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Review

of the doctoral dissertation by M.Sc. Eng. Nikhil Tatke entitled "A Computational Intelligence Framework for PDE-Constrained Topology Optimization"

The review was prepared at the request of Dr. Hab. Eng. Alicja Piasecka-Belkhayat, Chair of the Discipline Council of Mechanical Engineering at the Silesian University of Technology, dated April 23, 2026. The supervisor of the reviewed doctoral dissertation is Dr. Hab. Eng. Jarosław Kaczmarczyk.

1. Characteristics of the Dissertation

Design engineers strive to utilize materials as efficiently as possible in order to obtain structures with the best achievable properties. Various optimization methods, employing different criteria and constraints, are used for this purpose. Appropriate computational algorithms are required to perform optimization calculations. Topology optimization aims to determine the optimal distribution of material within a prescribed design domain while satisfying equilibrium equations and specified functional criteria. A significant computational burden in such analyses arises from the necessity of repeatedly solving large systems of equations using the finite element method during each design iteration. Computational costs increase substantially for engineering-scale resolutions and especially in three-dimensional analyses, limiting the practical applicability of high-resolution topology optimization in design-space exploration. With the growing capabilities of modern computing systems and the continuous development of optimization methods, this field has recently received increased attention as a means of reducing material usage while maintaining high-performance characteristics, thereby facilitating its application in engineering structures. The dissertation presents a multifidelity approach to compliance-minimizing topology optimization under a global volume constraint within the framework of linear elasticity theory, incorporating verification during the optimization process. Consequently, the dissertation entitled "A Computational Intelligence Framework for PDE-Constrained Topology Optimization" is highly relevant to current research trends. The dissertation has been carefully prepared. It consists of six numbered chapters, abstracts in English and Polish, lists of figures, tables, abbreviations and symbols preceding the main text, a bibliography, and four appendices. The Polish title of the dissertation is not distinguished in the abstracts. Furthermore, the list of symbols and notations is not arranged alphabetically, which would be the preferred format. The bibliography contains 134 cited references, including one co-authored publication by the doctoral candidate. The first chapter, entitled "Introduction," consists of seven clearly structured subsections covering the problem background, motivation, research objectives, research questions, the author's contributions, and a brief overview of the dissertation structure. The literature review is presented subsequently and divided into five subsections, each further organized into individual points. These subsections address the fundamentals of topology optimization, applications of machine learning in topology optimization, verification and reproducibility in topology optimization, and finally identify research gaps in the existing literature relevant to the dissertation topic. Chapter 3 provides a detailed description of the research methodology, including problem formulation, finite element methods, regularization techniques, optimization procedures, and multifidelity integration within the U-Net architecture. Chapter 4 presents the results of computational investigations, including benchmark problems, discretization approaches, and dataset generation. Both two-dimensional and three-dimensional studies are described, together with statistical reporting procedures. Chapter 5 presents the computational results and their discussion. Sections 5.1 and 5.3 address two-dimensional problems, while Sections 5.2 and 5.4 focus on three-dimensional cases. Cross-case synthesis, practical recommendations, and limitations are also discussed. The final Chapter 6 presents conclusions and future research directions. Although this chapter is relatively detailed, it lacks a concise list of final conclusions directly related to the stated objectives. Such a summary would improve clarity. Nevertheless, the inclusion of future research tasks is commendable, as it leaves the work open to further development.

2. Assessment with Respect to Statutory Requirements

2.1 Assessment of General Theoretical Knowledge

The literature review presented in Chapter 2 demonstrates the candidate's extensive knowledge of the state of the art and existing solutions in structural optimization for engineering applications. The review is comprehensive and reflects a thorough understanding of a relatively new but rapidly developing research field. The significance and importance of machine learning methods have been clearly demonstrated.

2.2 Assessment of the Ability to Conduct Independent Scientific Research

The doctoral candidate demonstrated independence in developing the methodology, conducting calculations and analyses, and presenting the obtained results. Based on these activities, the author was able to perform an appropriate analysis and discussion and provide a sound summary of the work.

2.3 Assessment of the Originality of the Scientific Contribution

The achievements presented, particularly in Chapters 4 and 5, demonstrate the scientific contribution, innovativeness, and relevance of the dissertation topic. The candidate successfully addressed the problem of topology optimization by developing a framework that accelerates computational processes while maintaining high-quality, reliable final solutions. The method is based on using coarse meshes for the majority of optimization iterations and periodically verifying results on a fine mesh. This enables a substantial reduction in computational time without significant deterioration of structural performance. Additionally, the framework integrates a U-Net neural network architecture. Its role is not to replace classical optimization methods but to generate improved initial solutions. The network predicts more organized material distributions, potentially accelerating convergence toward optimal designs. All U-Net predictions are subjected to the same verification procedure as solutions generated by traditional methods, ensuring that the reliability of the overall process remains preserved regardless of prediction quality. Four methodological variants were compared: M1 – classical optimization on a fine mesh, serving as the reference solution; M2 – optimization using only a coarse mesh without verification, providing the highest speed-up but resulting in significant quality degradation; M3 – the basic multifidelity framework incorporating acceptance and verification mechanisms; M4 – an extension of M3 incorporating U-Net-based initialization. Experimental results demonstrate that M3 and M4 offer the best compromise between computational efficiency and solution quality, enabling the safe use of simplified models and machine learning techniques in topology optimization. Despite my highly positive assessment of the dissertation and the candidate's achievements, several concerns are discussed in the following section.

