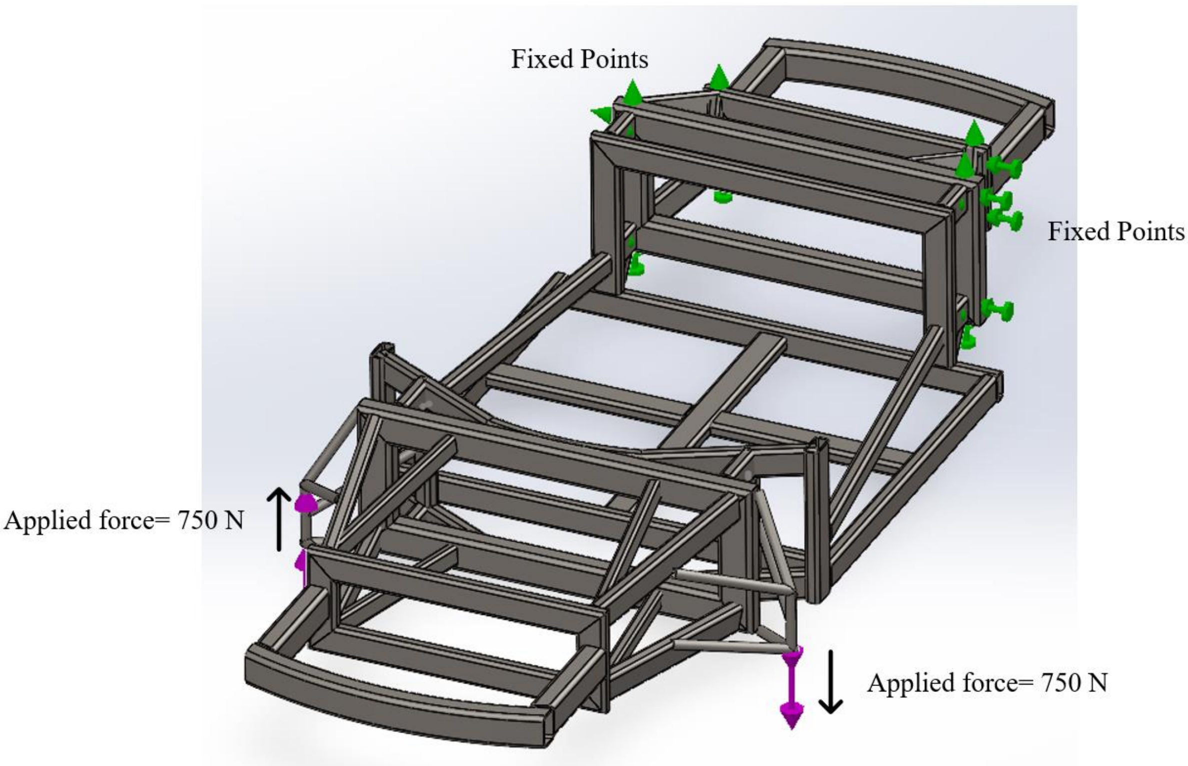


Figure 3.56: Boundary conditions on front modular platform

Same simulation settings have been used for the front engine layout. Figure 3.56 shows fixed joints and the loads applied on the model. The material used on the model is the same with previous model which is AISI 4130. Results have been shown in following figures (Figure 3.57 and Figure 3.58).

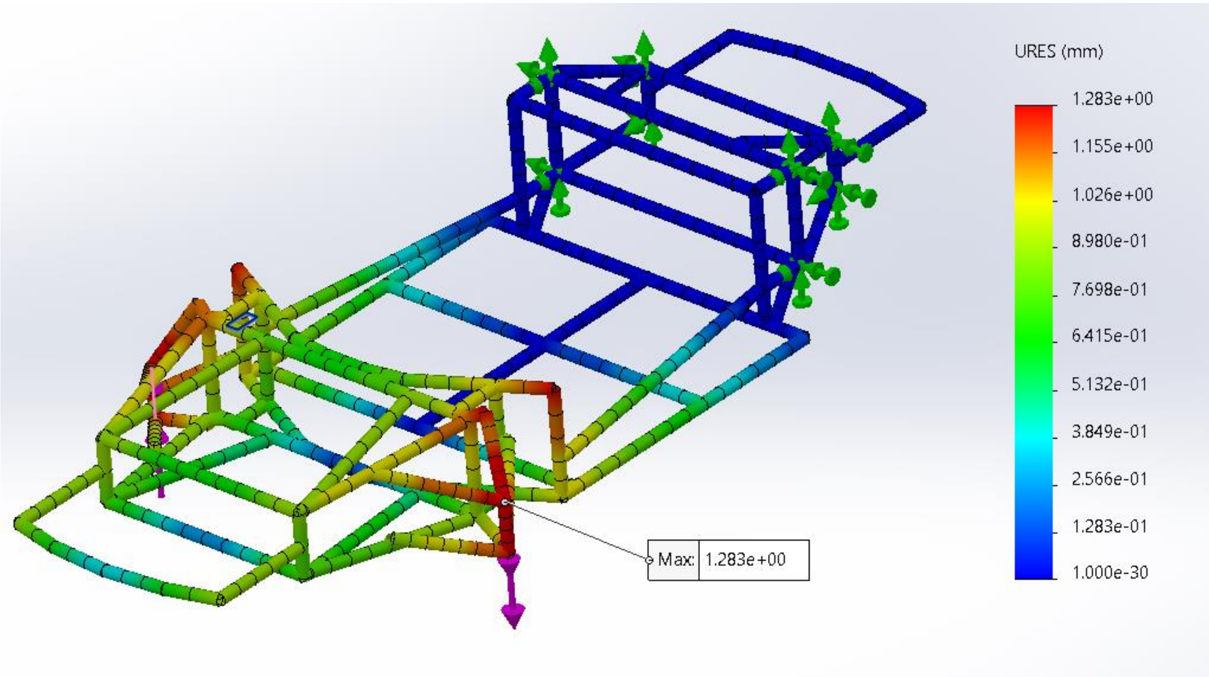


Figure 3.57: Displacement results of torsional test for front modular platform

Displacement results (Figure 3.57) are slightly higher than rear-mid modular platform design. Maximum displacement in this simulation is 1.283 mm occurs in the Part 3 upper section connection joints. In this simulation, lower and upper suspension arms are incorporated into the design to apply the forces that affect the geometry. However, the stresses on the simulation arms are excluded from the evaluation. As a result, the maximum stress occurs in Part 3, where the curved beam is connected to the vertical beam provides connection with passenger zone (Par2). Torsional rigidity for this design is calculated with Equation (c) and the final value is for angular deflection is 0.104 (deg). Another calculation involves the determination of torsional stiffness (K), which is calculated as 10024.024 (Nm. /deg).

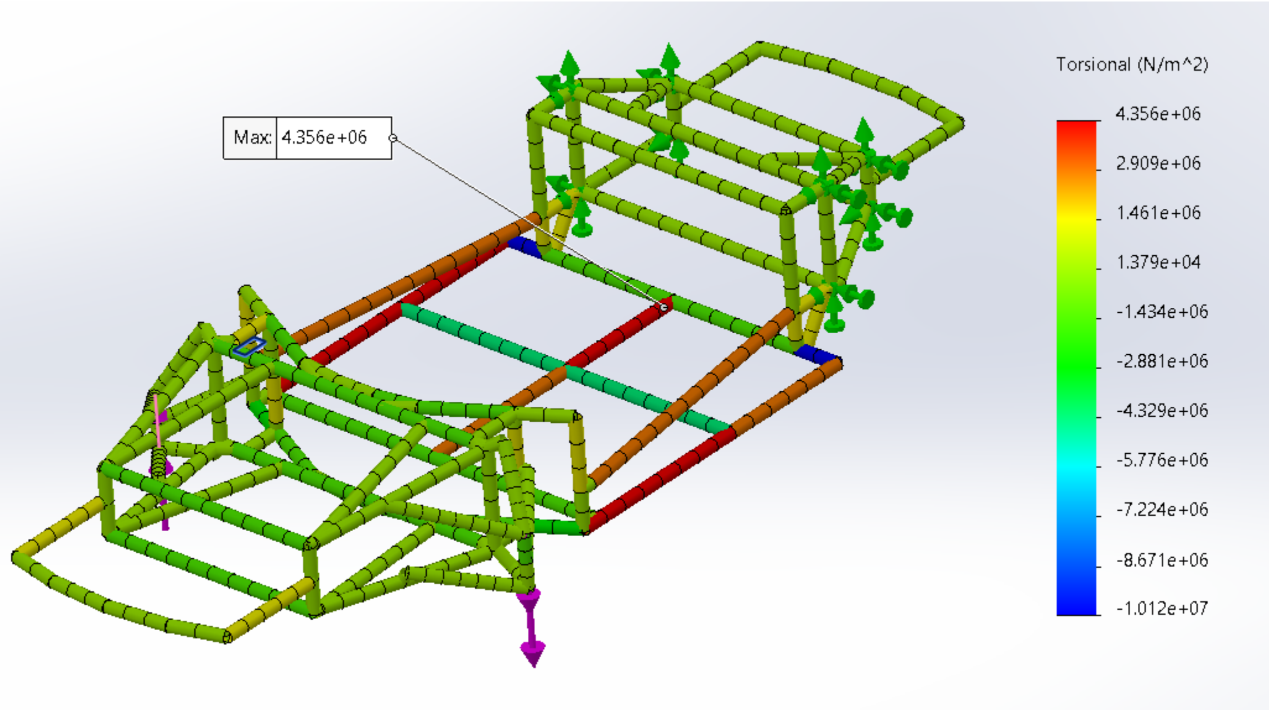


Figure 3.58: Torsional stress distribution of front modular platform

In this analysis, the maximum torsional stress has occurred in the passenger zone at the connection joints where Part 2 linked up with Part 1 and Part 3, with a value of 4.356 MPa. The upper chassis geometry, which will be placed on the platform to complete the chassis, is of great importance in relation to these stresses. Alternatively, the material type and geometry to be used in this area need to be arranged to absorb the stress, considering the stress analysis conducted on the beam model.

The reason for using beams instead of solid parts in simulations is to identify points of excessive stress and displacement after loading. The main objective of the project is to ensure the determination of the most critical loading points using the generative design method when pursuing a new design goal. By examining stress and displacement values, alternative designs will be proposed by using the Generative Design method for defined regions after stiffness simulations.

3.1.4.3.7. Bending Stiffness Analysis

- For Rear-Mid Engine Layout

Looking at the load cases, bending stiffness has second importance among the loads on a car. Thus, it is important to find bending angle to define where has the most stresses during the motion. Again, beam model has been used to perform this analysis. First step is to define boundary conditions of the platform (Figure 3.59).

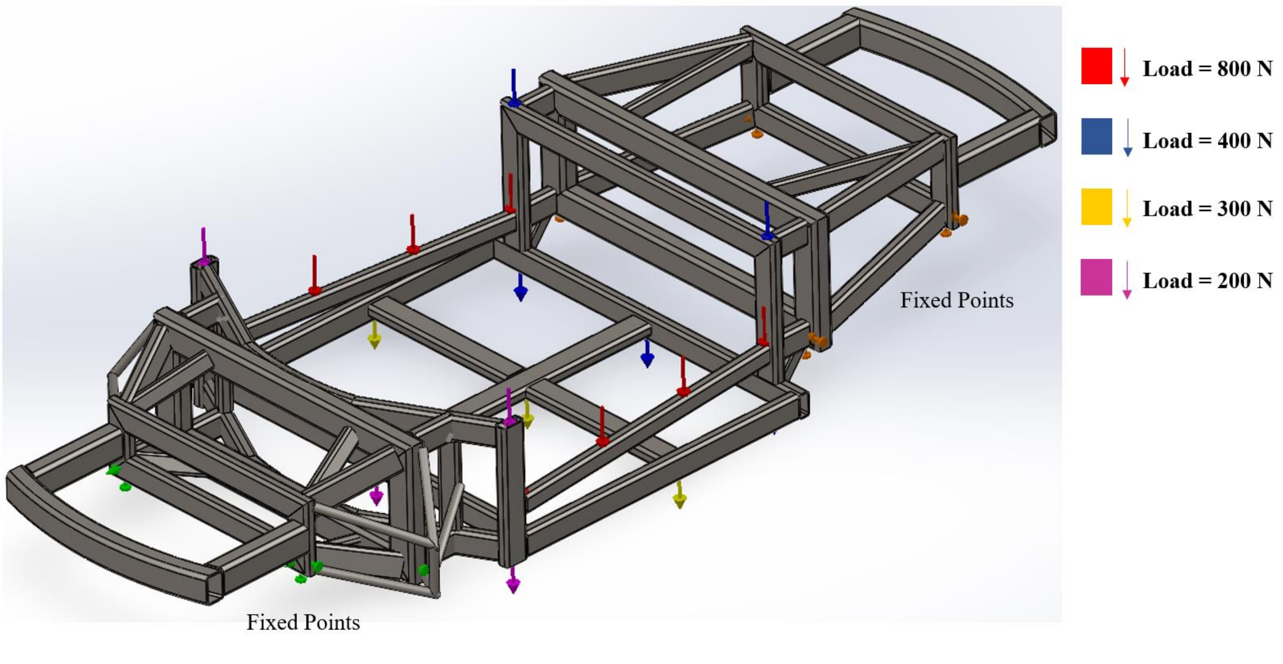


Figure 3.59: Boundary conditions on rear-mid modular platform for bending test

Applied loads on platform are referenced from (Hazimi et al., 2018) where a bending analysis applied on a formula student car. However, it should be noted that in the reference study, the bending test is applied to the entire chassis, while our design only encompasses the lower part of the chassis.

Therefore, this study actually demonstrates results by applying a load greater than what should be borne by our design. Bending test displacement values are shown in Figure 3.60.

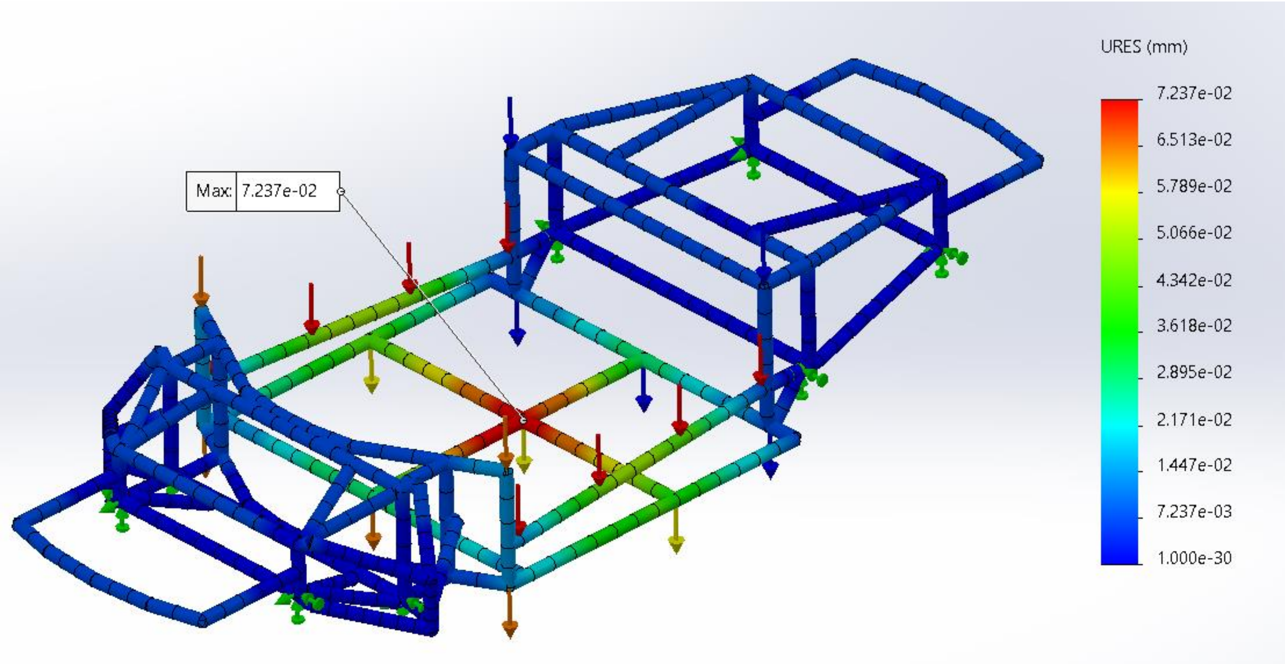


Figure 3.60: Displacement results of bending test for rear-mid modular platform

It has been observed in the bending test that the center of the passenger area is the area with the maximum displacement. But it should be taken into consideration that a metal composite sandwich panel will be used in this area and it will increase the rigidity of this section. From the Equation (d), bending angle can be calculated. α_{front} equals 0.00687 deg. From the Equation (e) and (f) bending stiffness K_{body} is 25786.02 (Nm /deg). Another result needs to be focused on is bending stress on beams (Figure 3.61).

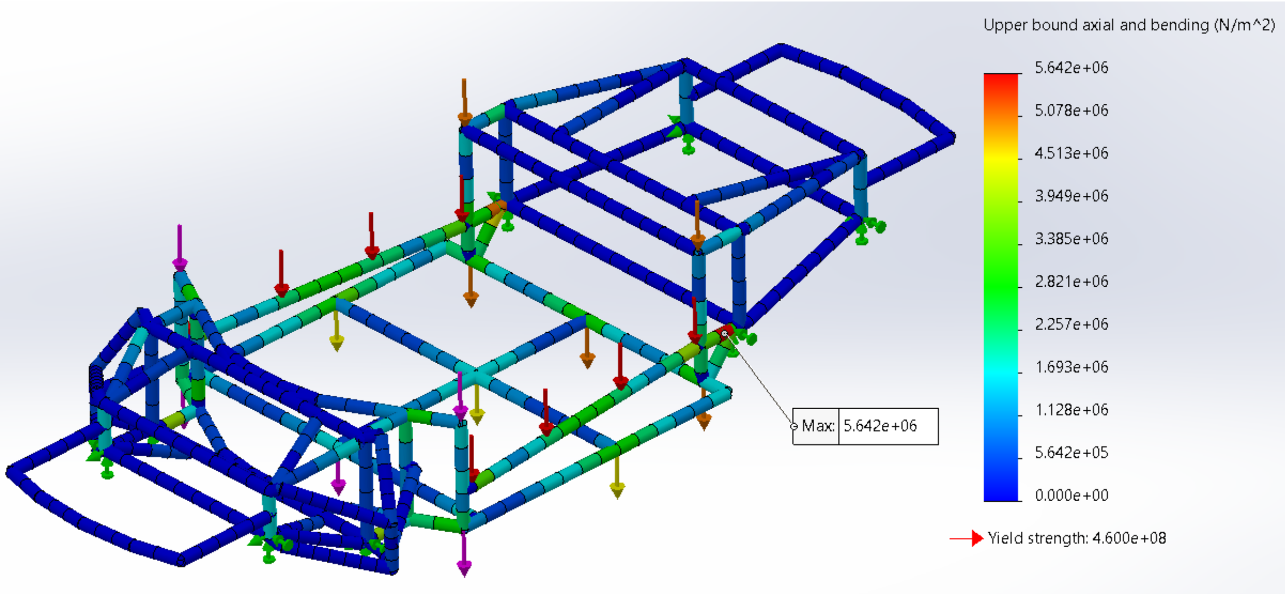


Figure 3.61: Bending stress distribution results of rear-mid modular platform

Axial and bending stresses on beams are occurred at the intersection points of the beams (Figure 3.61). Support beams in Part 1 and Part 3 connected with Part 2 have accumulative stresses. Maximum bending stress is 5.642 MPa, occurs on the connection beam at Part 2. All values will be evaluated with a comparison part at the end of simulations.

- For Front Engine Layout

The same bending simulation has been performed for front-engine layout modular platform (Figure 3.62). Even though these two geometries exhibit similarity as bending points due to the fixed geometry in this test,, still, where the Part 3 has connection with Part 4 has changed in this model with Part 1.

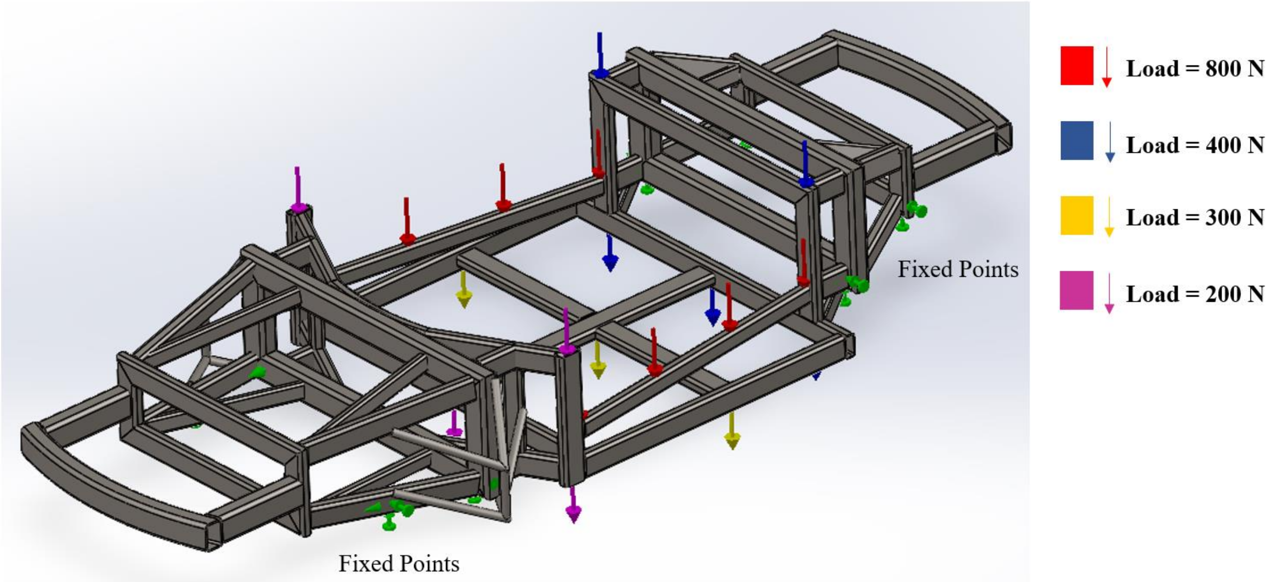


Figure 3.62: Boundary conditions on front modular platform for bending test

According to the force loading on this type of platform, results have been occurred as following (Figure 3.63).

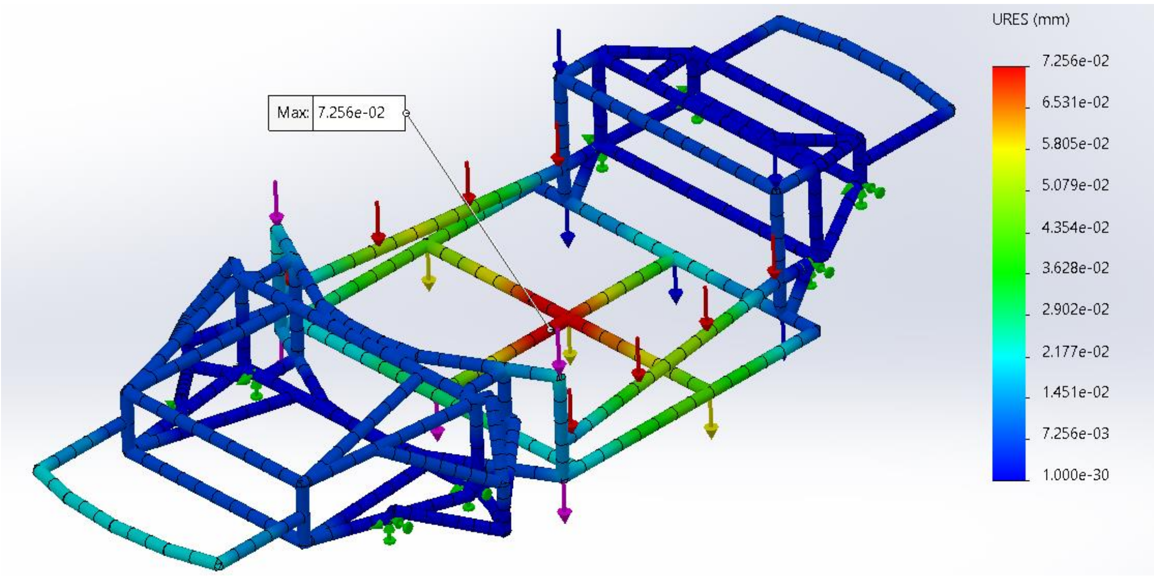


Figure 3.63: Displacement results of bending test for front modular platform

This layout has similar displacement results with rear-mid modular platform bending. From the equations used before for the bending, α_{front} is found 0.00703 deg and K_{body} is 25199.146 (Nm/deg). Later, bending stress distribution has been represented in Figure 3.64.

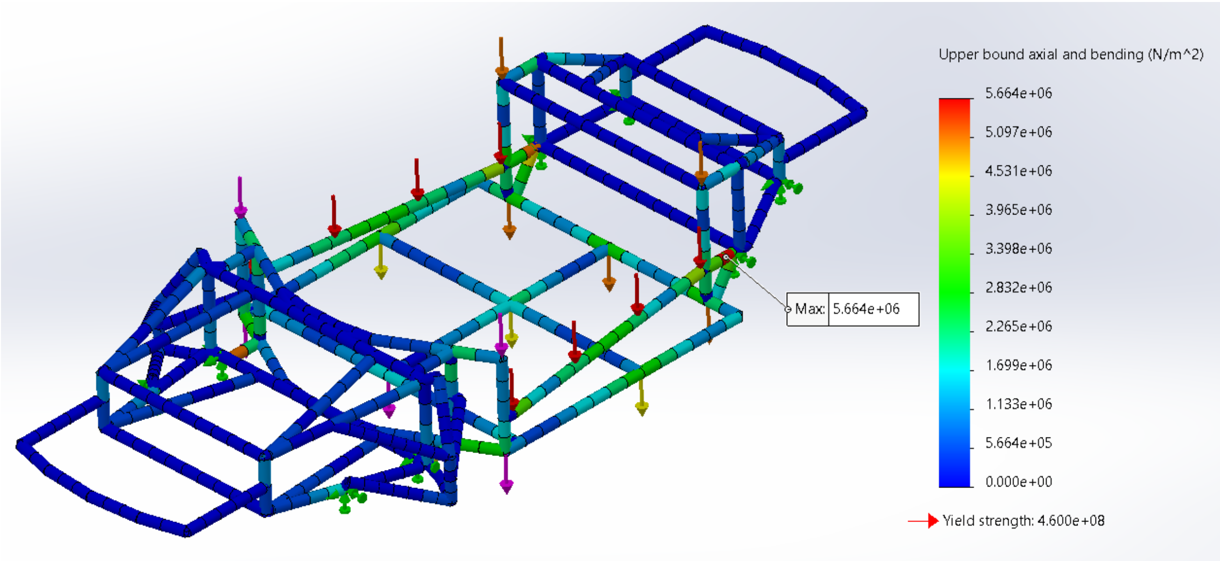


Figure 3.64: Bending stress distribution results of front modular platform

Maximum value is 5.664 MPa. Critical stresses occur at the beam intersection midpoints. Those results will be compared with the new modular platform geometry at the end of the title 3.2. Project Development section. The areas where tensions are most prominent are the main parameters for evaluation.

