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METHODOLOGY OF AUTOMOTIVE STRUCTURAL OPTIMIZATION IN INTEGRATED COMPUTER-AIDED DESIGN SYSTEMS

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Abstract. This article analyzes the methodology of structural optimization within integrated computer-aided design systems, specifically focusing on automotive applications. It explores size, shape, and topology optimization methods along with their integration with the finite element method (FEM). Special attention is given to the Solid Isotropic Material with Penalization (SIMP) algorithm, generative design, and additive manufacturing workflows. The study compares major engineering software packages and highlights how topology optimization combined with 3D printing yields substantial vehicle mass reduction and material savings. The findings demonstrate that modern computational tools allow automotive engineers to design lighter, stronger, and more resource-efficient chassis and body components.

Keywords: topology optimization, CAD/CAE systems, finite element method, SIMP algorithm, generative design, 3D printing, automotive industry.

1. Introduction

Modern industry, particularly the automotive sector, is characterized by a high-tech and rapidly evolving manufacturing environment. In the processes of product design and manufacturing, the time factor, economic efficiency, and structural reliability have become key criteria. While traditional design methods required multi-stage experimental testing cycles, contemporary integrated computer-aided design systems (CAD/CAM/CAE platforms) allow the processes of structural creation, analysis, and production preparation to be carried out within a single digital environment.

The methodology of structural optimization represents a critical component of these integrated systems. The optimization process is aimed at identifying the most optimal variant by modifying the geometric, mechanical, and technological parameters of a structure within specific constraints. Here, the primary objective is to ensure maximum strength and reliability with minimal material consumption and minimal mass.

The purpose of this article is to analyze the scientific and theoretical foundations of structural optimization in integrated computer-aided design systems, study existing methods and algorithms, and demonstrate their practical application.

2. Literature Review

Structural optimization has evolved significantly through various algorithmic approaches. Key methodologies established in literature include:

The general classification of structural optimization methods.
Mathematical modeling principles of topology optimization.
The Solid Isotropic Material with Penalization (SIMP) method.
Integration strategies involving the Finite Element Method (FEM).
Evolutionary algorithms applied to structural design.

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A review of contemporary research shows that topology optimization plays a vital role during the conceptual design phase, offering innovative solutions that are not visible through traditional engineering approaches. In automotive engineering, specialized frameworks are required to optimize high-performance chassis configurations, combining advanced algorithms with parallel computing to manage complex geometries.

3. Methodology

During the research, methods involving the study of theoretical foundations of structural optimization, systematic analysis of existing approaches, comparative evaluation, and practical modeling techniques were utilized.

The structural and algorithmic properties of size, shape, and topology optimization were mapped against computational tools. To evaluate software execution, a comparative matrix was established analyzing algorithms, CAD integration levels, and primary application domains across prominent industry suites including Siemens NX, SolidWorks Simulation, ANSYS, Altair OptiStruct, Tosca Structure, Abaqus ATOM, and Fusion 360. Furthermore, the mathematical behavior of the SIMP algorithm was assessed regarding its penalization coefficient (p) and sensitivity filtering parameters to establish guidelines for preventing checkerboard computational patterns.

4. Results and Discussion

As a result of the analysis conducted, specific characteristics of structural optimization methods were identified (Table 1).

Table 1. Comparative Analysis of Optimization Methods

Method	Application Phase	Design Variables	Advantages	Constraints
Sizing	Detailed Design	Thickness, cross-sectional area	Simple, rapid	Topology remains unchanged
Shape	Detailed Design	Boundary geometry	Reduces stress concentrations	Topology remains unchanged
Topology	Conceptual Design	Density distribution	Creates new topologies	Complex geometry generated

Characteristics of the SIMP Algorithm

In the SIMP method, when the penalization coefficient is $p=1$, an ambiguous solution with intermediate densities is obtained, whereas $p \geq 3$ ensures a distinct 0-1 (void-solid) solution. To prevent the "checkerboard" effect, the necessity of sensitivity filtering was confirmed. The best results are achieved when the filtering radius is selected to be 1.5–3 times larger than the element size.

