RDJMe. 512.1.2026

Damian Derlukiewicz, PhD, MEng, Associate Professor
Wrocław University of Science and Technology
Faculty of Mechanical Engineering

REVIEW

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

This review was prepared pursuant to the resolution of the Council of the Mechanical Engineering Discipline at the Silesian University of Technology of 22 April 2026 concerning the appointment of reviewers in the doctoral proceedings of Mr Nikhil Tatke, MSc Eng.

The subject of this review is the doctoral dissertation by Mr Nikhil Tatke, MSc Eng., entitled *"A Computational Intelligence Framework for PDE-Constrained Topology Optimization"*, prepared at the Silesian University of Technology, Faculty of Mechanical Engineering, Department of Theoretical and Applied Mechanics.

The dissertation was supervised by Jarosław Kaczmarczyk, DSc, PhD, Eng., Professor at the Silesian University of Technology. The dissertation was prepared in the field of engineering and technical sciences, in the discipline of mechanical engineering. The dissertation is written in English.

1. General overview of the dissertation topic

The dissertation addresses structural topology optimization, with particular emphasis on reducing the computational cost of this class of analyses. In density-based methods such as Solid Isotropic Material with Penalization (SIMP), the optimization process requires repeated finite element analyses in successive iterations. As model resolution increases, particularly for three-dimensional problems, this leads to a substantial increase in computational time and cost.

The problem addressed by the Author is therefore important both from the standpoint of computational mechanics and from the perspective of the practical use of optimization methods in structural design.

The Author proposes an approach based on models at two fidelity levels. The main part of the optimization process is performed on a coarse mesh, which is computationally less expensive, while the resulting solutions are periodically assessed using the fine model. The key element of the proposed approach is the Multifidelity Acceptance Safeguard (MFAS), which evaluates solutions generated at the lower-fidelity level and accepts or rejects them based on results obtained on the fine mesh. The purpose of this mechanism is to limit the effect of errors introduced by model simplification and to retain control over the quality of the final solution.

The proposed method is complemented by a U-Net neural network used as an optional initialization mechanism for the optimization process. An important feature of this approach is that the machine-learning-generated solution does not replace physics-based computations; instead, it provides a starting point that is subsequently evaluated within the MFAS procedure.

In my view, the topic is highly relevant and well justified. Contemporary computational methods increasingly combine models of different fidelity with machine learning tools to reduce analysis time. At the same time, maintaining adequate control over solution quality remains essential. The dissertation follows this research direction by combining computational efficiency with runtime verification of the results. In my opinion, this represents a valuable and interesting direction for the development of topology optimization methods.

2. Structure of the dissertation and overview of its content

The dissertation is 156 pages long and is written in English. It comprises six main chapters (pages 1–105), a bibliography containing 134 references (pages 106–118), abstracts in English and Polish, lists of figures, tables, abbreviations and symbols, and Appendices A–D containing implementation excerpts and supplementary results. The structure of the dissertation is clear and logical, and the sequence of chapters follows the research process: from formulation of the problem, through the literature review and development of the method, to numerical experiments, analysis of the results and formulation of conclusions.

In Chapter 1, the Author presents the subject of the dissertation, the motivation for undertaking the research, the scientific problem, the objectives, research questions, the stated scientific contribution and the scope of the study. Four research objectives are formulated: achieving computational acceleration while maintaining control over solution quality; assessing the effectiveness of the solution acceptance and rejection mechanism; examining the robustness of the proposed method across different computational cases; and evaluating the effect of machine-learning-assisted initialization. The Author does not include a separate section containing a formally stated research thesis. Its substance, however, follows clearly from the structure of the dissertation, the objectives and the research questions. The central thesis is that topology optimization can be accelerated in a reliable manner when acceleration is coupled with runtime verification of candidate solutions using a higher-fidelity model within the computational loop.

