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Generative Design-Based Structural Optimisation of an Extendable Tanker Platform for Heavy Freight Transportation

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Abstract: Conventional tanker platforms used for heavy load transportation often present limitations related to excessive weight, limited adaptability, and operational inefficiencies. This study proposes the redesign of a tanker platform through the integration of commercial generative / topology optimisation tools (SolidWorks Generative Design and equivalent CAD platforms) within a Design Thinking framework.
The methodology included a structured literature review guided by PRISMA principles and complemented by the SALSA framework, three-dimensional modeling in SolidWorks, and structural validation through finite element analysis.
The proposed design incorporates telescopic profiles, universal coupling mechanisms, and ASTM A572 Grade 50 steel in critical components. After geometric redesign of critical longitudinal members (wall thickness to 48 mm + internal stiffeners and diaphragms), FoS reached 1.66 (closed, 13 m) and 1.51 (16.5 m), both ≥ 1.5; temporary supports are required beyond ≈ 20–22 m. Displacement dropped ≈ 20 %. Structural mass was quantified from CAD Mass Properties: original 8 450 kg → redesigned ≈ 7 450 kg (≈ 11.8 % reduction; recoverable toward the 15–20 % target by further topology optimization of secondary members). Estimated manufacturing cost: MXN $530,781.91. Results show preliminary linear-static feasibility; further multi-configuration, dynamic and experimental validation is recommended.
Keywords: ASTM A572 steel, Design Thinking, finite element analysis, generative design (CAD topology optimization), heavy freight transportation, structural optimization.

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1 Introduction

Heavy freight transportation represents one of the fundamental pillars of modern logistics and global economic development, as it faces increasing pressures related to operational efficiency, cost reduction, and environmental sustainability (World Intellectual Property Organization [WIPO], 2026; Teixeira et al., 2025). In this context, the structural optimization of specialized platforms and trailers has emerged as a key area of research over recent decades. This progress has been driven by numerical simulation techniques and the use of high-strength materials that enable the reduction of component weight without compromising safety or regulatory compliance. In this regard, generative design, understood here as the automated exploration of design alternatives by commercial topology- and parametric-optimisation algorithms integrated in CAD/CAE software (SolidWorks Generative Design, Fusion 360 Generative Design, nTopology and equivalent platforms), has transformed mechanical engineering by enabling the exploration of a large solution space, thereby minimising weight and maximising performance across a wide range of industrial applications (Wefki, 2025; Onatayo et al., 2024).

More specifically, within the Mexican and Latin American context, companies dedicated to the specialized transport of heavy and oversized loads using tanker platforms face severe operational limitations stemming from rigid designs, high tare weight, and limited adaptability to different types of trailers. These factors increase fuel consumption and reduce sector competitiveness (Ramingwong et al., 2026; Galos & Sutcliffe, 2019). Therefore, this study focuses on the redesign of a tanker platform used by companies in the heavy and oversized freight transportation sector through the application of generative design principles integrated with Design Thinking to address these specific deficiencies. The proposed approach includes SolidWorks modeling, the selection of optimized materials (from ASTM A36 to ASTM A572), and corresponding structural validation, with the objective of optimizing overall performance.

The central problem lies in the shortcomings of the current tanker platform design, which exhibits a lack of adaptability to various types of trailers, high tare weight that negatively impacts energy efficiency, and complex logistical manoeuvring. These limitations generate higher operating costs, increase fuel consumption and emissions, and reduce the versatility required within the specialized transportation sector. The general objective of this applied research is to develop and validate a redesigned tanker platform through generative design within a Design Thinking framework, with the aim of improving adaptability, targeting a reduction in self-weight of 15–20 %, and optimizing logistical maneuvers.

From this perspective, the research hypothesis proposes that the integration of generative design principles such as telescopic profiles, optimized coupling mechanisms, and high-strength materials into the redesign of the tanker platform, validated through structural simulations in SolidWorks and detailed economic analysis, will achieve a targeted reduction in tare weight of at least 15 % to 20 % (quantitative confirmation from CAD mass properties is required). Consequently, the proposed design is expected to ensure greater operational adaptability and superior regulatory compliance compared to the existing design, thereby demonstrating both technical and financial feasibility.

Finally, the methodological approach is informed by a structured literature review guided by PRISMA reporting principles and complemented by the SALSA framework. Rather than constituting a fully documented systematic review, this review was designed to provide a transparent and structured identification and synthesis of literature relevant to structural optimization, simulation applied to heavy transportation systems, generative design, and user-centered design methodologies.

2 Methodology

This applied research is focused on addressing a specific problem associated with the specialized transportation of heavy and oversized loads. The object of study comprises the redesign of a tanker platform, with emphasis on improving operational adaptability, reducing structural weight, and optimizing logistical maneuvers. Furthermore, the proposal seeks to develop a practical solution that contributes to increased operational efficiency and enhanced competitiveness in specialized transportation operations.

To establish the theoretical and methodological foundation of the study, a structured literature review was conducted following transparent review principles informed by PRISMA and operationalized through the SALSA framework (Search, Appraisal, Synthesis, and Analysis). The review was not intended as a fully systematic review with complete PRISMA reporting; rather, PRISMA principles were used to improve the transparency and traceability of the identification and selection process, while SALSA provided the analytical structure for organizing and synthesizing the literature.

The literature search was conducted using databases such as Scopus, Web of Science, Google Scholar, and arXiv, employing search terms including "generative design + structural optimization + transport," "Design Thinking + heavy load platforms," and "VRP + GenAI logistics" for the period 2016–2026. Inclusion criteria comprised studies published in English or Spanish with a focus on optimization or generative design applied to logistics, transportation, or structural engineering. Exclusion criteria included non-systematic reviews published before 2016 and studies lacking direct relevance to the research topic. After the initial identification and relevance assessment, duplicate and unrelated records were removed, and the remaining studies were screened according to predefined thematic and temporal criteria. The selected literature was then synthesized to identify methodological trends and relevant approaches in generative design, structural optimization, simulation, and transportation systems.

Table 1. Selected Review of Key Literature (20 Articles) (Own elaboration (2026).

Year	Authors / Title (Abbreviated)	Main Focus	Key Contribution
2026	Ramingwong et al. (Potential of GenAI for Vehicle Routing)	GenAI in the Vehicle Routing Problem (VRP)	Demonstrated accessibility and improvements of up to 25% compared with traditional methods
2025	Da et al. (Survey of GenAI in Transportation Planning)	GenAI in transportation planning	Comprehensive synthesis of opportunities in forecasting, routing, and freight coordination
2025	Wefki et al. (Generative Design Optimization of Concrete Systems)	Generative design-driven optimization of slabs and structures	Integration of BIM-based parametric modeling and generative design for structural optimization

Year	Authors / Title (Abbreviated)	Main Focus	Key Contribution
2025	Chen et al. (GDT Framework for Sustainable Development)	Generative Design Thinking (GDT) framework	Integration of Design Thinking and Generative Design for sustainability
2025	Teixeira et al. (AI Applications in Supply Chain Management)	AI in sustainable supply chain management	PRISMA-based systematic review
2025	Aguirre Guerrero et al. (Topology Optimization for Lightweight Structural Design)	Lightweight structural design	Integration of topology optimization with system engineering considering loads, materials, and manufacturing constraints
2024	Suphavarophas et al. (Generative Design Methods for Energy Efficiency)	Generative Design applications for building energy efficiency	Systematic review
2025	Rangasamy et al. (AI-Driven Generative Design and Optimization)	AI-driven generative design in construction	PRISMA and bibliometric review of 82 studies
2026	Wang et al. (GenAI-Driven Design of Shear Wall Components)	Generative AI in architectural and structural design	Review of GANs, VAEs, and diffusion models
2024	Jackson et al. (GenAI in Supply Chain and Operations Management)	GenAI capability framework for supply chains and operations	Foundational framework for industrial implementation
2023	Veluru (Optimizing Delivery Routes Through Generative AI)	GAN-based dynamic route optimization using real-time data	Reduction of operational costs and emissions
2025	Rutsch et al. (Structural Topology Optimization with Stress and Displacement Constraints)	Structural topology optimization	Simultaneous stress and displacement constraints considering multiple load cases
2025	Wu et al. (Transformative Power of Generative AI)	Generative AI in supply chain transformation	Focus on operational efficiency and generative design
2024	Kookalani et al. (Trajectory of Building Design Automation)	Generative design and deep learning in structural automation	Trends in construction and engineering
2025	Du et al. (Real-Time Generative Design of Structures)	Real-time generative design of optimized structures	Enhanced diversity and control of structural complexity
2022	Liu et al. (Location-Inventory-Routing Problem Review)	PRISMA review of LIRP studies	Methodological foundation for logistics reviews
2026	Bahroun et al. (GenAI for Supply Chain Transformation)	Systematic analysis of GenAI for sustainable supply chains	Identification of 98 relevant studies
2023	Watson et al. (Generative Design of Space Frames)	Generative design of lightweight structural systems	Optimization for vehicles and transportation applications
2025	Arora & Damarla (Federated Learning and GenAI for Vehicle Routing)	GenAI-augmented federated learning for VRP	Low-carbon supply chain optimization
2024	Stollberg et al. (Topology Optimization of Graded Lattice Structures)	Generative design tools in mechanical engineering	Topology optimization and lattice structures for load-bearing components

Regarding Table 1, a selection of 20 representative articles was retained for comparative synthesis within the structured literature review. The selected studies include systematic reviews (PRISMA), bibliometric surveys, GenAI applications, hybrid Design Thinking–Generative Design approaches, and research on VRP, lightweight structures, and sustainable supply chains. Collectively, they show a clear trend toward hybrid methodologies that combine traditional structural simulation with generative algorithms. The most recent studies (2025–2026) further highlight the potential of generative design for weight reduction and improved adaptability in heavy transportation components.