3.1.4.3.8. Frontal Impact Analysis

- For Rear-Mid Engine Layout

A crash test has been performed on the modular platform models. This simulation has been implemented to understand the beams behaviour under collision from front and it will help to understand how our model is working under extreme conditions. These tests will not only provide insights into the deformation of the part but also allow us to present ideas regarding the change of material to be used. Conventional cars crash tests have been performed on full car assembly which has standard regulations. Average maximum speed of a sport car was used for the settings. And target during collision were defined as a fixed target such as wall which can be seen in Figure 3.65.

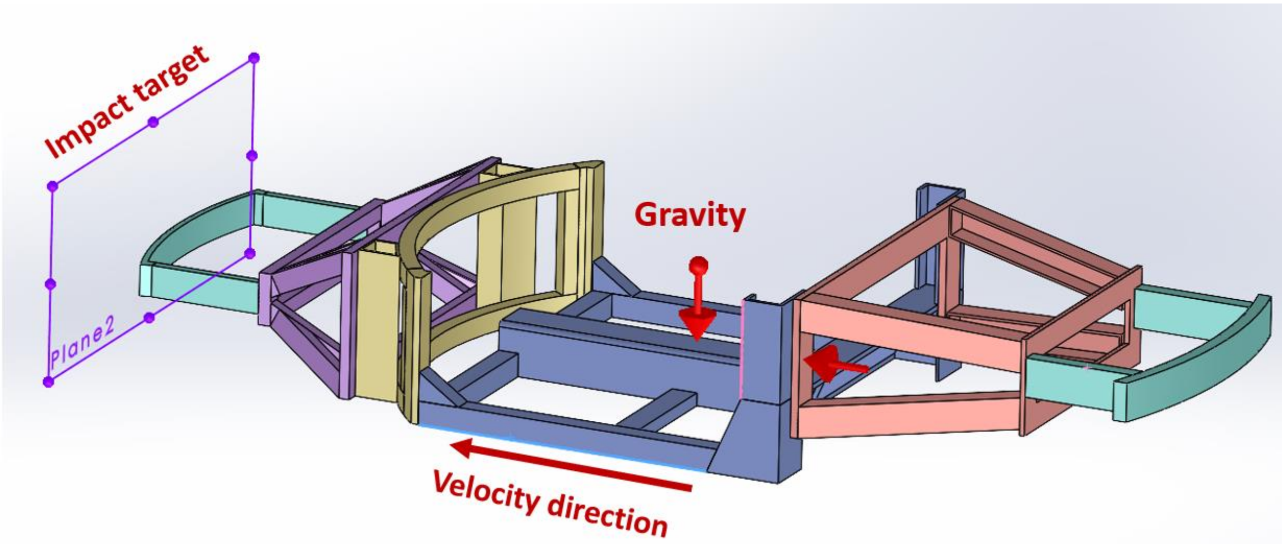


Figure 3.65: Impact test settings for rear-mid modular platform

Extreme conditions have been defined for the crash scenario. For example, the wall defined for the impact is quite close to the model before hitting. Another important setting is the velocity of the model which is 338.4 km/h calculated from the average maximum speeds of sports cars. At the end of this simulation, displacements of the parts for each section have been found. Below, the deformation image illustrating the values obtained from the impact test's animation, and another image displaying the stress distribution, are provided (Figure 3.66).

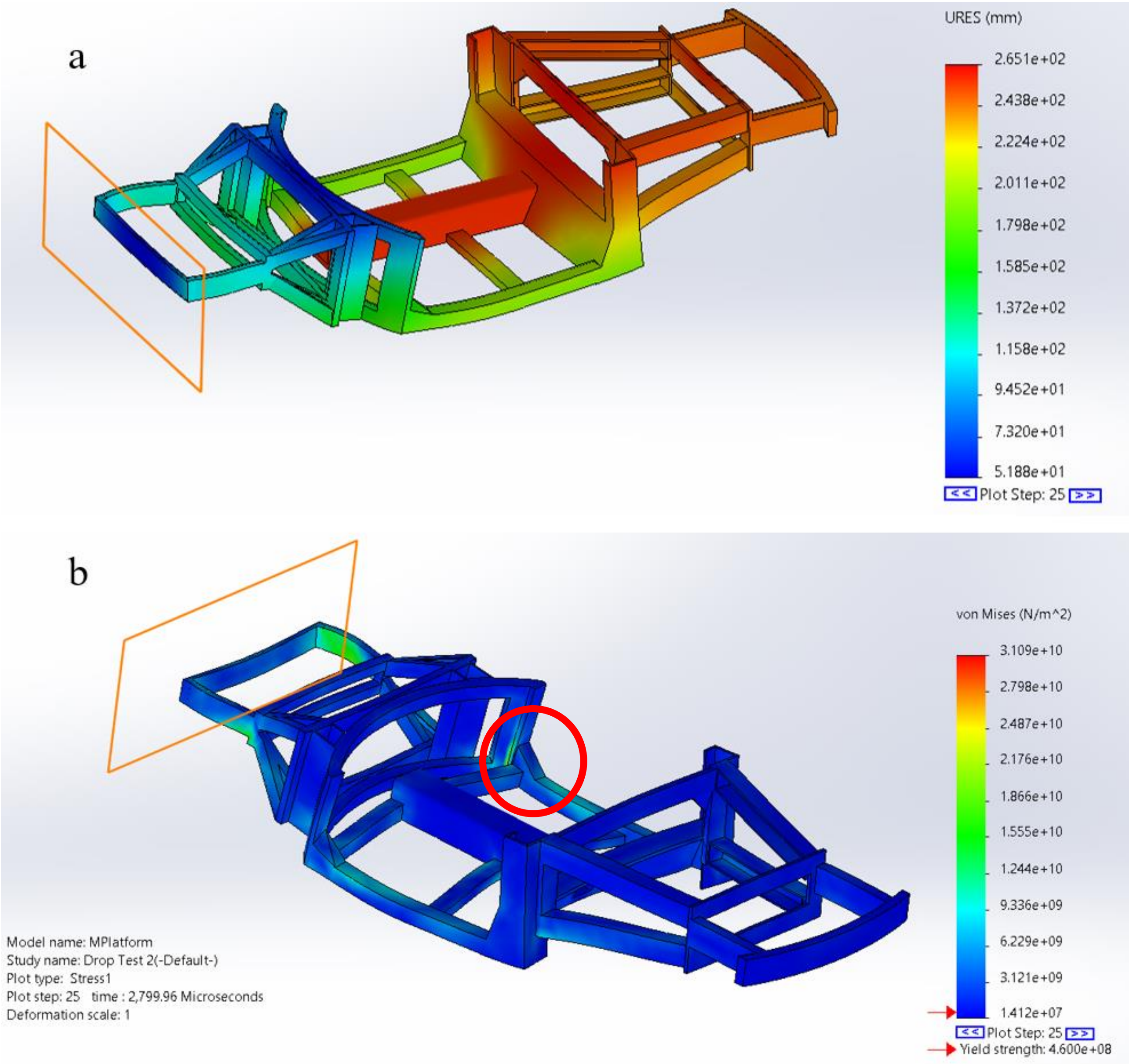


Figure 3.66: Impact test results (a) Displacement results, (b) Deformation distribution results

The force created by the impact has caused the rear parts to accumulate towards the front, resulting in a cumulative shape in the front parts (Figure 3.66: (a)). If we consider only the bottom part of the vehicle in the modular platform we designed, it is expected that, passenger area will undergo more displacement during the crash test.

The Von Mises distribution also indicates that, apart from the front bumper, the outer profiles of the passenger area are subjected to significant stress. A general conclusion that can be drawn from this, energy absorption must be higher at front in full assembly with absorbers. But in here, these results mean that there is the potential for improvement in the vertical components (Part 3) of the cockpit area, which is not subjected to excessive deformation, and an alternative geometry development case could be presented for the horizontal beams of the section (Part 4) right behind the bumper (Part 5) (Figure 3.67).

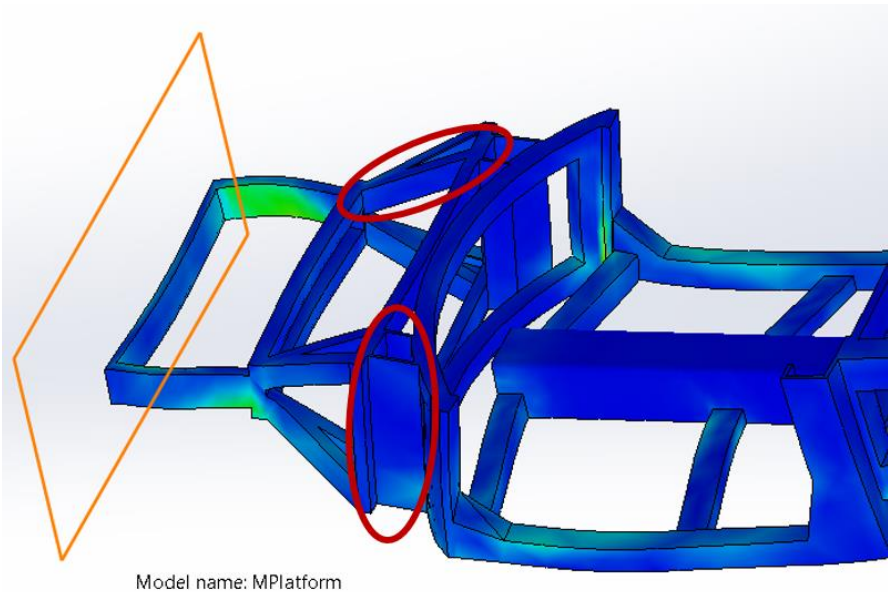


Figure 3.67: Defined sections for part development on Part 3 and Part 4

- For Front Engine Layout

Same simulation settings have been applied on front engine layout modular platform (Figure 3.68). In this layout, strength of the Part 1 will be evaluated.

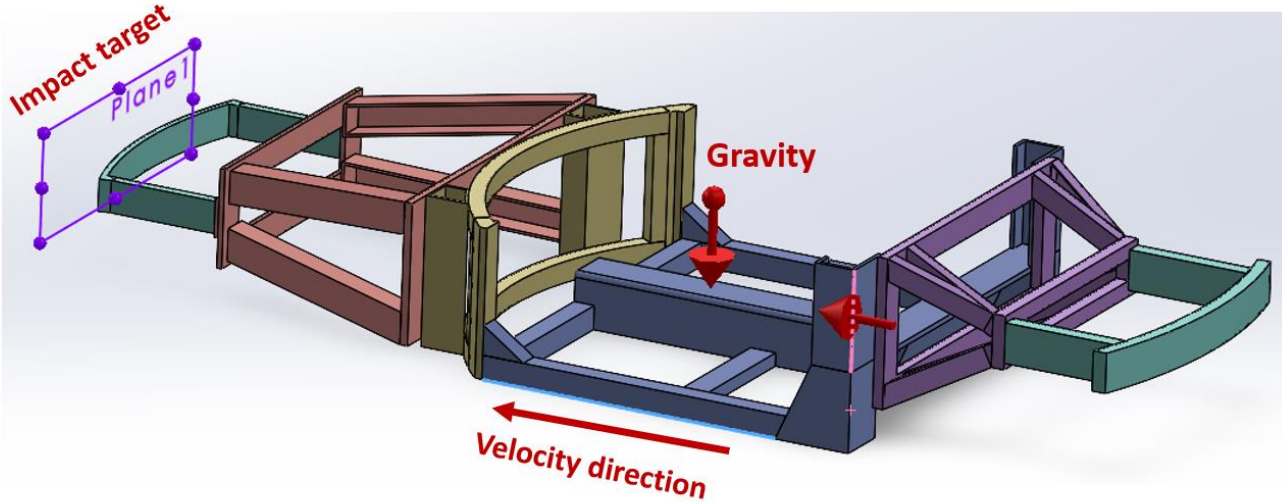


Figure 3.68: Impact test settings for front modular platform

Plane 1 defines the crash target, close to the model increasing the impact's intensity will also reduce the simulation time. Model velocity is 338.4 km/h as previous simulation. Figure 3.69 represents the deformation results in terms of displacements and stresses on the model with collision.

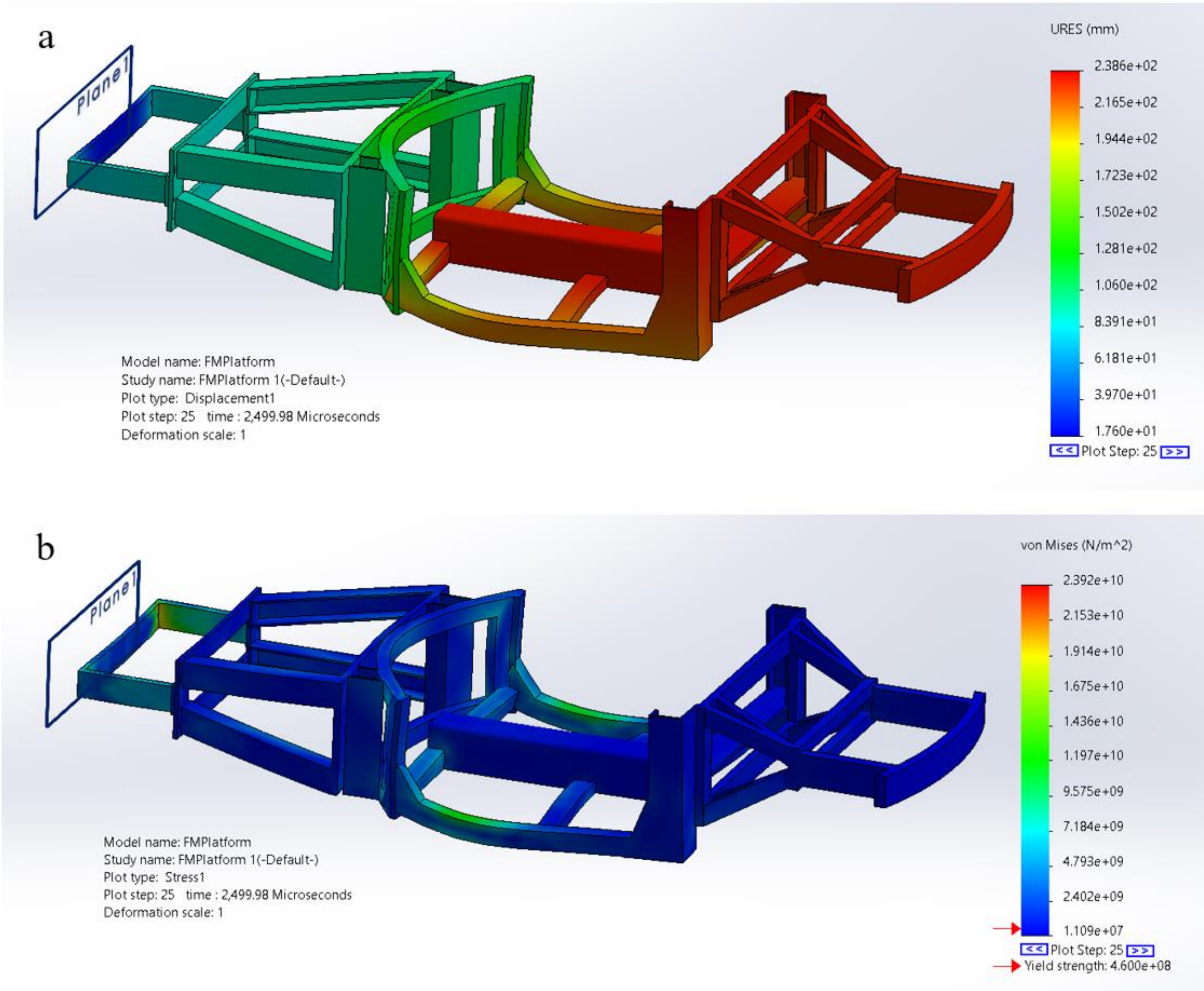


Figure 3.69: Impact test results (a) Displacement results, (b) Deformation distribution results

In this simulation, similar to previous model, frontal section of Part 2 is the section most affected by the transmission of force throughout the model. This is an unwanted situation. Because passenger zone has to be kept as far as possible from the impact load. Energy absorption of the Part 1 and Part 3 must be higher than this design. So, it is better to generate a new component for the Part 1 for more balanced force distribution (Figure 3.70).

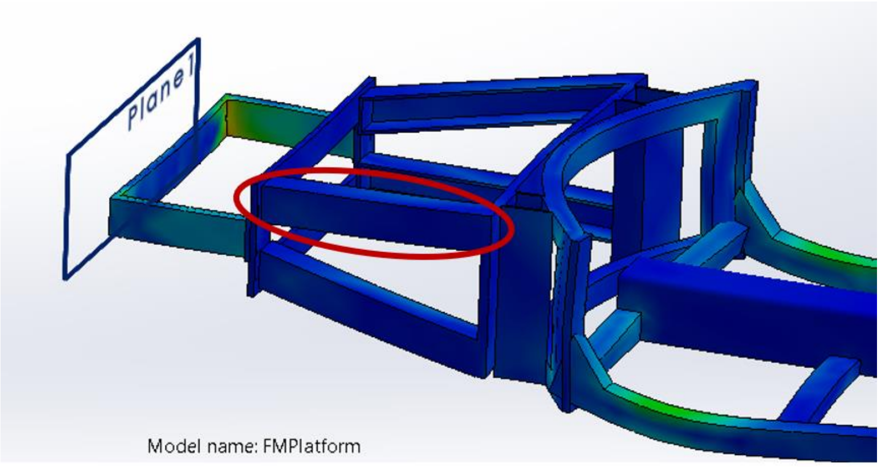


Figure 3.70: Defined section for the part development on Part 1

3.1.5. Styling

In styling section, Stylistic Design Engineering (SDE) method will be used to create an **innovative** car design. It serves as a highly effective tool for designing innovative and advanced models. In this method, the main idea is to analyse **compelling stylistic trends**. This will provide new stylistic idea for a new product. In this phase, collaboration with the customer is highly probable. This is attributed to the existence of four essential design trends outlined by the SDE: Advanced, Natural, Stone, and Retro. Exquisite and unique designs can be created for each of them and presented to the customer, facilitating the final decision-making process based on their preferences. Importantly, the customer or designer is not constrained to selecting just one of the proposed designs; the final design may incorporate a blend of multiple styles.

One of the methods that can be used to create different designs is sketching. Sketching is the method used in revealing these designs and the material used to implement this technique is **pencil sketch**." Once sketches have been created, technical transformations of the sketches are another step (2D Drawings). Technical sketches involve dimensional representations of the model and the verification of the proportions.

3.1.5.1. Sketches

3.1.5.1.1. Retro Design

The term "Retro" acknowledges the past by incorporating contemporary elements, essentially making it a new entity that evokes nostalgia. A retro-style car is a vehicle designed to emulate the aesthetics of automobiles from earlier decades, often incorporating modern technology and production methods. This design trend emerged in the early 1990s, prompting various automotive brands to introduce models reminiscent of cars from the 1950s and 1960s. Figure 3.71 represents the "retro" style of the car designed for this project. In this design model, the front headlights, side details, and wheel rims are inspired by the retro design for the vehicle.

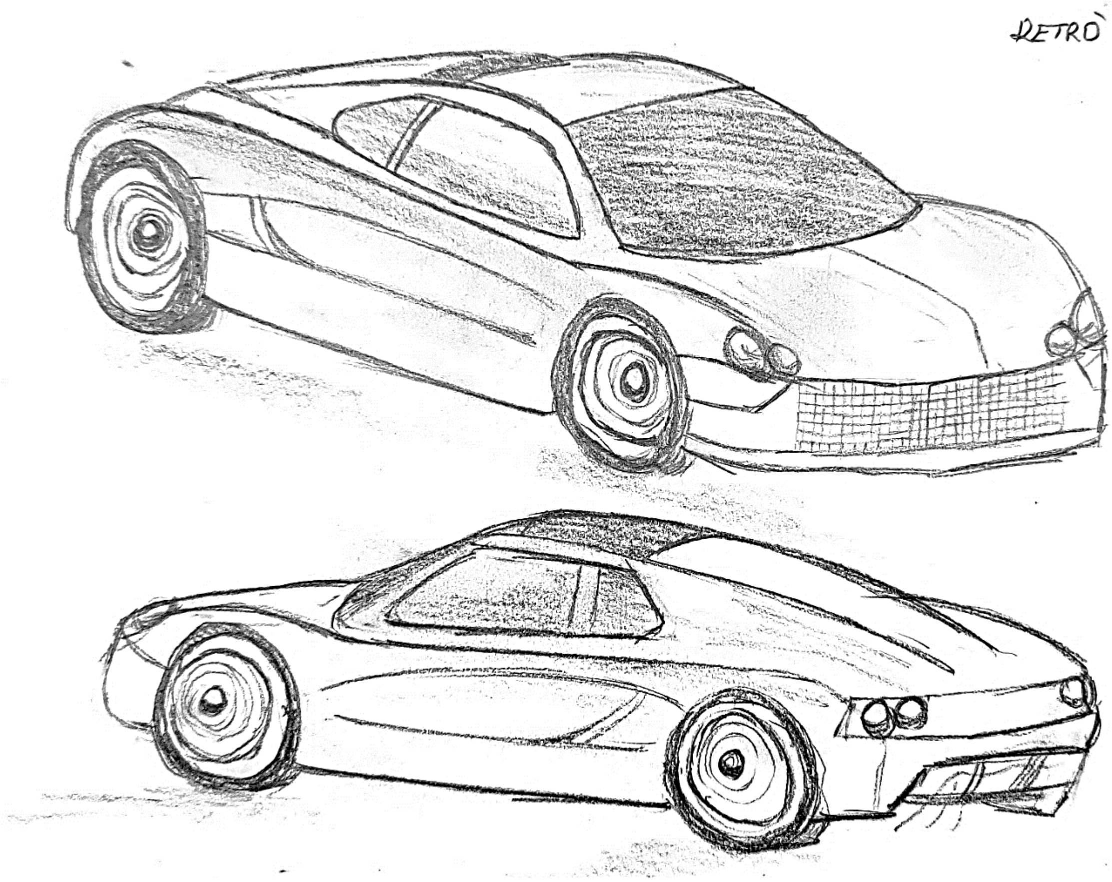


Figure 3.71: Retro design

3.1.5.1.2. Stone Design

As the name implies, the Stone style advocates for a sturdy, rugged, and substantial design. This aesthetic has become increasingly prevalent in the automotive industry in recent years, particularly in SUV models and luxury sports cars. The robust features of the Stone style are perceived by customers as a form of "protection," providing a sense of defence against the hazards of the road environment. Figure 3.72 represents the “Stone” style of the car.

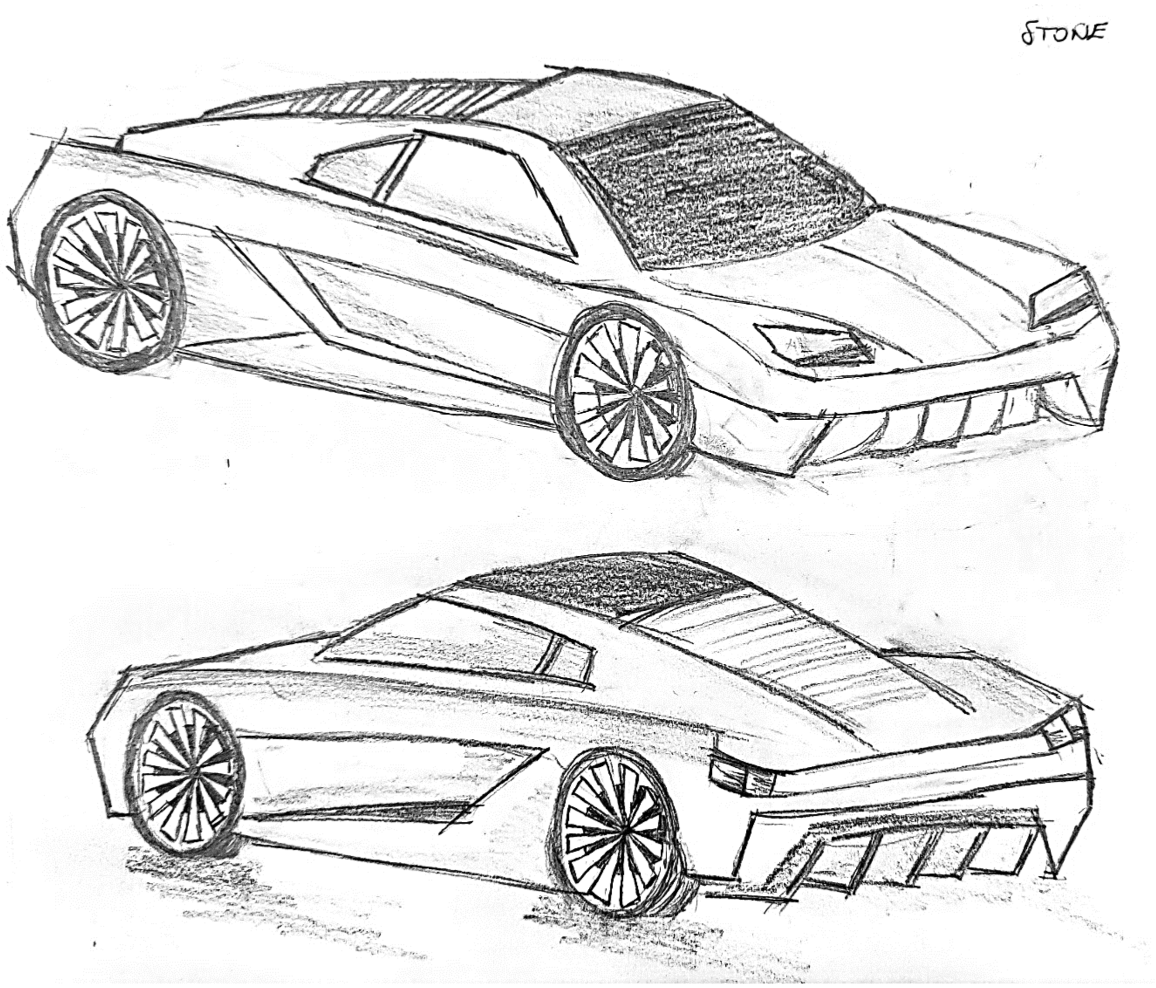


Figure 3.72: Stone design

3.1.5.1.3. Natural Design

Throughout history, designers have consistently drawn inspiration from nature, a pivotal influence in contemporary concepts. The Natural style aims to re-envision tradition through a modern lens, emphasizing the qualities of lightness, strength, and elegance found in the natural world. In this context, **biomimicry** is used as a tool for a new design which involves an **inspiration from nature.** Taking inspiration from the aerodynamic structure of the sailfish (the geometry of its dorsal line), the same has been used for the upper body of the vehicle (Figure 3.73).

