Quantum Algorithms for Lightweight Structural Design and Crash Energy Absorption Optimization

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***Abstract*—Lightweight structural design requires balancing conflicting objectives: minimizing mass while maximizing crashworthiness, energy absorption, and structural integrity. Conventional optimization techniques—such as gradient-based solvers, evolutionary algorithms, and surrogate modeling—often struggle with the nonlinear, multi-objective, and combinatorial nature of structural configurations, especially in applications like automotive chassis design, aerospace components, and protective systems. This study explores the use of quantum algorithms to accelerate and enhance the optimization of lightweight structures with respect to crash energy absorption. Leveraging quantum annealing, the Quantum Approximate Optimization Algorithm (QAOA), and hybrid quantum–classical variational methods, the framework maps topology, material distribution, and structural geometry to quantum-encoded optimization landscapes. Early simulation results indicate that quantum-enabled solvers can identify higher-performing structural designs and navigate the trade-off between stiffness and crash energy dissipation more efficiently than classical algorithms. These findings highlight the potential of quantum computing to revolutionize structural engineering workflows by delivering faster, more robust, and more scalable optimization for next-generation lightweight designs.**

The pursuit of lightweight structures with high crash energy absorption has become a central challenge in modern engineering, particularly in automotive, aerospace, and defense industries. Reducing structural mass directly contributes to improved fuel efficiency, lower emissions, and enhanced performance [8]. However, such reductions cannot compromise safety or durability. Engineers must therefore navigate a complex design space defined by non-linear material behavior, intricate geometry, multi-physics interactions, and strict safety constraints [5]. Traditional optimization tools—including finite element–based topology optimization, surrogate-assisted search, and heuristic algorithms—have achieved substantial progress. Yet, these methods often become computationally expensive or converge prematurely when solving large-scale, multi-objective structural optimization problems [6].

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The inherent complexity of crash energy absorption optimization arises from the coupling of dynamic deformation behaviors, material plasticity, and failure mechanisms under impact loading [3]. Simulating and optimizing these interactions require