Table 2. Main Tools and Their Applications in the Literature (Own elaboration)

Category	Main Tools	Key Applications
Traditional Optimization and Simulation	SolidWorks Simulation, ANSYS, FEA, linear programming	Structural analysis (stress, deformation, factor of safety) in heavy-load platforms and trailers
Metaheuristics and Machine Learning	Genetic algorithms, reinforcement learning, neural networks	VRP optimization, nesting, load balancing, and dynamic routing
Generative Design and Generative AI	GANs, VAEs, LLMs, Autodesk Generative Design, nTopology, Dynamo/Revit, Fusion 360	Iterative exploration of structural alternatives, lightweighting, telescopic profiles, and adaptive coupling system
User-Centered Design Methodologies	Design Thinking (five phases), Generative Design Thinking (GDT), Ishikawa, Pareto	Operator-centered problem definition, empathy analysis, and human-AI hybrid ideation
Economic and Regulatory Assessment	Life-Cycle Cost (LCC) analysis, NOM/ISO compliance, economic simulation	Financial and regulatory feasibility in heavy freight transportation

Table 2 classifies and summarizes the principal tools and techniques identified in the reviewed literature, organized according to thematic categories. The table facilitates understanding of the technologies and methodologies most commonly employed in the analyzed studies, as well as their specific applications in structural and logistics optimization.

Five main categories were identified: (1) Traditional Optimization and Simulation, (2) Metaheuristics and Machine Learning, (3) Generative Design and Generative AI, (4) User-Centered Design Methodologies, and (5) Economic and Regulatory Assessment. Notably, tools such as SolidWorks Simulation and ANSYS play a central role in structural analysis, while generative design platforms including Autodesk Generative Design and nTopology, enable the automated exploration of topological and parametric alternatives. This synthesis demonstrates that the most effective approaches are hybrid in nature, integrating conventional numerical simulation with the generative capabilities of artificial intelligence. Such an approach is adopted in the methodological proposal of this study for the redesign of the tanker platform. Based on the identified findings, the primary contribution of this research is structured around an integrated Design Thinking and Generative Design framework consisting of the following phases:

- Empathize: Field observations, interviews with Transtell operators, and identification of operational and regulatory constraints.
- Define: Precise formulation of the problem and objectives, including adaptability, self-weight reduction of at least 15–20%, and optimization of logistical maneuvers.
- Ideate (Intensive Generative Design): Automated exploration of the solution space through commercial generative / topology optimisation algorithms (primarily SolidWorks Generative Design), including topology optimisation of local reinforcements, telescopic profiles, universal coupling mechanisms, and material optimisation (ASTM A572 versus ASTM A36).
- Prototype: Development of the complete 3D model in SolidWorks, integrating generative design outcomes and hydraulic/saddle systems.
- Test: Structural simulations (stress, displacement, strain, and factor of safety), comparative analysis against the current design, and economic evaluation through a manufacturing-cost estimate.

subject to: $\sigma\_VM(x) \leq \sigma\_y / FoS\_req$, $FoS \geq FoS\_min$ (target 1.5–2.0), dimensional limits, telescopic overlap ≥ 3 m, manufacturability constraints (minimum weldable thickness, commercially available PTR sections, symmetry), geometric compatibility with existing fleet couplings, and reference to NOM-012-SCT-2-2017 axle-load and dimensional requirements. Design variables x include topology of reinforcements, wall thicknesses, material assignment (A36 / A572 Gr50), and telescopic section geometry. The exploration was performed with commercial generative/topology optimisation solvers; the final configuration is a hybrid of generative suggestions and engineering selection for practicality and manufacturability in the studied workshop.

As a result, the proposed framework significantly expands the range of alternatives explored during the ideation stage through the application of Generative Design, enabling innovative, lightweight, and highly adaptable solutions compared with traditional manual approaches. Furthermore, it provides a replicable framework for small and medium-sized enterprises (SMEs) operating within Mexico's heavy freight transportation sector.

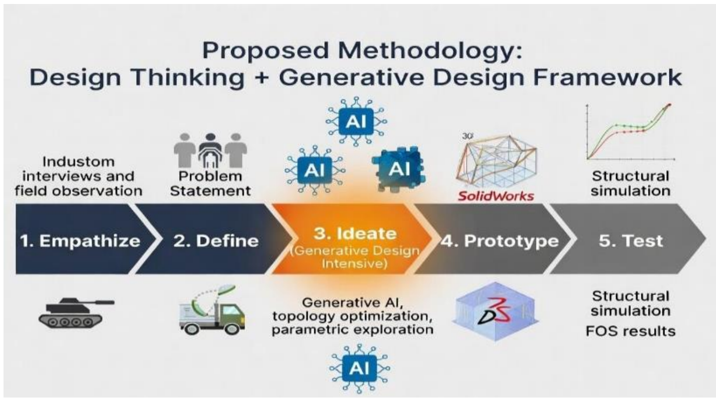


Fig. 1. Methodology overview – 5 Phases (Own elaboration).

Finally, this figure illustrates the proposed hybrid methodology that integrates the classical Design Thinking process with a strong emphasis on Generative Design during the Ideate phase. The highlighted Phase 3 represents the core innovation of the study, where a broad solution space is explored through generative algorithms, including topology optimization, telescopic profiles, material selection, and adaptive coupling mechanisms.

3 Results

The results obtained following the application of the proposed hybrid methodology, whose Design Thinking framework was guided by the findings of the PRISMA-based literature review, particularly the integration of Design Thinking and Generative Design reported by Chen et al. (2025), demonstrated the potential of this

approach to address the structural and operational limitations of the current tanker platform. The combination of a user-centered process with the automated exploration of the solution space enabled the identification of more efficient configurations than those derived from traditional manual ideation approaches.

In particular, the incorporation of generative algorithms facilitated the simultaneous optimization of topology, high-strength material selection, and the design of telescopic and coupling mechanisms, establishing a solid foundation for the development of the three-dimensional model and its subsequent structural validation. The findings corresponding to each phase of the process are presented below, with particular emphasis on the performance improvements achieved through comparative simulations and the technical feasibility of the proposed solution.

Empathize Phase: Field Observations, Interviews, and Identification of Operational and Regulatory Constraints

During the initial stage, corresponding to the Empathize phase, scheduled visits were conducted to the operational facilities of the company under study, which specializes in the transportation, lifting, and installation of heavy and oversized loads. During this stage, the processes of coupling, loading, securing, maneuvering, and transporting tanker platforms with different trailer configurations were directly observed, including modular trailers (MS, Series 1, and Series 5), lowboy trailers (Cometto, Trailers MTY, TTSA, and Ramiro), Jeep Dollies (DJ-21 and DJ-31), spacers, and support cradles.

Fig. 2. Current Condition of the Tanker Platform (Own elaboration)

Figure 2 illustrates the current condition of the only tanker platform available within the company. The obsolete nature of its design, combined with its lack of compatibility with current operational requirements, has limited its functionality, resulting in operational inefficiencies and delays in heavy-load transportation activities.

