World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

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ADAPTIVE LIGHTWEIGHT STRUCTURAL DESIGN FRAMEWORK FOR ALUMINIUM TRAILER PLATFORMS USING MULTI-OBJECTIVE FINITE ELEMENT OPTIMIZATION AND MANUFACTURABILITY CONSTRAINTS

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World Journal of Advanced Engineering Technology and Sciences, 2026, 21(01), 167–175

Publication history: Received on 06 September 2026; revised on 12 October 2026; accepted on 14 October 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.21.1.0429

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ABSTRACT

Adaptive lightweight design of aluminum trailer platforms is technically significant, as road-load requirements, payload, stiffness, fatigue, buckling, and manufacturability requirements often conflict. The review critically summarizes the published journal literature concerning multi-objective finite element optimization, manufacturing-oriented topology optimization, joining of aluminum, stress/buckling control and lightweight vehicle-related structural design. The literature review demonstrates that effective lightweight designs were not necessarily achieved by minimizing weight, but rather by considering the following factors: load-path continuity, minimum member size, weld access, structural feasibility of the trailer platform, interaction between the deck and the trailer platform, fatigue-prone details and the avoidance of local buckling. Existing research is well-grounded in the computational aspects, but is scattered over vehicle crashworthiness, aerospace topology optimization, additive manufacturing limitations, and general aluminum fabrication research. Validation of trailers, multi-objective optimization considering fatigue and the rules of manufacture of welded and extruded aluminum remain insufficiently developed. Such a framework should therefore integrate finite element fidelity, surrogate model adaptation, manufacturable geometry production, and production-based constraint screening.

Keywords: Aluminum Trailer Platforms; Finite Element Optimization; Lightweight Design; Manufacturability Constraints; Multi-Objective Optimization; Structural Performance

1 INTRODUCTION

Aluminum trailer platforms are challenging from a structural design standpoint due to the competing requirements for payload efficiency, corrosion resistance, manufacturability, fatigue durability, and highway-load reliability in a commercial product, all of which must be met within tight cost constraints. Trailer platforms differ from passenger-vehicle platforms because they have long-span longitudinal beams, transverse cross-members, deck panels, landing-gear reinforcements, axle-interface brackets, weld lines, and local bolted attachments that are loaded by a combination of bending, torsion, local bearing, vibration, and repeated road-induced loads. The main challenge, therefore, is not only

to minimize mass but also to establish an adaptive lightweight structural design framework in which the interplay among finite element analysis, multi-objective optimization and manufacturability constraints is considered prior to detailed production release. Previous vehicle-concept work has shown that optimal load-path layouts can differ between concurrent static and crash load cases and single-load-case stiffness optimization [1]. This finding is relevant to aluminum trailer bodies, especially when vertical payload cases, asymmetric wheel loads, braking loads, kingpin or drawbar loads and torsional curb events create conflicting structural needs.

The research area has shifted from unconstrained compliance minimization to manufacturing-based topology, size, shape and layout optimization. Manufacturing-oriented topology optimization has been reviewed as a mature but still developing field due to the fact that the ideal material distribution is rarely achieved due to mathematical restrictions, mesh regularity, minimum feature control, compatibility with joining methods and process restrictions [2]. For trailer platforms, this observation has a particular significance because optimized density fields must be converted into extrudable rails, weldable cross-members, parts from cut sheet, cast and machined brackets and inspectable joints. Aerospace structural optimization literature also has shown that topology optimization can lead to weight savings while maintaining a given stiffness and buckling resistance, however, successful implementation requires an explicit design rule, certification evidence and post-optimization interpretation [3]. Trailer-platform engineering also has similar barriers, with typically tighter allowable manufacturing variability and cost sensitivity.

Aluminum introduces another layer of complexity because of considerations involving alloy temper, softening of the HAZ, weld geometry, distortion control, availability of extrusions, galvanic isolation, and the need to account for fatigue-sensitive weld details. The literature review on aluminum joining demonstrates that the quality of the weld, friction stir process, hybrid joining, and process-induced property changes affect the reliability of the structure as much as the nominal strength of the base material [4]. Therefore, manufacturability cannot be treated as a late-stage drafting correction to a finite element optimization model. Constraints must be incorporated early through the minimum gauge rules, weld-access envelopes, local buckling limits, heat-affected-zone knockdowns, fixture access, assembly sequence, extrusion die limits, and inspection accessibility.

