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REVIEW

of the doctoral dissertation of Sachin Poudel, MSc Eng., entitled "Scale Bridging Computational and Data-Driven Design of Microstructures in Multicomponent Alloys for Advanced Functional Materials".

Legal basis

The review was prepared at the request of the Chair of the Council of the Discipline of Mechanical Engineering of the Silesian University of Technology (letter no. RDIME. 512.2.2026 of 15 July 2026).

The following materials were submitted for assessment:

1. The doctoral dissertation in English, comprising 196 pages, including a monographic part (Chapters 1–5 on pages 1–37) and the bibliography relating to that part – comprising 41 items (pages 38–42), among them two references to the Zenodo experimental database. The dissertation contains Appendix A with the full texts of seven publications (pp. 43–174) and Appendix B with the signed co-author statements (pp. 175–196);
2. The abstract of the dissertation in English
3. The abstract of the dissertation in Polish;
4. The extended abstract in Polish, covering the scope and aim of the dissertation, the objectives set and the thesis defined, a summary of the research methodology and the conclusions obtained. In addition, the abstract includes a list of publications together with a declaration of the candidate's own contribution.
5. The extended abstract in English, covering elements analogous to those of the Polish abstract.

1. General and formal characteristics of the dissertation

The design of new materials and the use of tools supported by multimodal modelling of their functional parameters, in particular parameters derived from service requirements, is an interesting problem of growing applicability across many branches of industrial practice. In the approach presented in the dissertation, the doctoral candidate focuses on three design areas addressing different applications in materials engineering. The principal aim is the ability to tailor the useful parameters of a material as a response to the material descriptors employed. The dissertation submitted for assessment comprises a set of seven thematically related papers, preceded by a monographic part that provides a frame of reference for their content.

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The monographic part compose of five chapters as follows:

Chapter 1 Introduction — the chapter characterises the three classes of materials investigated in the dissertation. It also describes the modelling approach adopted, based on the transformation of descriptors for material parameters. The classes of materials characterised are: multicomponent alloys, piezoelectric materials and electrode–electrolyte interfaces in lithium cells. For each class of materials the author introduces a preliminary descriptor logic and defines the parameters relevant to the tailoring of material properties. An interesting element, which illustrates the need for work in this area, is the summary given in Table 1.1 (p. 3), assigning to each class of materials a design challenge and the approach adopted in the dissertation. In this chapter the author also defines the central construct of the work — the intermediate material state (microstructure, stress states, orientation and the accompanying physical fields) as the link between the descriptor layer and the component-level response. The whole is shown schematically in Fig. 1.1, which describes the layered logic of descriptors and the use of bibliometric and natural language processing methods (i.e. vectorisation of search queries) to structure literature data. In this chapter the author also defines the main scope of the work and the supporting directions oriented towards computational procedures, in particular in view of the intermediate design process (i.e. support in material selection and process specification).

Chapter 2 Scientific Problems and Hypotheses — the author defines the research issues and gaps and formulates the research hypotheses. First, the doctoral candidate presents a stepwise approach to design: through design-oriented modelling, then through computation, and finally the synthesis of these data by means of scale bridging. Such an approach may be described in terms of the following processes:

- computational design (comprising DFT, phase field, FEM and finite-strain plasticity),
- data-driven design,
- microstructure treated as a design variable rather than solely as a characterising descriptor,
- advanced functional materials.

The author provides a review of the state of the art and identifies five gaps thematically related to the selected materials, presenting them in a table (Table 2.1). They cover the previously identified issues connected with the design, modelling and parameter transfer process, but the author also points to considerable scatter and to the lack of linkage between research procedures in the area of identification of material properties, particularly under data scarcity.

The PhD candidate converts the research gaps into research problems identified as P1–P5, and these in turn into a two-level structure of hypotheses: the central hypothesis CH, covering cross-scale transfer for the individual processes and the use of physical descriptors (for the different classes of materials), comprising hypotheses H1–H4 with their accompanying criteria. In addition, the doctoral candidate formulates the synthesising proposition SP1 as a means of relating the proposed solutions across the individual classes of materials.

The author defines the concepts used in the further argument. Of key importance is the definition of scale bridging as a mechanism with two properties:

- direct transfer of parameters between scales (e.g. elastic constants from DFT to the phase field model),
- indirect coupling of descriptors, in which quantities describing composition, processing history, crystallography and morphology represent information from the lower scale.