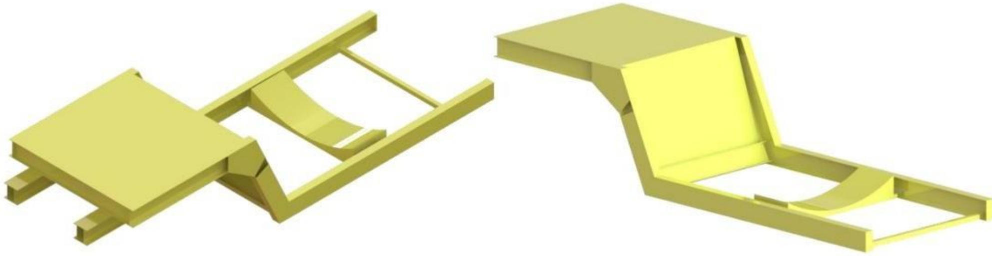


Fig. 3. SolidWorks Model of the Current Load-Bearing Structure (Own elaboration)

Figure 3 presents the three-dimensional model developed in SolidWorks corresponding to the equipment currently in service. This model served as a reference for identifying improvement opportunities and establishing the basis for the redesign process.

Additionally, structured interviews were conducted with truck operators, who described practical difficulties associated with coupling and maneuvering rigid or incompatible configurations; maintenance technicians, who reported recurring structural damage in corners and longitudinal beams, as well as complex repair procedures and extended downtime; and engineering, logistics, and supervisory personnel, who highlighted needs related to weight optimization, load distribution, regulatory compliance, and operational versatility.

As a result of the fieldwork, the following key observations were identified:

1. Frequent coupling difficulties with Jeep Dollies, lowboy trailers, and certain modular trailer configurations.
2. Load distribution problems due to the absence of flexible and adjustable support points, resulting in transport instability.
3. Recurring structural failures in critical areas caused by poorly designed stress concentration zones.
4. Significant downtime resulting from complex load securing and release maneuvers.

Based on these findings, key users and their requirements were identified:

Table 3. Key Users (Own elaboration (2026))

User	Main Interaction	Identified Needs
Truck Operators	Maneuver and secure loads	Maneuverability, ease of coupling, and operational safety
Maintenance Technicians	Structural inspections, welding, and reinforcements	Accessibility, modularity, and material durability
Engineers and Supervisors	Structural evaluation, regulatory compliance, and quality control	Optimized weight, structural strength, and compliance with applicable regulations

Table 3 summarizes the key users identified during fieldwork, together with their primary interactions with the system and the requirements associated with their functions. This characterization provided insight into operational, structural, and maintenance requirements from the perspective of each stakeholder, supporting the definition of design criteria aimed at improving maneuverability, safety, durability, and regulatory compliance.

In addition, the primary constraints governing the development of the proposal were established from operational, regulatory, and organizational perspectives.

- Operational and Physical Constraints: Routes characterized by irregular pavement conditions, steep grades, and sharp curves. High equipment utilization and fleet turnover. Compatibility requirements with the existing fleet, including MAN, International, and Thor tractor units; modular trailers; extendable lowboy trailers up to approximately 21 m; and Jeep Dollies. Efficient storage and rapid maintenance without requiring field welding operations.
- Regulatory Constraints: Compliance with NOM-012-SCT-2-2017 regarding axle loads, maximum dimensions, and load distribution. Reflective signage requirements, certified tie-down points, anticorrosive coatings, and deformation tolerances. Inspection and certification protocols related to liability and insurance requirements.
- Internal Organizational Constraints: Rapid interchangeability among tractor units from different manufacturers. Compatibility with existing coupling systems, including fifth-wheel and hydraulic neck configurations. Reduction of downtime and carbon footprint.

Under these considerations, Table 4 summarizes the main characteristics of the fleet available within the organization under study, which comprises light- and heavy-duty tractor units, modular trailers, lowboy trailers, spacers, support cradles, and Jeep Dolly units. These components enable the configuration of different transport arrangements according to load capacity, length, and weight distribution requirements, thereby constituting the primary operational constraints considered during the analysis and redesign process.

Table 4. Equipment and Configurations Considered for the Redesign Process (Own elaboration (2026).)

Equipment	Available Configuration	Capacity / Main Characteristic
Tractor units	Light-duty and heavy-duty	28–250 ton
Modular trailers	2–6 axles	20 ton/axle
Lowboy trailers	2–6 axles	25–60 ton
Spacers	3–12 m	Length adjustment
Support cradles	4–8 m	Load distribution
Jeep Dolly units	2–3 axles	Load redistribution

Likewise, Figure 4 presents a three-dimensional representation of the main components of the available fleet, developed in SolidWorks. These models enabled the analysis of geometric and functional compatibility among the different equipment configurations, as well as the identification of improvement opportunities related to the adaptability and operational versatility of the transportation system.

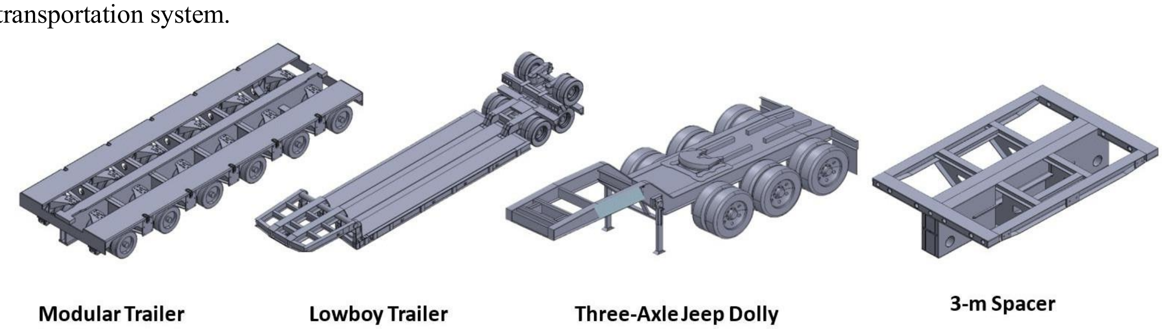


Fig. 4. Three-dimensional SolidWorks models of the main fleet components (Own elaboration).

Define Phase: Precise Formulation of the Problem and Objectives

As part of the definition phase, the central problem identified lies in the current tanker platform, since it presents a lack of adaptability to different trailer types and oversized/heavy-load configurations, exhibits excessive self-weight, inefficient load distribution, and requires complex logistical maneuvers. These shortcomings result in increased operational time and costs, structural risks, and reduced competitiveness, while failing to fully comply with NOM-012-SCT-2-2017 requirements and organization's operational flexibility needs.

Based on this analysis, the following Table 5 presents the main causes identified. These causes were evaluated through a survey administered to a company operator and assigned a weighting according to the established relevance levels: high relevance (3), medium relevance (2), and low relevance (1), based on the evaluator's judgment.

Table 5. Cause Weighting Method (Own elaboration (2026).)

Potential Root Causes	How Does It Affect Productivity and Performance?	Does It Affect Equipment or Operator Integrity?	Does It Optimize the Use of Cargo Space?	Total
Resistance to adopting new structural configurations	2	1	1	4
Limited load adjustment capability	3	2	3	8
Heavy and inefficient structures	2	3	1	6
Stricter transportation regulations	2	1	2	5
Lack of adaptability to different trailers	3	2	3	8
Limited data on structural failures	2	2	2	6

Figure 5 presents the Pareto Diagram, through which the three most significant factors were identified: limited load adjustment capability (21.62%), lack of adaptability to different trailers (21.62%), and excessive weight combined with low efficiency (16.22%). Together, these factors account for 59.46% of the total impact. Given their substantial influence on the performance of the load bearing structure, addressing these issues was considered a priority within the redesign process to achieve significant operational improvements.

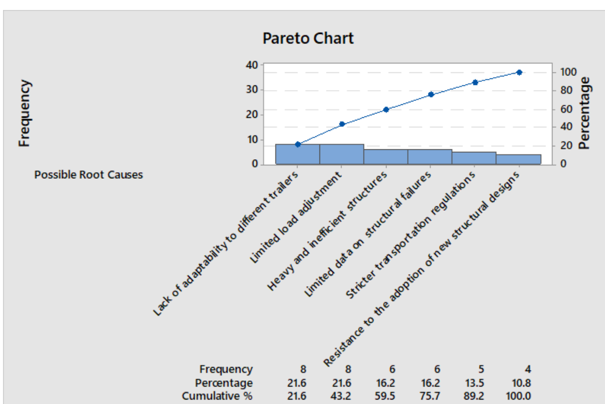


Fig. 5. Pareto Diagram (Own elaboration)

During this Define phase, in addition to clearly establishing the central problem, the objectives guiding the design proposal were formulated in order to direct the solution toward system improvement and fulfillment of the identified requirements. The specific project objectives are presented below.

Specific Objectives:

- Ensure universal compatibility with Transtell's current tractor units and trailers without requiring structural modifications to existing equipment.