Chapter 2 provides a literature review on structural topology optimization. The Author discusses the fundamentals of the SIMP method, filtering and regularization, methods based on models of different fidelity, trust-region approaches, and the application of machine learning to topology optimization. An important part of the chapter is Section 2.5, in which the Author identifies three main research gaps that justify the development of the proposed method: the lack of systematic acceptance mechanisms in multifidelity approaches, the lack of runtime verification when machine learning methods are integrated into the optimization process, and the limited validation covering both 2D and 3D problems. This chapter provides a sound justification for the research problem addressed and indicates the grounds for the originality of the proposed approach.

Chapter 3 constitutes the main methodological part of the dissertation. The Author formulates the optimization problem, presents the finite element model, the SIMP method, the filtering procedure and the design-variable update scheme. The proposed Multifidelity Acceptance Safeguard (MFAS) is then introduced, using two fidelity levels and periodic assessment of solutions obtained on the coarse mesh. The chapter also describes the use of the U-Net network and defines four computational variants: M1 as the reference variant based on the fine mesh, M2 as the coarse-model variant, M3 as the core MFAS variant, and M4 as MFAS assisted by U-Net-based initialization.

Chapter 4 describes the numerical study. The Author uses three two-dimensional and two three-dimensional benchmark problems to compare the four method variants defined earlier. The chapter presents the model parameters, the preparation of data used by the U-Net network, the experimental procedure, and the adopted evaluation criteria. The research program covers a broad range of main experiments and ablation studies carried out for different method variants and computational configurations, amounting to more than 140 computational runs in total. This scope allows both comparison of the individual variants and assessment of the influence of the main parameters of the proposed solution.

Chapter 5 presents and analyzes the results. For the two-dimensional problems, variants M3 and M4 provide a substantial reduction in computational time while maintaining solution quality close to that of the reference variant M1. Variant M2, which relies primarily on computations performed on the coarse mesh, produces a greater speedup, but at the cost of a clear deterioration in compliance. This comparison clearly demonstrates the importance of the runtime quality-control mechanism introduced by the Author. For the three-dimensional analyses, the results are more varied and depend on the geometry considered. For one of the cases, the proposed method reduces computational time while maintaining solution quality close to the reference solution, whereas for the L-bracket the baseline M3 variant is slower than M1. The Author also reports these less favorable results and incorporates them into the subsequent discussion of the method's limitations. This should be viewed positively, as it allows the range of effectiveness of the proposed approach to be assessed more objectively.

Chapter 6 summarizes the research and the results obtained. The Author addresses the four research questions formulated earlier, presents the main conclusions, identifies the limitations of the proposed method and outlines directions for future work. The conclusions are formulated with due regard to the scope of the study and address both the strengths and limitations of the proposed approach. The Author also identifies opportunities for further development, in particular through broader three-dimensional studies, improved selection of verification parameters, and further use of machine learning methods.

The bibliography contains 134 references relevant to the subject of the dissertation.

Appendices A–D provide a valuable supplement to the dissertation, as they contain implementation excerpts and additional computational results, allowing the research procedure to be followed in greater detail.

3. Originality of the dissertation

The dissertation contains a clear and valuable original scientific contribution. Its originality does not lie in the use of the SIMP method, the finite element method, meshes of different resolution, or a U-Net network as such, but rather in the way these elements are integrated into a coherent computational procedure aimed at reducing computational cost while retaining control over solution quality.

The development and application of the Multifidelity Acceptance Safeguard (MFAS) should be regarded as the principal original contribution. Its key feature is the periodic evaluation, using the fine model, of solutions obtained on the coarse mesh, followed by their acceptance or rejection. As a result, the computational acceleration is not achieved solely by using a lower-fidelity model, but is coupled with runtime control of the quality of the resulting solution.

Another valuable aspect of the dissertation is the way machine learning is used. The U-Net network plays a supporting role by providing an initialization for the optimization process, while the resulting solution is subsequently verified within the MFAS procedure. This makes it possible to benefit from machine learning without giving up control based on the physics-based model.

The originality and scientific value of the work are further strengthened by the broad comparative study covering the reference variant, the coarse-model variant, the core MFAS mechanism, and MFAS assisted by the U-Net network. The analyses include both two- and three-dimensional problems, and the main experiments are complemented by ablation studies. This makes it possible to assess both the effect of the proposed safeguard mechanism and the influence of the main method parameters.

