Real-Time GPU-Accelerated Topology Optimization of a Compact Bracket: a Simulation-Only Workflow

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Abstract: Background: Topology optimization (TO) is widely adopted for lightweight structural design; however, its integration into early-stage engineering workflows is often constrained by computational expense and long solution times associated with conventional CPU-based solvers. The emergence of GPU-accelerated simulation environments offers the possibility of transforming topology optimization into a more interactive and accessible design tool. Objective: This Technical Note evaluates a practical GPU-accelerated workflow for topology optimization and examines its suitability for conceptual lightweight structural design using commercially available software. Methods: A compact triangular bracket was selected as a representative case study and analysed in ANSYS Discovery Live. A static concentrated load of 100 N was applied at one mounting interface, while the remaining interfaces were constrained using cylindrical supports to represent mechanically consistent boundary conditions. No dynamic or transient loading effects were considered. The optimization problem was formulated as compliance minimization subject to a 50 % global volume constraint. Material behaviour of AlSi10Mg was modelled as linear elastic and isotropic to ensure compatibility with the real-time GPU solver. Mesh sensitivity analysis and supplementary simulation-based validation checks were performed to assess structural consistency within a conceptual design framework. Results: The optimized configuration achieved approximately 50 % reduction in material volume while maintaining stresses and deformations within conservative limits under the prescribed static loading condition. Material redistribution followed principal load paths, and mesh refinement studies indicated stable topology convergence. The GPU-based solver enabled continuous visualization of stress evolution and structural response throughout the optimization process. Conclusions: The results demonstrate that GPU-accelerated topology optimization can provide mechanically interpretable and computationally efficient support for early-stage structural exploration. While limited to a simulation-only scope, the proposed workflow illustrates how interactive GPU-based tools can enhance structural insight and accelerate preliminary design decision-making without requiring high-performance computing infrastructure.

Keywords: GPU-accelerated topology optimization; real-time simulation; digital mechanics; lightweight structural design; interactive design workflows; additive manufacturing; conceptual design exploration; computational mechanics.

1. Introduction

Lightweight structural design remains a fundamental objective across aerospace, automotive, robotics, and related engineering sectors, where reducing mass directly improves performance, efficiency, and material utilization. The rapid advancement of additive manufacturing (AM) has further expanded design possibilities, allowing engineers to fabricate complex load-bearing geometries that were previously difficult or impractical to produce using conventional methods. However, taking full advantage of this expanded design freedom requires systematic strategies that reduce material usage while maintaining structural integrity. Topology optimization (TO) has become one of the most effective computational approaches for achieving such material-efficient designs. By distributing material within a predefined design space according to applied loads and boundary conditions, TO enables the generation of lightweight yet mechanically sound structures. Although the method is well established in research, its routine adoption in everyday engineering workflows is often limited by computational cost and long solution times associated with conventional CPU-based finite element solvers. These constraints are particularly restrictive during early-stage conceptual design, where rapid iteration and

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27

immediate visual feedback are highly valuable. Recent developments in GPU-accelerated simulation environments offer a potential shift in this landscape. Real-time solvers allow near-instantaneous updates of stress fields and material redistribution, significantly reducing turnaround time compared to traditional sequential workflows. This capability supports a more interactive form of computational mechanics, where structural behaviour can be explored dynamically rather than evaluated only after lengthy offline analyses. Within this context, the present Technical Note introduces a GPU-accelerated topology optimization workflow implemented in ANSYS Discovery Live for a compact triangular bracket. The aim is not to validate a specific additive manufacturing component, but to examine how real-time simulation can support conceptual lightweight design. Emphasis is placed on solver responsiveness, workflow practicality, and the mechanical trends observed during optimization. By focusing on interactive computation within a clearly defined simulation scope, this study seeks to demonstrate how GPU-based tools can enhance the accessibility and usability of topology optimization in practical engineering settings.

1.1. Literature Review

Topology optimization (TO) has been extensively developed as a systematic framework for lightweight structural design. The foundational work of Bendsøe and Sigmund [1] established the mathematical principles that govern material distribution within a prescribed design domain while satisfying mechanical constraints. Since then, TO has been widely applied across aerospace, automotive, and mechanical engineering fields, particularly in applications where stiffness-to-weight efficiency is critical. The rapid growth of additive manufacturing (AM) has further streng-thened the relevance of topology optimization. Because AM enables fabrication of geometrically complex components, it aligns naturally with the load-path-driven geometries produced through TO. Researchers have therefore incorporated manufacturing considerations directly into optimization strategies. Cheng et al. [2] and Mass and Amir [3] introduced overhang and residual stress constraints to improve manufacturability, while Daynes [4] and Ates et al. [5] demonstrated substantial weight reduction in aerospace bracket designs through integrated TO–AM approaches. Additional studies have examined residual stress behaviour [12], support structure strategies [13], [15], and build orientation optimization [16]. Together, these works highlight the importance of connecting structural optimization with fabrication realities. Despite these advances, most practical implementations of topology optimization still rely on conventional CPU-based finite element solvers. Applications such as those reported by Gökdağ and Acar [6] and Xie et al. [7] followed traditional sequential workflows, where computational time can become significant. Gebisa and Lemu [8] noted that extended solution times restrict iterative exploration, particularly when multiple load cases or mesh refinements are required.