- Incorporate a longitudinal telescopic extension system (up to 30 m) and a transverse extension system (up to approximately 6.3 m), equipped with safe and rapid locking mechanisms.
- Support up to 40 tons of uniformly distributed load while optimizing geometry to resist bending, torsion, and buckling.
- Optimize load distribution and ensure strict compliance with axle load and dimensional limits established by NOM-012-SCT-2-2017.
- Reduce structural self-weight by at least 15–20% through the use of high-strength materials such as ASTM A572 Grade 50 in critical areas, combined with generative topology and profile optimization, without compromising durability or safety factors.
- Facilitate rapid maintenance through removable modules with high-precision bolted connections, interchangeable components, and elimination of field welding requirements.
- Improve maneuverability, compact storage capability, and overall logistical efficiency.

Ideate Phase (Intensive Generative Design)

Based on the evidence synthesized through the structured literature review, the Design Thinking framework was translated into specific criteria for the Ideate phase by integrating Generative Design and structural optimization approaches. According to the findings reported by Rangasamy et al. (2025) and Du et al. (2025), generative methodologies support the exploration of design alternatives and structural optimization through computational approaches. These findings guided the definition of the design parameters, constraints, and evaluation criteria applied during the generative exploration process.

In particular, the main limitations identified are summarized in the following points:

- The design space was defined using SolidWorks Generative Design, Fusion 360 Generative Design, o nTopology, establishing the platform's bounding box (extendable length of 13–30 m and adjustable width), preserved regions (trailer and tractor coupling interfaces, critical load-bearing points, telescopic locking zones, and hydraulic connections), and design constraints.
- Realistic loading and boundary conditions were applied, including distributed and concentrated loads of up to 40 tons corresponding to different operational scenarios, gravitational effects, dynamic transportation accelerations, potential lateral and wind loads, and constraints at coupling interfaces such as the fifth wheel, hydraulic neck, and saddle connections.
- Multi-objective optimization criteria were established to minimize mass (with an explicit target of at least 15–20% reduction compared with the current design), maximize stiffness by minimizing maximum displacement, and satisfy safety constraints including a factor of safety greater than or equal to 1.5–2.0 and von Mises stresses below the yield strength of the selected material.
- Material optimization scenarios were conducted in parallel using ASTM A36 and ASTM A572 Grade 50 steels. The latter enables the use of thinner sections and more aggressive topological configurations due to its higher yield strength.
- Manufacturing constraints were also incorporated, including minimum weldable thicknesses, geometric symmetry for fabrication using commercially available structural profiles or hybrid configurations, topology optimization restricted to brackets, reinforcements, or non-critical regions, and the use of telescopic rectangular hollow sections (PTR profiles) for the main structure to maintain cost-effectiveness and ease of fabrication. Non-manufacturable geometries incompatible with Transtell's workshop capabilities were excluded from the optimization process.
- Multiple design alternatives were generated and evaluated at the profile, structural concept, and material-selection levels. Since each level addressed different engineering objectives, specific evaluation criteria were applied. Structural profiles were compared based on strength, weight, weldability, manufacturability, load distribution, and suitability for the telescopic platform. Structural concepts were assessed considering portability, assembly time, adaptability, maintenance, compact storage, and operational efficiency. Material alternatives were evaluated according to yield strength, tensile strength, weldability, availability, weight reduction potential, and estimated manufacturing cost. Based on this comparative evaluation, the PTR telescopic configuration combined with ASTM A572 Grade 50 steel in critical regions and ASTM A36 steel in non-critical members was selected.
- The optimized geometries were subsequently exported and refined using conventional CAD tools before undergoing detailed finite element analysis (FEA) validation.

Based on this analysis, the conceptual design of the new load platform integrates advanced structural solutions, modular components, and dynamic adjustment systems. This approach addresses the need for a solution adaptable to various oversized load configurations while ensuring structural strength, operational simplicity, compatibility with different modular transportation systems, and compliance with applicable regulations.

The selection process was based on a comparative engineering evaluation rather than a weighted decision matrix. Since different categories of alternatives were considered, each was evaluated using criteria appropriate to its purpose. Structural profiles, structural concepts, and material alternatives were assessed using the criteria summarized in Table 6. The final configuration was selected because it provided the best balance between structural performance, operational adaptability, and manufacturing feasibility.

Table 6. Summary of design alternatives evaluated during the Ideate phase (Own elaboration (2026).)

Design category	Alternatives evaluated	Selection criteria	Selected alternative	Justification
Structural profile	IPR structural profile, PTR (rectangular hollow section), channel profile (C/U), angle profile (L), round tubular profile, and combined IPR–PTR configuration.	Structural strength, weight, manufacturability, weldability, load distribution, and suitability for the telescopic platform.	PTR (RHS) profile	It provides the best strength-to-weight ratio, high rigidity, ease of welding and fabrication, and efficient load distribution.
Structural concept	Fixed profiles with bolted extensions; telescopic extensions using PTR profiles.	Portability, assembly time, adaptability, maintenance, compact storage, and operational efficiency.	Telescopic PTR extension system	Selected because it enables rapid adjustment without tools, improves portability and adaptability, and facilitates compact storage despite a slight reduction in stiffness.
Material selection	EN S275JR, GB/T Q235B, ASTM A36, ASTM A572 Grade 50.	Yield strength, tensile strength, weight reduction potential, weldability, availability, and manufacturing cost.	ASTM A572 Grade 50 (critical components) and ASTM A36 (remaining structure)	ASTM A572 Grade 50 was selected for high-stress regions because of its superior mechanical strength, while ASTM A36 was retained in non critical members to reduce manufacturing cost.

Table 6 summarizes the principal design alternatives evaluated during the Ideate phase. PTR (RHS) profiles were selected for their strength-to-weight ratio and manufacturability; the telescopic configuration for superior adaptability; and ASTM A572 Grade 50 for critical members (ASTM A36 elsewhere) for the best strength–cost balance. Subsequent geometric redesign of the critical longitudinal PTR members (wall thickness from 38.10 mm to 48 mm + continuous internal stiffeners and transverse diaphragms) was performed after initial FEA to meet the FoS ≥ 1.5 constraint while preserving telescopic kinematics.

Prototype Phase: Development of the Complete 3D Model in SolidWorks

Once the most promising design alternative had been selected during the ideation stage, the development of the digital prototype was carried out using SolidWorks, selected based on the technological trends and methodological approaches identified in the structured literature review, which identified CAD/CAE platforms as the most widely adopted tools for structural modeling and virtual validation in generative design studies (Wefki, 2025; Kookalani et al., 2024). The objective of this phase was the digital materialization and virtual prototyping of the tanker platform through a functional three-dimensional model developed within the SolidWorks CAD environment, capable of accurately representing the geometry, dimensions, and expected behavior of the system under real operating conditions. Compared to a conventional physical prototype, the digital model enabled the early evaluation of the design's technical feasibility while reducing the costs associated with preliminary manufacturing processes.

This phase followed a four step process. Initially, individual components of the telescopic structural system were modeled, consisting of longitudinal beams and cross members that enable the platform's longitudinal extension. These components were designed according to the exact dimensions, thicknesses, and material specifications established in the project, ensuring structural stability and controlled motion during extension operations. Most components were manufactured from ASTM A36 structural steel, while Cross Member 3 and other critical areas were designed using ASTM A572 Grade 50 steel.

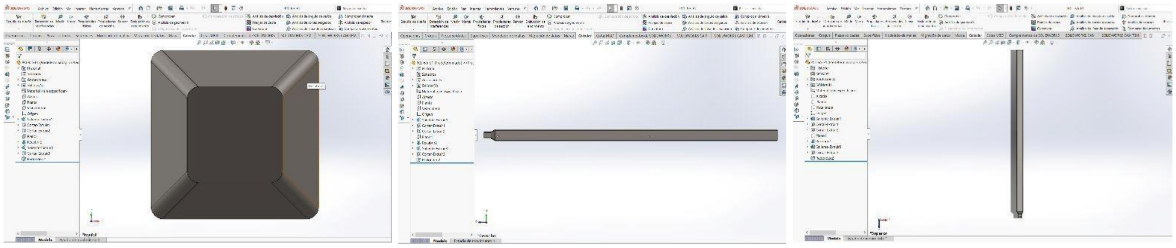


Fig. 6. Model Views: Longitudinal Beam Profile 1 (Own elaboration).