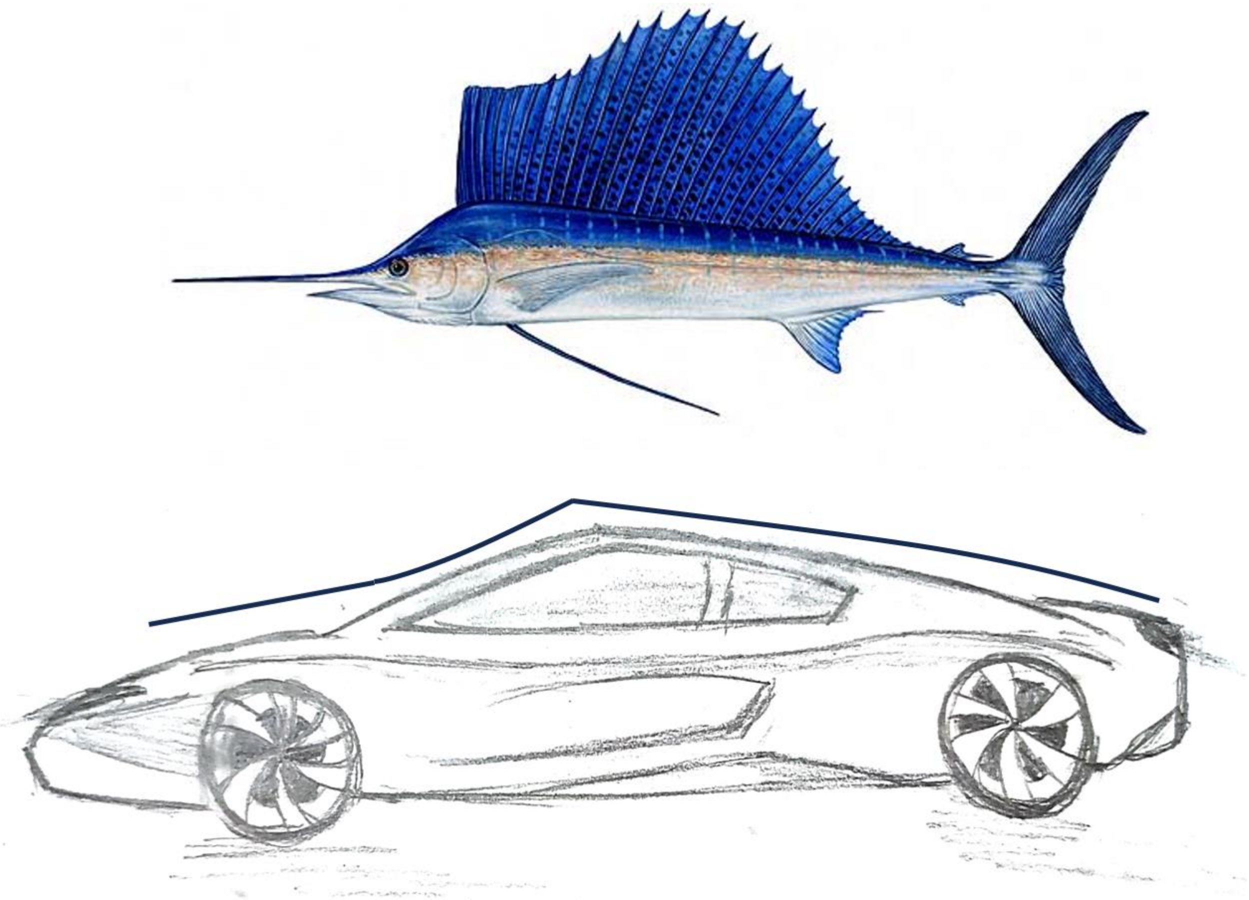


Figure 3.73: Natural design inspired from the dorsal lines of the sailfish

If we approach natural design in this context, the details of the vehicle will have rounded smooth lines that do not cause vortices from an aerodynamic perspective. An effort has been made to achieve a design with a simple, elegant, and at the same time, suitable for a sports car characteristic. Final drawings of the natural style are represented in Figure 3.74.

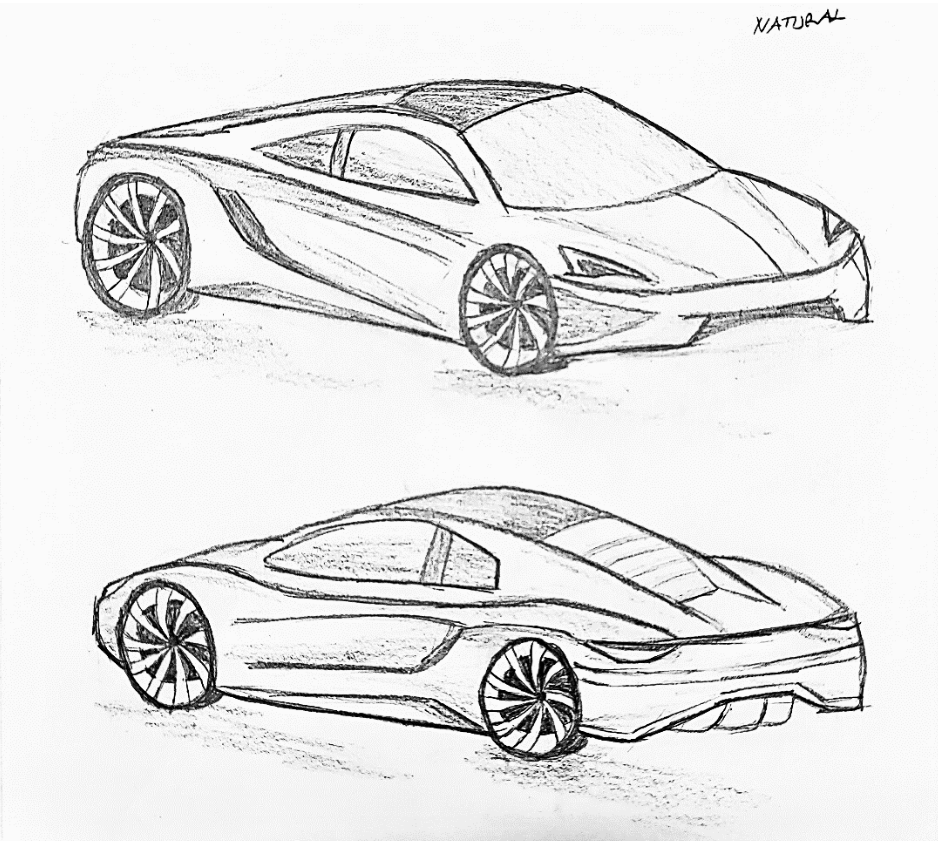


Figure 3.74: Natural design

3.1.5.1.4. Advanced Design

In the present day, we encounter novel and unconventional design types that truly appear to be derived from the future. This futuristic aesthetic, termed "Advanced," emerged in the 20th century, introducing an avant-garde perspective to innovative products. The primary characteristics of this trend include entirely new, groundbreaking, minimalistic, and geometrically regular forms. It also refers to embodying a future vision. In this design type, we kept following the method of drawing **inspiration from nature,** which is seen in the Figure 3.75. But this time, the model has been created by taking inspiration from results using **genetic algorithm,** which can be implemented through software.

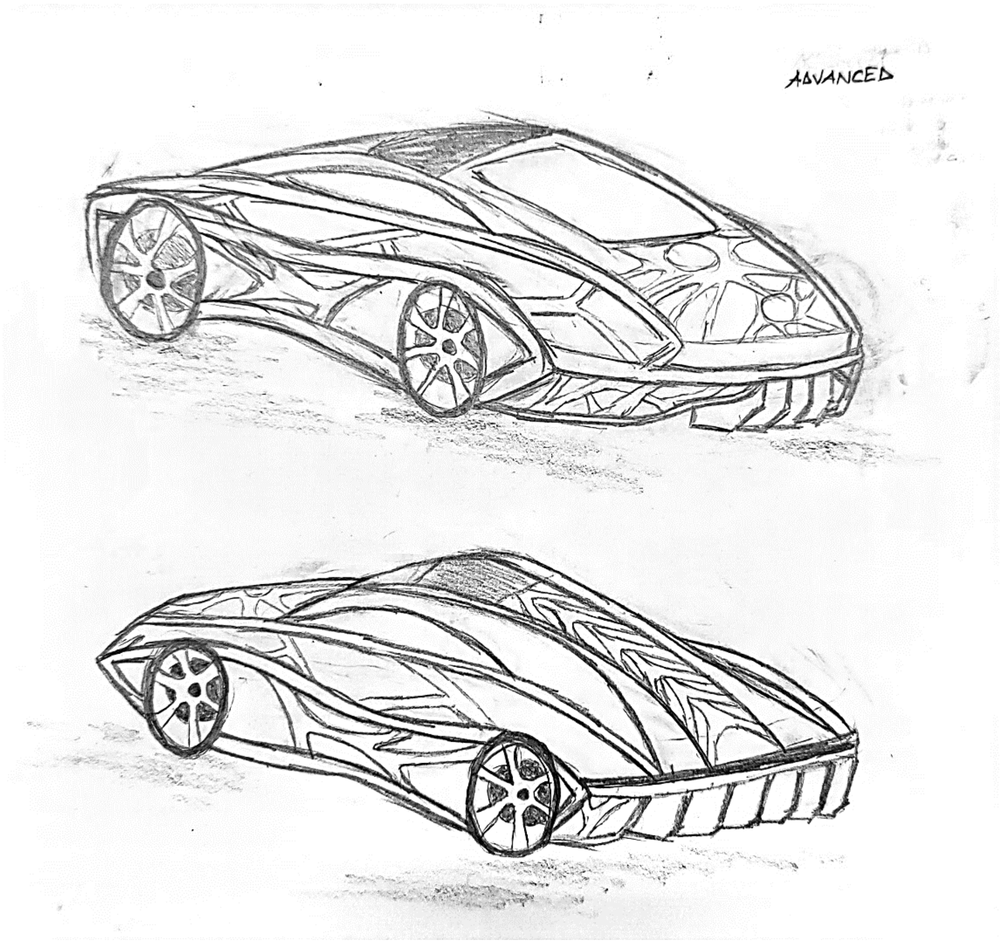


Figure 3.75: Advanced design

3.1.5.1.5. Final Design

The final version of the design has been decided with mixing the most utilized ideas/sections of each design style. Each line detail chosen from the four main drawings to create the final design has been presented in Figure 3.76.

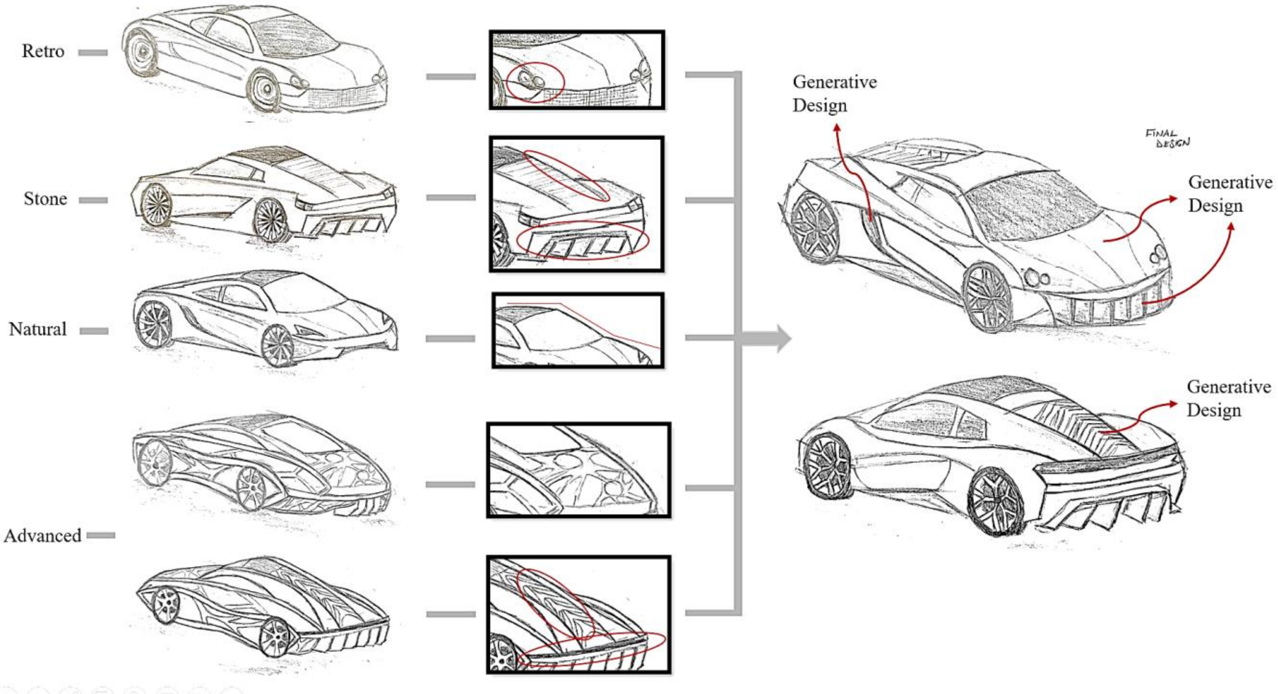


Figure 3.76: Representation of the details selected for the final design

The initial choice pertained to the headlights, drawing inspiration from Retro design. Subsequently, the rear view incorporated sharp edges reminiscent of stone design. The front section embraced a natural design inspired by nature. Finally, an advanced design style influenced by generative design was employed for both the rear and front sections of the car. Additionally, minor details will be incorporated on the side view to optimize airflow from the front to the rear engine. Final version of the car can be seen in Figure 3.77.

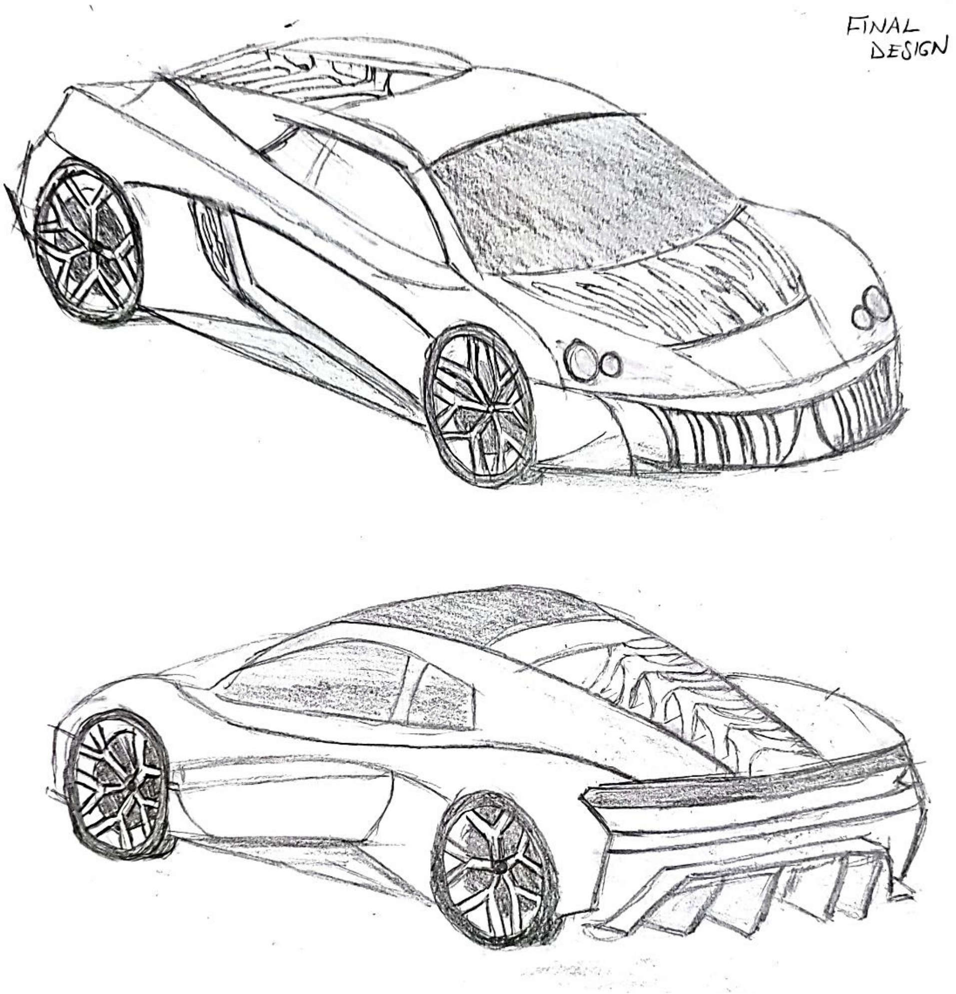


Figure 3.77: Final design sketching

The next step is to generate precise lines necessary for drafting the model, which can be accomplished by creating a blueprint. In the subsequent section, 2D drawings of the car will be executed.

3.1.5.2. 2D Drawings

Following the sketching phase, the initial step involves converting the final sketch into precise 2D drawings (Figure 3.78). Beyond aesthetics, ensuring accurate proportions was essential for a more precise transfer to the technical drawing. This stage is pivotal as it refines the approximate shapes from the sketches into an orthogonal design, enhancing the realism of lines. This transformation facilitates a clear understanding of dimensions and proportions, providing a comprehensive overview.

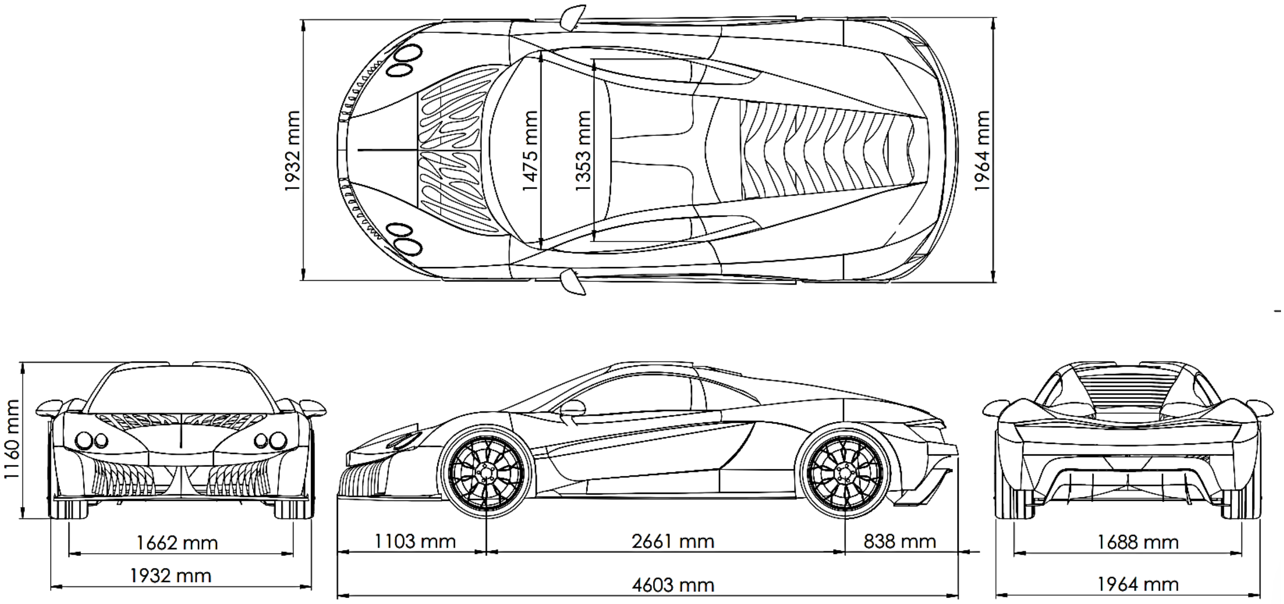


Figure 3.78: Blueprint of final sketch

In 2D Drawings, some minor improvements in the design have been performed. When looking at the innovation table (Table 3.3), it can be seen that the dimensions are within our limit values range. After the 3D modelling of the vehicle is completed, its compatibility will be checked by assembling it with the modular platform we designed.

3.1.5.3. 3D Modelling

Once a thoroughly detailed blueprint is built, the generation of a 3D representation of the design becomes a straightforward task. In this procedure, the SolidWorks surface feature has been utilized to create surfaces from the lines. 3D design began with the drawing of components that will form the main shape, primarily derived from a 2D drawing. The drawing of the main components is illustrated in Figure 3.79.

Figure 3.79: Raw design of final sketch

The final design was achieved by adding components such as the wheel, rim, and rear fender (Figure 3.80).

Figure 3.80: Final 3D design

However, details inspired by generative design is added as the last arrangements.

3.1.5.4. Rendering

Rendering involves generating a raster image from the 3D elements within a scene. A renderer is employed to compute the visual representation of materials applied to the objects within a scene, along with determining the lighting and shadows based on the placement of lights within the scene. For the rendering process, PhotoView 360 module of SolidWorks has been used. The rendered versions of the front and rear perspective views of the vehicle are presented in Figure 3.81.

Figure 3.81: Rendered final design

Before performing product development, current version of modular platform will be assembled with final 3D design of sketching (Figure 3.82).

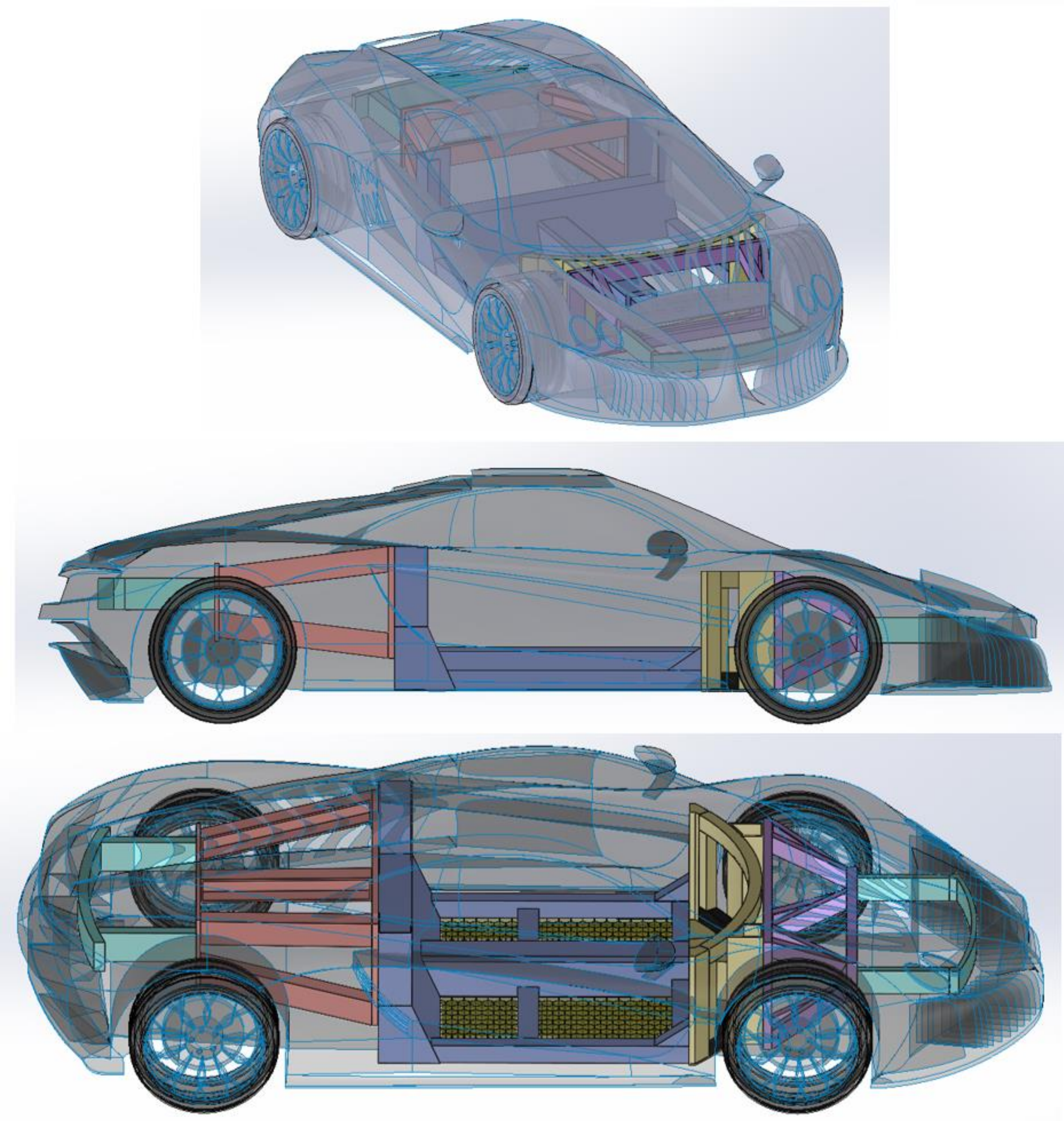


Figure 3.82: Modular platform and final design assembly

3.2. PROJECT DEVELOPMENT

Project development refers to the systematic process of planning, organizing, implementing, and managing various elements of a project from its inception to its completion. It encompasses a wide range of activities and tasks aimed at achieving specific objectives within a defined scope, budget, and timeframe. Successful project development requires a structured approach that includes identifying goals, defining tasks, allocating resources, managing risks, and ensuring effective communication.

3.2.1. What is Agile?

In simple terms, Agile can be described as an iterative and incremental approach to project management. Each iteration in an Agile project delivers a fully functional subset of the final product, likened to assembling a jigsaw puzzle where each piece contributes to completing the entire picture. Similar to solving a puzzle, Agile involves a sequence of steps, including identifying key pieces, placing them strategically, assessing their fit, and repeating the process.

Agile working emphasizes skilled improvisation over extensive planning and documentation. Recognizing the challenges of planning for all contingencies and an ever-changing external environment, Agile relies on flexibility to adapt without disrupting the entire process. In the Agile methodology, change is not just expected but welcomed. Agile is inherently adaptive rather than predictive.

Agile project management (APM) involves executing a project in **iterations,** with each **iteration** encompassing requirements analysis, design, development, testing, implementation, and integration. Each iteration results in a complete component of the final product, building upon the progress of the previous iteration. The final product is achieved through a series of these incremental **iterations** (Goncalves & Heda, 2010a)

3.2.2. The Relationship of the Agile Method with Product Development

Agile methods have a significant impact on product development, transforming the traditional approaches to project management. **Iterative** and **flexible** approach of Agile methods on project development works for managing projects that prioritizes **adaptability,** collaboration, and customer satisfaction. It originated as a response to the limitations of traditional, linear project management methodologies. Agile method on project development functions as a productivity framework, guaranteeing continual enhancement based on preferences and providing the flexibility to incorporate changes in the product throughout the process (Cohen et al., 2004).

While there are various agile methodologies, one of the most widely used frameworks is *Scrum*. It is a typical structure for project development in Agile. Scrum, as an agile project development methodology, adopts an iterative and incremental approach to project development. This empirical method proves particularly effective in creating innovative and fulfilling products, especially when initial product requirements lack clarity. The framework grants significant autonomy to the team, allowing them to self-manage, while providing a straightforward set of rules to follow. Customer requirements are specified before the project initiation, yet the product requirements may not be immediately apparent; however, these requirements are outlined in the early stages of Scrum (Cobb, 2011; Goncalves & Heda, 2010b; Oomen et al., 2017; Rosberg, 2008)

3.2.3. New Approach to Scrum Workflow

The Scrum framework (Figure 3.83) is one of the most adjustable methods among APM processes. The Scrum methodology assists the progress of the planned project by dividing it into smaller parts. These parts are called as “Sprints” and each sprint aims to complete the task in fixed-time cycle and to execute meetings to make development on products progressively (Hidalgo, 2019; Lei et al., 2017).

Even if Scrum is popular in software development sector, it is important to point out that this approach is now more widely used among different organizational levels. (Whiteley et al., 2021). Scrum has the important point with its dynamic and variable environment for the products that is managed by the teams (Cervone, 2011; Coram & Bohner, 2005). Besides its iterative and incremental structure, it involves adaptation, examination, and translucence during the workflow. One of the core and most powerful parts of Scrum is the qualified, self-organizing and cross-functional team with a highly collaborative and informative environment (Hossain et al., 2009; Ringstad et al., 2011; Srivastava et al., 2017).