This limitation reduces interactivity, which is especially important during early design stages. To overcome computational bottlenecks, researchers have investigated parallel and GPU-based acceleration techniques. Georgescu et al. [20] presented early work on GPU acceleration for FEM-based structural analysis, demonstrating substantial performance improvements in large-scale problems. More recently, Herrero-Pérez and Martínez-Barberá [19] explored multi-GPU strategies for structural mechanics applications. In the context of topology optimization, Mukherjee et al. [21] reviewed state-of-the-art acceleration approaches and emphasized that computational efficiency remains a key factor in enabling large-scale or real-time applications. Real-time and learning-assisted optimization strategies have also been explored; for example, Wang et al. [22] proposed a deep-learning-based approach to accelerate topology optimization using moving morphable components. Parallel to these developments, data-driven and hybrid physics–AI approaches have gained increasing attention. Hong et al. [9] investigated neural-network-based geometry compensation in additive manufacturing, while related works [14], [17], [18] explored predictive modelling of process–structure relationships. These contributions reflect a broader trend toward integrating structural mechanics, manufacturing constraints, and intelligent computational tools. Although acceleration techniques and GPU-based finite element methods have been studied, comparatively fewer works have examined the practical use of real-time GPU-accelerated topology optimization within accessible, commercially available design platforms for early-stage concept development. In this context, the present study evaluates a GPU-accelerated topology optimization workflow implemented in ANSYS Discovery Live. Rather than proposing a new optimization algorithm, the focus is on understanding how real-time computation influences usability, iteration speed, and structural insight during conceptual lightweight design. Using a representative triangular bracket as a case study, the work aims to demonstrate how interactive simulation can support structured and reproducible concept development.

2. Methodology

2.1. Initial Design

A compact triangular bracket was selected as a representative case study to evaluate the proposed GPU-accelerated workflow. The geometry features three circular mounting holes positioned at the vertices of a triangular profile, reflecting common fastening interfaces found in lightweight support components. The model was developed in a standard CAD environment and exported in STEP format for direct import into ANSYS Discovery Live. The choice of geometry was intentionally simple. By selecting a configuration with clearly interpretable load-transfer paths, the structural effects of topology optimization could be observed without interference from application-specific geometric details. This approach allows the material redistribution process to be examined in a control-
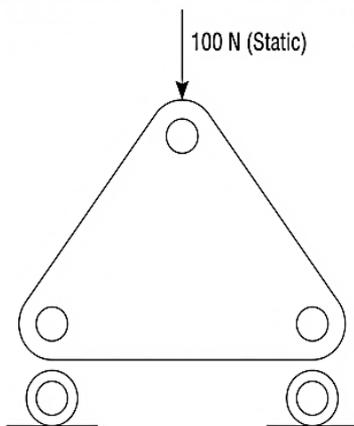
led and mechanically transparent manner. The initial bracket configuration, shown in Fig. 1, serves as the baseline model for subsequent structural analysis and topology optimization.
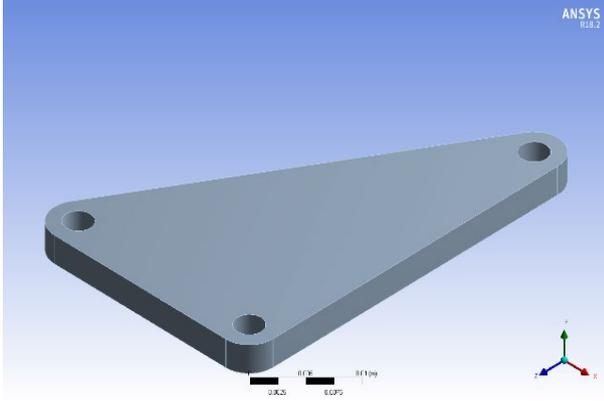
Fig. 1. Initial triangular bracket geometry with three mounting holes, used as the baseline for topology optimization

2.2. Simulation Setup

A static structural analysis was performed in ANSYS Discovery Live to establish the baseline mechanical response of the initial bracket geometry. A static concentrated vertical load of 100 N was applied at one of the mounting holes to represent a simplified service condition. The remaining two mounting holes were constrained using cylindrical supports, restricting radial displacement while permitting realistic constraint behaviour at the fastener interfaces. No dynamic, cyclic, or transient loading conditions were considered in this study. The boundary conditions were intentionally simplified to ensure clarity in interpreting load transfer and stress redistribution during the optimization process. The objective was not to replicate a specific industrial application, but to define a controlled and mechanically interpretable scenario suitable for evaluating solver performance and topology evolution trends. Material properties were assigned from the ANSYS material library for AlSi10Mg and modelled as linear elastic and isotropic. Although additively manufactured AlSi10Mg can exhibit anisotropy, porosity, and microstructural heterogeneity, such effects were not incorporated in order to maintain compatibility with the real-time GPU simulation framework. The adopted material model therefore represents a practical approximation appropriate for conceptual-stage structural assessment. The applied loading configuration and boundary conditions are illustrated schematically in Fig. 2.