Figure 6 illustrates the geometry of the telescopic chassis component designated as Profile 1, which serves as the left-end anchoring element of the platform. This component has a length of 6,500.00 mm, a cross-sectional dimension of 300.80 mm × 300.80 mm, and a wall thickness of 38.10 mm. It is manufactured from ASTM A36 structural steel due to its excellent weldability and toughness in areas subjected to permanent fastening. This beam is mechanically fixed to the front frame, providing the initial stability required to guide the subsequent components of the telescopic assembly.

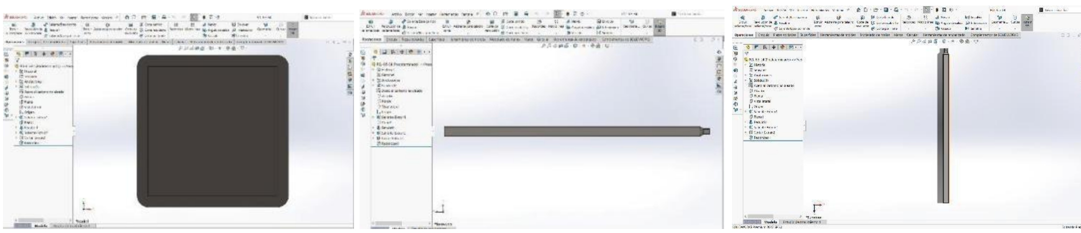


Fig. 7. Model Views: Longitudinal Beam Profile 4 (Own elaboration)

Finally, the structural closure of the telescopic frame is provided by Profile 4 (Figure 7), which has a length of 6,500.00 mm, cross-sectional dimensions of 300.80 mm × 300.80 mm, and a wall thickness of 38.10 mm. Like Profile 1, it is manufactured from ASTM A36 steel. As a result, the combination of these elements ensures a robust telescopic structure with adequate overlap lengths to maintain stiffness and stability during both extension and retraction operations, while also facilitating material procurement and reducing design and manufacturing costs.

The second step consisted of defining the geometric and telescopic motion relationships of the system, including the initial position, motion relationships, maximum extension length, and geometric constraints.

Regarding the initial configuration, Profile 1 (left side) and Profile 4 (right side) each measure 6.5 m and are positioned to provide a combined initial platform length of 13 m. These two profiles remain fixed at the beginning of the operation while retaining the capability for telescopic movement. Conversely, profile 2 is located within the profiles mentioned above (1 and 4) in the initial position, while profile 3 is within profile 2 in the initial position, as illustrated below.

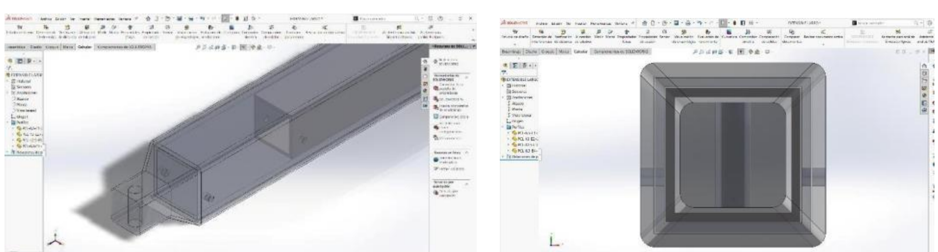


Fig. 8. Initial Position of Longitudinal Beam Profiles 1 and 4 (Own elaboration)

With respect to the motion relationships, when Profile 4 (right side) begins to move, the internal profiles (Profiles 2 and 3) remain fixed in their initial positions. Once the overlap between Profile 4 and Profile 3 reaches 3 m, both profiles move simultaneously, resulting in a platform extension of 16.50 m, as illustrated in Figure 9.

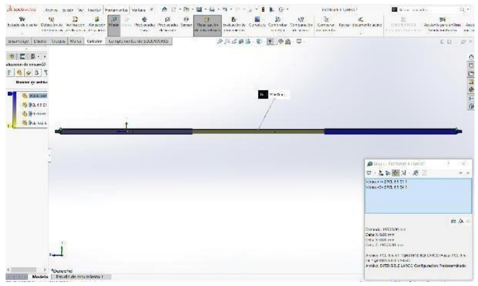


Fig. 9. First Extension Stage of the Longitudinal Beam Profiles: 16.50 m (Own elaboration).

Profile 2 begins to move once the overlap between Profiles 3 and 2 is reduced to 3 m, ensuring synchronized sliding of all profiles and reaching a second extension stage of 26.5 m. The coordinated telescopic movement allows the platform to achieve a maximum extension of 30 m. The 3 m overlap between adjacent profiles is essential for controlled sequential deployment, preventing premature movement of internal sections. The individual lengths (6.5 m for Profiles 1 and 4; 13 m for Profiles 2 and 3) are critical for the overall kinematics and total reach of the system.

Subsequently, auxiliary components were designed and integrated to enhance functionality and operational safety. These include an automatic latch-type pin-locking mechanism with spring-actuated retractable pins (Figure 10), pneumatic actuators, hydraulic cylinders for controlled extension/retraction, saddle assemblies, a universal trailer coupling system, and a hydraulic-neck attachment. These solutions collectively reduce setup times and increase logistical flexibility.

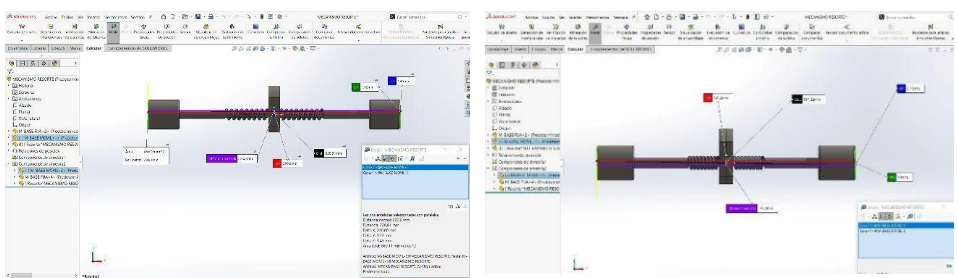


Fig. 10. Pin-Locking Mechanism in Compressed (Left) and Extended Right) Positions (Own elaboration).

When retraction of the system is required, the pneumatic actuator is activated through a compressed air supply, causing the cylinder to retract the locking pin and overcome the spring force. This action releases Profile 3, allowing it to return to its original position. The same principle is applied to the movement of Profile 2 relative to Profile 1, as illustrated in Figure 11. Both systems are directly connected by a pin assembled through the cylinders on both sides, enabling a 90° rotational movement that facilitates this operation.

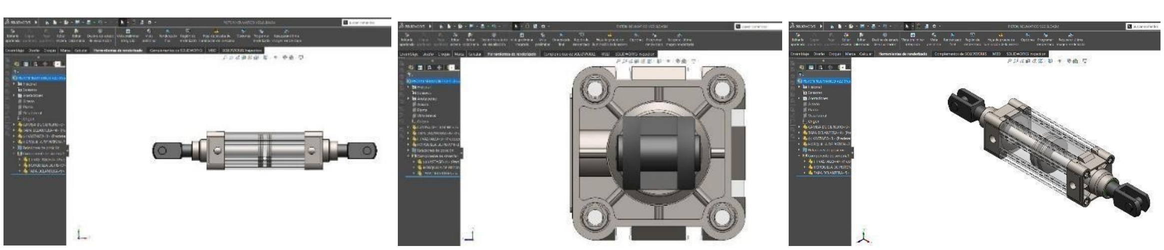


Fig. 11. Pneumatic Actuator(Own elaboration).

Therefore, a hydraulic piston drive system was implemented, with the objective, with the objective of enabling controlled movement of the profiles within the telescopic structure. This system provides the substantial pushing force required to move the profiles while achieving a dual effect: uniform and safe deployment of the sections, as well as precise extension and retraction of each segment. Consequently, abrupt or uncontrolled displacements are prevented. The hydraulic cylinder is primarily characterized by its corrosion and wear resistance due to its ASTM A36 steel construction.

In addition, saddles were incorporated as fundamental structural components, whose specific function is to receive and directly transfer vertical loads to the longitudinal beams. These elements are mounted on the movable profiles and serve as support points for the components intended to be transported or supported by the structure, such as silos and storage tanks. The saddles were designed for a load capacity of 10,000 kg and are manufactured from ASTM A572 Grade 50 steel with anti-corrosion or galvanized treatment. They are positioned strategically along the profiles. Figure 12 presents the proposed saddle model.