This review examines peer-reviewed journal studies published from 2015 onward to establish the technical basis for an adaptive lightweight structural design framework for aluminum trailer platforms. The literature specifically addressing trailer platforms is limited; therefore, relevant evidence is drawn from vehicle-related topology optimization, manufacturing-constrained structural optimization, stress and buckling constraints, aluminum joining, and lightweight shell and beam structures. Stress constraints, buckling constraints, aluminum joining and lightweight shell or beam-like structures. The review consequently assesses the feasibility of applying methods reported in neighboring literature, which are technically and conceptually relevant but not directly validated. Special focus is devoted to methodological transferability, limitation of the results reported, and research gaps not addressed by the present state of finite element-based optimization of aluminum trailer structures, which make it difficult to fully realize the practical application of the finite element approach as a design framework for the production of aluminum trailer structures.

2 LITERATURE REVIEW

The most pertinent methodological basis for adaptive lightweight design of trailer platforms is manufacturing-constrained topology optimization, since it reflects the difference between mathematically optimal material distributions and the design of parts, particularly aluminum, that can actually be manufactured. Minimum length-scale control is especially important for trailer platforms because it suppresses mesh-dependent features and helps ensure that structural members are sufficiently large for fabrication, inspection, and local-stability requirements. To realize the optimized layout, beam and plate assemblies have to be manufacturable; geometric constraints can provide minimum length scales and eliminate the fine features that would otherwise be nonphysical, as Zhou et al. [5] have shown. Allaire et al. [6] also extended the thickness-controlled level-set optimization introduced by them, which had a better geometric relationship with structural features like plates and ribs compared to density-controlled layouts. Vatanabe et al. [7] suggested the projection-based method for multiple manufacturing constraints, which means that the manufacturing constraints should be added during topology generation, rather than the correction step.

As with the welded and extruded aluminum trailer production, there are no direct equivalents to additive-manufacturing-oriented studies; however, there are several mechanisms that can be transferred from the production of the welded and extruded aluminum trailer. To permit only supported geometries, Langelaar [8] incorporated logical constraints into the filter, while Wu et al. [9] optimized shell-infill systems, like the coupling between the skin of a trailer and an internal support network of longitudinal and/or transverse members. Overhang and undercut restrictions were investigated by Gaynor and Guest [10] and Qian [11] respectively, in the context of directional access restrictions. Extrusion direction, access to weld guns, drainage-path, plasma/laser cutting access and fixture removal are all similar considerations for the trailer platforms. The problem is that AM constraints are often based on layer-wise fabrication

whereas the manufacturing of trailers is based on cutting, extrusion, forming, welding, bolting, and assembly tolerances. If translation is not available, then direct adoption could therefore lead to incorrect conclusions regarding manufacturability.

The second body of literature is related to the problem of multi-objective optimization used for vehicle-related problems. Aulig et al. [1] showed how concurrent static and crash demands can be handled in vehicle concept design by means of preference-based topology optimization. Although the study is done on a crash loading scenario, it can still be useful to describe the extent to which the structural layout is dependent on the objective priority and how the load cases are combined. The aluminum trailer platforms are the other elements that need balancing, in terms of mass, bending stiffness, torsional stiffness, first-mode frequency, fatigue damage, local buckling margin, cost and manufacturability. Literature is less convincing when optimization is not linked to the downstream fabrication, as a low-mass topology can lead to inaccessible welds or weak HAZ regions, or members too small to be extruded in practical dimensions.