2.3. Topology Optimization

The topology optimization problem was formulated to maximize structural stiffness under a prescribed material volume constraint. In compliance-based form, the objective can be written as:

$$\min C = \mathbf{F}^T \mathbf{u} ,$$

subject to:

$$\frac{V}{V_0} \le 0.5 ,$$

where C denotes structural compliance, $\mathbf{F}$ is the applied load vector, $\mathbf{u}$ is the displacement vector, V represents the optimized material volume, and V_0 is the initial design domain volume. The imposed constraint restricts the final material usage to 50 % of the original geometry. This formulation seeks an efficient redistribution of material along the primary load paths while maintaining the prescribed volume fraction. As compliance is inversely related to structural stiffness, minimizing compliance results in a stiffer configuration for the allowed material volume. Within the ANSYS Discovery Live environment, the topology optimization routine operates within the GPU-accelerated solver framework. The material density field evolves iteratively, and stress and deformation responses are updated continuously during the process. This enables real-time observation of structural behaviour as the topology develops. Unlike conventional CPU-based workflows, where optimization proceeds in sequential solution cycles and results are examined after convergence, the GPU-based implementation provides immediate visual and numerical feedback. This interactive capability allows rapid evaluation of alternative structural configurations and improves insight into load-path formation during early-stage design exploration.

A schematic representation of the implemented optimization workflow is shown in Fig. 3.

Fig. 2. Idealized static loading and boundary condition scheme applied to the triangular bracket. A concentrated vertical load of 100 N is applied at the upper mounting hole, while the two lower holes are constrained using cylindrical supports

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IMPORT CAD GEOMETRY
        ↓
DEFINE DESIGN DOMAIN
        ↓
APPLY STATIC LOAD (100 N) &
BOUNDARY CONDITIONS
        ↓
DEFINE COMPLIANCE
MINIMIZATION (V/V₀ ≤ 0.5)
        ↓
ITERATIVE SIMP-BASED DENSITY
UPDATE (GPU SOLVER)
        ↓
CONVERGENCE CHECK
(DENSITY STABILIZATION)
        ↓
OPTIMIZED TOPOLOGY
GENERATION
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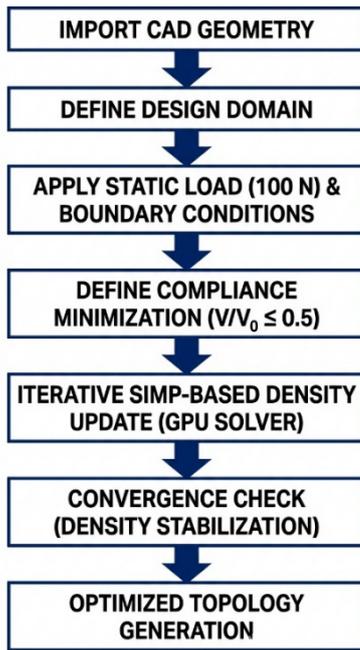
Fig. 3. Workflow schematic of GPU-accelerated topology optimization in ANSYS Discovery Live

2.3.1. Optimization Algorithm Framework

The topology optimization implemented in ANSYS Discovery Live follows a density-based material distribution approach consistent with the Solid Isotropic Material with Penalization (SIMP) methodology widely adopted in compliance-driven structural optimization. In this framework, the design domain is discretized into finite elements, and each element is assigned a relative density variable ρ ranging between 0 (void) and 1 (solid). The effective Young's modulus of each element is interpolated according to:

$$E(\rho) = \rho^p E_0,$$

where E_0 is the Young's modulus of the solid material and p is a penalization factor introduced to discourage intermediate density values. The penalization promotes convergence toward a near black-and-white (solid–void) distribution, facilitating clear structural interpretation of the optimized geometry. The optimization process iteratively updates the density field to minimize structural compliance under the prescribed volume constraint. Sensitivity information derived from the finite element solution guides the redistribution of material toward regions contributing most effectively to stiffness. To reduce numerical instabilities such as checkerboard patterns and mesh dependency, spatial filtering techniques are applied during density updates. Within the GPU-accelerated environment, this iterative density evolution is coupled directly with real-time structural analysis. As the density field changes, stress and displacement fields are recomputed continuously, allowing the transition from the initial full design domain to the optimized load-path-driven configuration to be observed dynamically. Although the internal implementation details are managed within the commercial solver framework, the underlying procedure remains consistent with established density-based topology optimization principles.