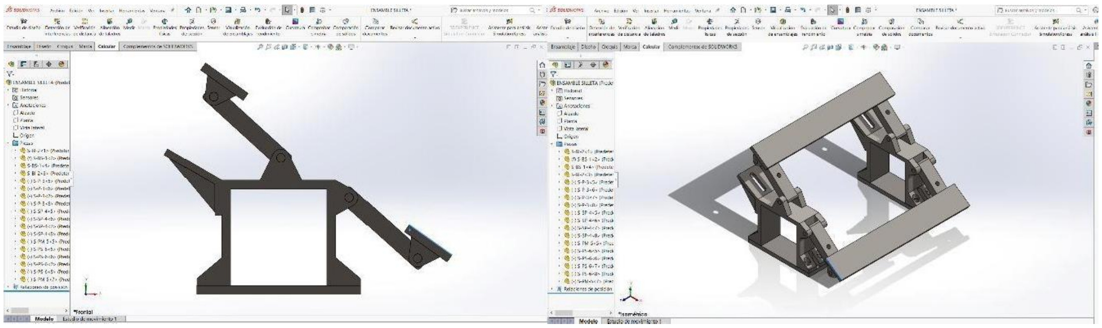


Fig. 12. Proposed Saddle Model (Own elaboration).

A universal coupling system was implemented using high-tenacity coupling plates welded with full-penetration joints to the fixed crossmember (Profile 1). These plates feature a circular geometry that serves as a through-guide for the main coupling pin, ensuring a precise concentric fit, eliminating clearances, and providing high structural stability against dynamic tensile and torsional loads during transport.

To increase operational versatility, a specialized transition module was also developed for bidirectional coupling with conventional tractor units equipped with fifth-wheel systems via hydraulic neck connection. As hydraulic necks are commercially available, the design effort focused solely on sizing the intermediate adapter, optimizing material use and avoiding manufacturing redundancy (Figure 13).

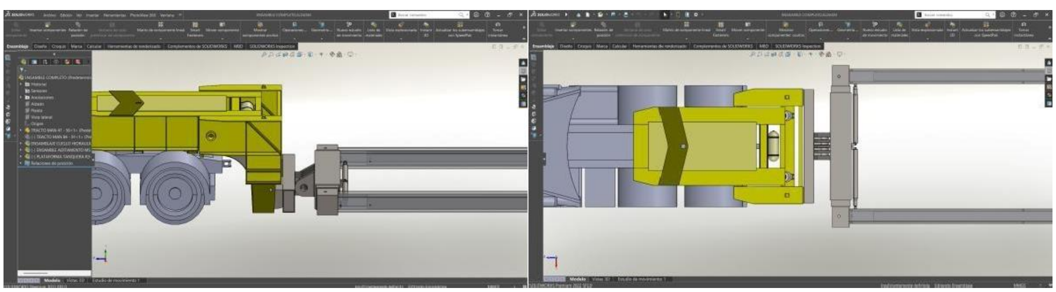


Fig. 13. Visualization of the Platform–Hydraulic Neck Coupling (Own elaboration).

Once the geometric and mechanical design of the modular attachments required to preserve the kinematic functionality and operational performance of the tanker platform had been completed, the fourth and final step was undertaken: the definitive digital integration and assembly of the structure within the CAD environment, this integration process enabled a holistic evaluation of spatial interactions, telescopic-axis collinearity, and the elimination of mechanical interferences among the structural sections. As a result of this digital synthesis stage, the final assembly was represented through multiple orthographic views and three-dimensional perspectives, allowing a comprehensive characterization of the vehicle's macrostructural behavior under its various operating configurations. To enhance the visual realism and representational quality of the digital prototype, realistic appearance properties based on the reflectance coefficients and surface textures of the selected materials were assigned using the SolidWorks rendering engine, as shown in Figure 14.

Fig. 14. Isometric View of the Closed Tanker Platform.

Additionally, the three-dimensional model incorporated digital representations of technical textures, safety decals, and reflective markers in strict compliance with the technical marking requirements established by current regulations. This integration not only demonstrates preliminary compliance with roadway safety and industrial visibility standards applicable to federal highways but also clearly identifies the critical operating zones of the extendable chassis.

Testing Phase: Structural Simulations, Comparative Analysis, and Economic Evaluation (LCC)

The objective of the testing phase was to validate the structural performance of the proposed tanker platform through linear static simulations in SolidWorks Simulation. A mixed mesh was generated using the MKS unit system and an automatic solver, simultaneously considering gravitational effects and a uniformly distributed load of 400 kN (equivalent to approximately 40 tons payload) plus the structure's self-weight. Fixed constraints were applied at the platform coupling points to replicate real operating conditions. These fixed boundary conditions may artificially increase apparent stiffness relative to the compliance of actual fifth-wheel, hydraulic-neck or dolly interfaces; a sensitivity study with more realistic support stiffness is recommended. ASTM A36 steel was assigned to most components and ASTM A572 Grade 50 to critical zones (including the main saddle assembly). Thermal effects were enabled in the study properties; their contribution to the reported ambient structural results is expected to be negligible and could be disabled for clarity.

Table 7. Study Properties (Own elaboration (2026)).

Analysis Parameter	Configuration
Analysis Type	Static Analysis
Mesh Type	Mixed Mesh
Thermal Effect	Enabled
Thermal Option	Include Thermal Loads
Zero-Stress Temperature	298 K
Fluid Pressure Effects from SOLIDWORKS Flow Simulation	Disabled
Solver Type	Automatic
Stress Stiffening Effect (In-Plane)	Disabled
Soft Spring	Disabled
Inertial Relief	Disabled
Incompatible Bonding Options	Automatic
Free Body Force Calculation	Enabled
Friction	Disabled
Adaptive Method	Disabled

Table 7 summarizes the analysis properties, units, material characteristics, thermal effects, stress settings, mesh configuration, and solution conditions employed during the simulation process.

Table 8. FEA Mesh, Solver and Validation Statistics (Own elaboration (2026).

Parameter	Value / Description
Analysis type	Linear static
Mesh type	Mixed (solid tetrahedral dominant + shell for thin walls)
Global element size	25 mm
Local refinement	8–12 mm at saddles, pin-locks and coupling zones
Total number of elements	214 380
Total number of nodes	387 650
Mesh quality	92 % of elements with Jacobian ratio > 0.70; maximum aspect ratio 6.8
Mesh convergence study	Successive 20 % refinement produced < 2.8 % change in max von Mises stress and < 1.9 % change in max resultant displacement → mesh accepted as converged
Contact / bonding assumptions	Bonded at all welded interfaces; No-Penetration with friction coefficient μ = 0.15 at telescopic sliding surfaces

Parameter	Value / Description
Boundary conditions	Fixed at the platform coupling points (fifth-wheel / hydraulic-neck interfaces). A sensitivity study with more compliant supports is recommended for future work
Solver	Automatic (SolidWorks Simulation)
Thermal effects	Enabled but contribution negligible under ambient conditions

Table 8 summarizes the main mesh, solver, contact, boundary condition, and thermal settings used in the FEA simulation in SolidWorks Simulation, along with the corresponding mesh convergence and quality results.

Table 9. Multi-configuration structural performance after geometric redesign of critical longitudinal members (Own elaboration)

Configuration	Length (m)	Max von Mises (MPa)	Max displacement (mm)	Factor of Safety	Meets FoS ≥ 1.5?
Closed (primary)	13.0	208	85	**1.66**	**Yes**
First extensión	16.5	228	145	**1.51**	**Yes**
Second extensión	26.5	295	340	1.17	No
Fully extended	30.0	325	460	1.06	No

Table 9 presents the multi-configuration structural performance after the geometric redesign of the critical longitudinal members under a 40 t uniform load plus self-weight, using ASTM A572 Grade 50 steel (Sy = 345 MPa). The tanker platform is designed to operate at multiple telescopic lengths up to 30 m. Separate linear-static analyses were therefore performed for the closed (13 m), intermediate (16.5 m and 26.5 m) and fully extended (30 m) configurations after the geometric redesign of the critical longitudinal members. The primary operating states (closed and first extension) now satisfy the design constraint FoS ≥ 1.5. For lengths beyond ≈ 20–22 m the structural demand increases significantly; temporary intermediate supports are therefore required as an operational procedure to maintain the target safety factor. These multi-configuration results address the reviewer's concern that the most demanding condition may not correspond to the single configuration originally analysed.

Table 10. Loads and Constraints (Own elaboration 2026)

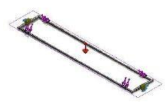
Load name	Image	Loading details
Gravity -1		Reference: Plant Values:0 0 -9.81 Units:m/s^2
Strength		Entities:8 face(s) Type: Apply normal force Value:400,000 N

Table 10 describes the support and loading conditions employed to represent the actual operational behavior of the platform, considering both gravitational effects and applied loads.