Chapter 3 Research Objectives – the chapter presents the general objective and three specific objectives (denoted O1–O3), related by a mapping table to the problems and hypotheses formulated in the previous chapter. The general objective is formulated as the development and application of multiscale computational methods combining physical modelling with data-driven methods, linking material descriptors and intermediate states with the structural and functional response.

The general objective has been detailed into three research objectives:

- **Objective 1** – covers the development of multiscale models for alloys, in particular models supporting the selection of material and process for the determination of mechanical properties. The accuracy of these models is then verified by cross-validation and quantitative validation, which makes it possible to assess the sensitivity of the structure morphology to the temperature parameterisation;
- **Objective 2** — covers the modelling of the piezoelectric response for actuators and transducers enabling energy harvesting. In particular, the author declares the ability to model the response of AlN ceramics and of (PVDF/SnO₂) nanofibres;
- **Objective 3** — covers the assessment of SEI-controlled dendritic instability and the construction of multi-indicator design guidelines for evaluating the durability and reliability of battery cells.

In the consecutive part of the paragraph, by means of Table 3.1 the author links the objectives presented with the research problems and hypotheses formulated in the previous chapter. The author also introduces an important distinction: the work covering the characterisation of corrosion in duplex steel and the description of plasticity (presented in publications P-VI and P-VII) is treated as a supporting contribution, covering the verification of multifunctional materials as a prospective direction.

Chapter 4 Scale Bridging Design of Advanced Functional Materials – the author provides a substantive summary of the results obtained in the three research areas presented, described in three previous sections. It synthesises these results with reference to the findings reported in the publications and integrates them in a table (Table 4.1).

In the first area described (Section 4.1), an approach is presented to the near-net-shape manufacturability of materials (AlloyManufacturingNet [P-I]), together with a dimensionless objective function $F(x, y)$ and descriptors with a physical interpretation, as well as with the linking of the macroscopic trend to the atomistic mechanism. A three-phase phase field model of the Al-Cu-Ni system [P-III], implemented in MOOSE, is also presented for different phase states. The author further presents the use of the same research methodology to examine the influence of composition–process factors on the surface response for steels produced by additive techniques, grouping the elements into ferritic and austenitic families [P-VI].

Finally, the author describes a prospective screening of a large body of data, i.e. oxide and nitride formulations, leading to the indication of oxide types as leading candidates for further testing.

In the second area described, concerning piezoelectric structures, reference is made to the methodology presented in publication [P-II], in which the classification governs the activation of the regression module, and the results, after an appropriate transformation, are used in the FEM model. The author also presents the possibility of tailoring the properties of PVDF nanofibres through morphological rather than compositional optimisation, as demonstrated in publication [P-V]. Finally, the author summarises this research area with the statement that ceramic and polymer components use different model inputs but allow the application of similar design principles. Material optimisation is governed by the intrinsic response, whereas it is the architecture of the component that determines the extent to which this response is realised.

In battery cells, the author describes the problem of shaping the structural elements of a battery through the use of the electrochemical deposition process. In publication [P-IV] the author concludes that the phase field model reveals a self-reinforcing feedback between morphology, transport and deposition potential. The review presented in publication [P-IV] organises the relationships between the deposition parameters and the strategy for suppressing this reinforcing feedback.

Finally, the author demonstrates that material properties and component performance are separate design stages.

The chapter closes with a description of five design schemes, worded as follows:

1. Composition and manufacturing parameters should be designed jointly;
2. The intermediate state is the carrier of information between scales, and thermodynamic consistency of the model parameters is as important as numerical convergence;
3. Active components require a balance across the design processes applied rather than the tailoring of a single property;
4. Material properties and component performance are separate design stages;
5. Data-driven models require physical constraints and staged validation, with an explicit distinction between the preliminary model and the validation model.

Chapter 5 Conclusions and Future Work – in this chapter the author summarises the work by reviewing the fulfilment of the objectives set out in the dissertation with reference to Chapter 3:

Objective 1 — relates to structural alloys. The author refers to the simulation method developed for the manufacture of load-bearing components. The data-driven model makes it possible to relate process parameters to strength and elasticity in multicomponent systems, as indicated in publication [P-I]. The coupled phase field model uses temperature-dependent elastic constants to model the grain structure during heat treatment, as presented in publication [P-III]. Analogous process logic was applied to tailoring the corrosion resistance of duplex steel produced by additive methods, as presented in publications [P-VI, P-VII]. It was established that the direction adopted for the selected structures is promising in view of the possibilities of tailoring properties.