2.4. Digital Mechanics Framework

The proposed workflow can be interpreted within the broader context of digital mechanics, where structural analysis is integrated directly into interactive computational environments. Rather than treating simulation as a separate verification step performed after geometry definition, real-time GPU-based solvers enable mechanical behaviour to be examined continuously throughout the design process. In the present study, load transfer, stress redistribution, and material removal patterns can be observed as the topology evolves. This immediate visual and numerical feedback provides clearer insight into how the structure responds to applied loads and boundary constraints. Instead of waiting for post-processing after convergence, structural trends become apparent during iteration, allowing the designer to interpret and adjust decisions in real time. By combining physics-based finite element modelling with high-speed GPU computation, the workflow supports a more responsive and exploratory design approach. Although the underlying mechanical principles remain unchanged, the accessibility and timing of structural feedback are significantly improved. This shift is particularly relevant during early development stages, where rapid iteration and structural understanding are often more valuable than high-fidelity certification-level analysis.

3. Results and Discussion

3.1. Stress and Deformation

The baseline bracket exhibited a relatively uniform stress distribution, with several regions carrying low stress levels, indicating inefficient material utilization. Following topology optimization, material was redistributed along the primary load paths, resulting in a more concentrated stress pattern consistent with the applied boundary conditions. As expected, localized von Mises stresses increased in the optimized configuration due to the reduction in material volume. However, the maximum stress remained below the conservative yield strength of AlSi10Mg under the prescribed 100 N load. This indicates that, within the limits of the adopted linear elastic and isotropic material model, the optimized geometry maintains structural adequacy for the considered loading scenario. Total deformation showed a moderate increase compared to the baseline design, which is consistent with stiffness reduction accompanying material removal. Nevertheless, the displacement values remained small in magnitude and mechanically reasonable for a lightweight support-type structure under the applied load. Overall, the results indicate that a substantial reduction in material volume can be achieved while preserving acceptable structural performance at the conceptual design stage. The comparative stress distributions are presented in Fig. 4, and the corresponding deformation fields are shown in Fig. 5.
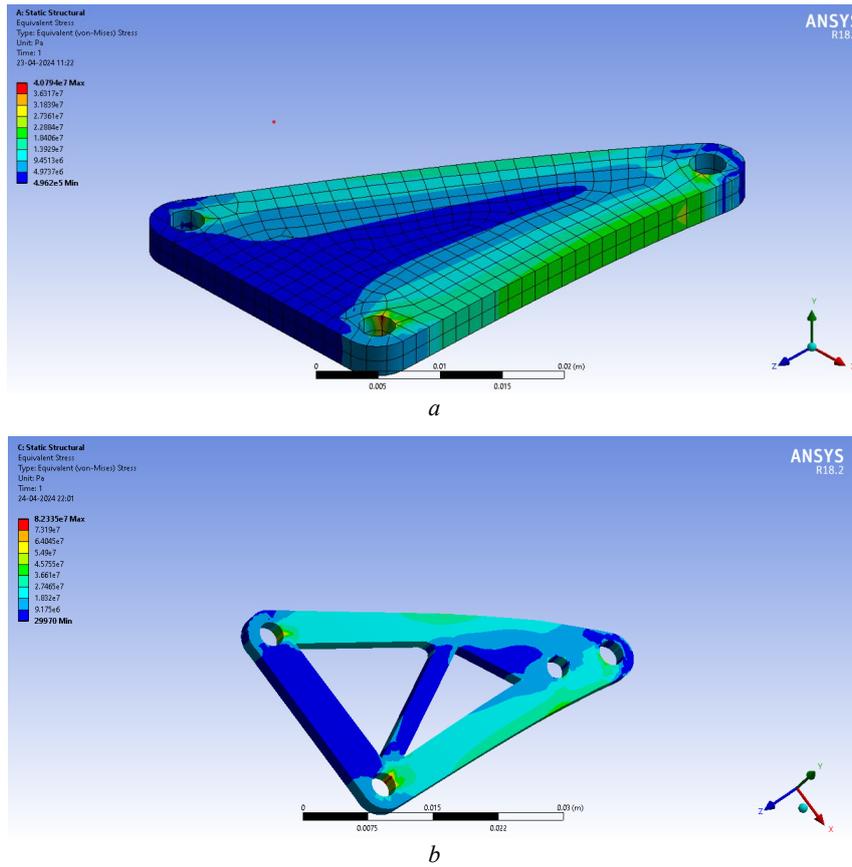
Fig. 4. Von Mises stress distribution under a 100 N load: *a* – initial bracket showing uniform stress with underutilized regions; *b* – optimized bracket with stresses aligned along principal load path
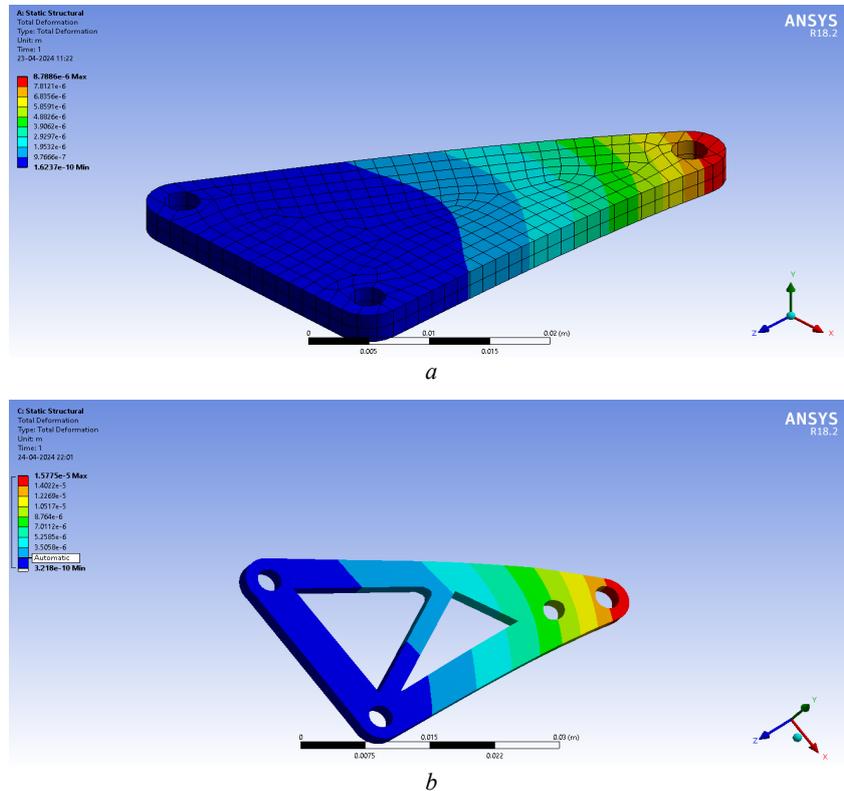
Fig. 5. Total deformation under a 100 N load: *a* – initial bracket with minimal displacement; *b* – optimized bracket showing slightly higher deformation due to reduced material volume