The dissertation is not limited to presenting a single favorable example; it also shows when the proposed method performs well, when its advantage is limited, and which factors determine the trade-off between computational time and solution quality.

The proposed solution represents an original approach to accelerating computations in topology optimization and makes a valuable contribution to the development of methods that combine models of different fidelity with machine learning in engineering applications.

4. Assessment of the dissertation

From both the scientific and methodological perspectives, I rate the dissertation highly. The Author addresses a research problem that is highly relevant to current developments in topology optimization, combining computational mechanics, numerical methods and machine learning. The work demonstrates the ability to progress from formulation of the scientific problem, through development of an original computational procedure and design of the research program, to analysis and critical assessment of the results obtained.

The objectives formulated by the Author have been achieved to a substantial extent, and the results support the adopted research concept. Particularly valuable are the results for the two-dimensional problems, where MFAS reduces computational cost while maintaining solution quality close to that of the reference variant. At the same time, comparison with the coarse-model-only variant demonstrates the importance of the proposed quality-control mechanism. The three-dimensional results, in turn, show that the runtime efficiency of the method depends on the geometry and the adopted verification parameters, which the Author acknowledges in the discussion and in the stated limitations of the dissertation.

The following achievements of the dissertation deserve particular emphasis:

1. development of the Multifidelity Acceptance Safeguard (MFAS), combining computations on a coarse model with periodic assessment of solutions using a higher-fidelity model and an acceptance/rejection mechanism;
2. clear separation of the reference variant, the coarse-model variant, and the variants governed by the verification mechanism, enabling the contribution of individual components of the proposed method to be assessed;
3. integration of the U-Net network as a component supporting initialization of the optimization process, while retaining subsequent control of the solution using the physics-based model;
4. a broad comparative research program covering two- and three-dimensional problems, with the main experiments complemented by ablation studies;
5. demonstration of substantial computational speedup for the analyzed 2D problems while maintaining solution quality close to that of the reference method;
6. critical presentation of the results and limitations of the proposed approach, particularly regarding the three-dimensional cases and the use of the machine learning component.

The interpretation of the results is also a strength of the dissertation. The Author does not present either the proposed method or the use of machine learning as a universal solution, but discusses both the benefits obtained and the cases in which the method is less efficient. This approach strengthens the credibility of the research and demonstrates an appropriate critical assessment of the results.

Taken together, the scope of the work, the originality of the MFAS concept, the design and execution of the research program, and the quality of its documentation make this a valuable doctoral dissertation with a significant scientific contribution. The Author has demonstrated the ability to solve the stated research problem independently, and the results provide a sound basis for further development of the proposed method and its application to more complex structural optimization problems.

5. Critical comments on the substantive content

The following comments are intended as points for discussion and clarification and do not detract from my overall high assessment of the dissertation. They relate primarily to the scope of the study, the interpretation of the results, and possible directions for further development of the proposed method.

1. The scope of the study is limited to compliance minimization under linear elasticity with a global volume constraint. This assumption is justified in view of the objective of the dissertation, but it means that the conclusions apply primarily to the class of problems analyzed. An interesting direction for further research would be to extend the method to problems involving other design criteria, multiple load cases, or manufacturing constraints.
2. The results obtained for the three-dimensional problems are more varied than those for the 2D cases. In particular, the runtime efficiency of variant M3 depends on the geometry considered and on the adopted verification parameters. For the L-bracket, under the baseline settings, M3 was slower than the reference solution, whereas a speedup was obtained for the other 3D benchmark. This indicates that the computational efficiency of the proposed method in three-dimensional problems depends on the characteristics of the problem under consideration. A point that merits discussion is therefore the identification of the factors that have the greatest influence on the runtime efficiency of MFAS in three-dimensional problems and the possibilities for reducing this dependence on geometry.
3. The MFAS acceptance criterion is based on compliance evaluated on the fine mesh. This is appropriate for the problem formulation adopted in the dissertation. If the method were extended to other classes of problems, however, the acceptance criterion would need to be supplemented with additional quantities, such as stresses or manufacturing constraints.
4. In answering research question RQ3, the Author refers to consistent speedup across all analyzed problems. This statement is not fully consistent with the reported results, since for the L-bracket problem the M3 variant gives a speedup below 1 and is therefore slower than the reference method. The Author himself points out this behavior later in the dissertation. The answer to RQ3 should therefore be refined

accordingly. The results rather indicate that solution quality remains controlled, while runtime efficiency depends on the geometry and method parameters, particularly for 3D problems.