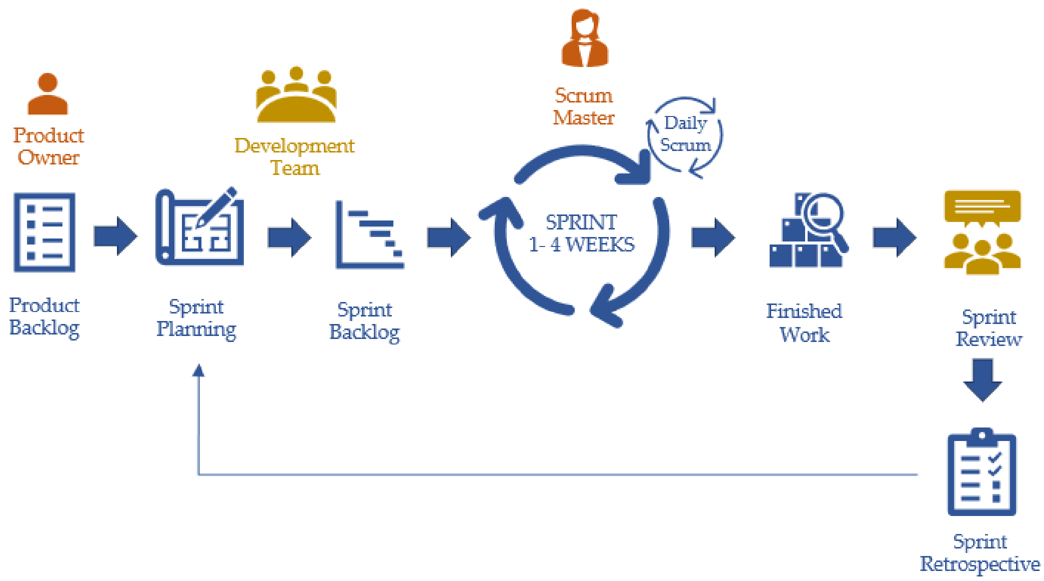


Figure 3.83: Scrum process

Sprints are the core of the Scrum methodology. Their outputs need to meet the customer requirements and therefore it represents the efficiency of whole process. If we take a closer look to the Sprint; a small team works on the defined task in the sprint which is a small part of the Scrum takes 1 to 4 weeks generally. The duration of a single sprint depends on the project and the needs defined in Product Backlog. Product Backlog contains the list of items for the requirements of the Sprint which is determined by the product owner. Later, Sprint Planning includes the methods how to perform a Sprint. The specific task to be worked on for each sprint is decided in the Sprint Backlog and documentation of all requirements is available at this step. It is created during the Sprint Planning meeting, where the Scrum Team collaboratively decides which items from the Product Backlog can be accomplished during the upcoming Sprint. There is a daily scrum to observe the progress of the sprint task (Diebold et al., 2015; Morandini et al., 2021; Rubin, 2012). A deliverable product must be obtained at the end of each sprint, and it is important to have Sprint Review to check the potential final product and its incremental situation. During the Sprint, sprint objectives are not possible to change, but product owner can add new goals to the project (Srivastava et al., 2017). After the Sprint Review is completed, a Sprint Retrospective has to be performed. Sprint retrospective is a meeting where teams review successes and identify areas for improvement in preparation for the upcoming sprint. Retrospectives play a crucial role in the ongoing enhancement of the sprint process, ensuring that valuable insights are integrated into future iterations. Sprint is also a time – limited process with its nature which takes more or less one month. Each sprint starts after at the end of the previous sprint. Each sprint includes the structure or design to be built with a flexible plan to attain a successful results. In extreme situations, a sprint can be cancelled but because of the limited timeline for a sprint, it becomes so rare (Garcia et al., 2022). The iterative and incremental nature of the agile life cycle provides the team to make feature improvement in sprints and set up their benefit. These sprints feed each other with the iteration of the process via increasing the feature quality from previous experience (Shafiee et al., 2023).

The key method to be utilized in the new approach to the Scrum workflow is the generative design method. In generative design there is no review until the end of the generation, it has to be done by the software or algorithm which is made to generate. The only interpretation can be done at the end of having the best options and engineers or customers may choose for the best option depends on their aim. How can generative design approach be defined? In the generative design, the problem and its objectives have been defined in a pattern of a computational model and generate multiple design solutions are obtained by using an algorithm (Figure 3.84). Design space where is being used during the generation has to be defined carefully to find the optimum solutions. This happens with an iterative process analysing for the design solutions which provides wider range of applicable solutions with evaluation. Wider solutions can give us more information about the performance or applicability of the design for developing further model if necessary (Gradišar et al., 2022).

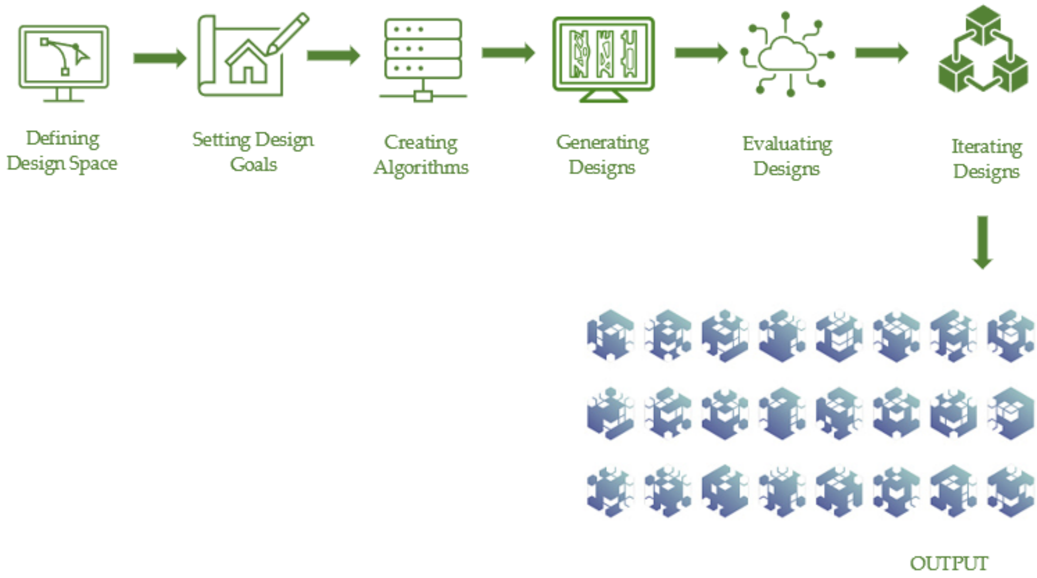


Figure 3.84: Generative design workflow

Additionally, this method includes design goals, evaluating designs and evolution with iteration. Especially when these steps are focused on, there is a similarity with the steps within Scrum. The similarities in the characteristics of these two approaches allow for their integration with each other. Figure 3.85 serves as evidence of the similarity between both approaches.

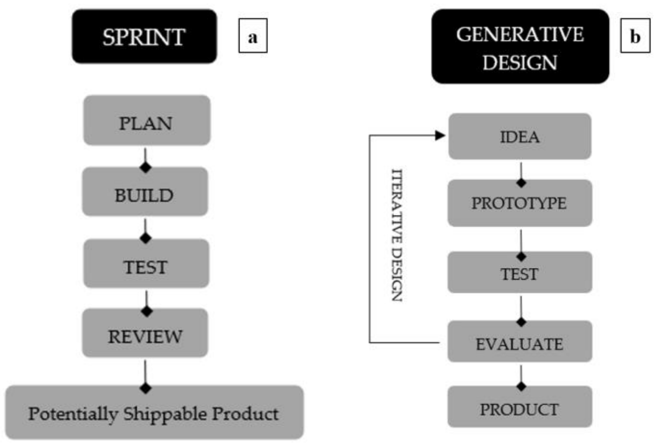


Figure 3.85: Comparison of methods a) Sprint steps (Srivastava et al., 2017) b) Generative design process steps (Ketterman, n.d.)

Sprint and generative design process are showing the same aspects and even steps similar to other methods. But the main difference here, as a key point, is to emphasize that while Sprint is an iterative process itself, Generative Design aims at an iteration inside, which makes these two methods possible to integrate. Figure 3.86 illustrates the new workflow developed in this project.

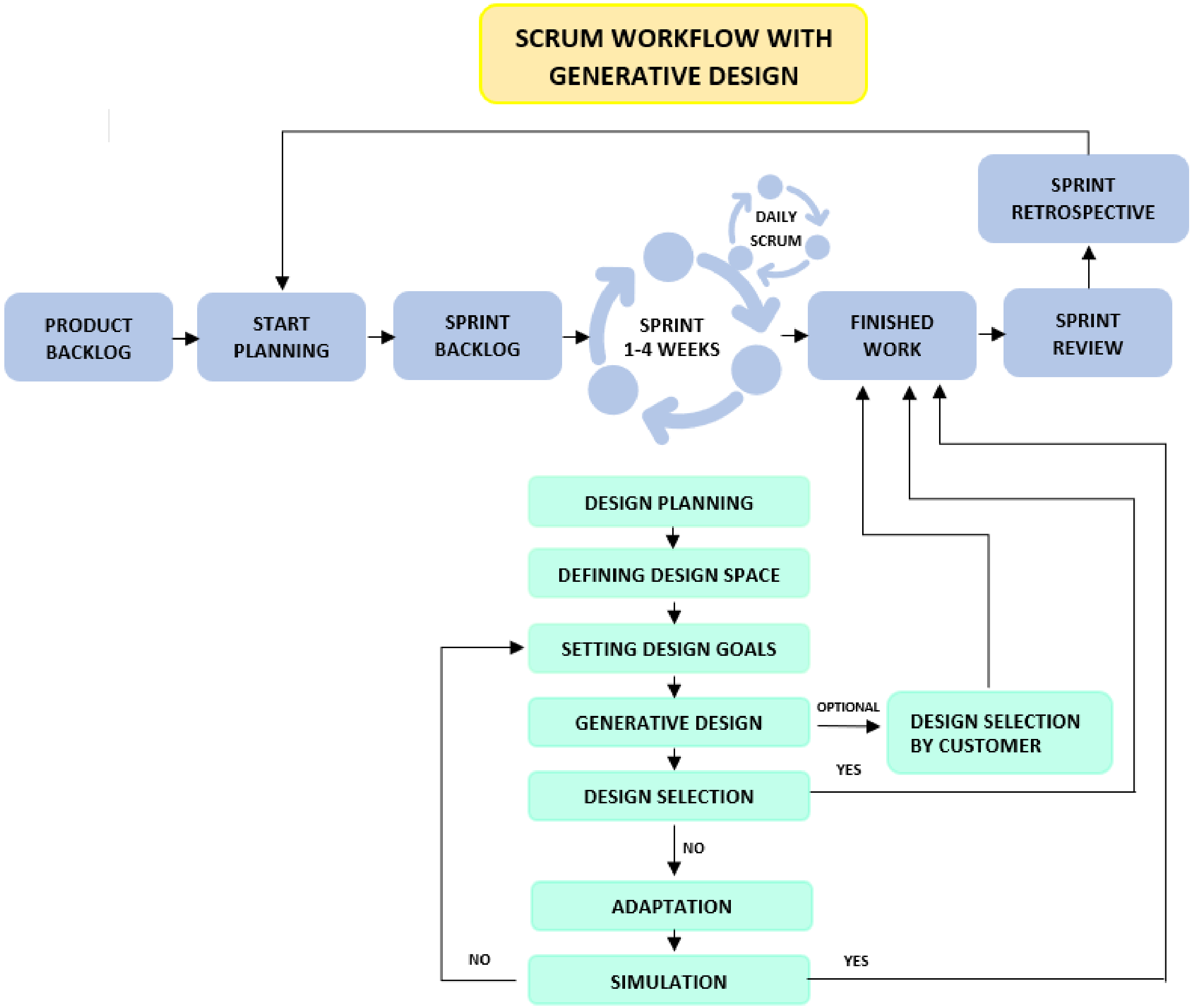


Figure 3.86: New scrum workflow model with generative design method

The workflow above represents the incorporation of generative design process into the sprint within the Scrum Framework. This new workflow will replace the current Project Development steps in the

IDeS workflow. At the end of each sprint, it is important to create an output which is an acceptable or preferable by customers. At this point, generative sign can help us to create innovative results to offer to the customer. But using generative design process can provide multiple results to serve many requirements than is needed after each sprint. Therefore, the Scrum methodology will serve as a *filter*, providing us with the chance to assess the outcomes generated based on customer requirements by the team or customer, instead of relying on filtering through code and engineer screening. Additionally, it is important to define specific requirements and how to perform it before starting sprint cycle.

On the other hand, using generative design can help to shorten each sprint time, while even having more innovative results. In this workflow, steps during the sprint are inspired by generative design mindset. According to this method, it is important to incorporate an iteration into the process, starting from the initial design decisions and progressing towards the final product. Design planning represents the decision-making process for design details. Later, defining the design space and setting design goals are crucial steps that need to be detailed to ensure reliable design results after this process. **Generative design** step can be achieved in some ways such as using an algorithm or by embedding the algorithm into the software to provide 3D results. As the mechanical properties of the parts obtained with generative design are also provided (von Mises stress, displacement value, safety factor, etc.), it can be decided whether these parts are suitable for use without the need for an additional test. Since the number of generative design outputs are being decreased by using sprints, these results can be directly presented to the customer for selecting the final product, or it can be chosen by the team. Generally, the design selection step is the final stage, but in cases where the obtained results do not meet the desired conditions, the adaptation step can be considered. **Adaptation** is one of the most innovative and crucial step of our newly created workflow diagram. It works in a more innovative manner when the design approach is not defined beforehand. In situations where complete foreknowledge is lacking, achieving absolute preparedness becomes challenging. Instead, one should be equipped for various scenarios and adjust based on the specific circumstances encountered. This logic helps in the development of parts through the **adaptation** method, indicating that generative design operates with this logic. Figure 3.87 represents the final version of modified IDeS workflow.

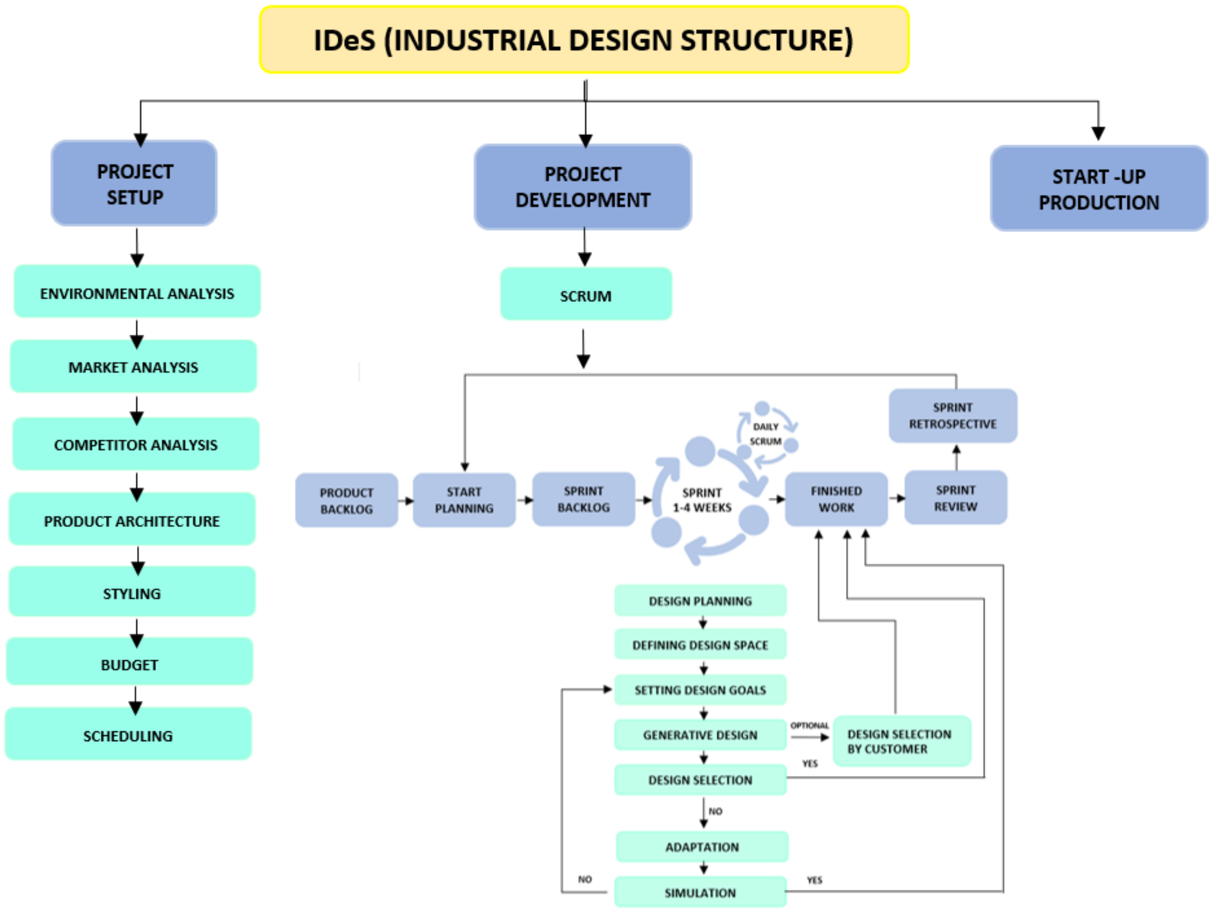


Figure 3.87: Modified IDeS workflow using Scrum and Generative Design method

3.2.4. Application of Scrum Process for Modular Platform Design

The implementation of the new workflow will be initiated with the Product Backlog. The Product Backlog is a developing and prioritized inventory of necessary improvements for the product implementing by Scrum Team. It includes the list of items for the requirements of the sprint. For modular platform design, the list of requirements are;

1) Modular design for different types of drivetrain and powertrain configurations
2) Lightweight platform design
3) High stiffness with different materials and design alternatives

3.2.4.1. Sprint (CYCLE 1)

In the first sprint cycle, according to sprint planning it will be focused on which is designing a modular platform suitable for different types of drivetrain and powertrain configurations. Sprint backlog emphasizes that the creation of a chassis platform with distinct sections, which, when assembled, forms the complete platform. One of the main purposes of the modular platform is to response more than one layout for the sports cars. Thus, especially it is important to have a platform which is constructed for both front and rear-mid engine layouts. Even if rear-mid engine is the most common layout on sports car, front engine can be preferred on high performance cars in the case of needed comfort and performance at the same time. Also, this platform can be used in SUV sports car with changing the length of the beams in flexible sections. These sections are Part 5, Part 6, and Part 2.

First thing to do is to divide the platform into subparts already defined in previous chapters. Each part is a candidate to make a development on modular platform. Therefore, it is essential an appropriate division on these components. Connection joints will guide us to create an alternative design as a preserve geometry, especially while performing generative design. In this project, in addition to the chassis of many car models, one of the inspirations for our modular platform for applying material and facilitate the segmentation of the platform.is Volkswagen's MQB platform (Figure 3.88).

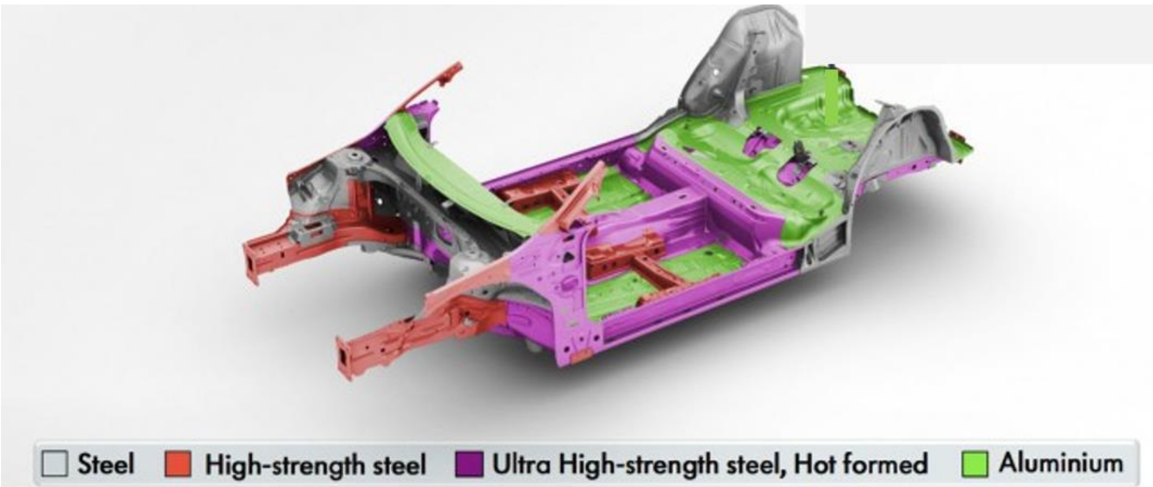


Figure 3.88: Volkswagen MQB platform with material details

Figure 3.89 illustrates the designated boundaries for the division of the modular platform into sub-components. Each section is represented by a different color. Especially, the delineations made due to the use of different materials have played a significant role in defining the sub-components in the modular platform we designed.

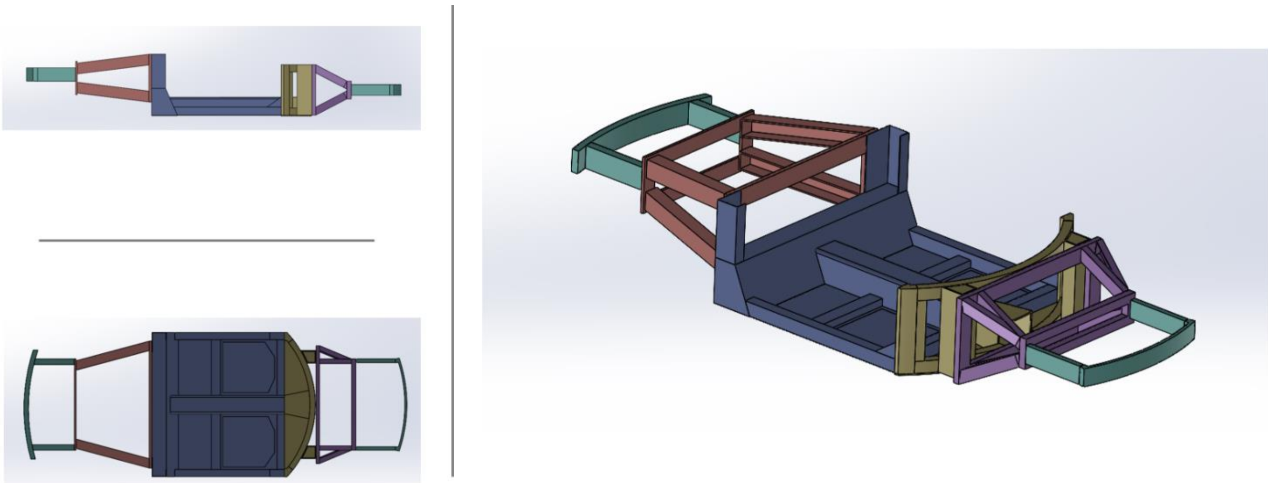


Figure 3.89: Boundaries of platform sections

For clearer visibility of the boundaries, an exploded view of the modular platform assembly is provided below (Figure 3.90).

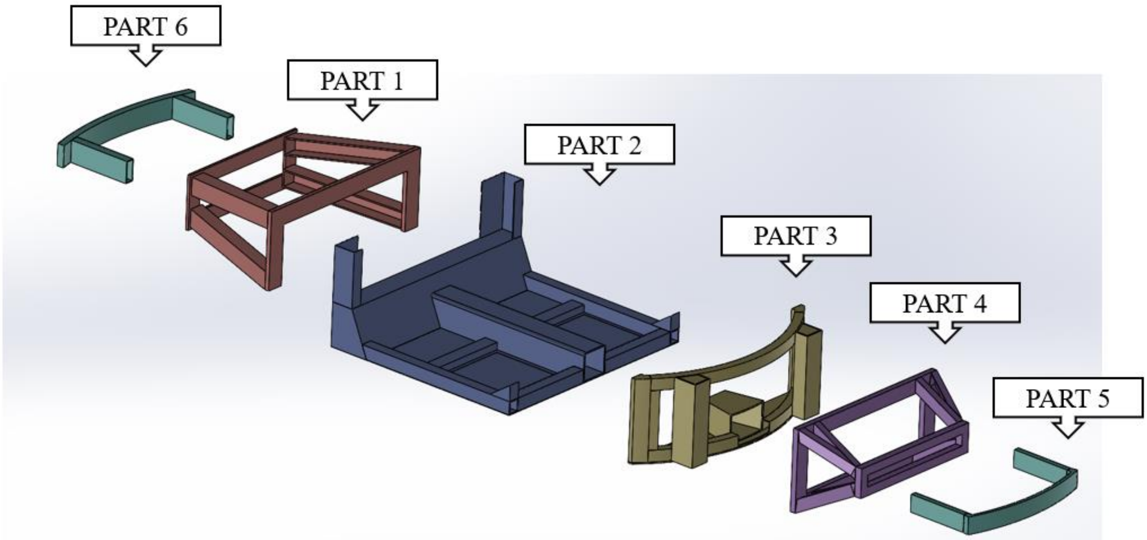


Figure 3.90: Exploded view of the modular platform assembly

This design has to be suitable for also front engine or longer or shorter cars. This can also be achieved through creating different modular platforms with the same components in various combinations. The rear-mid engine combination (Figure 3.91) and the front engine combination (Figure 3.92) are the focus in terms of the geometry shown below, which is sufficient for product development.

