APPLICATION OF QUANTUM ANNEALING TO STRUCTURAL DE-SIGN OPTIMIZATION

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ABSTRACT

1. Problem description and relevance

We present a novel approach to structural design optimization (SDO), which profits from quantum annealing's (QA) capabilities in efficiently exploring complex design spaces [1]. Depending on the choice of design variables, it can be used for different types of optimization, including topology, shape, size, or material optimization. SDO is a crucial area of numerical design optimization with applications in many fields such as aerospace, automotive, and civil engineering, and is thus of great relevance. In particular, we show that plain QA can solve a size optimization problem for a 1D rod on today's hardware. Additionally, we discuss practical challenges in this context and present the strategies we developed in response.

2. Methodology

Our methodology for applying QA to SDO is twofold: First, we use a novel way of formulating SDO problems to make them amenable to powerful optimization techniques like QA. In particular, we propose to use minimum energy principles of structural mechanics and combine them with the design optimization problem to state one overall minimization problem. The solution to this problem yields both the state and the optimal design of a structure. This contrasts existing methods that rely on evaluating an analysis model, such as the finite element model, and cannot profit from innovative optimization approaches. Second, we provide the SDO problems in QUBO form suitable for an efficient solution via QA and use them to generate optimal designs quickly.

3. Practical demonstration

To demonstrate that the proposed methodology works in practice, we consider the size optimization of a 1D rod composed of multiple components (see Fig. 1). In particular, we minimize the compliance of the structure while allowing different cross-sectional areas for each rod component. In this case, we use the analytic solution to the problem to validate our approach. We note that we are able to obtain reproducible results when using the QA hardware that is available today. In addition, we show that the strategies developed as a remedy for practical issues can increase the solution quality.
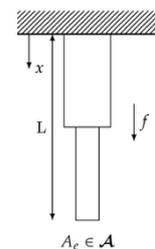
Figure 1

4. Application potential

Concerning the question of scalability, there are different directions that have the potential to allow for the solution of problems of increased size. First, the approach would profit from QA hardware architectures supporting higher-order terms in the objective function for minimization. Furthermore, hybrid strategies can be based on combining QA with local search strategies or the concept of a bi-level optimization, i.e., decomposing the combined optimization problem into hierarchical optimization problems. Here, the design optimization task and the structural analysis problem are the upper-level and lower-level problems solved with QA and classical methods, respectively.

REFERENCES

[1] Key, F., & Freinberger, L. (2024). A Formulation of Structural Design Optimization Problems for Quantum Annealing. Mathematics, 12(3), 482. https://doi.org/10.3390/math12030482

Preference for

(x) oral presentation

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