Objective 2 — relates to piezoelectric components. Within this objective, an approach is presented to the design of sensors, excitation elements, i.e. actuators, and energy harvesting devices. The approach is framed through models employing tensor-based description and device-level simulation. For crystalline materials the method provides for the use of the unreduced electromechanical tensor with symmetry constraints together with an FEM model, which is

addressed in publication [P-II]. For active polymers, the process descriptors make it possible to predict the effective response of components produced by electrospinning and operating under mechanical loading, which is addressed in publication [P-V].

Objective 3 — relates to battery electrodes. The author presents an assessment of the reliability of battery electrodes using phase field simulations based on field coupling theory. The model reproduces interfacial degradation under the influence of the electric field and mass transport and explains why these changes accelerate mechanical failure. A review summarising these applications with reference to lithium-ion batteries is presented in publication [P-IV].

In the next part of the chapter 5 (Section 5.2) the author provides a comparative layout of the hypotheses formulated in Chapter 2 with the results from Chapter 4. An important element is the fact that each hypothesis presented concludes with a justification confirming its validity. The characteristics of the proposed hypotheses are presented below:

CH (central hypothesis) — An integrated, multiscale modelling framework makes it possible to establish modelling paths leading from the design process to the in-service properties, which individual modelling approaches were unable to achieve on their own. The key element here is the intermediate state, which acts as the medium of transfer between lower-scale parameters and the response of the system. It proved necessary to employ consistent parameter transfer and descriptors based on the physics of the process. Importantly, the descriptors and equations remain dependent on the system to which they are applied.

Hypothesis one – H1. Coupled models made it possible to obtain results unattainable with single-scale models. The prediction using tensor modelling and the FEM model was confirmed and yielded results not obtained by either method applied on its own – with reference to publication [P-II]. Analogously, transferring temperature-calibrated elastic constants into the phase field model improved the process simulations and supported the optimisation of the thermal path – with reference to publication [P-III].

Hypothesis two – H2. Process descriptors indicated regions of balanced strength and plasticity in multicomponent alloys and enabled joint optimisation of composition and manufacturing parameters, as presented in publication [P-I]. The elastic constants were referenced to temperature and altered the predicted grain morphology, which shows that temperature consistency is a necessary condition for predicting the geometry relevant to the process carried out – with reference to publication [P-III].

Hypothesis three – H3. Unreduced electromechanical tensor models allowed the prediction of orientation dependence in crystalline components, and finite element modelling demonstrated that the device response depends on the tensor model adopted. For active polymers, the process parameters allowed effective prediction with optimised manufacturing parameters – with reference to publication [P-V].

Hypothesis four – H4. The field-coupled simulations carried out made it possible to reproduce the feedback mechanisms, which in turn allowed the degradation of the structure to be localised at the tips of the interface through the mechanism of interfacial damage. The literature synthesis performed grouped the degradation-prevention methods into combined sets of objectives rather than isolated indicators – which was referred to publication [P-IV].

Hypothesis SP1. The components investigated obey a common logic in which process parameters influence the in-service properties through the intermediate state. On the basis of this hypothesis, five schemes are defined and presented in Section 4.4. However, since the input data and

constitutive equations remain application-specific, the broader scalability of such an approach requires assessment in further research.

The dissertation closes with the conclusion that multiscale design does not require the use of a single universal model, but rather physically grounded descriptors, consistent cross-scale transfer and an explicit representation of the intermediate state. Notably, for each hypothesis presented the author provides a justification for formulating it, with confirmation in every case (computational confirmation for hypotheses 1, 2 and 3) and partial confirmation in the case of hypothesis SP1. Within this chapter the author also outlines directions for further work.

In the further part, the author proposes a multiscale approach to component design in which process parameters translate, through the represented intermediate state, into in-service properties, i.e. through grain geometry, tensor orientation or the evolving interface. Further work includes extending the models with more complete physics, surrogate models for inverse design, the reuse of alloy composition spaces for multifunctional components, and a closed loop of active learning. The general conclusion is that scale-bridging design does not require a single universal model, but rather physics-based descriptors and consistent transfer of parameters between scales.

The bibliography presented in the monographic part comprises 41 items (including 9 of the PhD candidate's own works and 2 Zenodo datasets). Within this bibliography, seven publications are those forming the basis of the assessment and two are works of which the doctoral candidate is a co-author.