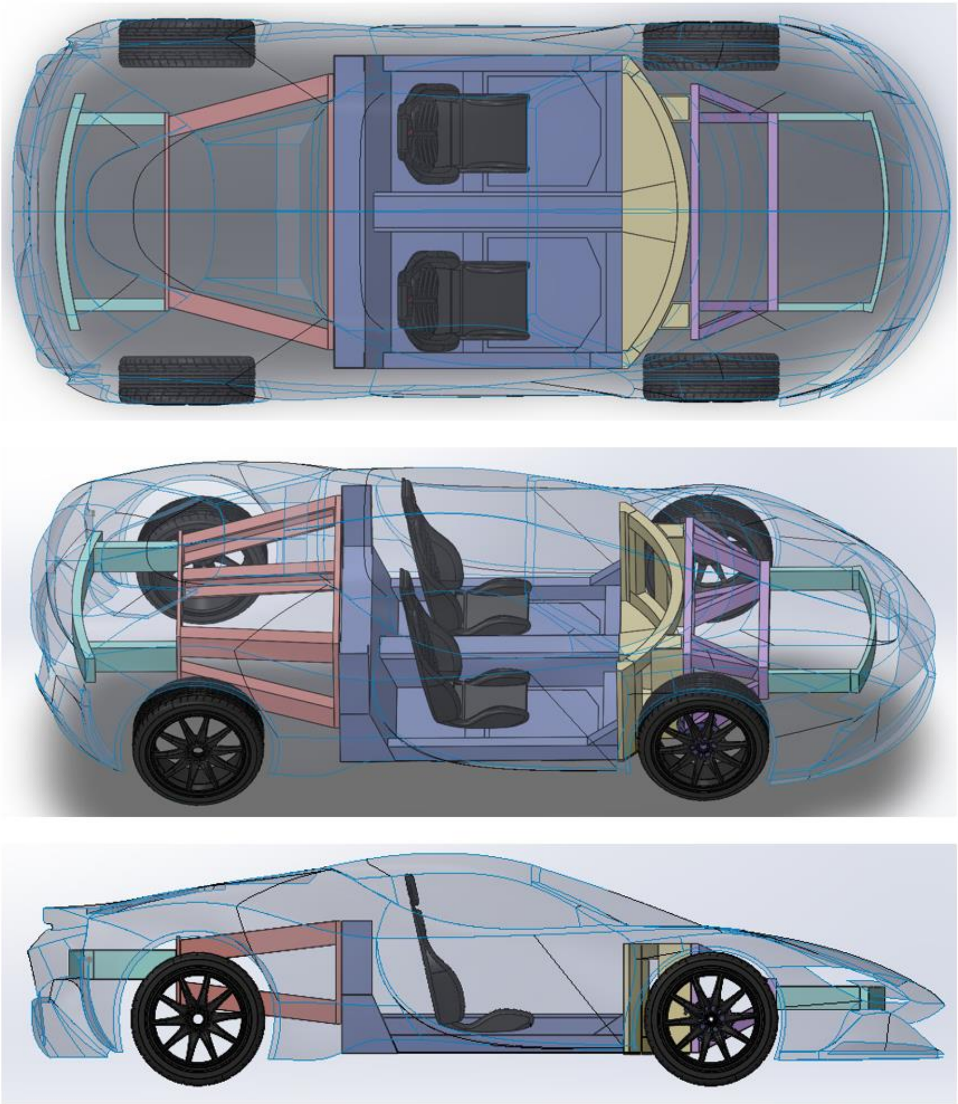


Figure 3.91: Modular platform for rear-mid engine

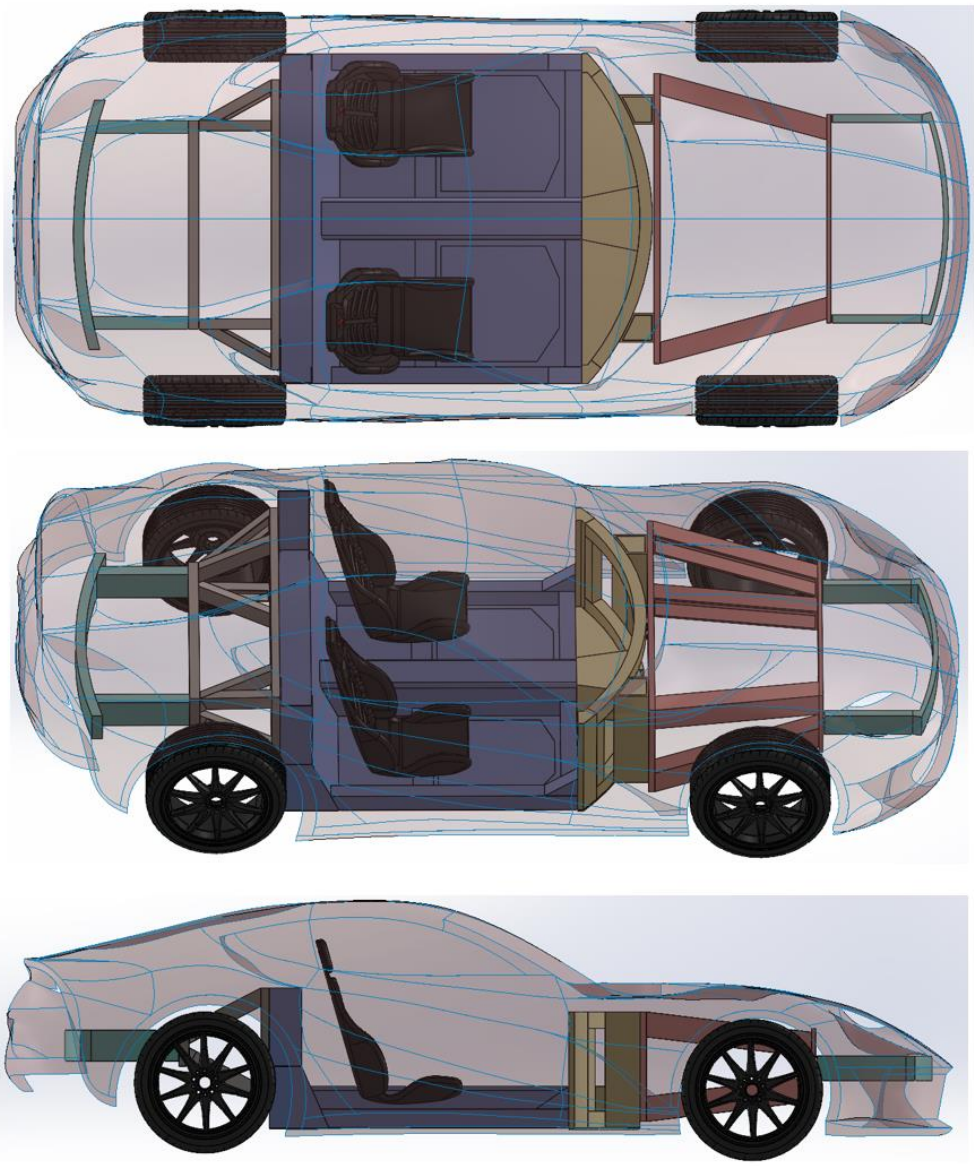


Figure 3.92: Modular platform for front engine

Achieving this also depends on having common connect points for each parts that is available for being replaced. Connecting points of the sections are fastened with screws, and the exact areas where the connections exist are shown in Figure 3.93.

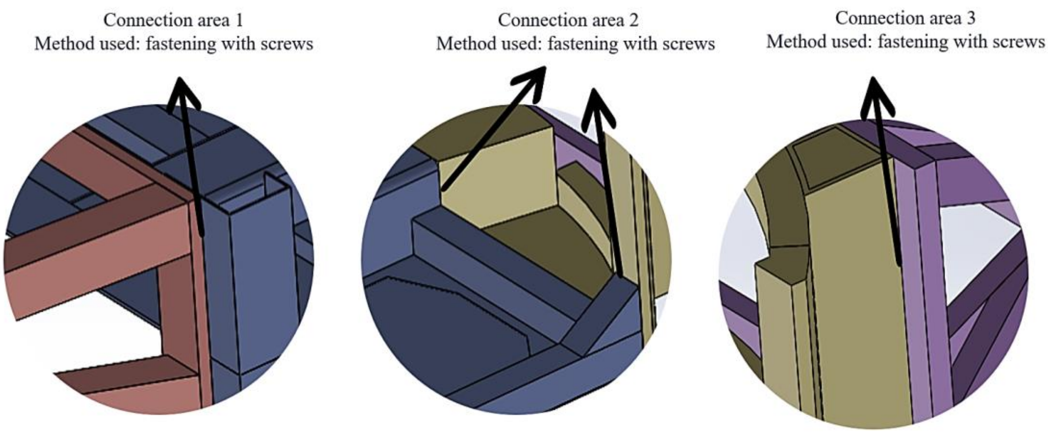


Figure 3.93: Bolted joints of the modular platform

These connection areas are crucial points in the design due to the variability of the section in the case of different layouts. Assembly points of Part 1 and Part 4 are the same in this design. Finally, when examining the design from the stiffness simulation results, it has been decided to replace and compare these parts with new ones obtained through the generative design method, due to the diversity of connection points that may arise from the fact that the areas shown in Figure 3.94.

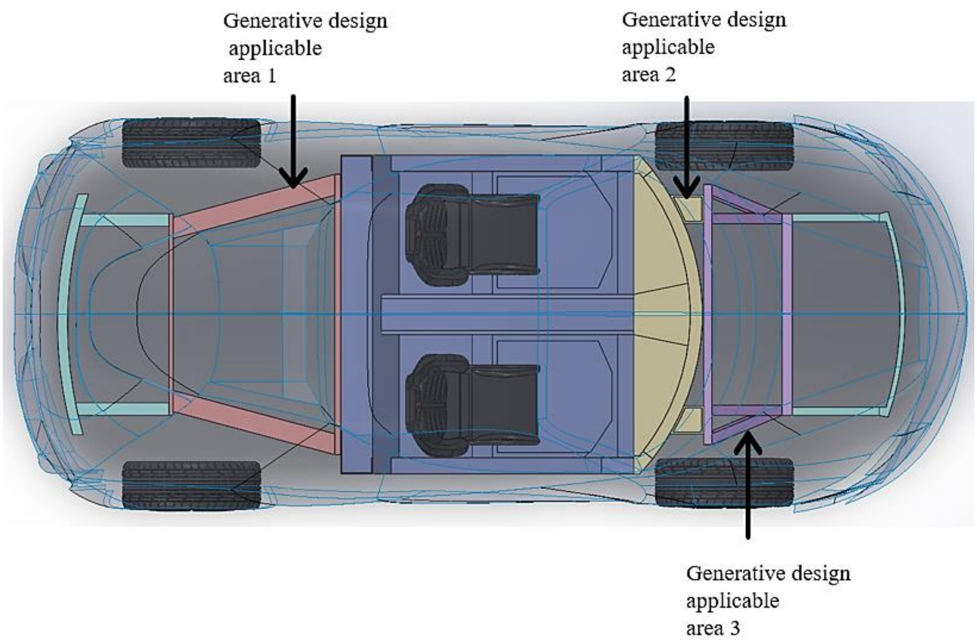


Figure 3.94: Areas defined for generative design

As shown in Figure 3.94, longitudinal beams are more suitable than the transverse beams for generative design application. According to the final design of the modular platform, Part 1 (Engine Compartment), Part 3 (Cockpit Underbody), and Part 4 (Electric Motor Compartment) are suitable for generative design process. It will be significant in offering innovative and alternative designs when the correct boundary conditions values are defined.

3.2.4.2. Sprint (CYCLE 2)

In the second sprint cycle, it will be worked on the requirements to reach a design which is lightweight and has high stiffness value. The Sprint Backlog for this sprint refers designing a lightweight part for each section of modular platform by using Generative Design module in Fusion 360. For this sprint steel alloys are the target as the material. The chosen objective is to "minimize mass", and the key focus here lies in creating a lighter design due to the high density of material. Moreover, in steel alloys with high tensile strength, reducing mass takes precedence.

Generative design applicable area 1: Part1 is designed according to the sizes of Internal Combustion Engines (ICE). One of the most important aspects here is the positioning of connection points for suspension arms and avoiding invasion into the space designated for engine assembly. When generating the design, these limitations must be taken into account.
Generative design applicable area 2: The cockpit underbody has been configured based on the dimensions of a sports car, as derived from benchmarking data. The key focus in this design is to maintain equivalent stiffness to that of traditional chassis platform designs. Consequently, its primary objective is to ensure consistent strength between Part 3 and either Part 1 or Part 4, depending on the chosen layout.
Generative design applicable area 3: Part 4 is designed based on the dimensions of sports cars taken from benchmarking. This section requires proper connection points for both suspension, Part 3, and Part 2. Design space for each section will be defined into Generative Design feature under Fusion 360 Software. For more precise results, exact boundary conditions should be defined.

Figure 3.95, Figure 3.96, and Figure 3.97 below represents the boundary conditions for Part 1, Part 3, and Part 4 respectively. The red parts represent obstacle geometry, indicating that the part cannot extend beyond these areas during generation. The green parts represent preserved geometry, signifying that these areas will be incorporated into the final geometry. Preserved areas have been determined by taking into account connections relative to the centers of mass of objects and connecting with other components. The yellow area indicates the total space that the generated part should utilize.

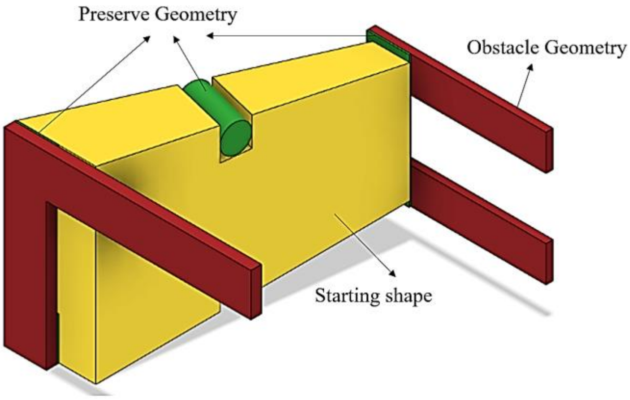


Figure 3.95: Boundary conditions of engine compartment (Part1)

Figure 3.95 defined for Part 1. Generation has been provided for this area from load-bearing points rather than connection sections with other parts. But still, connection points with other sections have been defined as “preserve geometry” (green areas) which will be involved in generated designs.

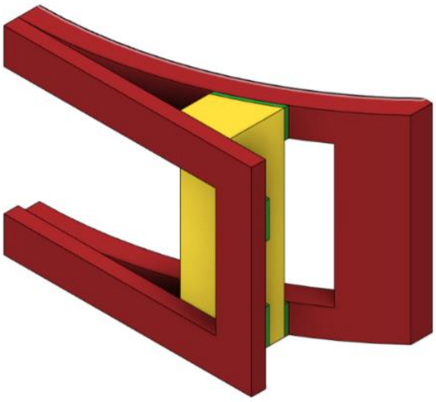


Figure 3.96: Boundary conditions of cockpit underbody (Part3)

Figure 3.96 is created for Part 3. This section is the geometry which requires lower strength than horizontal beams, so it works to keep the geometry rigid.

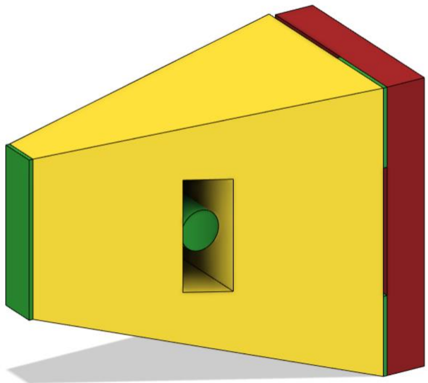


Figure 3.97: Boundary conditions for electric motor compartment (Part 4)

Figure 3.97 represents the boundary definitions for Part 4. In this design, the load bearing points are important as Part 1 due to its relation with suspension systems arms. This component is connected to suspension load-bearing points regardless of the type of layout; therefore, it is crucial to accurately determine the connection points under the preserve geometry (green areas).

In this step, all loads acting on the component will be defined (Figure 3.98), and the necessary points for structural constraints and other limitations will be identified.

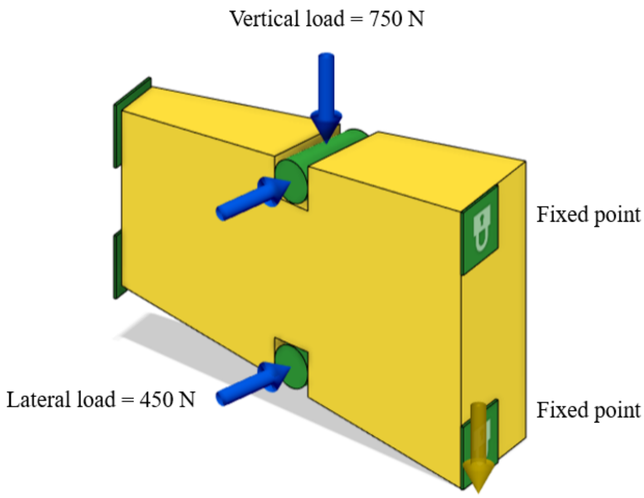


Figure 3.98: Structural constraints and loads on Part 1

Yellow arrow represents the gravity. There are two main loads defined on the Part 1 to create the generated version of the part which are the vertical load caused by torsional load is defined 750 N and approximate lateral forces which is 450 N (Ary et al., 2021; Hazimi et al., 2018).

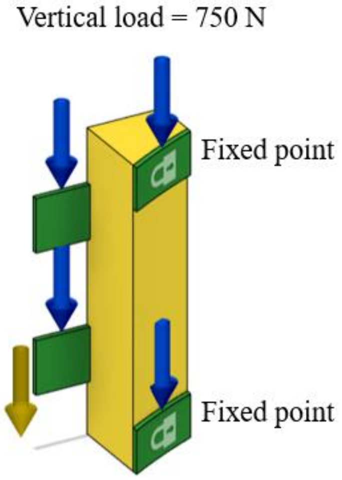


Figure 3.99: Structural constraints and loads on Part 3

The main force acting on Part 3 is the vertical load, and it is caused by a torsional load with a defined value of 750 N (Figure 3.99).

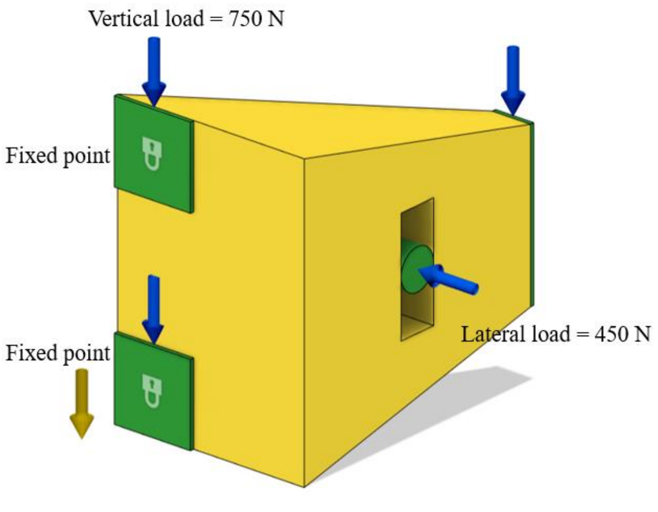


Figure 3.100: Structural constraints and loads on Part 4

In this section of the component, two primary loads impact the part. First part is the vertical load (750 N) caused by torsional movement and the lateral force (450 N) caused by the suspension system (Figure 3.100).

Before performing generation, “minimize mass” option is chosen, safety factor is defined 2.00 in software. The steel alloys most commonly used in automotive chassis design, AISI 4340, AISI 4130 and AISI 1060, have been applied on the part. Lastly, manufacturing types are chosen for additive manufacturing and milling with 3-axis. Later, “generate” command gave us some design results which include all defined requirements (Figure 3.101).

Figure 3.101: Generative design results steel alloys applied Part 1

Figure 3.102 displays the Part 3 for which the generation has been successfully completed among the obtained results. When design requirements are separated into sprints, there has been a decrease in the quantity of results and a reduction for generation and ultimately, in selection time.

Figure 3.102: Generative design results steel alloys applied Part 3

For different types of steel alloys, again, results have only minor differences. It is quite important to define exact manufacturing process even with axis. In conventional aspect, results would change the facility of the manufacturer. Figure 3.103 represents generation on Part 4.

Figure 3.103: Generative design results steel alloys applied Part 4

All these generative design processes were made using minimize mass option depending on high density of steel alloy. Design selection is being done by the requirements given by customers. In the case of safety factor is inside the limits, the part has lower mass with higher or equal strength with initiative part can be chosen. Later, chosen and initiation parts will be compared in terms of mass values and mechanical properties to evaluate lightweightness success of the process. Below are shown the best design solutions taken from Fusion 360 results (Table 3.6).

Table 3.6: Best generated part outputs for steel alloy used Part 1

			
Name	Outcome 3	Outcome 5	Outcome 14
Material	Steel AISI 1060	Steel AISI 4130	Steel 4340
Manufacturing method	Additive Z+	Additive Z+	Additive Y+
Volume (mm3)	7.396e+6	7.381e+6	7.428e+6
Mass (kg)	58.055	57.939	58.309
Max von Misses stress (MPa)	8.684	8.456	7.938
Min Factor of safety	43.669	92.008	79.872
Max displacement (mm)	0.144	0.134	0.119

As seen from the Table 3.6, the best design results have minor differences. Thus, factors such as mass, von Misses stress, displacement, or manufacturing method will assist to choose the best option. The decision to select the part can be made by considering factors such as the production method or supply of materials or cost which can be differentiating points. Outcome 5 has been chosen among the best results. Because, while it is the lightest part, it has high von Misses stress and safety factor besides average displacement value.

Table 3.7: Best results of the generation for steel alloy used Part 3

			
Name	Outcome 1	Outcome 5	Outcome 11
Material	Steel AISI 1060	Steel AISI 4130	Steel AISI 4340
Manufacturing method	Unrestricted	Unrestricted	Additive Z-
Volume (mm3)	1.353e+6	1.354e+6	1.346e+6
Mass (kg)	10.617	10.627	10.565
Max von Misses stress (MPa)	6.41	6.442	7.415
Min Factor of safety	59.157	120.779	85.504
Max displacement (mm)	0.015	0.015	0.022

Table 3.7 represents the results for steel alloys used Part 3. Safety factor here is the most distinctive result. Taken into consideration of the impact force for this part, which is related with cockpit, output which is highest safety factor can be chosen (Outcome 5). Even if Outcome 11 has the highest von Misses stress value, due to its highest displacement value it cannot be chosen as the best outcome at that section of the platform. Still, final decision will be made after the sprint for aluminium alloys (Sprint 3) to compare all results and find out best option. On the other hand, at the end of the generation process for all sections, stiffness results have to be compared to determine the final modular platform assembly, which includes the best design options.

Table 3.8: Best generated part outputs for steel alloy used Part 4

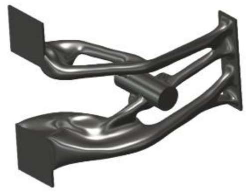
			
Name	Outcome 2	Outcome 5	Outcome 12
Material	Steel AISI 1060	Steel AISI 4130	Steel AISI 4340
Manufacturing method	Additive Z+	Unrestricted	3- Axis Milling
Volume (mm3)	1.826e+6	1.847e+6	1.839e+6
Mass (kg)	14.335	14.496	14.436
Max von Misses stress (MPa)	11.615	8.584	10.601
Min Factor of safety	32.648	90.635	59.807
Max displacement (mm)	0.079	0.058	0.084

Table 3.8 represents best three output which has best values among the result. As in the other result tables, part selection should be based on customer requirements rather than the part with the strongest results. Because each part excels in different areas independently. According to these results, Outcome 2 has been chosen as the best design with its highest strength. But the final decision will be made after comparing with the outcomes of the aluminum alloy used in third sprint cycle. Overall, in this sprint, steel alloy materials have been assigned within generative design. When looking at the results, it was observed that numerical data and designs are similar for different materials. While parts using different steel alloys yielded similar design outcomes with minor differences, another difference noted was achieved through a change in the manufacturing method, a significant geometrical change in the part was obtained when the production method was altered.

3.2.4.3. Sprint (CYCLE 3)

In the third sprint cycle**,** target is to create a design which is lightweight and has high stiffness value. For this reason, aluminium alloys are applied on the parts. In previous sprint, minimum mass option has been used because of the high tensile strength and density properties of steel alloys. Now, the decision has been made to use an aluminum alloy in the component due to its low density. Therefore, the option of "maximum stiffness" option will be activated during generation to achieve sufficient stiffness while making an advantage with the lighter design.

Since the raw components to be used, the loads applied to them, and their directions are the same as in the previous sprint, only the exception of a material change. Therefore, it will be proceeded to the explanation of the generative design step. At this sprint, "maximize stiffness" option is chosen because aluminium will provide its advantage with its lighter density than steel, but at the same time parts have to provide high or sufficient strength. The aluminium alloys most commonly used in automotive chassis, such as 5052, 6061 and 7075 will be chosen as materials. Manufacturing options can be unrestrictive, additive manufacturing, and 3-axis milling (Figure 3.104).

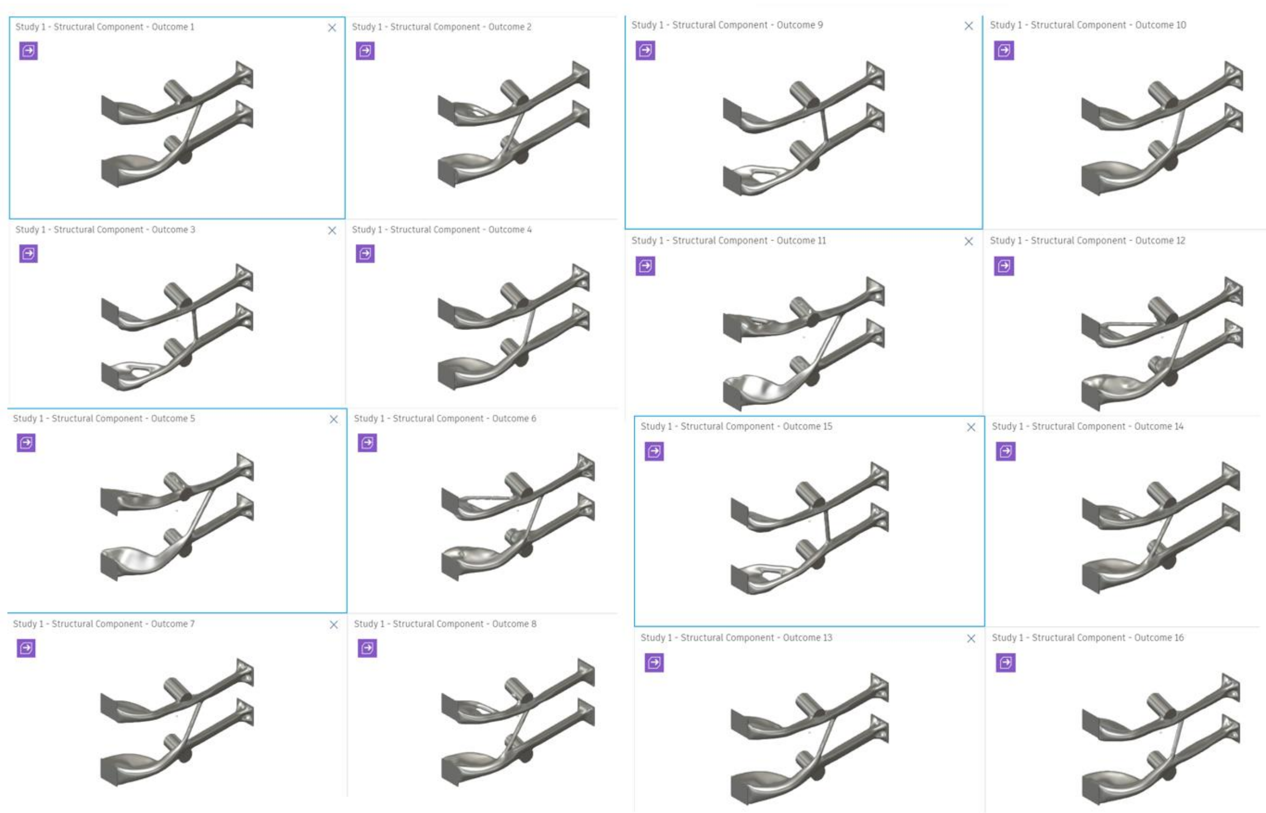


Figure 3.104: Generative design results aluminium alloys applied Part 1

As mentioned before, manufacturing method of part alters the diversity and shape of the generatively designed part. In this project, we adjusted the milling process by entering parameters that allow it to be performed on each axis. This increases the variety of outcomes.