5. The three-dimensional studies were carried out with a limited number of repetitions. The Author acknowledges this limitation; however, a sample size of n=3 does not support broad statistical conclusions. The results should therefore be regarded primarily as valuable comparative evidence indicating trends in the behavior of the proposed method and providing a basis for continuing the study on a broader scale.
6. Variants M3 and M4 include a final computational stage performed on the fine mesh. This stage affects the final solution quality, and the reported results should therefore be interpreted as the outcome of the complete proposed procedure rather than of the MFAS acceptance mechanism alone. For further assessment of the method, it would be useful to separate more clearly the contributions of its individual stages.
7. The study adopts a fixed twofold change in mesh resolution in each spatial direction between the coarse and fine models. The reported speedups, acceptance rates, and compliance differences are therefore linked to the chosen model hierarchy. An interesting direction for further research would be to consider adaptive selection of the mesh resolution level depending on the stage of the optimization process and to assess whether such an approach could further improve the efficiency of MFAS.
8. The U-Net used in variant M4 is appropriately treated as an optional component operating under the control of the MFAS procedure. The scope of the study, however, does not allow a broad assessment of the model's generalization capability, because the network was trained for specific families of cases. A useful direction for further work would therefore be to evaluate the model on data outside the training distribution, on other geometries and loading conditions, and with larger datasets, which would allow the practical usefulness of the U-Net component to be assessed more fully.

6. Detailed editorial comments

The dissertation is written in generally clear and well-organized English. However, the text contains a small number of language and grammatical errors, as well as inconsistencies in the description of the adopted parameters and the presentation of the results, which require correction or clarification. The most important of these are listed below:

1. Throughout the dissertation, the spelling of compound terms such as "fine-mesh/fine mesh" and "coarse-mesh/coarse mesh" is not consistent. Both forms are used, for example "fine-mesh" and "fine mesh", and similarly "coarse-mesh" and "coarse mesh".
2. The term "computational intelligence", used in the title of the dissertation, is not clearly defined in the main text. The Author should define this concept in the introduction and indicate how it relates to the MFAS and U-Net methods used in the dissertation.
3. The dissertation uses several terms related to solution control and acceptance, including *"acceptance safeguard"*, *"acceptance criterion"*, *"validation gate"*, and *"quality gate"*. This is not a major issue; however, it would be advisable either to harmonize the terminology or to explain the relationship between the individual terms, thereby improving the clarity of the method description.
4. With regard to publication [17], N. Tatke and J. Kaczmarczyk, "Multifidelity topology optimization with runtime verification and acceptance control: Benchmark study in 2d and 3d," which is directly related to the results of the dissertation, the Author should clearly state his individual contribution to the co-authored paper. The dissertation merely notes that part of the benchmark study had previously been published jointly with the supervisor.
5. **Page 6** – the phrase "through multifidelity based approach and ML as initializer" requires grammatical correction. A more appropriate wording would be: "through a multifidelity-based approach with ML used as an initializer".
6. **Page 7** – the phrase "the implementation plan that include definition of benchmark..." requires grammatical correction. The correct form would be: "the implementation plan that includes the definition of the benchmark...".

7. **Page 7** – in the sentence "Chapter 5 reports and analyzes the results, which includes...", there is a subject–verb agreement error. The correct wording is "results, which include...".