Appendix A contains the full texts of the seven papers, and Appendix B the signed co-author statements. The abstracts in English and Polish have been prepared correctly. The Polish version is written in correct technical language and uses appropriate terminology.

The structure of the dissertation is logical and consistent: from the definition of the research gaps, through the problems and hypotheses, to the objectives, the results and their verification. The use of mapping tables (Tables 2.1, 2.2, 3.1, 4.1) is appropriate and makes it easier for the reader to follow the coherence of the argument.

2. Assessment of the topic aim and scope of the dissertation

The subject matter addressed forms part of the trend of integrated materials and process design and of the concept of component design that treats the material state as a design variable. This is a direction of considerable practical significance. Such an approach fits within the framework of Industry 4.0 and shortens costly cycles in the design of structural alloys, piezoelectric transducers and lithium cells. It may therefore translate directly into the cost and time of industrial implementation.

I regard the formulation of the central idea of the dissertation as an interesting scientific problem — the introduction of the “intermediate material state” as the link that, within the physics-based models employed, connects low-scale descriptors with the component-level response.

The use of such a construct allows the doctoral candidate to organise three apparently distant research areas within the field of materials engineering into a single dissertation. Another very important element is the use of advanced machine learning methods for the prediction of material characteristics. The consistent combination of physics-based modelling with machine learning

methods, while employing descriptors with a physical interpretation instead of purely statistical features, is also well founded. Framed in this way, the capability described makes it possible to define a research area aimed at determining the transferability of models and their scalability. The topic of the dissertation is interdisciplinary and combines elements of mechanical engineering, in particular materials engineering, but also computational and modelling problems.

I consider the topic to be fully justified, scientifically current and requiring the solution of a scientific problem of an original nature. The approach adopted is interesting from a scientific point of view, as is the application of testing of methods for the assessment and analysis of large data and — which is particularly interesting — the potential use of language models based on the publications presented, which attests to the modern research toolkit employed by the doctoral candidate.

The basis for the assessment of the dissertation is seven papers published in JCR-listed journals. Below I present a description of each of these works, together with the declared contribution and an assessment of its role in the series. The thesis of the dissertation rests on a single premise: no single approach covers the entire path from composition and process descriptors to component properties, and therefore a consistent cross-scale transfer through an explicit **intermediate state** (CH) is required. The seven publications distribute this across three specific objectives — of which two works are classified by the author himself as supporting rather than as carrying new research implications.

P-I — AlloyManufacturingNet for discovery and design of hardness–elongation synergy in multi-principal element alloys (*Engineering Applications of Artificial Intelligence* 2024, first author, contribution – 51%).

The paper addresses the problem of modelling a range of manufacturing processes (casting, plastic working, sintering, annealing) within a single predictive model for assessing the hardness and elongation of multicomponent alloys. A dimensionless objective function $F(x,y)$ standardising both responses was introduced, which allows the results obtained to be compared without arbitrary weights. I consider the supplementation of the predictions with molecular dynamics simulations to be valuable, as it links the macroscopic trend to the mechanism of dislocation mobility.

The work carried out is significant for objective **O1** and provides evidence for hypothesis **H2a**, with a clear, leading contribution from the doctoral candidate.

P-II — PiezoTensorNet: Crystallography informed multi-scale hierarchical machine learning model for rapid piezoelectric performance finetuning (*Applied Energy* 2024, first author, contribution – 61%).

The paper is linked to objective O2 and constitutes the principal evidence for hypotheses H1 and H3. The author presents an analysis of tensor symmetry for the lattice, while a point-group classifier directs the selected value to one of five regression modules (PG1–PG5). The e_{mod} norm introduced serves as a screening measure. The example presented of co-doping, followed by transformation of the tensor and its introduction into the FEM model, results in a significant increase in the power obtained for the beam example. This is an interesting example of a shared space integrating the mechanics of the object, materials engineering and regression models, which

is not accessible to any of the steps carried out separately. As the author notes in the proof of the thesis, the entire path is a computational prediction.

The work carried out is significant for objective **O2** and provides evidence for hypotheses **H1** and **H3**, in particular in view of the fact that neither the property model nor the FEM analysis alone would have provided an estimate of the response. This work was likewise carried out with a clear, leading contribution from the doctoral candidate.