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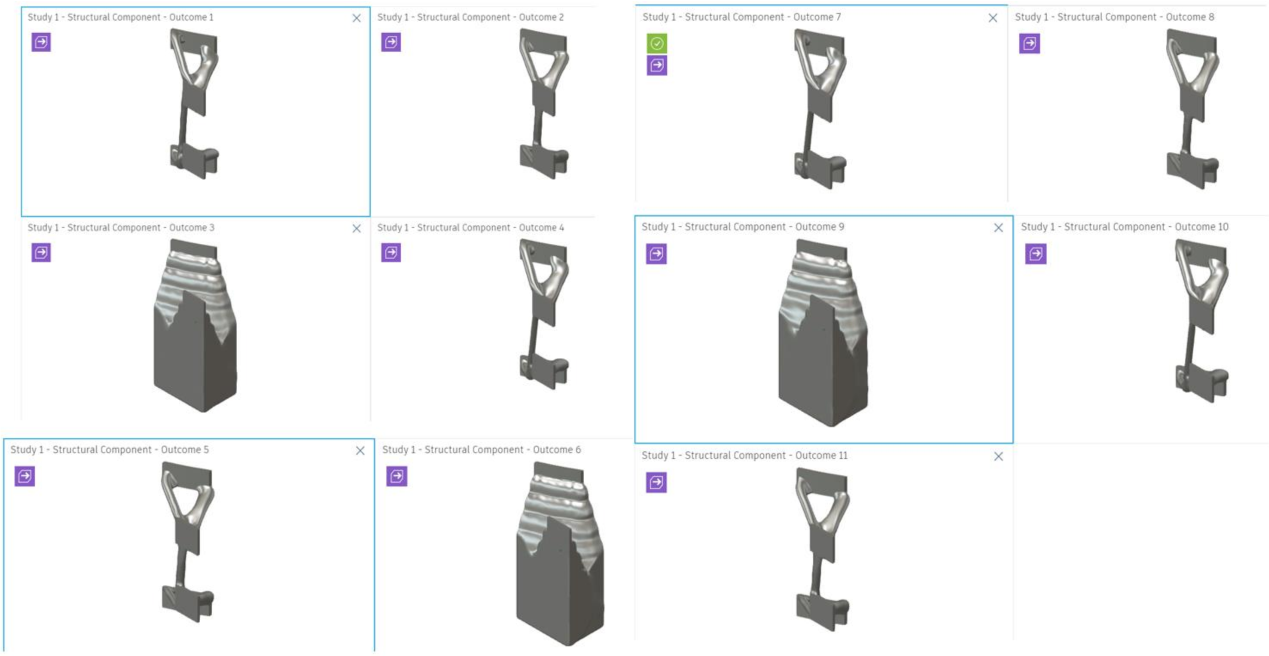


Figure 3.105: Generative design results aluminium alloys applied Part 3

These are shown above the design results for cockpit underbody (Part 3). Unlike other outcomes, during this generation, not all parts have achieved with an ideal evolution. The processes of some parts have failed, as seen in Figure 3.105, Outcome 3, 6, and 9.

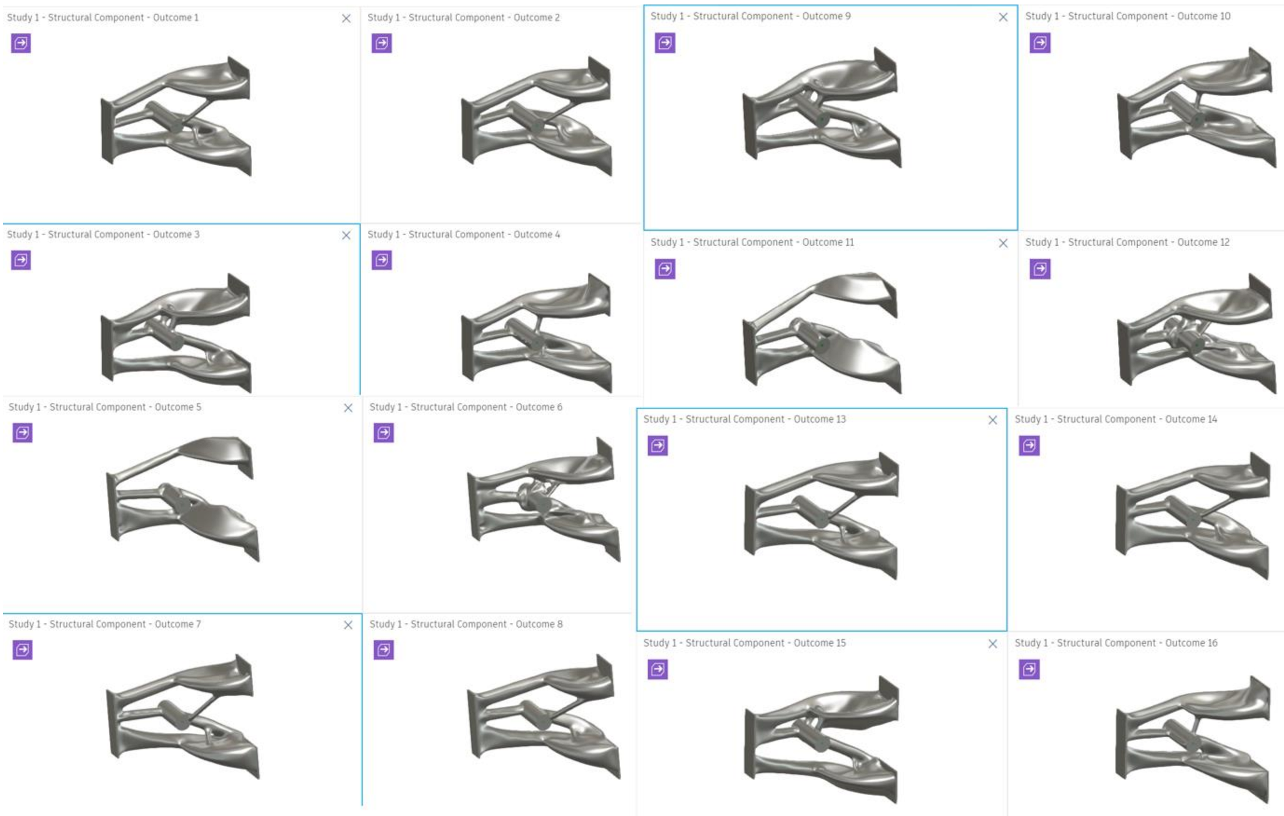


Figure 3.106: Generative design results aluminium alloys applied Part 4

The reason for multiple outputs is the diversity in the manufacturing method (Figure 3.106). In other words, in the Fusion 360 program, the manufacturing methods and details such as the milling axes on which the material will be processed can be defined in the software. Therefore, the manufacturing method and capacity of the facility where the customer will produce the part will also affect the number of final parts. Below is shown the best results taken from the generation results (Table 3.9, Table 3.10, and Table 3.11).

Table 3.9: Best generated part outputs for aluminium alloy used Part 1

			
Name	Outcome 3	Outcome 8	Outcome 18
Material	Aluminium 5052	Aluminium 7075	Aluminium 6061
Manufacturing method	Additive Z+	Additive Y +	3-axis milling
Volume (mm3)	7.386e+6	6.986e+6	7.393e+6
Mass (kg)	19.794	19.632	19.96
Max von Misses stress (MPa)	8.585	7.671	8.47
Min Factor of safety	22.481	18.903	32.466
Max displacement (mm)	0.417	0.353	0.448

According to the design results, additive manufacturing can be the favourite manufacturing process for this part. In generation settings, there was a mass limit for the part, and this worked as a boundary limits. Even if **maximum displacement value increased sharply** when compared with the outputs attained from steel alloy applied generation, still, von Misses stress and factor of safety results are satisfying in this generation. Additionally, **mass value decreased on a large scale** which makes these results valuable for the final evaluation.

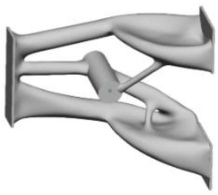
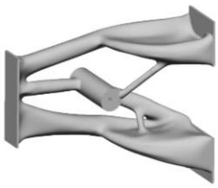
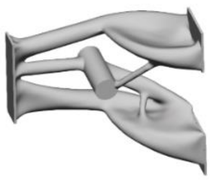
Table 3.10: Best generated part outputs for aluminium alloy used Part 3

			
Name	Outcome 1	Outcome 4	Outcome 7
Material	Aluminium 7075	Aluminium 5052	Aluminium 6061
Manufacturing method	Unrestricted	Unrestricted	Unrestricted

Volume (mm3)	1.41e+6	1.465e+6	1.456e+6
Mass (kg)	3.962	3.931	3.932
Max von Misses stress (MPa)	9.747	8.75	8.807
Min Factor of safety	14.887	29.154	35.539
Max displacement (mm)	0.082	0.06	0.06

Based on the design outcomes, Outcome 4, and Outcome 7 exhibit advantages over Outcome 1 in terms of displacement and von Mises values. Due to slight differences, Outcome 7 is selected as the ultimate design choice, primarily based on its higher safety factor. This value will guide us in the subsequent assembly simulations.

Table 3.11: Best generated part outputs for aluminium alloy used Part 4

			
Name	Outcome 1	Outcome 7	Outcome 13
Material	Aluminium 7075	Aluminium 5052	Aluminium 6061
Manufacturing method	Unrestricted	Unrestricted	Unrestricted
Volume (mm3)	3.183e+6	3.314e+6	3.292e+6
Mass (kg)	8.944	8.891	8.89
Max von Misses stress (MPa)	5.083	4.841	4.889
Min Factor of safety	28.526	52.694	56.25
Max displacement (mm)	0.074	0.072	0.074

Examining design results show that Outcome 7 has advantage on Outcome 1 and 13 with safety factor and max displacement values. There has not been a significant difference between the load-bearing stress and design masses.

3.2.4.4. Sprint (CYCLE 4)

In the last sprint cycle, all numerical values taken from previous Sprints will be compared and evaluated. From the results obtained in the previous sprints, the design that is the lightest and has the highest strength will be chosen for each section, resulting in the creation of the most **ideal modular platform design**. Thus, first comparison Table 3.12 is representing the mechanical properties of the best outputs taken from each GD process.

Table 3.12: Comparison table for generated parts

		MATERIAL	*MASS (kg)*	*VOLUME (mm3)*	*VON MISSES STRESS (MPa)*	*MAX DISPLACEMENT (mm)*
Part 1	***Outcome 5***	AISI 4130	57.939	7.381e+6	8.456	0.134
Part 1	***Outcome 3***	Aluminium 5052	19.794	7.386e+6	8.585	0.417
Part 3	***Outcome 5***	AISI 4130	10.627	1.354e+6	6.442	0.015
Part 3	***Outcome 7***	Aluminium 6061	3.932	1.456e+6	8.807	0.06
Part 4	***Outcome 2***	AISI 1060	14.335	1.826e+6	11.615	0.079
Part 4	***Outcome 7***	Aluminium 5052	8.891	3.314e+6	4.841	0.072

Table 3.12 shows us comparison between the best outcomes obtained with generative design. Based on these results, the most suitable components for the applied generative design modular platform will be selected. Accordingly, Outcome 5 which is AISI 4130 used part has been chosen for Part 1.
Although Outcome 3 is significantly lighter than Outcome 5, when looking at the displacement, we see that the product using steel is much more advantageous. Therefore, steel alloy used part have been preferred with the aim of being a region that includes the internal combustion engine in this area. For Part 3 selection, Outcome 7 has been chosen. Because, due to its geometry at the connection points which is shorter length when compared with other cases, it will not be significantly affected by

dislocations. For the last case, Outcome 2 has been chosen due to its high von Misses stress result. This outcome has advantage since the maximum displacement is similar in both products, and there is not a significant difference in masses. Considering all the selected parts, the final version of the modular platform for rear-mid engine layout represented in Figure 3.107.

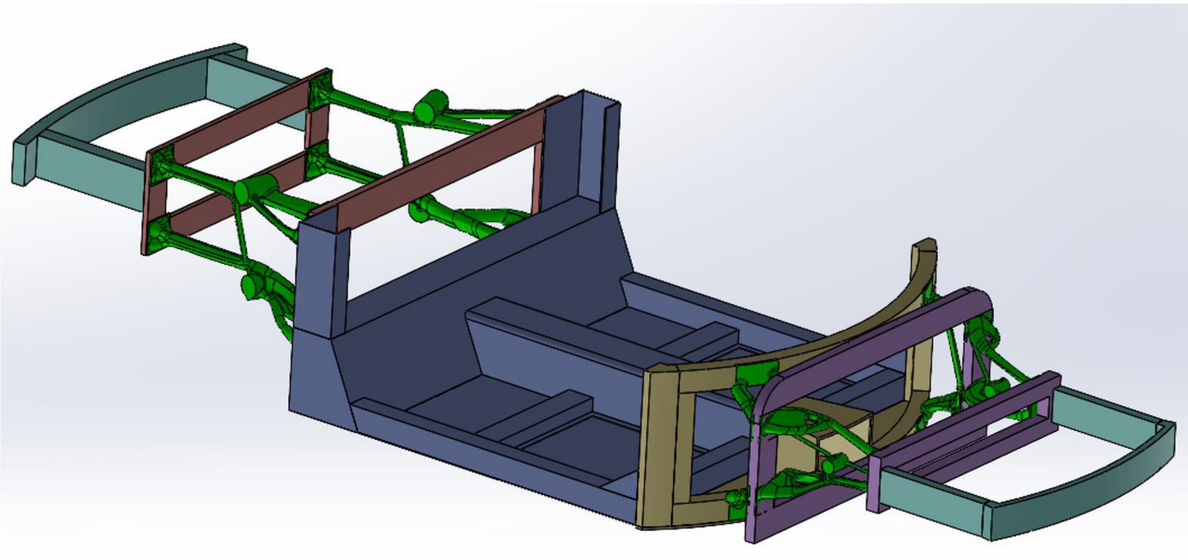


Figure 3.107: Generative design applied "Ideal Modular Platform"

The mechanical behaviors of the obtained design will be verified through torsion testing. As in previous sections, the elements in the model to be simulated have been defined as beams. While Fusion 360 shows individual mechanical results for parts, in order to see how the generated parts will respond in the system, they need to experience a test with whole modular platform assembly. At the end of this simulation, modular platforms will be compared in terms of the stiffness, stress, and displacement values.

3.2.4.4.1. Adaptation of Ideal Modular Platform

- Torsional Stiffness Analysis for Rear -Mid Engine Layout Ideal Modular Platform

In Fourth Sprint Cycle, design selection needs a modification which can be achieved thanks to **adaptation** feature of Scrum Workflow. In generative design, parts are evolved by **adapting** to the conditions that need to be achieved rather than being optimized. Bu using beam model and referencing the joints of this innovative design, we can verify our new model in terms of rigidity (Figure 3.108).

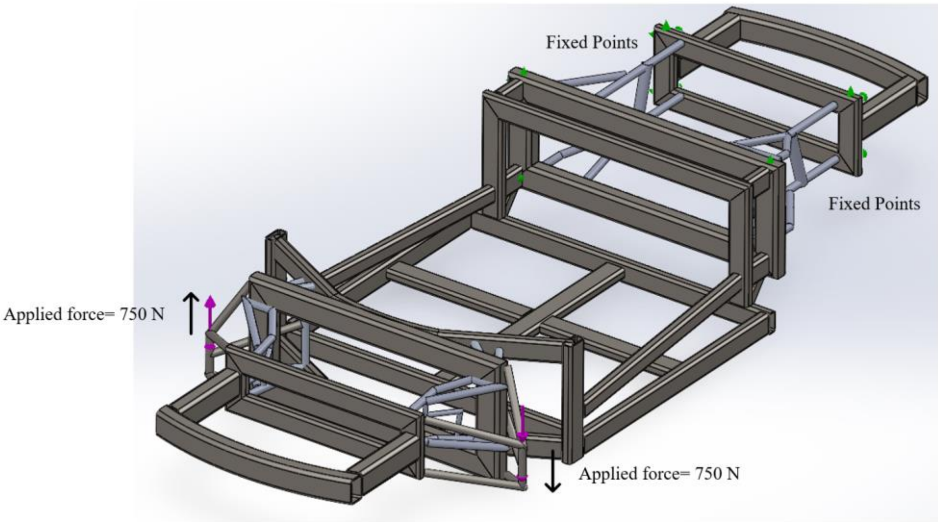


Figure 3.108: Beam model of ideal modular platform

All simulation settings were copied from the torsion test simulation performed in the title from "3.1.4.3.6 Torsional Stiffness Analysis". Materials used on GD applied parts have been applied according to the generative design results. Steel alloy AISI 4130 was used for Outcome 5 in Part 1 while aluminium 6061 was used for Outcome 7 which is inside the Part 3. Lastly, Outcome 2 was chosen for Par 4 and its material is steel alloy AISI 1060. Displacement results are given in Figure 3.109.

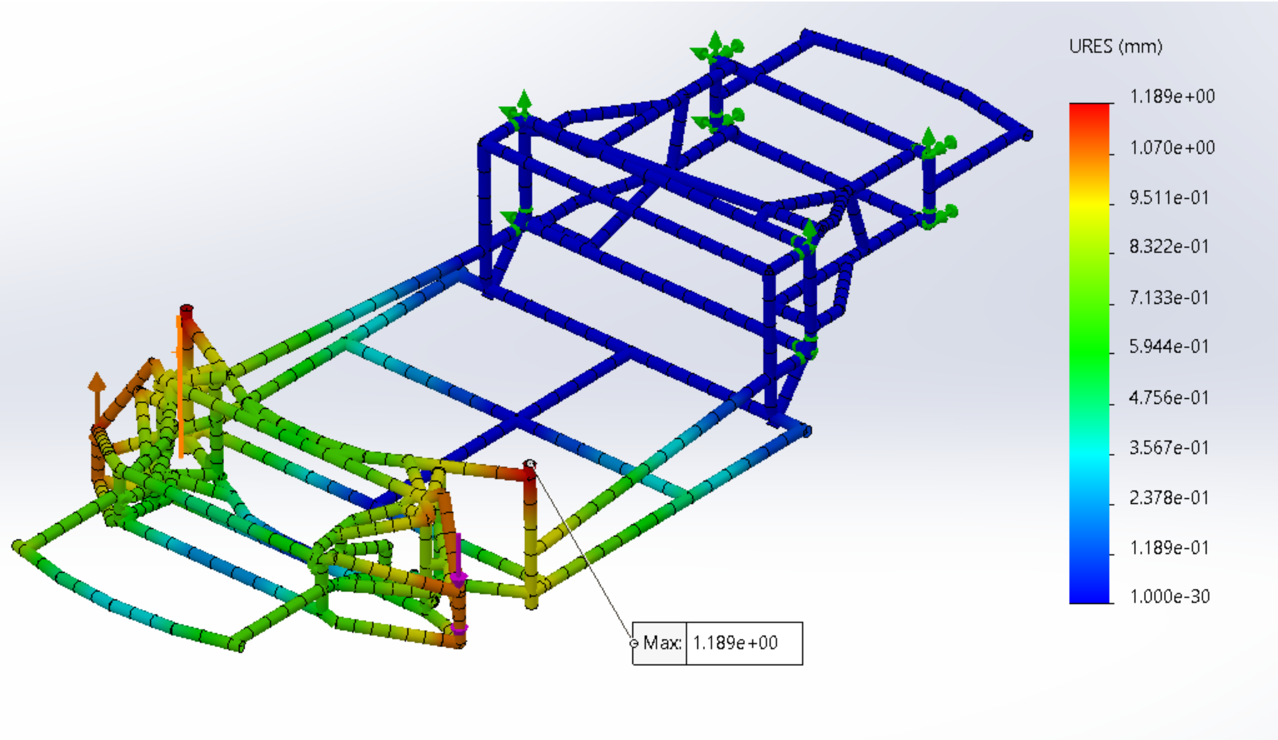


Figure 3.109: Displacement results of ideal modular platform for rear-mid engine layout

The area of maximum displacement occurred in the Part 3 which is the same area as initial modular platform design (Chapter Product Architecture Figure 3.54.) From the max. displacement value (1.189 mm), angular deflection value is calculated 0.1054 (deg) and torsional stiffness is 9179.317 (Nm. /deg). In the new design, the maximum displacement value has increased slightly. Second important parameter for validation is the torsional stress distribution given in Figure 3.110.

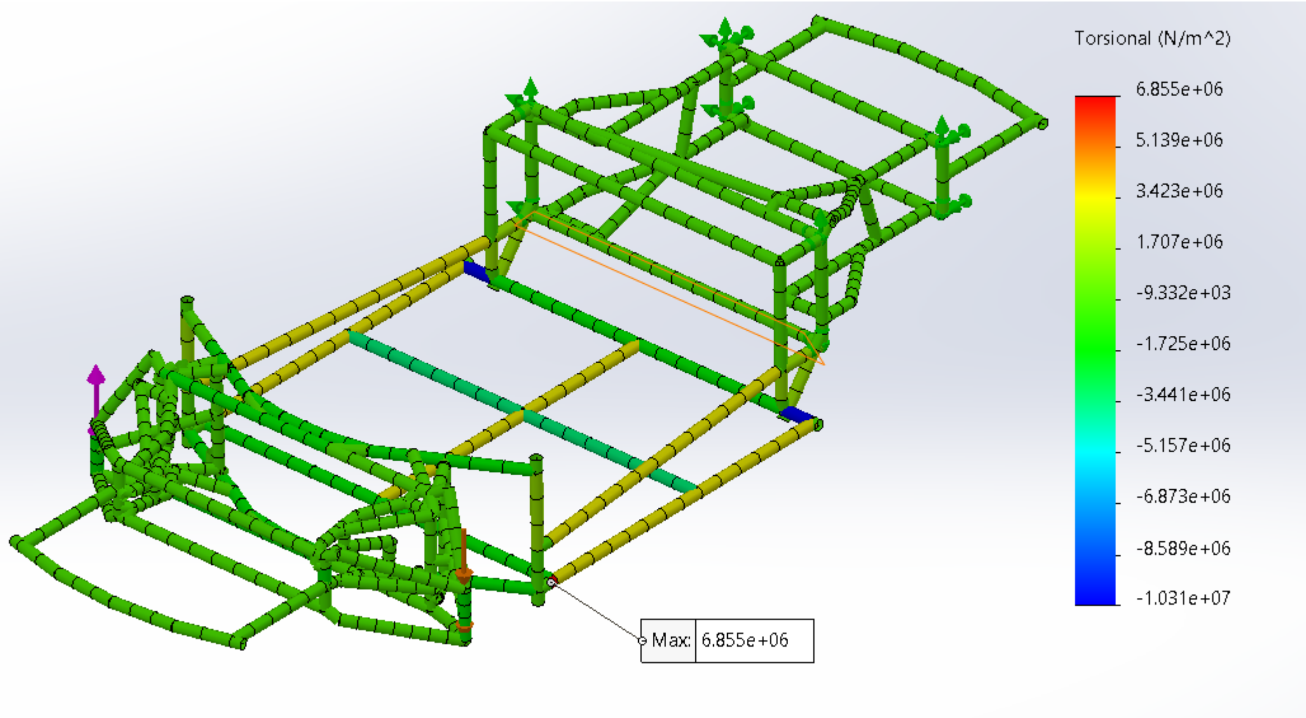


Figure 3.110: Torsional stress distribution of ideal modular platform for rear-mid engine layout

Maximum torsional stress value is 6.855 MPa which occurs frontal part of the passenger zone. As the initial rear mid layout modular platform, it emerges at the connection edge (Connection area of Part 2 and Part 3). The biggest difference from the initial rear mid platform is to have a higher torsional stress where the Part 2 connected with Part 3.

- Torsional Stiffness Analysis for Front Engine Layout Ideal Modular Platform

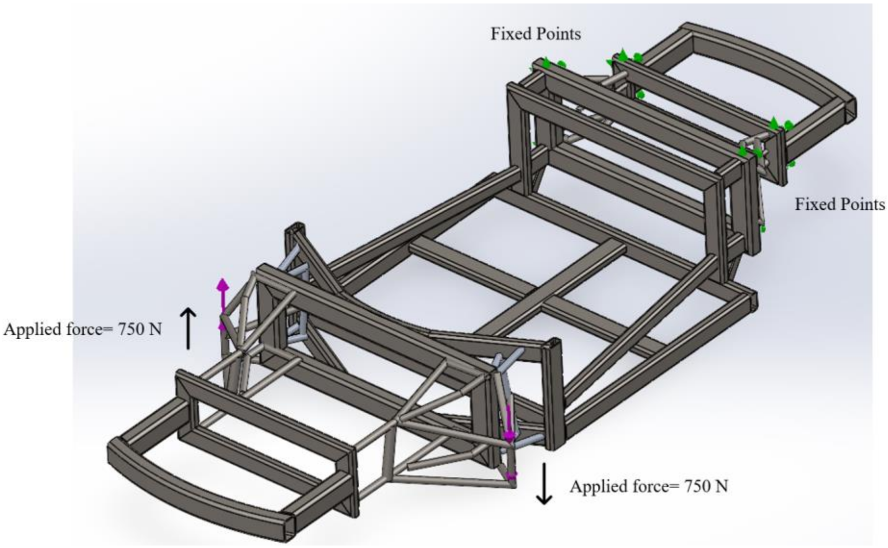


Figure 3.111: Boundary conditions on front ideal modular platform

This is the modified design for front engine configuration (Figure 3.111). The materials used in the previous test have been used exactly in this design. Simulation results are seen in Figure 3.112 and Figure 3.113.

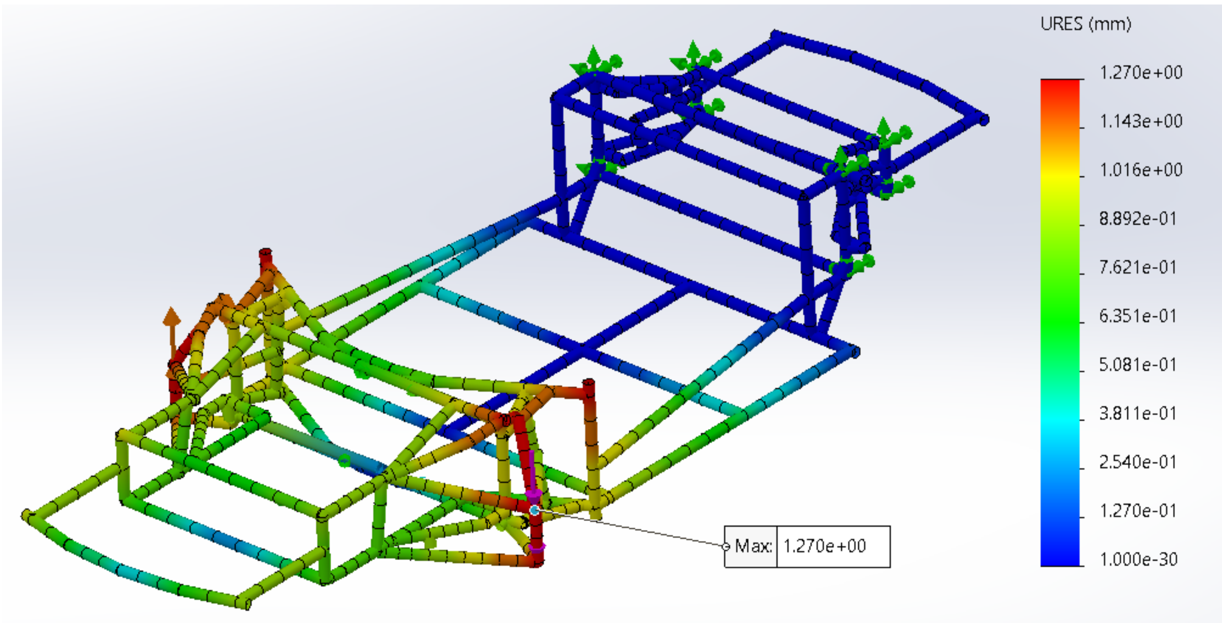


Figure 3.112: Displacement results of ideal modular platform for front engine layout

Maximum displacement value is almost same with initial parts. It was calculated as 1.27 mm. All simulations were conducted under the conditions in which suspension arms are connected to the platform. Therefore, the point where the red area is located, rather than the suspension area, will be taken into account which has almost same displacement. Angular deflection value is 0.10427 (deg) and torsional stiffness is 9998.081 (Nm. /deg).