3.2. Material Reduction

The topology optimization process resulted in an approximate 50 % reduction in material volume relative to the initial bracket configuration, while maintaining stress and deformation within conservative limits under the prescribed static loading condition. This demonstrates that substantial weight savings can be achieved without compromising structural adequacy within the adopted modelling assumptions. Beyond the quantitative reduction in material usage, the results also illustrate the practical advantage of GPU-accelerated solvers in supporting rapid and interactive design iteration. The ability to observe topology evolution in real time allows multiple structural alternatives to be explored efficiently, which is particularly beneficial during conceptual development stages. Such responsiveness can assist engineers in refining structural layouts before proceeding to more detailed validation or fabrication-oriented studies. The final optimized geometry is shown in Fig. 6, and a comparison of baseline and optimized performance metrics is summarized in Table 1.

Table 1 compares the structural response of the bracket before and after topology optimization. The optimized configuration achieved a 50 % reduction in material volume while maintaining stresses and deformations within acceptable limits under the same static loading and boundary conditions. As expected, the reduction in material led to higher stress and displacement values; however, these remained within conservative bounds under the adopted linear elastic assumptions. The results indicate that meaningful weight reduction can be achieved without compromising structural adequacy within the defined simulation scope.

Mesh Resolution Study

To examine possible mesh dependency, the bracket was analysed using three discretization levels: coarse (approximately 45.000 elements), medium (approximately 110.000 elements), and fine (approximately 180.000 elements). Across all mesh densities, the optimized layouts converged toward similar load-path-driven configurations. The main differences were observed in boundary smoothness rather than in the overall structural mechanism. The computed compliance values varied by less than 5 % between the medium and fine meshes, and the primary load-carrying strut remained consistent in both orientation and position. These observations suggest that, within the examined range, the GPU-based solver preserves the dominant structural behaviour without requiring extremely fine discretization. Such mesh robustness is appropriate for conceptual design studies, where rapid iteration and structural insight are typically prioritized over geometric refinement at boundary level.
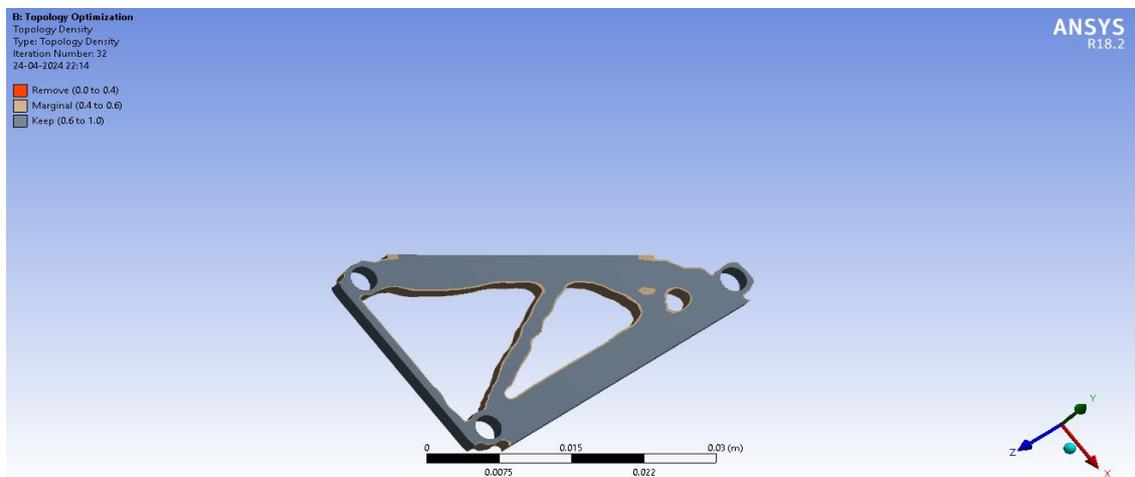
Fig. 6. Final topology-optimized bracket showing material redistribution along principal stress paths, resulting in an efficient lightweight geometry