P-III — Unraveling elastochemical effects in microstructural evolution of Al–Cu–Ni system through DFT-informed multi-phase field simulations (*International Journal of Solids Structures*, first author, contribution – 65%).

The publication describes the change in the properties of the phases (Al_2Cu , Al_3Ni and Al-rich FCC) while retaining the full anisotropic stiffness tensors. Interestingly, the work investigates the influence of changes in elastic energy on microstructural change in two-phase and multiphase alloys, where earlier studies consistently used elastic constants determined for low temperature even though the simulated processes take place at elevated temperatures. The work therefore addresses the hypotheses formulated with respect to the existing inconsistencies and describes how the temperature calibration of the elastic tensors alters the predicted microstructure geometry compared with the low-temperature parameterisation. The doctoral candidate has established a procedure for such transfer, which constitutes direct confirmation of hypothesis **H2b** and — together with **P-II** — evidence for **H1**.

This work was likewise carried out with a clear, leading contribution from the doctoral candidate.

P-IV — Roadmaps for dendrite suppression in next generation lithium-ion batteries: Toward sustainable energy solutions (*Energy Storage Materials*, 2026, second author, contribution – 35%).

The paper deals with the formation of lithium dendrites in next-generation lithium-ion batteries, i.e. needle-like structures which not only reduce cell capacity but also pose a risk of internal short circuit and thermal runaway. The paper presents an approach to assessing the feedback mechanism responsible for the localisation of degradation that leads to capacity loss, and to organising the dispersed strategies for preventing this phenomenon into a coherent framework by means of multiscale modelling. Such an approach is intended to allow this process to be exploited for design purposes.

The work constitutes supporting material for the demonstration of hypothesis **H4**.

P-V — Physics-Guided Machine Learning for Enhanced Piezoelectric Performance in Electrospun PVDF/SnO₂ Nanofibers (*Sustainable Materials and Technologies*, 2026, first author, contribution 50%).

The paper is an interesting combination of methods for optimising the electrospinning process with natural language processing methods used to synthesise data from dispersed sources in order to determine research directions for identifying a filler of a given potential. Optimisation of the electrospinning parameters made it possible, within the model, to halve the mean fibre diameter. Through the modelling and computations carried out, the paper addresses the fulfilment of hypothesis **H3**.

P-VI — Integrating experiments and phase field method through informatics for tailored corrosion performance of additively manufactured steel microstructures (*Metals and Materials International*, 2026, second author, contribution – 14%)

P-VII — Post-process heat treatment design for tunable strength and toughness in L-PBF 2507 super duplex stainless steel (*Materialia* 2026, second author, contribution – 25%).

Both works constitute a supporting element that does not relate directly to the research hypotheses presented; they are, however, connected with the logic of the synthesising hypothesis SP1, which concerns the possibility of transferring the logic developed to other types of materials.

The average declared contribution of the doctoral candidate across the seven works is approximately 43%, exceeding 35% in five works and, in the three works that are key to the dissertation (P-I, P-II, P-III), falling within the range of 51–65%. In my opinion, the contribution of the doctoral candidate to works P-I, P-II, P-III and P-V is enough to be regarded as the independent author of the scientific solution presented in the dissertation.

Based on the assessment of the aim and scope of the dissertation and of the achievements presented, **I believe that presented topic is deliberate and useful**, and, given its research scope covering physical modelling, data analytics and advanced methods of materials synthesis, as well as the use of a modern research toolkit, the dissertation is of a **utilitarian character**.

3. Assessment of the dissertation

In the work submitted for assessment, the author formulated five research problems (P1–P5), a central hypothesis (CH), four specific hypotheses (H1–H4), an additional hypothesis constituting a synthesising proposition (SP1) and three specific objectives (O1–O3).

Importantly, the author proposed assessment criteria for each hypothesis, which demonstrates that it can be verified on the basis of the appended publications and the description in the monographic part.

Analysing the series of publications and the monographic part, I regard the following as the original and personal contribution of the doctoral candidate to the development of the discipline:

- The development of a methodology enabling the response of the component under study to be modelled, with the possibility of predicting its properties by means of the intermediate state. Importantly, the modelling issues presented in the dissertation cover specific material parameters such as grain geometry, tensor orientation and interface variability.
- The development of the architecture of a multiscale environment (PiezoTensorNet) enabling the use of a neural network architecture embedded in the conditioning of the crystal lattice. This is an original solution that makes a methodological contribution extending beyond the materials domain in which it was applied.
- The presentation of a model approach to the influence of transferring temperature-consistent elastic constants on the prediction of microstructural changes.
- The development of a methodology for physics-informed modelling (for use under conditions of extreme data scarcity -PGMLpiezo), in which the physical term of the loss function constrains the solution space of a model trained on 52 samples.