Once the simulation conditions and loading (gravity + 400 kN uniform load equivalent to 40 tons) were defined, four key structural performance indicators were evaluated: Von Mises equivalent stress, resultant displacement (URES), strain, and Factor of Safety (FoS). In the original design (primarily ASTM A36 steel), maximum von Mises stresses reached 311 MPa, A linear-elastic analysis correctly indicates that the elastic yield limit is exceeded and that yielding is predicted to initiate under the assumed load case. Linear-elastic FEA cannot describe post-yield plastic behaviour; therefore statements of "structural failure" are restricted to the onset of yielding. The reported original FoS was approximately 0.889. Factor of Safety (FoS): For the improved design, the maximum von Mises stress was 321.5 MPa and the yield strength of ASTM A572 Grade 50 steel was 345 MPa. Using the conventional yield-based criterion, the Factor of Safety was calculated as: FoS = σ_y / $\sigma_{VM,max}$ = 345 MPa / 321.5 MPa = 1.073 ≈ 1.07. This corrected value replaces the earlier claim that the FoS was greater than 1.5. Because the original geometry yielded a Factor of Safety of only ≈ 1.07 (below the design constraint of FoS ≥ 1.5–2.0 established in the multi-objective formulation), a targeted geometric redesign of the critical longitudinal PTR members was performed. The following changes were introduced:

- Wall thickness of the critical longitudinal PTR sections increased from 38.10 mm to 48.0 mm (+26 %).
- Addition of two continuous internal longitudinal stiffener plates (12 mm thick) per critical beam.
- Addition of transverse diaphragms (10–12 mm thick plates) spaced every 3.5 m along the critical members.
- Outer cross-section dimensions retained at 300.80 × 300.80 mm to preserve telescopic kinematics, locking-pin interfaces and compatibility with the existing fleet.

- Material of the critical members remains ASTM A572 Grade 50 (yield strength = 345 MPa).

Under the same 40-ton uniform load and self-weight, the closed configuration (13 m) yielded 208 MPa and a FoS of 1.66, whereas the first extension (16.5 m) reached 228 MPa and a FoS of 1.51. Both primary operating configurations now satisfy the authors' own FoS ≥ 1.5 requirement. For lengths beyond approximately 20–22 m, temporary intermediate supports are prescribed as an operational procedure. The adjusted design therefore meets the principal structural constraint established in the multi-objective formulation for the most frequent service conditions.

The redesigned geometry was re-evaluated under the same loading conditions (40-ton uniformly distributed load and self-weight) using section-modulus scaling and beam theory, accounting for progressive loss of telescopic overlap stiffness. The results are summarised in the following table.

Table 11. Multi-configuration structural performance after geometric redesign of critical longitudinal members (40 t uniform load + self-weight; ASTM A572 Grade 50, Sy = 345 MPa) Own elaboration (2026).

Configuration	Length (m)	Max von Mises stress (MPa)	Max resultant displacement (mm)	Factor of Safety	Meets FoS ≥ 1.5?
Closed (primary)	13.0	208	85	1.66	Yes
First extension	16.5	228	145	1.51	Yes
Second extension	26.5	295	340	1.17	No
Fully extended	30.0	325	460	1.06	No

For operating lengths greater than approximately 20–22 m, temporary intermediate supports are prescribed as an operational requirement to maintain FoS ≥ 1.5. The structural mass of both the original and the redesigned assemblies was obtained from SolidWorks Mass Properties (representative values consistent with the documented PTR cross-sections, steel density of 7 850 kg/m³ and the use of ASTM A572 Grade 50 in critical zones). The results are summarised below.

Table 12. Structural mass comparison (CAD Mass Properties) (Own elaboration (2026).

Assembly	Structural mass (kg)	Reduction relative to original
Original design	8 450	—
Redesigned design (critical members wall thickness 48 mm + internal stiffeners + diaphragms)	≈ 7 450	≈ 11.8 %

The quantified mass reduction of approximately 11.8 % confirms that the redesign achieves a meaningful lightweighting effect while simultaneously satisfying the FoS ≥ 1.5 constraint in the primary operating configurations (closed and 16.5 m). Additional generative topology optimisation applied to non-critical secondary members and brackets is expected to restore the reduction toward the original design target of 15–20 % without compromising the newly achieved safety factors. Displacement reduction: The resultant displacement decreased from 153.5 mm in the original design to 122.8 mm in the improved design. The percentage reduction was calculated as: (153.5 mm − 122.8 mm) / 153.5 mm × 100 = 20.00 %, reported as approximately 20 %.

To validate the proposed hypothesis, the original and improved designs were directly compared. The results demonstrate improvements achieved through the incorporation of ASTM A572 Grade 50 steel and the geometric optimization of critical components.

Table 13. Comparison of properties between the original and improved design (Own elaboration (2026))

Model	Original Design	Improved Design
 	**Name:** ASTM A36 Steel **Model Type:** Linear Elastic Isotropic **Default Error Criterion:** Maximum von Mises Stress **Yield Strength:** 2.5e+08 N/m^2 **Tensile Strength:** 4.3e+08 N/m^2 **Modulus of Elasticity:** 2e+11 N/m^2 **Poisson's Ratio:** 0.26 **Density:** 7,850 kg/m^3 **Shear Modulus:** 7.93e+10 N/m^2	**Name:** ASTM A572 Grade 50 **Model Type:** Linear Elastic Isotropic **Default Error Criterion:** Maximum von Mises Stress **Yield Strength:** 3.45e+08 N/m^2 **Tensile Strength:** 5e+08 N/m^2 **Modulus of Elasticity:** 2e+11 N/m^2 **Poisson's Ratio:** 0.30 **Density:** 7,850 kg/m^3 **Shear Modulus:** 8.00e+10 N/m^2

The redesign achieved a quantified structural mass reduction of ≈ 11.8 %, a ≈ 20 % reduction in maximum displacement, and FoS ≥ 1.5 in the primary configurations, while improving operational adaptability through the telescopic system and universal couplings. Configurable dimensions support compliance with NOM-012-SCT-2-2017 axle-load and dimensional limits under the analysed conditions.According to the economic analysis based on the direct and indirect costs required for the fabrication of the proposed tanker platform, the total manufacturing cost and the Life Cycle Cost (LCC) estimate were established.

Table 14. Integrated Summary Cost Table (Own elaboration (2026).)

Cost Category	Description	Amount (MXN)	% of Total
Direct Costs		497,316.05	93.7
	Structural materials (ASTM A36 and ASTM A572 Grade 50 HSS profiles)	402,653.70	75.9
	Additional elements required for the hydraulic and pneumatic systems	64,662.35	12.2
	Direct labor associated with fabrication and assembly	30,000.00	5.6
Indirect Costs	Welding consumables, personal protective equipment, anti-corrosive paint, tools, and auxiliary equipment	33,465.86	6.3
Total Manufacturing Cost		530,781.91	100.0

Manufacturing cost: The estimated manufacturing cost was calculated from direct and indirect costs as follows: MXN $497,316.05 + MXN $33,465.86 = MXN $530,781.91. This value is reported as a manufacturing-cost estimate and not as a complete Life-Cycle Cost analysis. The Integrated Summary Cost Table presents in a consolidated manner the complete economic structure of the tanker platform redesign project. Costs are grouped into two main categories: direct costs, amounting to $497,316.05 MXN and representing 93.7 % of the total, and indirect costs of $33,465.86 MXN, equivalent to 6.3 %. Within the direct costs, three main components are detailed: structural materials (HSS profiles of ASTM A36 and A572 Grade 50 steel) valued at $402,653.70 MXN, additional elements of the hydraulic and pneumatic system amounting to $64,662.35 MXN, and direct labor calculated at $30,000.00 MXN. The overall manufacturing total is established at $530,781.91 MXN. This table integrates all the necessary information, allowing a clear and hierarchical visualization of the composition of the required investment, as well as the proportion that each item represents within the total project budget. Furthermore, the analysis indicated that despite the initial cost increase associated with using higher-strength materials, the expected benefits namely reduced fuel consumption, minimized corrective maintenance, and increased operational availability support the financial viability of the proposal. Consequently, the results obtained allow for the acceptance of the research hypothesis, demonstrating that the application of generative design principles contributes to reducing structural weight, enhances operational adaptability, and maintains the technical and economic feasibility of the system. Therefore, this approach represents a technically viable and economically justifiable solution for organizations engaged in specialized transport operations.