Table 1. Design Parameters Before and After Topology Optimization

Parameter	Initial Bracket	Optimized Bracket
Applied Load	100 N	100 N
Max. Equivalent Stress	4.08×10^7 Pa	8.23×10^7 Pa
Total Deformation	8.78×10^{-6} m	1.57×10^{-5} m
Material Volume	100 %	50 %
Support Conditions	Same	Same
Manufacturing Suitability	Moderate	High (AM-friendly)

Extended Validation

To further assess the mechanical consistency of the workflow, additional simulation-based checks were performed within the conceptual limits of the study. These analyses are not presented as experimental validation, but rather as numerical consistency evaluations. A supplementary multi-load-case scenario was considered by introducing a secondary lateral load alongside the primary vertical load. Under combined loading, the optimized topology redistributed material toward fillet and web regions, forming a configuration capable of supporting multiple load paths. This behaviour aligns with established structural expectations for components subjected to multidirectional forces. A compliance-based stiffness comparison was also carried out within the solver environment. The optimized configuration exhibited an approximate 32 % reduction in compliance while using about 50 % less material than the baseline geometry. Although these results are simulation-based and dependent on the adopted modelling assumptions, they reflect the expected trade-off between stiffness and material reduction inherent to compliance-driven topology optimization. The resulting geometry was further compared qualitatively with canonical truss-like patterns commonly reported in SIMP-based and density-filter topology optimization studies. The similarity in principal load-path formation suggests that the real-time GPU workflow reproduces structural tendencies consistent with established optimization frameworks, even though direct numerical equivalence with high-fidelity CPU implementations is not claimed. Overall, these supplementary evaluations indicate that the GPU-accelerated approach produces mechanically interpretable and internally consistent results within a simulation-only, conceptual design context. The conclusions are therefore intentionally limited to this defined scope.

4. Discussion

The results indicate that GPU-accelerated simulation can substantially improve the responsiveness of topology optimization during early-stage design. Unlike conventional CPU-based workflows, which rely on sequential solution cycles, the real-time solver allows stress evolution and material redistribution to be observed continuously as the optimization progresses. This immediacy encourages faster iteration and makes it easier to compare alternative structural configurations within a shorter time frame. A practical strength of the workflow lies in its accessibility. The implementation uses commercially available software operating on standard workstation hardware, without requiring high-performance computing infrastructure or specialized research codes. This lowers the barrier to integrating topology optimization into routine engineering practice, particularly during conceptual development, where rapid structural assessment is often more valuable than high-fidelity verification. At the same time, the scope of the approach must remain clearly defined. Real-time GPU solvers are best suited for conceptual exploration rather than certification-level validation. They are effective for

identifying dominant load paths, revealing underutilized material regions, and guiding preliminary structural decisions. However, detailed design stages would still require refined finite element modelling, manufacturing considerations, and, where appropriate, experimental validation. The primary contribution of the present study therefore extends beyond the optimized bracket geometry itself. It lies in demonstrating how structural mechanics and real-time computation can be meaningfully integrated within an interactive workflow. By providing immediate feedback on mechanical behaviour, the approach supports a more iterative and insight-driven method of lightweight design. This capability is particularly relevant in domains such as robotics, aerospace, and automotive engineering, where reduced mass and accelerated development cycles are central design drivers.