A third group is related to structural constraints beyond stiffness. In the case of thin-walled aluminum structures, however, control of local instability plays an important role because of the significant changes in the optimized topology that were shown by Ferrari and Sigmund [13]. Verbart et al. [14] provides a stress-aggregation and relaxation approach that could be adapted to local regions such as weld toes, bracket transitions, deck cut-outs, and kingpin or axle-interface reinforcements. Local stress control, however, is challenging in topology optimization due to the fact that the results can be influenced by the mesh density, the stress aggregation parameters and/or the smoothing of the local geometry. Such restrictions are substantial for trailer platforms as the fatigue-limiting factor is the local ranges of stress and not the global static stiffness. A summary of the most relevant peer-reviewed research from the core method literature [5]–[12] is summarized in Table 1. The table indicates that manufacturability has been discussed in the following ways: length scale, thickness, projection, directionality and shell-infill logic; but none of the studies presents a full production process for the welded and extruded aluminum trailer platforms.

Table 1: Summary of key findings

Ref	Focus	Key Findings
[5]	Minimum member scale in topology optimization	Geometric constraints suppress mesh-dependent fine features and support producible rib, beam, and bracket dimensions.
[6]	Thickness control through level-set optimization	Explicit thickness regulation improves conversion of optimized boundaries into plate-like structural members.
[7]	Unified projection-based manufacturing constraints	Projection operators allow draw, extrusion, symmetry, and minimum-size restrictions to enter topology generation.
[8]	Directional manufacturability filtering	Access-oriented filtering prevents geometries that violate fabrication-direction constraints.
[9]	Shell-infill structural optimization	Coupled skin–infill design supports lightweight sandwich-like layouts relevant to deck and rib interaction.
[10]	Overhang-constrained structural optimization	Directional restrictions demonstrate how fabrication accessibility can reshape optimal load paths.
[11]	Undercut and overhang angle control	Gradient-based manufacturing rules improve directional feasibility of optimized geometries.
[12]	Topology optimization to manufacturable structures	Review evidence shows persistent gaps between optimized concepts, process constraints, and validated parts.

The studies reviewed here all agree that an adaptive aluminum trailer-platform is likely to benefit from both a global layout optimization and a local enforcement of design rules. There is a significant lack of journal research combining service-load spectra, weld fatigue evaluation, manufacturability assessment, and multi-objective finite element optimization within a single validated framework applicable to the trailer industry. Therefore, the existing literature provides well-developed computational tools but limited domain-specific integration

3 METHODOLOGY

There is a conceptual framework within the literature that can be followed for adaptive lightweight structural design of aluminum trailer platforms, which includes the definition of the finite element model, multi-objective optimization,

incorporation of manufacturability constraints, and adaptation based on the validation process. In the first layer, shell, beam, solid, or connector elements are used to represent the deck, rails, cross-members, welds, brackets, bolted interfaces, suspension mounts, and local reinforcements. Optimization studies of vehicles and aircraft indicate that, given significantly idealized boundary conditions and load combinations, the result will be a topology and/or size optimization that is insufficiently reliable for practical application [1,3]. The load distribution on the trailer platform, the concentrated loads applied to the equipment, axle reactions, torsional events, braking events, loads due to the kingpin or coupling, and local support interaction on the deck structure should be incorporated in the finite element model for a trailer platform.

The second layer is multi-objective optimization. However, reducing mass alone does not necessarily produce a structurally superior trailer; for instance, decreasing the gauge, increasing the span, and using perforated members can reduce torsional stiffness and natural frequencies while increasing stress range and susceptibility to buckling. The final topology is determined by the preference-based methods that are used – stress aggregation [14] and buckling-constrained optimization [13] are both methods that show this. It is not established which of these approaches is most appropriate for a trailer platform objective. The goals that are defensible include minimization of mass, minimization of compliance, maximization of torsional stiffness, minimization of fatigue damage, maximization of buckling load factor and reduction in manufacturing costs. Once the topology is interpreted, weld placement is modified, or standard extrusions are substituted, the accuracy of surrogate models trained on early design variations may degrade, requiring adaptive re-optimization.