3. Detailed Comments and Questions

Some remarks have already been mentioned above. Additional observations include:

- The scope of the work is presented in Section 1.7. However, research objectives and scientific questions are introduced earlier. These elements should ideally follow the literature review and arise naturally from identified research gaps. It should be demonstrated that existing literature lacks the proposed solutions or that current solutions remain insufficient.
- The notation involving brackets is used inconsistently throughout the dissertation, making interpretation difficult. For example, on pages 96, 151, and 281, the notation [...] appears. This typically denotes a set rather than an interval. If an interval is intended, (...) or <...> should be used depending on endpoint inclusion. Similar ambiguities appear on pages 46, 48, 49, 50, and 61, as well as in Table 4.1 and related values on page 57.
- The vector multiplication symbol "×" is frequently used where ordinary multiplication is intended. Examples occur on pages 29, 30, 32, 37, 38, 44, and 45, where the number of elements N does not result from vector multiplication. Its use on page 34 is particularly unclear. An even more inappropriate application appears on pages 486 and 625, where the notation should instead be written as $5 \cdot 10^{-4}$. In Chapter 5, the symbol "×" often appears where the word times would eliminate ambiguity.
- The terms Chapter and Section are used inconsistently. A single hierarchical system should be adopted throughout the dissertation, such as Chapter – Subchapter – Point or Section – Subsection – Point.
- On page 35, an ellipsis (...) follows references [51,127]. Its intended meaning is unclear.

Although these comments concern mathematical notation, mathematics constitutes the foundation of the computational methods employed. Therefore, notation should be precise and unambiguous.

4. General Remarks and Conclusions

The dissertation demonstrates a very strong understanding of the research problem in structural optimization. In particular, the candidate successfully applied acquired knowledge and experience to optimization analysis incorporating machine learning methods. The relatively few comments raised in this review may serve as useful guidance for the candidate's future research and publication activities. Most of them should be regarded as questions and suggestions rather than direct criticism. In future work, greater attention should be paid to mathematical notation and presentation. The most significant scientific achievements of the dissertation include:

- **Development of a verified Multifidelity Framework** - A novel topology optimization approach combining fast computations on coarse meshes with periodic verification on fine meshes, balancing computational efficiency and solution quality.
- **Introduction of an acceptance/rejection and rollback mechanism** - An effective safeguard against solution degradation, ensuring that any solution generated by a simplified model is verified and automatically reverted if quality criteria are not met.
- **Significant computational acceleration while maintaining solution quality** - For two-dimensional problems, computational speed-ups of approximately 2.1–2.3 times were achieved relative to classical optimization, while maintaining compliance differences below 1%.
- **Safe integration of artificial intelligence into topology optimization** - Demonstration that a U-Net network can generate improved starting points without compromising process reliability, since all predictions undergo the same verification procedure as classical solutions.
- **Comprehensive validation on a broad range of test cases** - A total of 142 experiments covering two-dimensional and three-dimensional problems as well as parameter sensitivity studies confirmed the effectiveness, reliability, and robustness of the developed framework.

The dissertation can be positively assessed in terms of theoretical knowledge, independent scientific research skills, and the originality of the proposed solution. Moreover, the work is interdisciplinary and could be associated with multiple scientific disciplines, including Mechanical Engineering, Technical Computer Science, and Mathematics. Since computational and mathematical aspects primarily serve as tools supporting engineering investigations, the dissertation is most appropriately classified within the discipline of Mechanical Engineering. Certain mathematical inconsistencies somewhat reduce the quality of the work by introducing uncertainty in interpretation.

5. Final Recommendation

Based on the overall evaluation of the doctoral dissertation, I conclude that it satisfies, to a sufficient degree, the requirements specified in the Act on Higher Education and Science of July 20, 2018, as amended, and therefore I recommend that the dissertation by M.Sc. Eng. Nikhil Tatke, entitled: "A Computational Intelligence Framework for PDE-Constrained

Topology Optimization" be admitted to public defense at the Silesian University of Technology within the discipline of Mechanical Engineering.

Yours sincerely,

Prof. Tadeusz Łagoda