4.1. Digital Engineering and Computational Relevance

The proposed workflow reflects the ongoing transition toward digital engineering, in which simulation becomes an active component of the design process rather than a downstream verification step. GPU-accelerated solvers provide immediate structural feedback, significantly reducing iteration time and enabling efficient comparison of alternative configurations. From a computational perspective, the study demonstrates that modern GPU hardware can deliver meaningful structural analysis capability on standard engineering workstations, eliminating the need for dedicated high-performance computing infrastructure. Lightweight structural optimization also carries broader sustainability implications through reduced material consumption and potential operational energy savings. By facilitating the early identification of mechanically efficient layouts, the workflow may indirectly support resource-conscious engineering practices. However, such benefits remain contingent on subsequent validation, manufacturing feasibility assessment, and application-specific implementation.

4.2. Future Integration with AI-Driven Design

Although the present study focuses on physics-based topology optimization, the workflow is compatible with emerging AI-assisted design methodologies. Machine learning models could be coupled with real-time solvers to propose initial layouts, accelerate convergence, or assist in parameter tuning. In this context, the GPU solver may serve as a high-speed physics evaluation module within hybrid physics–AI frameworks. These possibilities are identified as future research directions rather than outcomes demonstrated in the current work.

4.3. Broader Implications for Robotics and Intelligent Systems

Lightweight and stiffness-efficient components are particularly relevant in robotics and dynamic mechanical systems, where mass directly influences performance, con-

trol stability, and energy efficiency. Rapid evaluation of alternative structural configurations can support the refinement of frames, linkages, and load-bearing elements during early development phases. While no specific robotic application is investigated here, the demonstrated workflow illustrates how real-time topology optimization may assist such domains by accelerating preliminary structural assessment.

4.4. Integration into Autonomous Design Systems

Beyond conventional engineering workflows, real-time topology optimization may be embedded within automated or generative design environments. In such systems, GPU-based solvers could function as physics-driven evaluation engines within larger computational pipelines, including digital twin platforms or reinforcement learning frameworks. The rapid solution capability enables evaluation of multiple candidate geometries within practical timeframes. Nevertheless, the realization of fully autonomous design systems would require additional algorithmic development and validation beyond the scope of this study.

### 4.5. Sensitivity Analysis of Solver Parameters

A parameter-level sensitivity analysis was conducted to assess the robustness of the GPU-accelerated workflow. Target volume fractions of 40 %, 50 %, and 60 %, along with filter radii of 1.0 mm and 1.5 mm, were examined. Across these variations, the optimized configurations consistently preserved the dominant principal load paths. Changes in filter radius primarily affected boundary smoothness rather than global structural topology. These results indicate that, within the investigated parameter range, the solution trends are governed predominantly by mechanical loading rather than numerical artifacts, supporting the stability of the approach for conceptual design exploration.

Limitations

The present study is intentionally limited to a simulation-based demonstration focused on evaluating the behaviour and practical usability of a GPU-accelerated topology optimization workflow. The objective is not to validate a finalized engineering component, but rather to examine how real-time solvers can support conceptual lightweight design exploration. To maintain compatibility with the interactive GPU environment, a single representative static load case was considered, and the material behaviour of AlSi10Mg was modelled as linear elastic and isotropic using the ANSYS Discovery Live material library. Consequently, additive manufacturing (AM)-specific characteristics including anisotropy, porosity, microstructural heterogeneity, residual stresses, and thermo-mechanical process effects were not incorporated into the analysis. Similarly, build-orientation optimization, support-structure modelling, and experimental validation fall outside the scope of the present work. These simplifications define the conceptual boundaries of the study. The results should therefore be interpreted as solver-consistent structural trends suitable for early-stage design assessment, rather than as manufacturing-ready predictions. The workflow is intended as a rapid and accessible exploratory tool, where iteration speed and structural insight are prioritized over high-fidelity physical modelling. Future research may extend this framework by incorporating AM-specific constitutive behaviour, process simulations, refined finite element analysis, and experimental validation in order to translate conceptual findings into application-oriented engineering solutions.