The third layer puts constraints on manufacturability. Methods for minimum length-scale control, thickness regulation, projection, and directional filtering [6, 8, 10, 11] can inform constraints on minimum extrusion-wall thickness, weld-access clearance, maximum unsupported span of deck panels, minimum bend radius, minimum cut-out ligament, fixture access and rules for assembly sequence. This is reflected by literature on aluminum joining [4] which emphasizes the need for the representation of HAZ strength degradation and choice of the joining process in the design loop. The best-performing topology in base material finite element analysis may no longer be optimal after accounting for weld softening, distortion or fatigue-detail classification.

Validation-based adaptation is the fourth layer. Even if manufacturing is constrained, optimization does not mean that there is no need for recalibration, as the assumptions made with the finite elements and the reduction of material properties, weld geometry and support conditions are still uncertain. The adaptive framework should include updating the constraints following prototype tests, strain measurements, modal correlation, fatigue hotspot assessment, and manufacturing feedback. This process goes beyond verification by refining the feasible design space because it eliminates inaccessible or impractical weld configurations, excessive distortion, inaccessible joints, or local failure not detected by global constraints.

Table 2: Method comparison

Ref	Method	Strengths	Limitations
[1]	Preference-based topology optimization under static and crash load cases	Captures competing vehicle load paths and supports design trade-off selection.	Concept-level load abstraction limits direct transfer to trailer fatigue and weld details.
[5]	Geometric minimum length-scale control	Produces member sizes more compatible with rails, ribs, gussets, and brackets.	Does not directly encode extrusion catalogues, weld sequence, or fixture restrictions.
[6]	Level-set thickness control	Improves boundary clarity and plate-like manufacturability.	Sensitive to parameterization and requires interpretation for assembled platforms.
[7]	Projection-based manufacturing constraints	Allows multiple process restrictions within a single optimization formulation.	Constraint tuning can bias topology before trailer-specific validation.
[13]	Buckling-constrained topology optimization	Prevents overly slender webs and compression-sensitive layouts.	High computational expense for large shell-platform models.
[14]	Stress aggregation and relaxation	Addresses local stress limits relevant to weld toes and bracket transitions.	Local fatigue interpretation remains dependent on mesh and detail modelling.

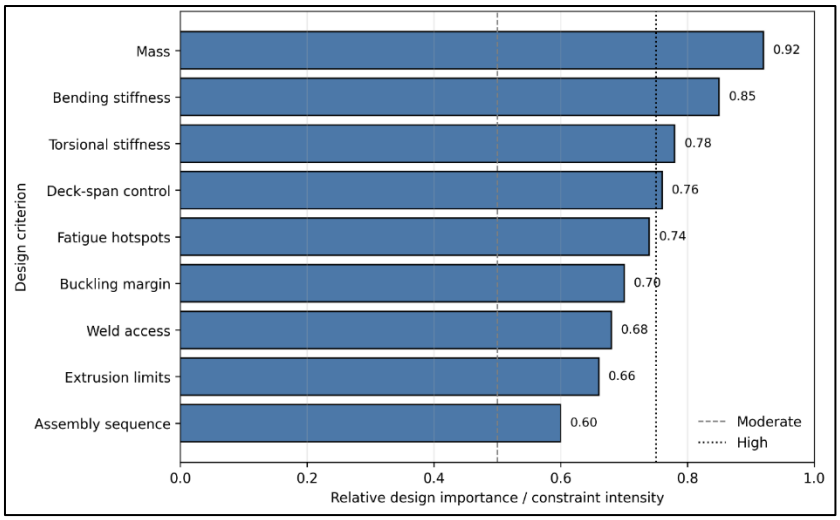


Figure 1: Constraint priority profile for aluminium trailer-platform optimization

Figure 1 is a horizontal bar chart illustrating the relative importance of structural performance criteria and manufacturability constraints in aluminum trailer-platform optimization. The reason is that the axis of the design space is not solely the minimization of mass, but also an adapted design space that is constrained by stiffness, fatigue, buckling, weldability, extrudability and assembly considerations for the aluminum platform. Conceptual knowledge of techniques and limitations summarized in [1]–[14].