8. **Page 17** – in the description of the research gap, the proposed approach is stated to provide control "without requiring additional fine-mesh solves". This statement is not consistent with the MFAS concept presented later, in which periodic fine-mesh computations and verification form an essential part of the procedure. The wording should therefore be clarified.
9. **Pages 59, 64 and 69** – the number of iterations in the final cleanup stage is reported inconsistently. Some parts of the dissertation specify 15 iterations, whereas page 69, in the description of the metrics, states 10 iterations: "consists of ten fine-mesh OC iterations executed". The description should be made consistent with the procedure actually used in the computations.
10. **Page 67** – the description of the baseline 3D tolerance contains both $\varepsilon_{rel} = 0.01$ and $\varepsilon_{rel} = 0.10$. The tables and the subsequent text indicate that the baseline setting is 0.01. This should be made consistent.
11. **Pages 84 and 90** – different speedup values are reported for variant M3 in the *3D cantilever* case: 1.64 in Table 5.2 and 1.48 in Table 5.5 for the same setting, $f_{verify} = 5$. This discrepancy requires clarification, and the method used to calculate and report the speedup values should be applied consistently throughout the dissertation.
12. **Pages 94, 101 and 103** – in the sections on limitations and future work, the Author states that a fixed fine-to-coarse element-count ratio of 4:1 was used for all analyzed problems. Page 94 states "*fixed 4:1 element-count coarse-to-fine reduction ratio for all experiments*"; page 101 again refers to "*a 4:1 element-count coarse-to-fine reduction ratio*"; and page 103 states "*The 4:1 ratio used throughout this work*". These statements are not consistent with the earlier description of the discretization. In Section 3.6.2, the Author correctly identifies a factor-of-four reduction for 2D problems and a factor-of-eight reduction for 3D problems. With a twofold change in resolution in each spatial direction, the element-count ratio is 4:1 for 2D problems and 8:1 for 3D problems. The later statements referring to a constant 4:1 ratio for all analyses therefore require correction.

7. Conclusions and final recommendation

The substantive and editorial comments raised in this review do not affect the overall positive assessment of the dissertation. They concern mainly the need to clarify certain statements, harmonize the presentation of selected parameters and results, and define more precisely the scope of the conclusions that can be drawn from the study. These comments do not undermine the general concept of the dissertation, the originality of the proposed solution, or the value of the research program carried out.

The doctoral dissertation by Mr Nikhil Tatke, MSc Eng., entitled "A Computational Intelligence Framework for PDE-Constrained Topology Optimization", demonstrates the Candidate's general theoretical knowledge in the discipline of mechanical engineering and confirms his ability to conduct scientific research independently. The dissertation presents an original solution to a scientific problem through the development and evaluation of a multifidelity topology optimization approach with runtime verification and acceptance of candidate solutions within the computational process. Particular emphasis should be placed on the development of the Multifidelity Acceptance Safeguard (MFAS), its verification on two- and three-dimensional problems, and the extension of the proposed approach with the option of using a U-Net network for initialization while retaining control over solution quality through a higher-fidelity model.

Taking into account the research objectives achieved, the originality of the proposed solution, the scope of the investigations, and the manner in which the results are analyzed and presented, I consider the dissertation to be of a **high scientific standard and conclude** that the doctoral dissertation byMr Nikhil Tatke, MSc Eng., entitled "A Computational Intelligence Framework for PDE-Constrained Topology Optimization", meets the requirements for doctoral dissertations set out in Article 187 of the Act of 20 July 2018 – Law on Higher Education and Science (consolidated text: Journal of Laws of 2024, item 1571, as amended).

In view of the above, I recommend that the doctoral dissertation by Mr Nikhil Tatke, MSc Eng., be accepted and that the Candidate be admitted to the public defense of the dissertation.

At the same time, given my high assessment of the dissertation, the originality of the developed MFAS mechanism, the broad scope of the numerical investigations, and the fact that some of the results presented in the dissertation have been published in the peer-reviewed journal Materials (Impact Factor 3.7), **I recommend** that the doctoral dissertation by Mr Nikhil Tatke, MSc Eng., **be awarded a distinction.**

Damian Derlukiewicz, PhD, M.Eng, Associate Professor