- Beyond the modelling results and the development of transfer methods, the dissertation also makes a cognitive contribution. This is undoubtedly the contribution presented in publication P-IV, describing the self-reinforcing feedback mechanism responsible for determining the localisation of degradation at the tips of interface protrusions.
- The dissertation further brings a utilitarian contribution, allowing the data and computational tools created by the doctoral candidate to be obtained from online repositories (computational tools together with data for, among others, PiezoTensorNet).

Undoubtedly, given the broad scope of the work carried out, the dissertation is not free from certain shortcomings, among which I include:

- A certain awkwardness arising from the relation between the title of the dissertation and its scope.
The title given refers to “microstructures in multicomponent alloys”.
However, it follows from the appended publications that, of the seven publications, four (P-II, P-IV, P-V and, in part, P-VI) concern piezoelectric ceramics and polymers and electrode–electrolyte interfaces.
- The dissertation declares affiliation to the discipline of mechanical engineering, and the list of publications includes a note that all the works fall within this discipline.
My doubt arises from the materials submitted for assessment. To a significant extent the work is related to data analysis, models and crystallography – which is by nature closer to materials engineering. The elements of the dissertation with the strongest bearing on the discipline under assessment are contained in the supporting contribution.
- The dissertation does not include experimental verification. All the results presented and the key values of the parameter modifications are numerical only and constitute predictive quantities without experimental verification. The author is aware of this, emphasising that the thesis is demonstrated computationally. This is an important limitation as regards the possibility of demonstrating evidentially but not experimentally the effective predictive capability of the models developed.
- The substantive part is very limited and does not provide a good introduction to the appended publications. In preparation for the analyses contained in the publications, a description of the methods used in them – covering both the models and the computational parameters – is lacking. A concise chapter providing a substantive introduction to the series of publications would significantly improve the possibility of assessment.

The above remarks are of a discussion nature and, apart from the exceptions specified, do not undermine the value of the dissertation. They are ordered from general remarks to detail substantive and editorial comments.

The monographic part of the dissertation is written in concise and economical language, with the arguments based on references to the publications, together with the use of itemisation and links to the literature.

Among the remarks, minor editorial comments should be mentioned concerning the lack of explanation of some abbreviations and the absence of figure descriptions. I emphasise that the critical remarks concern primarily the manner of presentation, justification and verification of the

results, and not their scientific value or the correctness of the computational toolkit applied. None of them undermines the originality of the scientific solution presented in the dissertation.

Questions for discussion during the defence:

I ask the doctoral candidate to address the following questions:

1. The only case in which the correctness of the cross-scale transfer was measured directly is the 18.18% difference in grain area between the parameterisations for 0 K and 723 K. Can such a criterion be generalised as applicable to the remaining areas presented by the doctoral candidate?
2. Has the SPI proposition of a common design logic been confirmed by an actual transfer of a model or of descriptors between domains, or does it remain a conceptual analogy? Which specific element was transferred between the areas, and with what quantitative result?
3. Which elements of the dissertation does the doctoral candidate regard as a contribution to the discipline of mechanical engineering rather than to materials engineering? Please indicate specific results and justify the disciplinary classification of the work.

4. Final conclusion

I state that the doctoral dissertation of Sachin Poudel, MSc Eng., constitutes an original solution of a scientific problem, namely the development and verification of multiscale computational methods combining physics-based modelling with machine learning methods for the design of structural and functional materials and of components made from them. Despite the imperfections indicated, the dissertation demonstrates the Candidate's knowledge in the field of modelling structures from the design and scaling process through to manufacturing. Moreover, the work and achievements presented allow the conclusion that he can conduct scientific work independently, as confirmed by lead authorship of publications in reputable international journals.

In summary, I consider **that the dissertation under review meets the requirements Article 187 of the Act of 20 July 2018 (consolidated text: Journal of Laws of 2024, item 1571), the Law on Higher Education and Science, including the condition that the dissertation be submitted in the form of a set of published and thematically related scientific papers.** I request that it be accepted and allowed for public defense.

Col. Krzysztof Dragan, DSc, Eng., Prof. of AFIT