4 DISCUSSION

The literature reviewed indicates that the most significant technical development is from unconstrained mass reduction to constrained structural performance. When the platform is made of aluminum, this change is crucial since a topology optimized for compliance can lead to thin diagonal webs, isolated material islands, narrow ligaments and impractical or unmanufacturable joints. Minimum length-scale control [5], thickness regulation [6], projection-based manufacturing constraints [7], and directional filtering [8, 10, 11] can be translated into rules for minimum extrusion-wall thickness, weld-access clearance, maximum unsupported deck-panel span, minimum bend radius, minimum cut-out ligament, fixture access, and assembly sequence. However, these methods still require adaptation to the production rules before they can be used in these methods. The minimum feature size defined by numerical considerations may not necessarily correspond with the wall thickness of the extrusion, weld throat, edge distance of fasteners, or spacing between deck panels. The implication is that manufacturability constraints are not the same for all materials, so the values must be specific to the aluminum alloy, the joining process, the platform span, the payload class, and the shop.

The second trend is the growing recognition that no single optimum exists when objective conflicts arise. Vehicle concepts for both static and crash requirements have been demonstrated to be dependent on preference structures rather than solely on mathematical minima by Aulig et al. [1]. Reducing the mass of the cross-members may increase the deck deflection, fatigue stress range, and floor vibration in aluminum trailer platforms, for the same reasons. Raising the depth of the rails longitudinally may increase bending stiffness but may make the rails more sensitive to buckling in other areas, may increase the product cost, or may increase interference with suspension hardware. Stress-constrained topology optimization [14] and buckling-constrained optimization [13] suggest that the incorporation of realistic structural constraints directs material to smoother transitions, thicker compression zones, and braced load paths. The results go against the widely held belief that topology optimization primarily eliminates excess material. For trailer-platform applications, constrained optimization may move material from low-value areas to areas that are susceptible to fatigue in joints, rail cut-outs, deck-support points and axle-interface brackets.

There is also a lack of resolution in the literature on global versus local model fidelity. Global finite element models are suitable for platform-level bending, torsion, modal response and load-path screening, however, local mesh refinement and assumptions on detail behavior have to be used for weld toes, bolted brackets, cut-out edges and heat-affected zones. Aluminum joining research [4] demonstrates that heat input, distortion, residual stresses, and metallurgical softening affect the mechanical behavior of local joint regions. A well-designed platform that meets global stiffness and stress limits could still be vulnerable to road loading failure under repeated stresses if the representation of weld termination, bracket geometry and local deck discontinuity is suboptimal. Naturally, stress aggregation methods [14] make optimization more tractable, but there is no one unique stress index that can be used for local fatigue design. The more believable approach is then hierarchical: a global topology or sizing model determines the load paths, the finite

element submodels of the local areas determine the hotspot areas, and the constraints are adjusted adaptively according to the results for the next iterations.

Topology optimization for manufacturing has given rise to powerful tools, which are not yet fully developed in the case of aluminum trailer platforms. Trailer platforms are a combination of several fabrication processes in one assembly, while projection-based constraints [7] can model drawing, directions that are similar to extrusion, symmetry, or minimum size; examples of which are shown in Figure 1. Each of the different types of extruded components (long rails), formed cross-members, cut deck plates, welded brackets, bolted attachments, and machined local reinforcements dictates a set of rules. Studies that are oriented towards AM are important for their directionality as well, since trailer production also has direction-dependent accessibility constraints, but the physical meaning is different from that of the AM studies [8, 10, 11]. Direction may mean build orientation and/or avoidance of supports in AM, or it may mean extrusion length, weld-gun access, fixture withdrawal, drainage, inspection line-of-sight, or tool clearance in the context of trailer fabrication. The difference is significant, because if weld order, thermal distortion, and inspection access are overlooked, a design that meets the requirements of a directional filter may not be possible to put together.