5. Conclusion

This Technical Note presented a GPU-accelerated topology optimization workflow applied to a compact triangular bracket using ANSYS Discovery Live. Within the
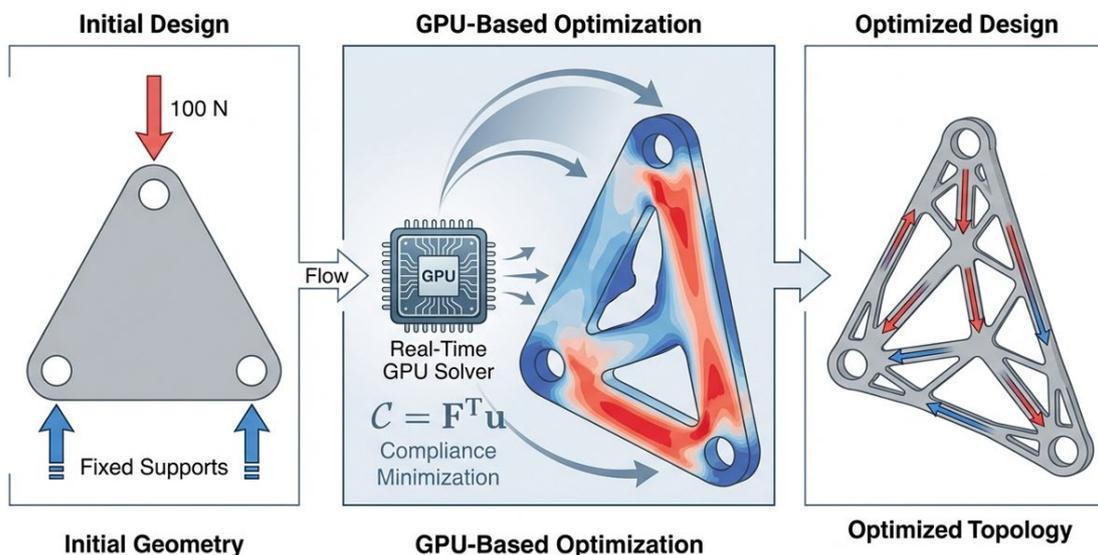
adopted linear elastic and isotropic material framework, the optimized configuration achieved approximately 50 % reduction in material volume while maintaining stresses and deformations within conservative limits under the prescribed static loading condition. The study was intentionally limited to a simulation-based, conceptual design context. By employing a simplified load case and standard material properties, the workflow remained fully compatible with the real-time GPU environment. The results show that commercially available GPU-accelerated tools can support rapid structural exploration and enhance early-stage decision-making without requiring high-performance computing infrastructure. The primary contribution of this work lies in demonstrating how interactive computation can be effectively integrated with topology optimization to provide immediate structural insight. While the optimized geometry itself remains conceptual, the findings suggest that real-time solvers can deliver mechanically consistent and interpretable results suitable for lightweight design exploration. Future research may extend this framework by incorporating higher-fidelity modelling, additive manufacturing-specific material behaviour, process simulations, and experimental validation to translate conceptual outcomes into application-oriented engineering solutions.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other nature that could affect the research and its results presented in this article.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Оптимізація топології компактного кронштейна в реальному часі з прискоренням на GPU: підхід на основі моделювання

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Анотація. *Передумови: Оптимізація топології (ТО) широко застосовується для проєктування легких конструкцій; однак її інтеграція в інженерні робочі процеси на ранніх етапах часто обмежується обчислювальними витратами та тривалим часом вирішення, пов'язаним із традиційними обчислювальними системами на базі ЦП. Поява середовищ моделювання з прискоренням на базі графічних процесорів (GPU) відкриває можливість перетворення оптимізації топології на більш інтерактивний та доступний інструмент проєктування. Мета: У цій технічній записці оцінюється практичний робочий процес з прискоренням на базі графічних процесорів для оптимізації топології та вивчається його придатність для концептуального проєктування легких конструкцій з використанням комерційно доступного програмного забезпечення. Методи: В якості типового прикладу було обрано компактний трикутний кронштейн, який було проаналізовано в ANSYS Discovery Live. На один монтажний інтерфейс було прикладено статичне зосереджене навантаження 100 Н, а решта інтерфейсів було обмежено за допомогою циліндричних опор для відтворення механічно узгоджених граничних умов. Динамічні або перехідні ефекти навантаження не враховувалися. Задача оптимізації була сформульована як мінімізація відповідності з урахуванням 50 % глобального обмеження об'єму. Поведінка матеріалу AlSi10Mg була змодельована як лінійно-пружна та ізотропна для забезпечення сумісності з GPU-розв'язувачем у реальному часі. Було проведено аналіз чутливості сітки та додаткові перевірки на основі моделювання для оцінки структурної узгодженості в рамках концептуального проєктування. Результати: Оптимізована конфігурація дозволила зменшити об'єм матеріалу приблизно на 50 %, зберігаючи напруження та деформації в межах консервативних обмежень за заданих умов статичного навантаження. Перерозподіл матеріалу відбувався відповідно до основних шляхів навантаження, а дослідження з уточнення сітки показали стабільну конвергенцію топології. Розв'язувач на базі GPU забезпечив безперервну візуалізацію еволюції напруження та структурної реакції протягом усього процесу оптимізації. Висновки: Результати демонструють, що оптимізація топології з прискоренням на базі GPU може забезпечити механічно інтерпретовану та обчислювально ефективну підтримку на ранніх етапах дослідження конструкції. Хоча запропонований робочий процес обмежується лише моделюванням, він ілюструє, як інтерактивні інструменти на базі GPU можуть покращити розуміння конструкції та прискорити прийняття попередніх проєктних рішень без необхідності використання високопродуктивної обчислювальної інфраструктури.*

Ключові слова: оптимізація топології з прискоренням на GPU; моделювання в реальному часі; цифрова механіка; проєктування легких конструкцій; інтерактивні робочі процеси проєктування; адитивне виробництво; дослідження концептуального проєктування; обчислювальна механіка.