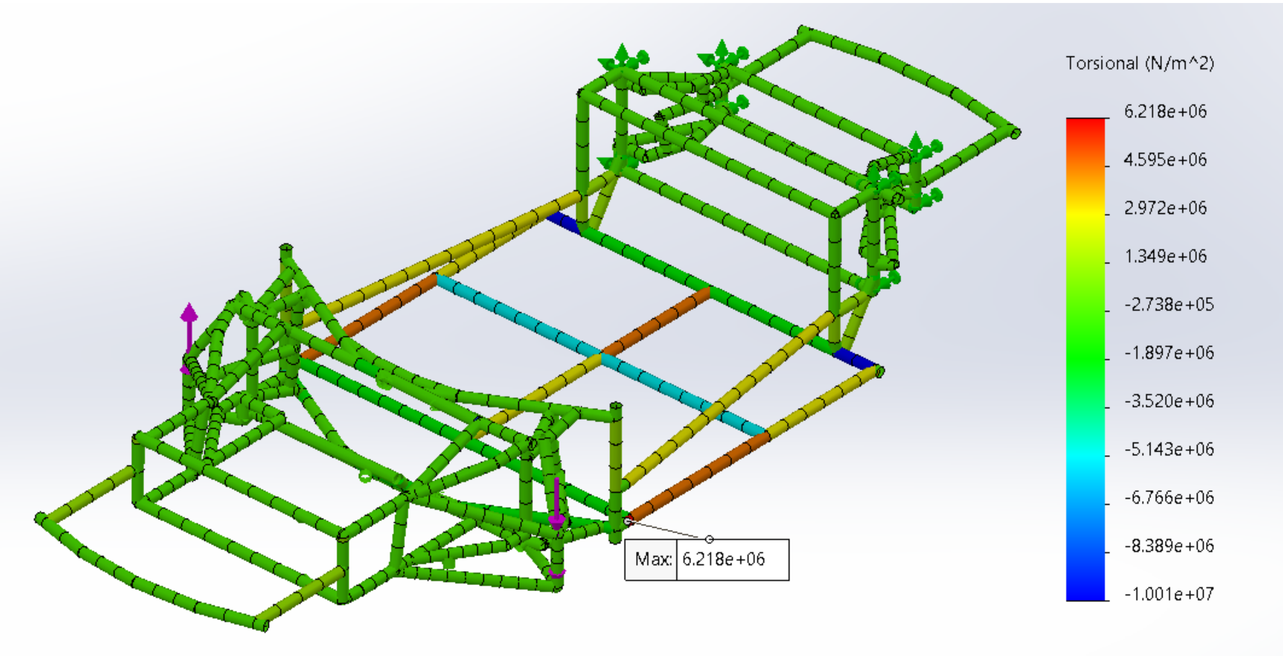


Figure 3.113: Torsional stress distribution of ideal modular platform for front engine layout

Maximum stress (6.218 MPa) is at the connection point between the passenger zone (Part 2) and the cockpit underbody (Part 3). The displacement in torsion indicates that, regardless of the direction in which Part 1 is assembled, it creates an above-average stress on Part 2 in both cases (front or rear-mid engine layout). Design reinforcement can be considered by taking into account the areas where maximum torsion occurs.

- Bending Stiffness Analysis for Rear -Mid Engine Layout Ideal Modular Platform

Bending stresses on the ideal modular platform will be analysed with same parameters that has been already set in Chapter 3.1.4.3.7. Bending Stiffness Analysis. Loading points have been illustrated in Figure 3.114.

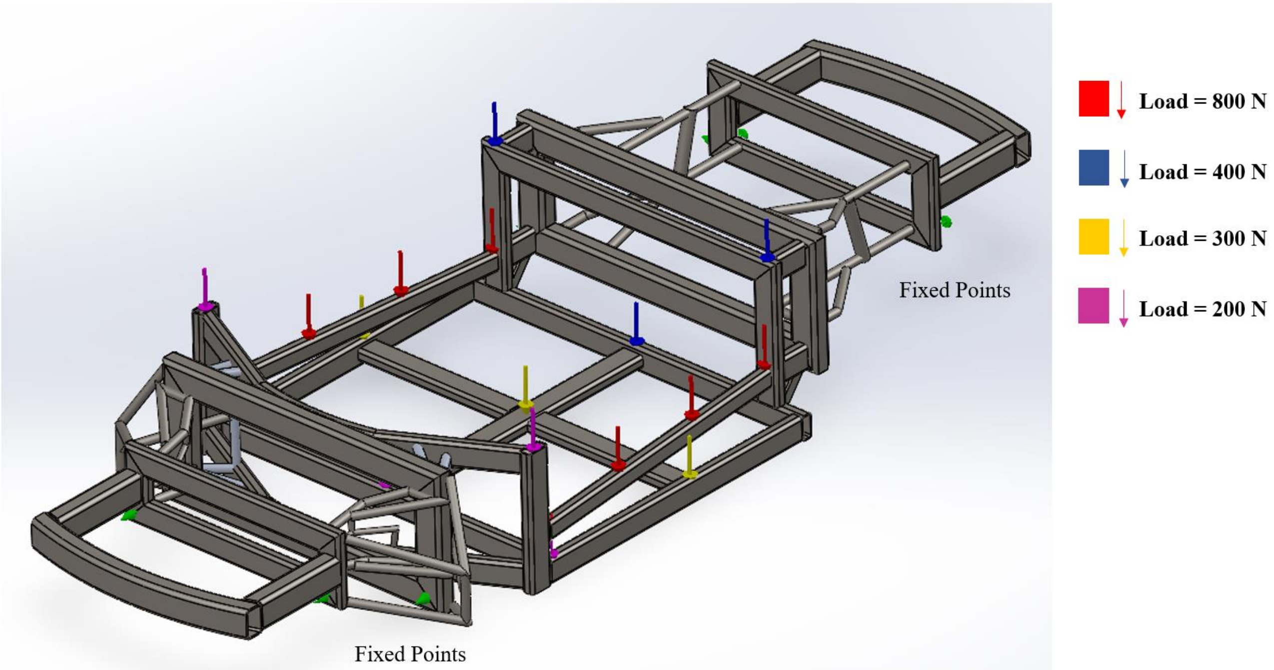


Figure 3.114: Boundary conditions on rear-mid ideal modular platform for bending test

Maximum loads of 800 N distributed load have been applied to the beams in the passenger zone (Part 2). The center beam, highlighted in yellow, bears 300 N. The last applications consist of 200 N on the front section of Part 2 and 400 N on the rear section of Part 2. The higher rear loads are attributed in Part 1 due to the positioning of the engine. The displacement results obtained by the given constraints are as shown in the Figure 3.115.

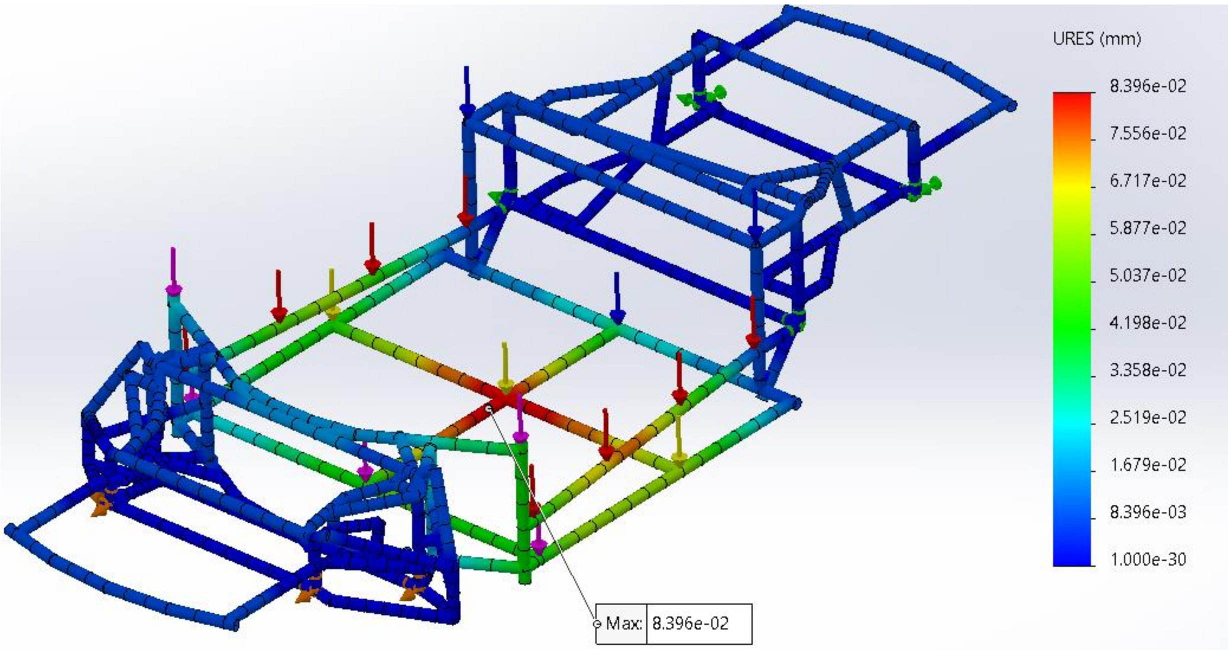


Figure 3.115: Displacement results of bending test for rear-mid ideal modular platform

Bending stiffness is calculated using maximum displacement value taken from the results. α_{front} is 0.008136 and K_{body} equals to 21773.6 (Nm /deg).

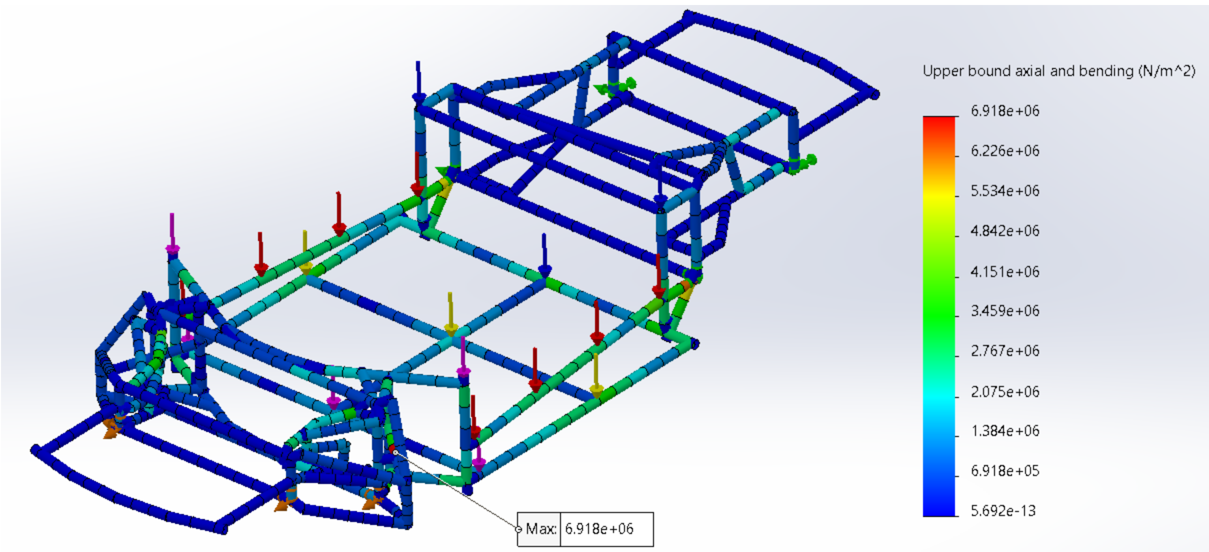


Figure 3.116: Bending stress distribution results of rear-mid ideal modular platform

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In this output (Figure 3.116), different from the previous initial platform results that in Part 1 and Part 2, the beams on top has more stresses than the beams in the bending tests for rear-mid initial modular platform. Connection areas where the Part 1 has connection with Part 2, especially the support beams on bottom has higher stresses. Maximum stress (6.918 MPa) occurred in where the suspension multi-link arm connected with generated part (Outcome 7). The result of a dynamic part in the static test (suspension arms) will be excluded.

- Bending Stiffness Analysis for Front Engine Layout Ideal Modular Platform

The values obtained from the bending test and calculated using formulas will be assessed in the comparison table. Constraints have been defined for generated part used ideal modular platform (Figure 3.117).

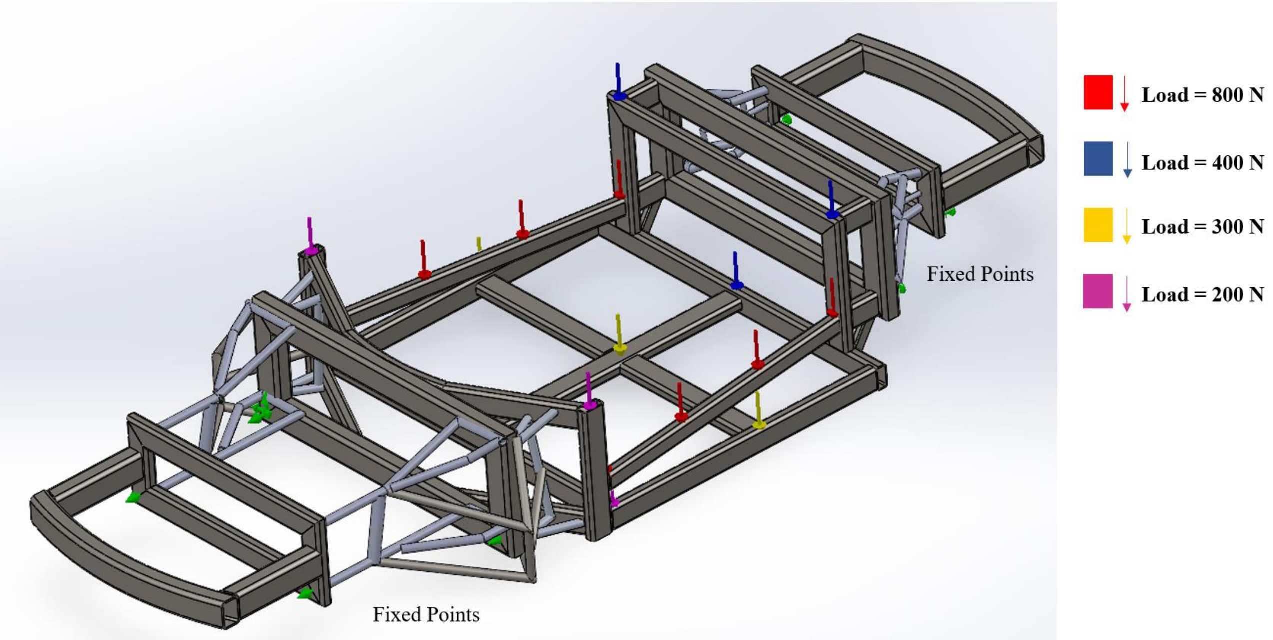

Figure 3.117: Boundary conditions on front ideal modular platform for bending test

Following figures include displacement and bending stress results of this design (Figure 3.118 and Figure 3.119).

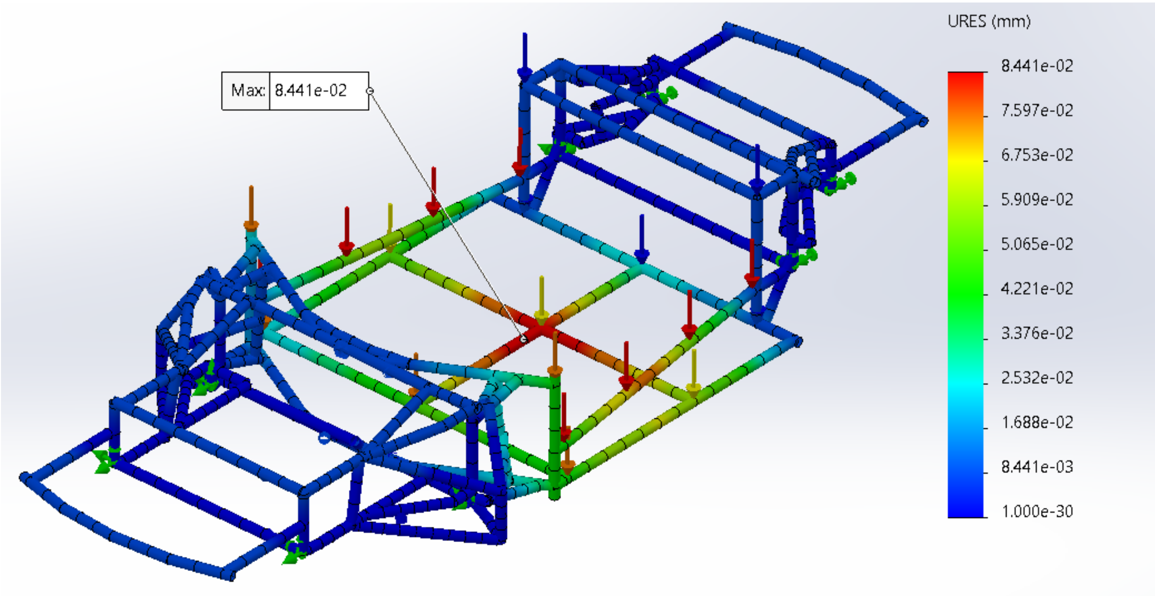

Figure 3.118: Displacement results of bending test for front ideal modular platform

Maximum displacement occurred in the midpoint of passenger zone and calculated, α_{front} is 0.008187 deg and K_{body} is 21637.962 (Nm/deg).

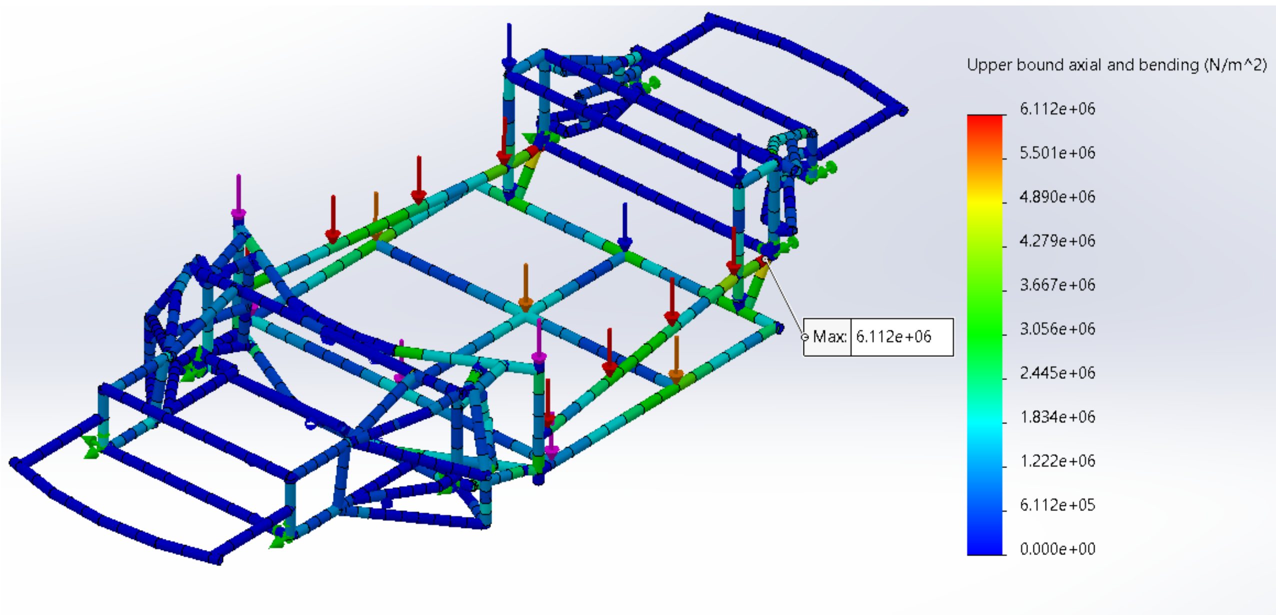

Figure 3.119: Bending stress distribution results of front ideal modular platform

The bending stress results (Figure 3.119) indicate that in areas where horizontally located profiles, beam connection joints will be subjected to greater bending. Since the vehicle's powertrain assemblies are located at the front and rear, higher bending stress is inevitable to occur most in these regions. All calculated and attained results are given in comparison Table 3.13.

Table 3.13: Comparison of stiffness tests

	Max torsional displacement (mm)	**Torsional Angular Deflection (deg)**	**Max. Torsion Stress (MPa)**	**Torsional Stiffness (Nm. /deg)**	**Bending Displacement (mm)**	**Bending Angle (deg)**	**Bending Max Stress (MPa)**	**Bending Stiffness (Nm. /deg)**
Rear Mid Initial	1.123	0.09969	3.795	9705.0857	0.07237	0.00687	5.642	25786.02
Front Initial	1.283	0.104	4.356	10024.038	0.07256	0.00703	5.664	25199.146
Rear Mid GD	1.189	0.1054	6.855	9179.317	0.08396	0.008136	6.918	21773.6
Front GD	1.270	0.10427	6.218	9998.081	0.08441	0.008187	6.112	21637.962

Common values for torsional stiffness in a passenger car typically fall within the range of 17000 to 40000 Nm/deg, accompanied by a roll stiffness of 1000-2500 Nm/deg per axle. This implies a chassis/roll stiffness ratio ranging from 6.8 to 40 (Danielsson, 2015). It should be explicitly stated that since the model we obtained is not a full chassis, its torsional rigidity will not fall within the limit values of the vehicles on the market. Therefore, it would not be appropriate to compare the obtained value with the existing sports car torsional rigidity. What needs to be emphasized here is that if we consider the lowest rigidity value (around 17000 – 20000 (Nm. /deg)), our modular platform covers an average of 50% of the total rigidity. There was no noticeable change in displacement values for both type of stiffness tests. In fact, the torsional angular deflection on the front platform has remained almost the same. Similarly, bending angle is quite similar with both models because the section change does not include defined load areas.

As can be understood from the results, although the maximum stress values on models using generated parts is higher, when we examine the distribution of stress, it is observed to occur at almost the same points. The aim here is to achieve the transformation of a material with the same mass or volume into a more efficient part through the use of generative design. This can be achieved by not using straight beams for engine compartments but by using more efficient parts with connection points, thanks to generative design. Another point that we need to assess is the differences in mass values between the parts obtained through generative design and the initial part (Table 3.14).

Table 3.14: Mass comparison of generated parts

		MATERIAL	***MASS (kg)***	***VOLUME (mm3)***
Part 1	***Initial***	AISI 4130	42.8	10.764e+6
Part 1	***Outcome 5***	AISI 4130	57.939	7.381e+6
Part 1	***Outcome 3***	Aluminium	19.794	7.386e+6
Part 3	***Initial***	AISI 4130	23.952	3.051e+6
Part 3	***Outcome 5***	AISI 4130	10.627	1.354e+6
Part 3	***Outcome 7***	Aluminium 6061	3.932	1.456e+6
Part 4	***Initial***	AISI 4130	13.288	1.693e+6
Part 4	***Outcome 2***	AISI 1060	14.335	1.826e+6
Part 4	***Outcome 7***	Aluminium 5052	8.891	3.314e+6

When looking at the comparative table, especially when examining Part 3 Initial and Part 3 Outcome 5, it is evident that generative design enables the creation of a lighter part with the same material. The use of lighter materials provides a significant advantage in terms of mass. The compared parts here are the most efficient ones obtained through generation and can be interchangeably used with each other at the same assembly point.

DISCUSSION

The results indicate that it is possible to create a versatile platform serving multiple purposes. The ability of this platform to serve multiple purposes depends on the capabilities of the components used. This is achieved by ensuring that innovative components reach their maximum efficiency. This can also be achieved through the interchangeability of standardized components. However, designing these standardized components for maximum performance will enhance the innovative and efficient aspects of the created model. This can be achieved with more connection areas or points with same amount of material according to the components that have to be assembled with. This means that creating more effective part having same volume. With Generative Design method, parts with connection areas only where needed can be obtained. This involves creating an entirely new design with a new mindset, rather than relying on the engineer's experience or sticking to previous designs.

Another crucial aspect here is to determine a comprehensive scenario detail for the program. The evolution in the program will allocate more material to the areas with the highest demand, ensuring that the connection points are more secure in these regions. This method, discarding the currently used approaches, may enable us to predict previously untested design solutions without trial and error, using the natural selection method. However, the new workflow functioned as a filter to decrease the output of generative design. Nevertheless, it is necessary to determine the type of manufacturing process that will be applied during the production of the part. This is crucial because the manufacturing process is one of the most important parameters in generating the part, and it significantly influences the shape of the outputs.

CONCLUSIONS AND FUTURE WORK

In this study, a suitable modular platform design for sports vehicles has been developed, and an attempt has been made to achieve design efficiency using generative design, a method that employs genetic algorithms instead of manual design changes. The steps in the IDeS method for determining the requirements for design have been systematically applied to create a full design solution, it was determined that the placement of the powertrain, layouts of all types of engines used in sports cars, the focus on the lightweight nature of the components and efficiency of the model in terms of material and part costs are crucial points for an improvement in this design. An innovative model for product development has been achieved by modifying the existing workflow. Scrum method which has iteration inside with Sprints provided efficient development process for this project and worked in harmony with generative design mindset. This can be further evidenced by the natural filtration that occurs through the generative design output, which inherently narrows down the selection based on the required criteria. As inferred from the findings, even though the models employing generated parts exhibit slightly maximum stress values, an examination of the stress distribution reveals that it occurs at nearly identical points and close values. This demonstrates that we are selecting the correct components to generate.

The suitability of this platform for use with different components has been detailed through technical drawings, and two distinct designs have been obtained for multiple engine layouts. In addition to mechanical design, the Stylistic Design Engineering method has been employed to achieve an innovative exterior design that is aesthetically pleasing and inspired by nature within the specified dimensional limits, in order to verify the suitability of the modelled platform. There were effects of nature inspired design effects which is the initial point of the generative design method. The design results have shown that this platform, drawn in modular sections, can be utilized for multiple types of vehicles, and this can be achieved through the interchangeability of the sections.
After undergoing stiffness tests to assess the usability of modular platform, this model has been subjected to product development. Specific parts in Part 1, Part 3, and Part 4 have been performed

with generative design for more efficient parts. Aluminium alloys have huge advantage for the part in the cockpit lower body (Part 3). Alternatively, aluminium alloy used parts for Part 1 and Part 4 have strong advantage on steel alloys in terms of mass. However, it is observed that in the current load model, the maximum stress values are close for both materials. Overall, in terms of the innovative nature of the produced components, it has been designed a new solution with more connection points without significantly increasing the weight by providing the necessary boundary conditions. This design aims to facilitate the transition of the design to production without requiring any additional material. The initial design was a simplified design and lacked this feature. In conclude, it was performed to have a multi-purpose modular platform for sports car which is not common in current industry. Through the conducted research, efforts have been made to demonstrate the possibility of obtaining a design that includes all acquired components, meeting the required dimensions and functionality. The results indicate that with the advancement of new technologies, such as the use of generative design algorithms in software, there is potential for an increase in alternative designs.

A conclusion from this specific study is there was no noticeable change in displacement values for both type of stiffness tests. In fact, the torsional angular deflection on the front platform has remained almost the same. This also indicates that when boundary conditions are correctly defined, a part can exhibit the same mechanical outcomes when its shape is altered (create more efficient design results in terms of connection points with generative design, for example). The generated part that are defined for this design achieved this aim with their close stiffness values in assembly. However, it's important to consider that, besides the applied force, the lower section in this area will utilize a metal composite sandwich panel, and it will also be required to bear the weight of the batteries to be employed. Therefore, additional profile reinforcement can be applied to this region, or the material to be used can be strengthened.

Based on this study, it can be anticipated that part design may vary significantly depending on the manufacturing methods and material types available. The results indicate that, by using this method, a preference for lighter materials can lead to the development of much more diverse design alternatives. This variation can be achieved in a diverse range through the use of the generative design method. Under suitable conditions, the execution of tests will shed light on a more comprehensive evolution. Furthermore, this diversity in the field of sports car manufacturing might contribute to a standardization within the realm of diversity.