Trailer platforms are especially interesting for shell-infill optimization since the decks and support grids are in coupled skin–rib structures. This deck is not only a payload surface, but it also distributes concentrated loads across the deck members and along the deck's longitudinal rails. Therefore, the following structural responses should be evaluated: deck-plate bending, local indentation, weld-line shear flow, and panel vibration. It is reported in the literature that a stiffer outer surface with an optimized inner support pattern may generate high stiffness-to-mass efficiency for a shell structure. However, typical limitations of trailer decks include wear resistance, anti-slip characteristics, easy repair, and damage caused by cargo contact, which are typically not addressed in shell-infill optimization. There is, therefore, a research gap in the field of optimization of decks in which surface durability and support-grid efficiency are treated together. The results of representative studies are presented in Table 3 in the context of the aluminum trailer platforms. Comparative results indicate that the most significant transferable evidence is in the areas of manufacturable feature control, buckling constraint effects, and directional feasibility. The evidence is more limited for full-platform validation, weld fatigue and production cost.

Table 3: Results comparison

Ref	System / Context	Metric / Basis of Comparison	Outcome
[1]	Vehicle concept structure	Static and crash load-path preference	Concurrent objectives changed topology relative to single-load stiffness layouts.
[5]	Density-based topology layouts	Minimum geometric feature size	Fine mesh artifacts were suppressed, supporting producible members.
[6]	Level-set optimized structures	Minimum and maximum thickness control	Thin or vanishing members were reduced through explicit thickness regulation.
[7]	Manufacturing-constrained topology cases	Projection-based feasibility rules	Multiple process constraints were embedded during optimization rather than after redesign.
[8]	Directionally constrained optimized parts	Support-free manufacturability	Directional filtering produced fabrication-aware topologies.
[9]	Shell-infill structural systems	Skin–infill stiffness efficiency	Coupled shell and internal support optimization improved lightweight structural layout.
[13]	Buckling-constrained topology cases	Stability-controlled optimum	Buckling requirements shifted material toward compression-resistant patterns.
[14]	Stress-constrained topology cases	Aggregated local stress control	Stress restrictions generated smoother, less concentrated load paths.

Figure 2 illustrates the literature reviewed in an evidence-distribution plot that demonstrates the level of support from the referenced journal studies for the technical requirements. The figure is significant because it reveals a focus on evidence in the areas of topology, manufacturability, and structural constraints as well as a lower density for evidence in the areas of trailer-specific fatigue, joining calibration, and production validation. A classification of cited peer-reviewed studies [1]–[14] that were coded by the author, with binary relevance scores for trailer-platform requirements.

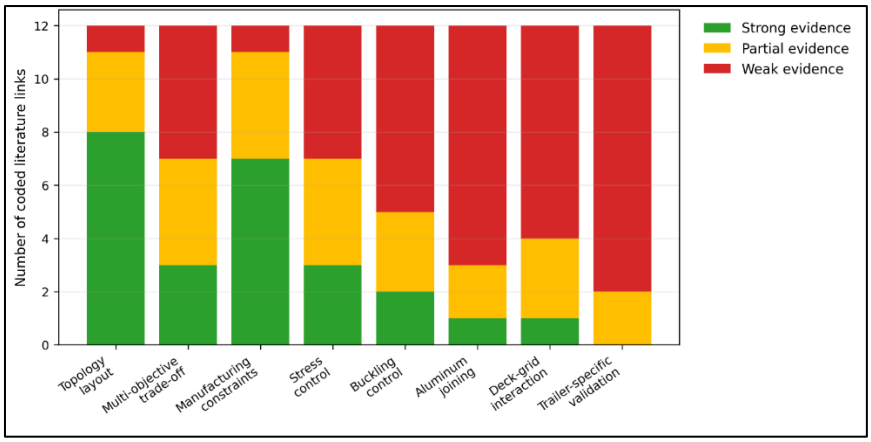


Figure 2: Evidence distribution across trailer-platform design requirements

The third finding relates to adaptivity. The methods listed above are generally closed-loop, computational optimizations, but the optimization of the design of a trailer-platform is an adaptive optimization process, in which the idealized constraints are revised following manufacturing assessment. This may include numerically optimized members that meet minimum length-scale requirements [5] which may be feasible members, but some members may be replaced by standard aluminum extrusions during production engineering. That substitution changes stiffness, weld positions, stresses, and costs. Similarly, buckling-constrained topology optimization [13] can suggest buckling-resistant designs, but in practice the buckling limits may be smaller due to buckling limitations from the welds or due to the curvature of the deck panels. It is therefore critical that adaptive finite element optimization can be used to reanalyze the structure following geometric rationalization, manufacturing substitution and prototype test correlation.

