CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Civil Engineering
Department of Science and Research
Thákurova 7, 166 29 Praha 6

e–mail: obhajoby@fsv.cvut.cz tel.: 224 358 736

Opponent's review of the Doctoral Thesis

Candidate Ing. Martin Doškář

Title of the doctoral thesis Wang tiling for modelling of heterogeneous materials

Branch of study Civil Engineering

Tutor Ing. Jan Novák, Ph.D. and prof. Ing. Jan Zeman, Ph.D.

Opponent prof. Ing. Miroslav Vořechovský, Ph.D.

e-mail vorechovsky.m@vut.cz

Topicality of the doctoral thesis theme

Commentary: The topic of modeling and analysis of materials with stochastic/disordered internal structure such as geomaterials, metalic foams, is a modern and very important one.

Advanced modeling and computatinal strategies helps to understand comlicated behavior such as crack initiation and propagation in composites, thermal properties of metalic foams etc. Incorporation of knowledge about material microstrusture with fine geometrical details will greatly enhance the predictive power of computer models and increase safety, economy and also ecology. The topic is relevant not only to materials studied in the thesis, but also for the emerging field of architectured meta-materials: alternatives enabled by new production technolgies.

☒ excellent	☐ above average	☐ average	☐ below average	☐ poor

Fulfilment of the doctoral thesis objectives

Commentary: The exact list of tasks of the thesis objectives, if it exists, is not known to me and therefore I comment on to what extent the thesis explored the apsects of Wang tiling for modelling heterogeneous materials. The concept of Wang tiling has been introduced, described rigorously and studied with quite advanced mathematical tools. The candidate built the thesis on five manuscripts/papers in which he is the main author: he carried most of the studies, implemented the software and proposed the algorithms for them, postprocessed and intepreted the resutls and drafted the manuscripts. The thesis is well focused on the topic and there is no superfluous text or tangential material. The state of the art is well reflected; the bibliography consists of almost 200 references and these sources were clearly actively used by the candidate.

From this point of view, the objectives of the work have been fulfilled, in an excellent way.

☒ excellent	☐ above average	☐ average	☐ below average	☐ poor

Research methods and procedures

Commentary: The research methods and tools are very advanced and they represent the cutting edge in the field. Deep insight into a complex combination of advanced topics in modern micromechanics and the theory of homogenazation, computational geometry, selected topic from computer graphics and material science, spatial variability, mathematics in general, probability theory and mathematical statistics is clearly demonstrated; not to mention the programming skills of the candidate.

☒ excellent	☐ above average	☐ average	☐ below average	☐ poor

Results of the doctoral thesis – dissertant's concrete achievements

Commentary: The thesis is a collection of journal papers (or manuscripts under review) accompanied by the introduction that guides the reader through the text.

Chapter two is reproduced from a paper published in Physical Review E. It presents a technique to compress and syntesize complex material morphologies based on Wang tiles. The performance of this automatic tile design is demonstrated for various types of microstructures.

Chapter three is based on a manuscript under review and presents tile design based on level-set approach. The method is an extension of an existitng Sonon et al.'s method to Wang tiles to produce representations of microstructures intractable by former techniques.

Chapter four is built on a paper published in Computers & Structures journal and it presents an approach to homogenization of high porosity metallic foams. Wang tiling approach has been combined with guaranteed upper and lower bounds on the effective stiffness coefficients and enables generating large material samples along with their finite element discretization.

Chapter five reproduces a paper from European Journal of Mechanics on RVE determination methodology. It presents the approach based on matching the user-defined significance level and discrepancy between bounds on the apparent properties. It builds on a combination of statical sampling and the Partition theorem. It is very insightful chapter and shows that the Wang tiling approach is an appealing framework for numerical homogenzation and problems of RVE size determination.

Chapter six is a manuscript in preparation. The idea is to extract characteristic fluctuation fields from the compressed representation based on Wang tiles, without any prior knowledge about the shape or loading of the macroscopis domain. Then, using the ansatz of GFEM, these fields are combined with a coarse FE discretization to create reduced models for a specific problem.