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References

Ary, A. K., Sanjaya, Y., Prabowo, A. R., Imaduddin, F., Nordin, N. A. B., Istanto, I., & Cho, J. H. (2021). Numerical estimation of the torsional stiffness characteristics on urban Shell Eco-Marathon (SEM) vehicle design. *Curved and Layered Structures*, *8*(1), 167–180. https://doi.org/10.1515/cls-2021-0016

Attar, R., Aish, R., Stam, J., Brinsmead, D., Tessier, A., Glueck, M., & Khan, A. (2009). *PHYSICS-BASED GENERATIVE DESIGN*.

Benajes, J., García, A., Monsalve-Serrano, J., & Martínez-Boggio, S. (2019). Optimization of the parallel and mild hybrid vehicle platforms operating under conventional and advanced combustion modes. *Energy Conversion and Management*, *190*, 73–90. https://doi.org/https://doi.org/10.1016/j.enconman.2019.04.010

Bire, S. R. (2014, March 2). *Design Criteria for Automobile Seat*. Slideshare. https://www.slideshare.net/sarangbire/sarang-bire-seat-design

Boeriu, H. (2020, November 4). *2025 CLAR: BMW CEO announces new cluster architecture*. https://www.bmwblog.com/2020/11/04/bmw-clar-2025/

Bonsanto Oliveira, A., A Rodrigues, A. F., Gertz, L. C., Cervieri, A., Poncio, A., Oliveira, A. B., & Pereira, M. S. (2018). Static and Dynamic Analysis of a Chassis of a Prototype Car. *SAE Brasil*.

Briard, T., Segonds, F., & Zamariola, N. (2020). G-DfAM: a methodological proposal of generative design for additive manufacturing in the automotive industry. *International Journal on Interactive Design and Manufacturing*, *14*(3), 875–886. https://doi.org/10.1007/s12008-020-00669-6

Buiga, A. (2012). Investigating the role of MQB platform in volkswagen group’s strategy and automobile industry. *International Journal of Academic Research in Business and Social Sciences*, *9*, 391–399.

Buonamici, F., Carfagni, M., Furferi, R., Volpe, Y., & Governi, L. (2020). Generative design: An explorative study. *Computer-Aided Design and Applications*, *18*(1), 144–155. https://doi.org/10.14733/cadaps.2021.144-155

Caldas, L. (2001). *An evolution-based generative design system : using adaptation to shape architectural form*. https://api.semanticscholar.org/CorpusID:109280128

Carroll, J., Adolph, T., Chauvel, C., Labrousse, M., Trosseille, X., Pastor, C., Eggers, A., Smith, S., & Hynd, D. (2010). OVERVIEW OF SERIOUS THORAX INJURIES IN EUROPEAN FRONTAL CAR CRASH ACCIDENTS AND IMPLICATIONS FOR CRASH TEST DUMMY DEVELOPMENT. *IRCOBI Conference*. www.gidas.org

Cervone, H. F. (2011). Understanding agile project management methods using Scrum. *OCLC Systems & Services: International Digital Library Perspectives*, *27*(1), 18–22. https://doi.org/10.1108/10650751111106528

Chandak, A., Gandhe, N., Choudhari, K., Gaikwad, N., & Thorat, P. (2021). To enhance crashworthiness of an automobile by introducing energy absorbers and to study its implementation. *Materials Today: Proceedings*, *47*, 3006–3011. https://doi.org/10.1016/j.matpr.2021.05.477

Cheli, R. : F. (2013). *Study on the influence of the car body flexibility on handling performance and forces distribution with CAE methods*. Politecnico di Milano.

Chen, X., Tao, Y., Wang, G., Kang, R., Grossman, T., Coros, S., & Hudson, S. E. (2018). Forte: User-driven generative design. *Conference on Human Factors in Computing Systems - Proceedings*, *2018-April*. https://doi.org/10.1145/3173574.3174070

Cobb, C. G. (2011). *Making sense of agile project management [electronic resource] : balancing control and agility*. Hoboken, NJ : Wiley, 2011.

Cohen, D., Lindvall, M., & Costa, P. (2004). An Introduction to Agile Methods. In *Advances in Computers* (Vol. 62, pp. 1–66). Elsevier. https://doi.org/https://doi.org/10.1016/S0065-2458(03)62001-2

Coram, M., & Bohner, S. (2005). The impact of agile methods on software project management. *12th IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'05)*, 363–370. https://doi.org/10.1109/ECBS.2005.68

Crolla, D., & Mashadi, B. (2011). *Vehicle powertrain systems*. John Wiley & Sons.

Cui, J., & MingXi, T. (2011). *GENERATIVE DESIGN EXPLORATION FRAMEWORK BASED ON SUBJECTIVE EVALUATION*.

Cusumano, M. A., & Nobeoka, K. (1998). *Thinking beyond lean: how multi-project management is transforming product development at Toyota and other companies*. Simon and Schuster.

Czerwinski, F. (2021). Current Trends in Automotive Lightweighting Strategies and Materials. *Materials*, *14*(21). https://doi.org/10.3390/ma14216631

Dalpadulo, E., Pini, F., & Leali, F. (2020). Integrated CAD platform approach for Design for Additive Manufacturing of high performance automotive components. *International Journal on Interactive Design and Manufacturing*, *14*(3), 899–909. https://doi.org/10.1007/s12008-020-00684-7

Danielsson, O. (2015). *Influence of Body Stiffness on Vehicle Dynamics Characteristics in Passenger Cars* [Master's Thesis]. Chalmers University of Technology.

Daruis, D. D. I., Deros, B. M., & Nor, M. J. M. (2011). Malaysian sitting anthropometry for seat fit parameters. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *21*(5), 443–455. https://doi.org/https://doi.org/10.1002/hfm.20237

Diebold, P., Ostberg, J.-P., Wagner, S., & Zendler, U. (2015). What Do Practitioners Vary in Using Scrum? In C. Lassenius, T. Dingsøyr, & M. Paasivaara (Eds.), *Agile Processes in Software Engineering and Extreme Programming* (pp. 40–51). Springer International Publishing.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Du, B., Li, Q., Zheng, C., Wang, S., Gao, C., & Chen, L. (2023). Application of Lightweight Structure in Automobile Bumper Beam: A Review. *Materials*, *16*(3). https://doi.org/10.3390/ma16030967

Elliott, A. (2016, April 19). *2017 BMW X5 to Use New 7-Series CLAR Platform*. GTspirit. https://gtspirit.com/2016/04/19/2017-bmw-x5-use-new-7-series-clar-platform/

Emadi, A., Lee, Y. J., & Rajashekara, K. (2008). Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles. In *IEEE Transactions on Industrial Electronics* (Vol. 55, Issue 6, pp. 2237–2245). https://doi.org/10.1109/TIE.2008.922768

Fellini, R., Kokkolaras, M., & Papalambros, P. (2006). Quantitative platform selection in optimal design of product families, with application to automotive engine design. *Journal of Engineering Design*, *17*, 429–446. https://doi.org/10.1080/09544820500287797

Feloy, M., Dsouza, R., Jones, R., & Bayliss, M. (2013). *Technology and Skills in the Aerospace and Automotive Industries i Technology and Skills in the Aerospace and Automotive Industries*. www.ukces.org.uk

Fenoon, M., Alquabeh, O., Nisar, M. M., & Zia, S. (2021). Generative Design of a Mechanical Pedal. *International Journal of Engineering and Management Sciences (IJEMS)*, *6*(1). https://doi.org/10.21791/IJEMS.2021.1.5

Ferrari 488 Spider. (n.d.). Retrieved January 21, 2024, from https://www.ferrari.com/it-IT/auto/488-spider

Florea, M., Croitorescu, V., & Oprean, M. (2016). Smart Solutions for Vehicle Chassis. In C. Andreescu & A. Clenci (Eds.), *Proceedings of the European Automotive Congress EAEC-ESFA 2015* (pp. 233–244). Springer International Publishing.

Freddi, M., Borri, N., Alessandri, G., Galiè, G., Donnici, G., & Frizziero, L. (2022). IDeS Method Applied to the Concept of a Sports Car. *Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management*.

Frizziero, L., Liverani, A., Giuliano, I., Grazia Picciariello, M., Tucci, L., & Donnici, G. (2020). Application of IDeS (Industrial Design Structure) to Sustainable Mobility: case study of an innovative bicycle. *Symmetry*, *12*. www.mdpi.com/journal/symmetry

Frizziero, L., Liverani, A., & Ricciardelli, G. M. (2019). Design for Six Sigma (DFSS) Applied to a New E-Segment Sedan. *Applied Sciences*, *12*(3). www.mdpi.com/journal/applsci

Ganesh Sarvankar, S., & Yewale, S. N. (2019). *Additive Manufacturing in Automobile Industry*. *7*(4).

Garcia, L. A., OliveiraJr, E., & Morandini, M. (2022). Tailoring the Scrum framework for software development: Literature mapping and feature-based support. *Information and Software Technology*, *146*, 106814. https://doi.org/https://doi.org/10.1016/j.infsof.2021.106814

Gauss, L., Lacerda, D. P., & Cauchick Miguel, P. A. (2021). Module-based product family design: systematic literature review and meta-synthesis. *Journal of Intelligent Manufacturing*, *32*(1), 265–312. https://doi.org/10.1007/s10845-020-01572-3

Genta, G., & Morello, L. (2009). Chassis Structures. In *The Automotive Chassis Volume 1: Components Design* (pp. 351–381). Springer Link.

Goncalves, M., & Heda, R. (2010a). A Case for Agile. In M. Goncalves & R. Heda (Eds.), *Fundamentals of Agile Project Management: An Overview* (p. 0). ASME Press. https://doi.org/10.1115/1.802960.ch1

Goncalves, M., & Heda, R. (2010b). *Fundamentals of Agile Project Management: An Overview*. ASME Press. https://doi.org/10.1115/1.802960

Gruss, M., Nagel, M., & Hofel, P. (2012). *HD - High ductility, low-alloy, fine-grain structural steels: A new product series for cold forming*. 28–31.

Gulanova, J., & Vereš, M. (2014). *COMPUTER AIDED GENERATIVE DESIGN OF AUTOMOTIVE SHAPED COMPONENTS*. https://www.researchgate.net/publication/294892055

Ha, N., & Lu, G. (2020). A review of recent research on bio-inspired structures and materials for energy absorption applications. *Composites Part B*, *181*.

Hannan, M. A., Azidin, F. A., & Mohamed, A. (2014). Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*, *29*, 135–150. https://doi.org/https://doi.org/10.1016/j.rser.2013.08.097

Hazimi, H., Ubaidillah, Setiyawan, A. E. P., Ramdhani, H. C., Saputra, M. Z., & Imaduddin, F. (2018). Vertical bending strength and torsional rigidity analysis of formula student car chassis. *AIP Conference Proceedings*, *1931*(1), 030050. https://doi.org/10.1063/1.5024109

Hidalgo, E. S. (2019). Adapting the scrum framework for agile project management in science: case study of a distributed research initiative. *Heliyon*, *5*(3), e01447. https://doi.org/https://doi.org/10.1016/j.heliyon.2019.e01447

Hirsch, J. (2011). Aluminium in innovative light-weight car design. *Materials Transactions*, *52*(5), 818–824. https://doi.org/10.2320/matertrans.L-MZ201132

Hirsch, J. (2014). Recent development in aluminium for automotive applications. *Transactions of Nonferrous Metals Society of China*, *24*(7), 1995–2002. https://doi.org/https://doi.org/10.1016/S1003-6326(14)63305-7

Holweg, M. (2008). The evolution of competition in the automotive industry. In *Build To Order: The Road to the 5-Day Car* (pp. 13–34). Springer London. https://doi.org/10.1007/978-1-84800-225-8_2

Homes, J. (2016, April 14). *Next BMW X5 to Use 7 Series "CLAR" Platform*. Automobile Magazine. https://www.motortrend.com/news/report-next-bmw-x5-use-7-series-clar-platform/

Hossain, E., Babar, M. A., & Paik, H. (2009). Using Scrum in Global Software Development: A Systematic Literature Review. *2009 Fourth IEEE International Conference on Global Software Engineering*, 175–184. https://doi.org/10.1109/ICGSE.2009.25

Hou, W., Shan, C., Yu, Y., Hu, P., & Zhang, H. (2017). Modular platform optimization in conceptual vehicle body design via modified graph-based decomposition algorithm and cost-based priority method. *Structural and Multidisciplinary Optimization*, *55*(6), 2087–2097. https://doi.org/10.1007/s00158-016-1629-5

Jiang, P., Hu, Y.-C., Yen, G.-F., & Tsao, S.-J. (2018). Green supplier selection for sustainable development of the automotive industry using grey decision-making. *Sustainable Development*, *26*(6), 890–903. https://doi.org/https://doi.org/10.1002/sd.1860

Junk, S., & Rothe, N. (2022). Lightweight design of automotive components using generative design with fiber-reinforced additive manufacturing. *Procedia CIRP*, *109*, 119–124. https://doi.org/https://doi.org/10.1016/j.procir.2022.05.224

Kale, H. N., & Dhamejani, C. L. (2015). DESIGN PARAMETERS OF DRIVER SEAT IN AN AUTOMOBILE. In *IJRET: International Journal of Research in Engineering and Technology*. http://www.ijret.org

Kallioras, N. Ath., & Lagaros, N. D. (2020). DzAIℕ: Deep learning based generative design. *Procedia Manufacturing*, *44*, 591–598. https://doi.org/https://doi.org/10.1016/j.promfg.2020.02.251

Kazi, R. H., Grossman, T., Cheong, H., Hashemi, A., & Fitzmaurice, G. (2017). DreamSketch: Early stage 3D design explorations with sketching and generative design. *UIST 2017 - Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*, 401–414. https://doi.org/10.1145/3126594.3126662

Ketterman, S. (n.d.). *Data-driven Design and Generative Design – An Overview*. Designers. Retrieved November 14, 2023, from https://www.toptal.com/designers/product-design/data-driven-generative-design-overview

Khademian, nima, & Peimaei, Y. (2020, February 5). Lightweight materials (LWM) in transportation especially application of aluminum in light weight automobiles (LWA). *International Conference on Interdisciplinary Studies in Technology*.

Kokkolaras, M., Fellini, R., Kim, H. M., Michelena, N. F., & Papalambros, P. Y. (2002). Extension of the target cascading formulation to the design of product families. *Structural and Multidisciplinary Optimization*, *24*(4), 293–301. https://doi.org/10.1007/s00158-002-0240-0

Krish, S. (2011). A practical generative design method. *Computer-Aided Design*, *43*(1), 88–100. https://doi.org/https://doi.org/10.1016/j.cad.2010.09.009

Kumar Jauhar, S., Jauhar, S., Asthankar, K. M., & Kuthe, A. M. (2012). Cost benefit analysis of Rapid Manufacturing in Automotive Industries 1. In *Advances in Mechanical Engineering and its Applications (AMEA)* (Vol. 181, Issue 3). www.worldsciencepublisher.org

Kuziak, R., Kawalla, R., & Waengler, S. (2008). Advanced high strength steels for automotive industry. *Archives of Civil and Mechanical Engineering*, *8*(2), 103–117. https://doi.org/10.1016/S1644-9665(12)60197-6

Lampón, J. F. (2023). Efficiency in design and production to achieve sustainable development challenges in the automobile industry: Modular electric vehicle platforms. *Sustainable Development*, *31*(1), 26–38. https://doi.org/10.1002/sd.2370

Lampón, J. F., Cabanelas, P., & González Benito, J. (2015). *The impact of implementation of a modular platform strategy in automobile manufacturing networks*. http://webs.uvigo.es/infogen

Lampón, J. F., & Rivo-López, E. (2022). Modular product architecture implementation and decisions on production network structure and strategic plant roles. *Production Planning & Control*, *33*(15), 1449–1464. https://doi.org/10.1080/09537287.2021.1877367

Leary, M. (2020). Generative design. *Design for Additive Manufacturing*, *Chapter 2*, 203–222. https://doi.org/10.1016/b978-0-12-816721-2.00007-5

Lei, H., Ganjeizadeh, F., Jayachandran, P. K., & Ozcan, P. (2017). A statistical analysis of the effects of Scrum and Kanban on software development projects. *Robotics and Computer-Integrated Manufacturing*, *43*, 59–67. https://doi.org/https://doi.org/10.1016/j.rcim.2015.12.001

Lightweight heavy impact. (2012). *McKinsey&Company*.

Mallick, P. K. (2020). *Materials, design and manufacturing for lightweight vehicles*. Woodhead publishing.

Marinov, M., Amagliani, M., Barback, T., Flower, J., Barley, S., Furuta, S., Charrot, P., Henley, I., Santhanam, N., Finnigan, G. T., Meshkat, S., Hallet, J., Sapun, M., & Wolski, P. (2019). Generative Design Conversion to Editable and Watertight Boundary Representation. *CAD Computer Aided Design*, *115*, 194–205. https://doi.org/10.1016/j.cad.2019.05.016

Market Research Report. (2018). Automotive Chassis Market by Chassis Type, Material, Electric Vehicle, Vehicle Type and Region - Global Forecast to 2025. In *Markets and Markets*.

Market Research Report. (2023). Automotive Chassis Market Size, Share & COVID-19 Impact Analysis, by Vehicle Type, by Chassis Type and Regional Forecast, 2023-2030. In *Fortune Business Insights*.

Marsh, J. (2013). *Efficient Modular Platform 2 The New Vehicle Platform by PSA Peugeot Citroën Platform: definition and purpose*. Citroenet. www.citroenet.org.uk/miscellaneous/emp2/emp2.html

Mehta, P. S., Solis Ocampo, J., Tovar, A., & Chaudhari, P. (2016). Bio-Inspired Design of Lightweight and Protective Structures. *SAE Technical Papers*. https://doi.org/10.4271/2016-01-0396

Mendes Costa, P. (2020). *Chassis Loading Scenarios*.

Milliken, W., & Milliken, D. (1995). *Race Car Vehicle Dynamics*. SAE International.

Modi, S. (2016). *Material Qualification in the Automotive Industry*. www.cargroup.org

Modular Transverse Matrix. (n.d.). Volkswagen Newsroom. Retrieved December 5, 2023, from https://www.volkswagen-newsroom.com/en/modular-transverse-matrix-3655

Morandini, M., Coleti, T. A., Oliveira, E., & Corrêa, P. L. P. (2021). Considerations about the efficiency and sufficiency of the utilization of the Scrum methodology: A survey for analyzing results for development teams. *Computer Science Review*, *39*, 100314. https://doi.org/https://doi.org/10.1016/j.cosrev.2020.100314

Muehlbauer, M., Song, A., & Burry, J. (2017). *Towards Intelligent Control in Generative Design*.

Muffatto, M., & Roveda, M. (2000). Developing product platforms: analysis of the development process. *Technovation*, *20*(11), 617–630. https://doi.org/https://doi.org/10.1016/S0166-4972(99)00178-9

Naik, A. (2016). *What Is Volkswagen's MLB Platform All About?* Car and Bike. https://www.carandbike.com/news/what-is-volkswagens-mlb-platform-all-about-1449884

New CMP Platform. (2018). *The New Modular, Multi-energy Platform for Groupe PSA-Groupe PSA CMP: The New Modular, Multi-energy Platform for Groupe PSA*. Stellantis. https://www.groupe-psa.com/en/newsroom/corporate-en/cmp-modular-platform/

Nissan Motor Corporation. (2013). Common Module Family (CMF): A New Approach to Engineering for the Renault-Nissan Alliance. In *Nissan Motor Corporation*.

Ntintakis, I., & Stavroulakis, G. E. (2020). Progress and recent trends in generative design. *MATEC Web Conf.*, *318*. https://doi.org/10.1051/matecconf/202031801006

Oh, S., Jung, Y., Kim, S., Lee, I., & Kang, N. (2019). Deep generative design: Integration of topology optimization and generative models. *Journal of Mechanical Design, Transactions of the ASME*, *141*(11). https://doi.org/10.1115/1.4044229

Oomen, S., De Waal, B., Albertin, A., Ravesteyn, P., & Waal, D. (2017). *HOW CAN SCRUM BE SUCCESFUL? COMPETENCES OF THE SCRUM PRODUCT OWNER*. http://aisel.aisnet.org/ecis2017_rp/9

Oymak, Y. A., & Feyzullahoğlu, E. (2021). Formula Student Race Car Chassis Design and Analysis. *Journal of Advanced Research in Natural and Applied Sciences*, *7*(2), 201–218. https://doi.org/10.28979/jarnas.957134

Patchong, A., Lemoine, T., & Kern, G. (2003). Improving Car Body Production at PSA Peugeot Citroën. *Interfaces*, *33*(1), 36–49. http://www.jstor.org/stable/20141221

Piran, F. S., Lacerda, D. P., Sellitto, M. A., & Morandi, M. I. W. M. (2021). Influence of modularity on delivery dependability: analysis in a bus manufacturer. *Production Planning & Control*, *32*(8), 688–698. https://doi.org/10.1080/09537287.2020.1776411

Qureshi, O. M., Bertocchi, E., Qaiser, Z., & Aslam Awan, K. (2014). Frequency embedded box beam crash absorbers under oblique impacts. *Thin-Walled Structures*, *75*, 1–7. https://doi.org/10.1016/j.tws.2013.09.020

Refiadi, G., Aisyah, I. S., & Siregar, J. P. (2019). Trends in lightweight automotive materials for improving fuel efficiency and reducing carbon emissions. *Automotive Experiences*, *2*(3), 78–90.

Research and Markets. (2021, June 21). *Automotive Modularization Trend Research Report 2021: Creation of Electric Modular Platforms, Reduction of the Number of Platforms, Development of Core Platforms*. Cision PR Newswire.

Ringstad, M. A., Dingsøyr, T., & Brede Moe, N. (2011). Agile Process Improvement: Diagnosis and Planning to Improve Teamwork. In R. V O'Connor, J. Pries-Heje, & R. Messnarz (Eds.), *Systems, Software and Service Process Improvement* (pp. 167–178). Springer Berlin Heidelberg.

Rosberg, J. (2008). *A Requirement process for Scrum development*.

Roy, R., Souchoroukov, P., & Shehab, E. (2011). Detailed cost estimating in the automotive industry: Data and information requirements. *International Journal of Production Economics*, *133*(2), 694–707. https://doi.org/https://doi.org/10.1016/j.ijpe.2011.05.018

Rubin, K. S. (2012). *Essential Scrum: A practical guide to the most popular Agile process*. Addison-Wesley.

Saidpour Shsaidpour, H. (2004). Lightweight High Performance Materials for Car Body Structures. *NTI Technology Conference*, 14.

Seghal, B., & Gorai, P. (2012). *Platform strategy shaping the future of Automotive OEMs Flexibility to drive growth*. www.evalueserve.com

Seyfried, P., Taiss, E. J. M., Calijorne, A. C., Li, F.-P., & Song, Q.-F. (2015). Light weighting opportunities and material choice for commercial vehicle frame structures from a design point of view. *Advances in Manufacturing*, *3*(1), 19–26. https://doi.org/10.1007/s40436-015-0103-8

Shafiee, S., Wautelet, Y., Poelmans, S., & Heng, S. (2023). An empirical evaluation of scrum training's suitability for the model-driven development of knowledge-intensive software systems. *Data & Knowledge Engineering*, *146*, 102195. https://doi.org/https://doi.org/10.1016/j.datak.2023.102195

Shamsuzzoha, A., & Helo, P. (2017). Development of sustainable platform for modular product family: a case study. *Production Planning & Control*, *28*(6–8), 512–523. https://doi.org/10.1080/09537287.2017.1309715

Shea, K., Aish, R., & Gourtovaia, M. (2005). Towards integrated performance-driven generative design tools. *Automation in Construction*, *14*(2), 253–264. https://doi.org/https://doi.org/10.1016/j.autcon.2004.07.002

Singh, M., Www, W. :, & Singh, M. K. (2016). Application of Steel in Automotive Industry International Journal of Emerging Technology and Advanced Engineering Application of Steel in Automotive Industry. In *Certified Journal* (Vol. 9001, Issue 7). www.ijetae.com

Sköld, M., & Karlsson, C. (2007). Multibranded Platform Development: A Corporate Strategy with Multimanagerial Challenges. *Journal of Product Innovation Management*, *24*(6), 554–566. https://doi.org/https://doi.org/10.1111/j.1540-5885.2007.00271.x

Society of Automotive Engineers. (2001). SAE J1100: Motor Vehicle Dimensions. *CC0 1.0 Universal*.

Srivastava, A., Bhardwaj, S., & Saraswat, S. (2017). SCRUM model for agile methodology. *2017 International Conference on Computing, Communication and Automation (ICCCA)*, 864–869. https://doi.org/10.1109/CCAA.2017.8229928

Subaru Global Platform. (n.d.). Subaru Canada.

Suh, E. S., de Weck, O., Kim, I. Y., & Chang, D. (2007). Flexible platform component design under uncertainty. *Journal of Intelligent Manufacturing*, *18*(1), 115–126. https://doi.org/10.1007/s10845-007-0008-x

Sun, H., & Ma, L. (2020). Generative design by using exploration approaches of reinforcement learning in density-based structural topology optimization. *Designs*, *4*(2), 1–20. https://doi.org/10.3390/designs4020010

Tisza, M., & Czinege, I. (2018). Comparative study of the application of steels and aluminium in lightweight production of automotive parts. *International Journal of Lightweight Materials and Manufacture*, *1*(4), 229–238. https://doi.org/https://doi.org/10.1016/j.ijlmm.2018.09.001

Tran, M.-K., Akinsanya, M., Panchal, S., Fraser, R., & Fowler, M. (2020). Design of a Hybrid Electric Vehicle Powertrain for Performance Optimization Considering Various Powertrain Components and Configurations. *Vehicles*, *3*(1), 20–32. https://doi.org/10.3390/vehicles

Trzesniowski, M. (2014). Rennwagentechnik. In *Springer*. Springer. https://doi.org/10.1007/978-3-658-04919-5

Turker, H., Bacha, S., & Chatroux, D. (2010). Impact of plug-in hybrid electric vehicles (PHEVs) on the French electric grid. *IEEE PES Innovative Smart Grid Technologies Conference Europe, ISGT Europe*. https://doi.org/10.1109/ISGTEUROPE.2010.5638948

Tyflopoulos, E., Flem, D., Steinert, M., & Olsen, A. (2018). *State of the art of generative design and topology optimization and potential research needs*.

Wesselmecking, S., Kreins, M., Dahmen, M., & Bleck, W. (2022). Material oriented crash-box design – Combining structural and material design todoc_improve specific energy absorption. *Materials and Design*, *213*. https://doi.org/10.1016/j.matdes.2021.110357

Whiteley, A., Pollack, J., & Matous, P. (2021). The origins of agile and iterative methods. *Journal of Modern Project Management*, *8*(3), 21–29. https://doi.org/10.19255/JMPM02502

Yao, S., Zhou, Y., Li, Z., Zhang, P., Cao, Y., & Xu, P. (2021). IMP-Energy absorption char lattice structure. *Composite Structures*.

Zhen Hui, L. (2012). *DESIGN, ANALYSIS AND EXPERIMENTAL VERIFICATION OF TUBULAR SPACEFRAME CHASSIS FOR FSAE APPLICATION* [MASTER'S THESIS]. NATIONAL UNIVERSITY OF SINGAPORE.

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Zhuang, W., Li (Eben), S., Zhang, X., Kum, D., Song, Z., Yin, G., & Ju, F. (2020). A survey of powertrain configuration studies on hybrid electric vehicles. In *Applied Energy* (Vol. 262). Elsevier Ltd. https://doi.org/10.1016/j.apenergy.2020.114553