A fourth insight concerns the importance of joining. Çam and İpekoğlu [4] highlighted that the selection of joining methods has important consequences for the performance of aluminum structures. However, many optimization studies treat joints as idealized connections or model the joining material as homogeneous. For trailer platforms, this practice may be unreliable because welded 6xxx-series aluminum alloys can experience local strength reductions, and fatigue life may be governed by weld-toe geometry. Bolted or riveted joints can eliminate some welding-related thermal effects but introduce bearing, slip, sealing, and inspection considerations. The joints have to be treated, then, as design variables, or constraint regions, rather than as a part of the model if a serious optimization framework is to be developed.

The fifth finding is that the benefits of optimization are often context-specific. If the manufacturing processes, safety factors, fatigue life or service environment of the baseline designs are not equivalent, the optimal topology can result in a significant apparent mass reduction. Trailer platforms are subjected to different loading conditions, road surface irregularities, corrosion, impact of cargo, repair events and operator-induced overloading. Thus, the capabilities of an optimized platform should be assessed according to a robust performance envelope rather than a single deterministic finite element load case. Although there are some strong directions, stress control and buckling-aware layouts in the literature, no validated multi-objective framework specifically for aluminum trailer platforms has been identified. The integrative relational mapping given in Figure 3 is not a workflow diagram, but it is a diagram of the relations between the design variables of the trailer platform, the objective functions, the manufacturability constraints and the validation gates. It is important because it shows that in the same geometry, four different responses are influenced by the cross-member spacing, the deck gauge, the weld layout and the dimensioning of the cross-members' reinforcement, all of which are in competition with one another and therefore a multi-objective finite element optimization is necessary. This interpretation integrates the relationships between design variables and constraints discussed in the reviewed literature [1]–[14].