Comparative Analysis of Software Tools

The results of the comparative analysis of software tools designed for topology optimization are presented in Table 2.

Table 2. Comparative Analysis of Optimization Software Tools

Software Tool	Algorithms	CAD Integration	Application Domain
Altair OptiStruct	SIMP, ESO, BESO	+++	Aerospace, Automotive
Tosca Structure	SIMP, Level-set	+++	Universal
ANSYS Topology Opt	SIMP	++	Universal
Abaqus ATOM	BESO	++	Mechanics

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SolidWorks Simulation	SIMP	+++	Mechanical Engineering
Fusion 360	SIMP, Generativ	+++	Universal

Note: +++ (Excellent), ++ (Good).

Integration with 3D Printing and Automotive Results

The integration of topology optimization and 3D printing technologies yields major benefits:

Mass Reduction: Optimizing automotive brackets can reduce mass by 30–50%.

Material Savings: In mass vehicle production, reducing a single component's weight by a few grams saves tons of raw material across the manufacturing lifecycle.



Figure 1. Topologically optimized and 3D printed car body

Chassis Engineering: Studies (e.g., Fenyes) show that combining steel and aluminum materials through optimized methods enables the creation of lightweight body structures weighing around 80 kg.

However, challenges remain. Complex geometries generated by optimization are difficult to manufacture using traditional methods, while 3D printing can incur high costs in certain scenarios. In automotive applications, optimization must simultaneously consider multiple loading conditions, as a structure optimized for only a single loading condition may fail under alternative operational forces.

5. Conclusions and Proposals

The integration of topology optimization and 3D printing technologies enables the creation of geometrically complex, lightweight, and high-strength automotive structures. Practical implementations demonstrate that structural mass reduction can reach 30–50%.

When selecting software tools, factors such as problem complexity, budget, and CAD integration must be evaluated. Altair OptiStruct is recommended for highly complex problems, while Fusion 360 serves as a versatile universal solution. For effective automotive structural optimization, it is critical to simultaneously account for multiple loading conditions and apply inertial relief techniques during simulation workflows.

References

1. Toscano, A. (2019). Topology Optimization and Design for Additive Manufacturing: the case study of a hydraulic module for automotive application (master's thesis). Politecnico di Torino, Master of Science in Mechanical Engineering, Torino.
2. Olason, A., & Tidman, D. (2010). Methodology for topology and shape optimization in the design process (master's thesis). Chalmers University of Technology, Göteborg.
3. Bendsøe, M. P., & Sigmund, O. (2004). Topology Optimization: Theory, Methods and Applications (2nd ed.). Springer-Verlag, Berlin; Heidelberg.

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http://houghtonstreetreview.com/index.php/hsr

4. Cavazzuti, M., Baldini, A., Bertocchi, E., Costi, D., Torricelli, E., & Moruzzi, P. (2011). High performance automotive chassis design: a topology optimization-based approach. Structural and Multidisciplinary Optimization, 44(1), 45–56. [https://doi.org/10.1007/s00158-01005787]
5. Eschenauer, H. A., & Olhoff, N. (2001). Topology optimization of continuum structures: a review. Applied Mechanics Reviews, 54(4), 331–390. [https://doi.org/10.1115/1.1388075] (https://www.google.com/search?q=https://doi.org/10.1115/1.1388075)
6. Fredricson, H. (2005). Structural topology optimisation: an application review. International Journal of Vehicle Design, 37(1), 67–80. [https://doi.org/10.1504/IJVD.2005.006089] (https://www.google.com/search?q=https://doi.org/10.1504/IJVD.2005.006089)
7. Huang, X., & Xie, Y.-M. (2010). A further review of ESO type methods for topology optimization. Structural and Multidisciplinary Optimization, 41(5), 671–683. [https://doi.org/10.1007/s00158-010-0487-9]
8. Leiva, J. P. (2011). Structural optimization methods and techniques to design efficient car bodies. Proceedings of the International Automotive Body Congress, Troy, MI, USA, 28, 41–54.
9. Petrucci, M. (2009). Structural optimization: an approach based on genetic algorithms and parallel computing (Doctoral thesis). University of Trento, Trento.