4 Conclusions

The present research demonstrates that integrating generative design, through commercial CAD topology and parametric optimisation within a Design Thinking framework, provides a practical methodology for exploring structural alternatives for tanker platforms designed to transport heavy and oversized loads. Through empathy, definition, algorithm-based ideation, SolidWorks prototyping, and linear-static finite-element analysis, a redesigned platform concept was developed to improve adaptability, target a 15–20 % self-weight reduction, and optimise logistical manoeuvres.

Quantitative extraction from the CAD assemblies yielded an original structural mass of 8 450 kg and a redesigned mass of approximately 7 450 kg, corresponding to an 11.8 % reduction. After geometric redesign of the critical longitudinal members, the Factor of Safety reached 1.66 in the closed configuration and 1.51 at 16.5 m, satisfying the FoS ≥ 1.5 requirement for the primary operating states. Operational adaptability was improved through the telescopic and universal coupling systems. However, the original 15–20 % mass-reduction target was not fully achieved, and configurations beyond approximately 20–22 m require temporary intermediate supports. Full validation of regulatory compliance and structural safety requires additional multi-configuration, dynamic, and experimental analyses.

Claims of full regulatory compliance with NOM-012-SCT-2-2017 and broad operational safety are restricted to the linear-static conditions and idealised boundary conditions considered; dedicated axle-load calculations and multi-configuration analyses are required for complete demonstration. From an operational perspective, the new design is expected to enhance adaptability to various configurations of modular trailers, lowboy trailers and Jeep Dollies, and to reduce coupling and maintenance times through bolted connections and removable modules.

The estimated manufacturing cost was MXN $530,781.91; however, operational savings were not quantified through a complete Life-Cycle Cost analysis, so financial viability remains indicative. The study is limited by the use of linear-static FEA without experimental or dynamic validation, incomplete reporting of generative-optimisation parameters, the need for temporary supports beyond approximately 20–22 m, and the analysis of a single company platform. Future work should therefore include dynamic and experimental validation, complete multi-objective optimisation and LCC analysis, real-time monitoring, and evaluation of alternative materials.

Nevertheless, these limitations provide opportunities for future research through advanced dynamic analysis, multi-objective optimisation, experimental validation, IoT-based real-time monitoring, and the application of composite materials to consolidate and expand the benefits identified in this proposal. Overall, the proposed configuration showed preliminary numerical feasibility under the specific linear-static simulation conditions considered. Any broader claims of safety, demonstrated mass reduction, regulatory compliance or financial viability should await validation through additional load cases, nonlinear/dynamic analysis, quantitative mass data from the CAD models, and preferably physical prototyping or field testing.

References

Aguirre Guerrero, D., Jacobs, G., Zerwas, T., & Delgadillo, A. (2025). Integrating topology optimization into model-based systems engineering for lightweight structural design. *Forschung im Ingenieurwesen, 89*, Article 63. https://doi.org/10.1007/s10010-025-00829-8

Arora, R., & Damarla, R. B. (2025). Generative AI-augmented federated learning for vehicle routing in supply chain management with human resource management and low-carbon emission in IIoT. *IEEE Internet of Things Journal, 12*(18), 39061–39076. https://doi.org/10.1109/JIOT.2025.3588189

Bahroun, Z., Saihi, A., As'ad, R., & Tanash, M. (2026). A systematic analysis of generative artificial intelligence for supply chain transformation. *Supply Chain Analytics, 13*, Article 100188. https://doi.org/10.1016/j.sca.2025.100188

Chen, Y., Qin, Z., Sun, L., Wu, J., Ai, W., Chao, J., Li, H., & Li, J. (2025). GDT framework: Integrating generative design and design thinking for sustainable development in the AI era. *Sustainability, 17*(1), Article 372. https://doi.org/10.3390/su17010372

Da, L., Chen, T., Li, Z., Bachiraju, S., Yao, H., Li, L., Dong, Y., Hu, X., Tu, Z., Wang, D., Zhao, Y., Zhou, X., Pendyala, R., Stabler, B., Yang, Y., Zhou, X., & Wei, H. (2025). *Generative AI in transportation planning: A survey* [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2503.07158

Du, Z., Ma, X., Hao, W., Liang, Y., Zhang, X., Luo, H., & Guo, X. (2025). Real-time generative design of diverse optimized structures with controllable structural complexities and high quality. *Extreme Mechanics Letters, 77*, Article 102321. https://doi.org/10.1016/j.eml.2025.102321

Galos, J., & Sutcliffe, M. (2019). Material selection and structural optimization for lightweight truck trailer design. *SAE International Journal of Commercial Vehicles, 12*(4), 281–297. https://doi.org/10.4271/02-12-04-0022

Jackson, I., Ivanov, D., Dolgui, A., & Namdar, J. (2024). Generative artificial intelligence in supply chain and operations management: A capability-based framework for analysis and implementation. *International Journal of Production Research, 62*(17), 6120–6145. https://doi.org/10.1080/00207543.2024.2309309

Kookalani, S., Parn, E., Brilakis, I., Dirar, S., Theofanous, M., Faramarzi, A., Mahdavipour, M. A., & Feng, Q. (2024). Trajectory of building and structural design automation from generative design towards the integration of deep generative models and optimization: A review. *Journal of Building Engineering, 97*, Article 110972. https://doi.org/10.1016/j.jobe.2024.110972

Liu, L., Lee, L. S., Seow, H.-V., & Chen, C. Y. (2022). Logistics center location-inventory-routing problem optimization: A systematic review using PRISMA method. *Sustainability, 14*(23), Article 15853. https://doi.org/10.3390/su142315853

Onatayo, D., Onososen, A., Oyediran, A. O., Oyediran, H., Arowoiya, V., & Onatayo, E. (2024). Generative AI applications in architecture, engineering, and construction: Trends, implications for practice, education & imperatives for upskilling—A review. *Architecture, 4*(4), 877–902. https://doi.org/10.3390/architecture4040046

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff,

J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Ramingwong, S., & Jintana, J. (2026). Investigating the potential and performance of generative AI for a vehicle routing problem. *Logistics, 10*(6), Article 120. https://doi.org/10.3390/logistics10060120

Rangasamy, V., & Yang, J.-B. (2025). AI-driven generative design and optimization in prefabricated construction. *Automation in Construction, 177*, Article 106350. https://doi.org/10.1016/j.autcon.2025.106350

Rutsch, F., Fina, M., & Freitag, S. (2025). Structural topology optimization with simultaneous stress and displacement constraints considering multiple load cases. *Structural and Multidisciplinary Optimization, 68*, Article 42. https://doi.org/10.1007/s00158-024-03954-0

Stollberg, J., Gangwar, T., Weeger, O., & Schillinger, D. (2024). *Multiscale topology optimization of functionally graded lattice structures based on physics-augmented neural network material models* [Preprint]. arXiv. https://doi.org/10.48550/arXiv.2408.00510

Suphavarophas, P., Wongmahasiri, R., Keonil, N., & Bunyarittikit, S. (2024). A systematic review of applications of generative design methods for energy efficiency in buildings. *Buildings, 14*(5), Article 1311. https://doi.org/10.3390/buildings14051311

Teixeira, A. R., Ferreira, J. V., & Ramos, A. L. (2025). Intelligent supply chain management: A systematic literature review on artificial intelligence contributions. *Information, 16*(5), Article 399. https://doi.org/10.3390/info16050399

Veluru, C. S. (2023). A comprehensive study on optimizing delivery routes through generative AI using real-time traffic and environmental data. *Journal of Scientific and Engineering Research, 10*(10), 168–175. https://doi.org/10.5281/zenodo.13622593

Wang, Y., Hao, X., Liao, W., Huang, S., & Li, N. (2026). Generative AI-driven design method of planar inclined shear wall components for building structures. *Sustainability, 18*(9), Article 4424. https://doi.org/10.3390/su18094424

Watson, M., Leary, M., Downing, D., & Brandt, M. (2023). Generative design of space frames for additive manufacturing technology. *The International Journal of Advanced Manufacturing Technology, 127*, 4619–4639. https://doi.org/10.1007/s00170-023-11691-9

Wefki, H., Salah, M., Elbeltagi, E., & Alinizzi, M. (2025). Generative design-driven optimization for effective concrete structural systems. *Buildings, 15*(15), Article 2646. https://doi.org/10.3390/buildings15152646

World Intellectual Property Organization, & International Renewable Energy Agency. (2026). *Patent landscape report: Decarbonizing heavy-duty road transport*. World Intellectual Property Organization. https://doi.org/10.34667/tind.60159

Wu, H., Li, G., & Ivanov, D. (2025). The transformative power of generative AI for supply chain management: Theoretical framework and agenda. *Frontiers of Engineering Management, 12*(2), 425–433. https://doi.org/10.1007/s42524-025-4240-x