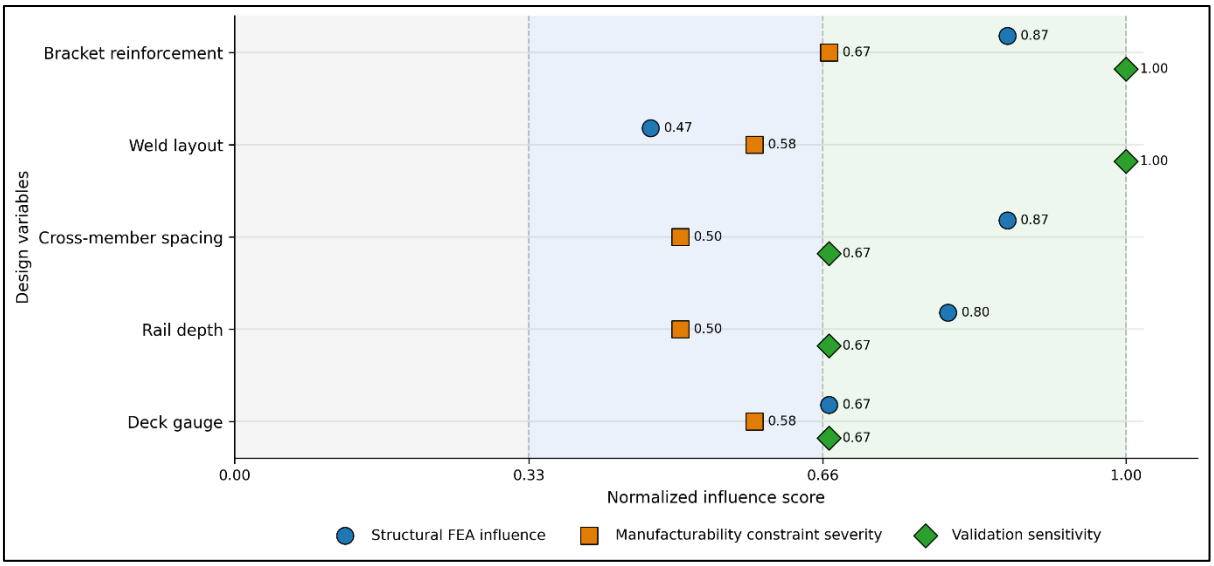


Figure 3: Dependency matrix for adaptive aluminium trailer-platform optimization

The practical implication of these findings is that adaptive lightweight trailer-platform design should not begin with a single optimization algorithm. It should begin with a constraint taxonomy tied to the actual product architecture. For an aluminum trailer platform, the taxonomy must separate global structural constraints, local fatigue constraints, geometric manufacturability rules, joint-process restrictions, and validation gates. Only after that taxonomy is defined can a multi-objective finite element workflow generate meaningful alternatives. Otherwise, optimization may simply produce visually efficient but commercially unusable structures.

4.1 Future Directions

Future research should develop benchmark trailer models with openly documented load cases and boundary conditions, aluminum material properties, weld-zone strength reductions, and manufacturability rules. Although some methodological studies of trailer platforms are available, there are no common benchmarks for both trailer-platform and mass, stiffness, fatigue, buckling and manufacturability results. A helpful reference on which such comparisons could be made is a flatbed or equipment-trailer platform having longitudinal rails, cross-members, a deck plate, axle brackets, coupling loads, and asymmetric road cases.

Second, manufacturability constraints must be tuned to the case of welded and extruded aluminum and not taken from the AM literature. The following constraints must be reformulated as requirements for directional filters [8, 10, 11] to be feasible: extrusion-axis feasibility, weld-gun access, fixture withdrawal, drain-path constraints, and inspection-line constraints. Process-based rules should include extrusion catalogue limits, minimum weld spacing, clearances at cuts and knockdowns at the heat-affected zone [7]. From the aluminum joining evidence [4] it can be concluded that optimization studies could be performed for the design variables of the weld process, the weld placement, and the four categories of joint details.

Fatigue and buckling checks should be incorporated directly into the optimization objectives and constraints rather than evaluated only during post-processing. Stress aggregation [14] and buckling-constrained approaches [13] can be used as foundations but improved modeling is needed for trailer-specific road-load spectra, overload events and deck-impact loads, as well as local weld geometry. Hierarchical global-local finite element workflows might be used to incorporate global optimization of the platform and local submodels at weld toes, bracket transitions, deck cut-outs and axle mounts.

Fourth, manufacturing feedback should be incorporated into adaptive surrogate modelling. Following topology interpretation or extrusion substitution, response surfaces s should be retrained with new results from finite element analyses, rather than retained unchanged from the idealized design domain. This will reduce what is often referred to as "the gap" between an optimized concept and a platform that can be produced. Finally, experimental correlation should include strain mapping, modal testing, deck deflection and weld distortion and accelerated fatigue loading to make the computational rules an effective design constraint rather than a nominal requirement.

5 CONCLUSION

A lightweight structural design framework for aluminum trailer platforms that is adaptive must address four key elements finite element fidelity, multi-objective decision logic, manufacturability constraints and validation feedback from the early design stage. A substantial body of literature supports topology optimization, minimum feature control, thickness control, Directional manufacturability, Stress constraints and Buckling control. However, a portion of the evidence is found in adjacent research areas and provides only limited direct evidence for the welded and extruded aluminum trailer platforms. Importantly, mass reduction alone is insufficient; it must all be complemented by stiffness, torsional response, fatigue resistance, local stability, joint feasibility, access for assembly and production cost.

A comprehensive platform-level solution is not yet available, which can convert optimized density fields to validated structures of trailers without any engineering interpretation. There are significant issues left to address with weld-aware optimization, extrusion-constrained geometry generation, modelling the interaction of decks, fatigue-spectrum integration and adaptive recalibration following manufacturing-related substitutions. The next step will rely on the use of benchmark trailer models, calibrated aluminum process constraints, hierarchical finite element validation and optimization procedures that incorporate manufacturability as a mathematical design condition and not a review item at the end of the design process. This approach could enable lightweight aluminum trailer platforms to be more reliable, more efficient and production-ready.

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