With the candidate being the first author on all these five papers/manuscripts, there is no doubt about his contribution to this work.

☐ excellent	☐ above average	☐ average	☐ below average	☐ poor

Importance for practice and for development within a branch of science

Commentary: The candidate made several important advancements in the development of Wang tiling approach and its applicability to heterogeneous materials.

The sample-based design method for tiles introduced in the first part of the thesis was shown computationally very efficient and suitable mainly concrete-like materials. Then the algorithm for tile design based on extended level set approach enables generating compressed representations of complex microstructural geometries (e.g. foam-like microstructures) which previously were impossible or very expensive to generate for Wang tiles. It represents an important advancement from the Periodic Unit Cell approach.

The thesis presents advancements on the concept of Wang tilings in mechanics: the approach to homogenization of metallic foams presented in chapter four is an important step towards utilization of Wang tiling concept in mechanics.

Chapter five tackles a hard topic of RVE size determination. The idea is simple yet very useful: the RVE size being judged based on discrepancy between bounds on the apparent properties and the illustration with the homogenization of thermomechanical properties of various kinds of microstructures showed that the approach works.

The idea of pre-computed fluctution fields that are obtained without prior knowledge about the shape and loading of a macroscopics domain was shown to drastically reduce the number of DOFs compared to fully detailed model. In this way, chapter six represents a culmination of the thesis and provides a stepping stone for practical analysis of heterogenous materials usign the concept of Wang tiles.

☒ excellent	☐ above average	☐ average	☐ below average	☐ poor

Formal layout of the doctoral thesis and the level of language used

Commentary: The theis is well structured and organized, written in English with excellent language level. The text is typeset using LaTeX, figures and plots are just perfect. For example, various mathematical objects are typeset with various fonts which illustrates the thoroughness and attention to details.

The number of typos is at absolute minimum (ellip soidal in section 3.4.3, fourth line or missing space in section 4.5, third line). Occasionally, the text oveflowed the paragraph; \begin{sloppypar} would fix this.

The formalities are at outstanding level.

☒ excellent	☐ above average	☐ average	☐ below average	☐ poor

Remarks

The concept of Wang tilings seems to an alternative that removes some disdvantages of other concepts and yet is still tractable by advanced tools from micromechanics.

What remains to me as a question is to what extent the stochastic tiling can represent features that in real materials can occur only very occasionally. For example, a very unlikely cluster of particles or a region with unusual local shape of bubble in a foam that is not contained in the sample set used for design of the tiles. One can think of analogy to exceedances of sample paths of random fields over high thresholds or so. Are these aspects relevant for the analyses of heterogenous materials?

Looking at Figs. 4.5 on page 49 or 5.5.2 on page 78: what is the statistical distribution of angles of "beams" in the boundary region of the Wang tiles? Is it comparable with the angle distribution of links in the interior of the tiles? Can the difference between these distributions be a source of systematically different mechanical behavior in the vicinity of boundaries (microstresses, poisson ratio,...).
On page page 56, the candidate discussed the appropriatness of the two-dimensional setting for homgenzation of three-dimensional microstrcture. It seems that the planar analysis can not account for stifness of the out-of-plane beams and membranes. Is the candidate planning to extend his work to 3D Wang cubes?

Final assessment of the doctoral thesis

The candidate submitted an outstanding thesis. He clearly proved his ability to conduct excellent research, deliver new results and present the findings to a scientific community.

From the acknowledgement and authorship of his papers, it is clear that the candidante already gained an international experience and showed his ability to collaborate on advanced research topics.

Based on the thesis, he mostly deserves the doctoral degree.

Following a successful defence of the doctoral thesis I recommend the granting of the Ph.D. degree

yes ☒	***no*** ☐

Date: December 5, 2019

Opponent's signature: .....

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
Fakulta stavební
Ústav stavební mechaniky
Veveří 331/95, 602 00 Brno