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Opponent's review of the Doctoral Thesis

Candidate Ing. Michal Kovarik

Title of the doctoral thesis Critical assessement of 3D printing technology regarding its general applicability under technological and material constraints

Study Programme Building Engineering

Tutor doc. Ing. Pavel Svoboda, CSc.

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Topicality of the doctoral thesis theme

Commentary: The work submitted by Ing. Kovarik addresses 3D Concrete Printing (3DCP). This is a relatively new construciton technology that has been receiving attention from both industry and academia over the past ten years. There exist several research aspects related to 3DCP that still need to be explored, some of these include the development of a) mixing design protocols to enable the use of locally-available materials, b) quick experimental protocols for adjusting the mix design in order to accommodate on-site variations, and c) experimental datasets to evaluate the robusteness of the technology for precast and on-site applications. All of these research needs are addressed in Ing. Koviracik thesis, highlighting the relavance of the topic to an audience that goes beyond the boundaries of academia.

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

Fulfilment of the doctoral thesis objectives

Commentary: In the objectives section, Ing. Kovarik presents eight research topics - ranging from materials and machinery development to design and case studies. The research work presented in the thesis answers to the eight target objectives. Note that these could have been presented in a more scientific way and supported by a more comprehensive review and references to existing literature. Nonetheless, given the timeline when Ing. Koviracik's research was carried out, it is understandable that some experimental protocols for 3DCP mixes were either inexistent or there was not a common agreeement between researchers on what methods worked best. I participated in several scientific discussions in the RILEM TC on Digitial Fabrication with Cementitious Materials from 2016-2020, and several of these orbited around topics such as "characterisaiton protocols" and "underlying physics of 3DCP".

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

Research methods and procedures

Commentary: The research methods and procedures in Ing. Kovarik's thesis are rather empirical - but that is considered acceptable based on my statements in the previous section. Nonetheless, the research methods are hardly associated with published data or compared to various characterisation methods that were published up to now. That being said, the research work carried out on Ing. Kovarik's thesis comes across as a engineering work with a practical / empirical flare. While the methods utilised in the thesis are valid, there is a lack of criticism against other methods. In the final presentation of Ing. Kovarik's work, it would be interesting to

hear the author's arguments on other methods and reasons why the author's suggested methods can capture the underlying physics necessary to describe / characterise the behaviour of the 3DCP mixes (when tested in lab and printing scales).

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

Results of the doctoral thesis – dissertant's concrete achievements

Commentary: Ing. Kovarik delivered concrete results and research insights into the following areas: a) mixing design protocols to enable the use of locally-available materials, b) quick experimental protocols for adjusting the mix design, accommodating on-site variations, and c) experimental datasets to evaluate the robusteness of the technology for precast and on-site applications - with several cases studies where 3DCP has been applied with great success. Altogether, Ing. Kovarik's research results provide valuable information to an audience that goes beyond the boundaries of academia.

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

Importance for practice and for development within a branch of science

Commentary: From a practical perspective, the work carried out by Ing. Kovarik is of high importance. It addresses a very relevant topic and a challenge that is experienced on a daily basis for 3DCP operators, i.e. process / material robustness. The provided proposition of quick characterisation methods contributes the use of 3DCP from an engineering perspective, enabling technology users to rapidly adapt their mixes on site. From a scientific outlook, the results presented in the thesis can be used as a metric to validate numerical models describing 3DCP processes - assuming the author builds synergies with other researchers and shares specific data from the printing process. In additiong, based on a detailed look of the prepared mixes, the author presents an interesting contribution to science when it comes to the application of a cement free binder - there is a handful set of scientific articles deadling with low CO2 emissions binders for 3DCP applications, mostly limited to geopolymers and/or alkali-activated binders. The results from the cement free binder prints could easily be extended and formulated as scientific research paper to be published in a high impact factor journal e.g. Cement and Concrete Research.

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

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

Commentary: There are fundamental "presentation layout" aspects that are missing in the thesis. 1) There is not a cover page with the title of the thesis; 2) the figures are rather small and hard to read - except when using digital formats; 3) some tables are out of established margins; 4) I do not recognise a standard layout from the University (in case one has been provided at all); and 5) there is no harmony on how images are presented, especially when it comes to image size and and reference length scales (so readers can identify the size of the printed elements). These do not compromise the quality of the scientific work, but they limit the visual appeal of the thesis.

On the "level of language", the thesis is written in English and there are not major grammar issues to comment on. The sentences are clear and well written; the statements are sound. The only drawback is that most paragraphs are rather long, which makes the act of reading rather tiring. Once again, these aspects do not compromise the quality of the work - they are merrely a writing style aspect that the author is suggested to look upon in his future publications.

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

Statement on compliance with citation ethics
N.A.

Remarks
The thesis covers a wide range of knowledge: a) custom mix designs for 3DCP applications, b) specifics of equipment (mixing, pumping and extrusion); c) boundary conditions affecting the outcome of the printing process (i.e. material / process robustness); d) design aspects showcasing the form-freedom that is enables by the use of additive manufacturing; e) case studies that put science into practice and prove the industrial relevance of applied research. This is a rather compeling set of skills to showcase in a single piece of research work; most 3DCP researchers are heavily specialised in on aspect, e.g. material, design, structural engineering, durability, to mention a few. Ing. Kovarik's work comes across as a very complex puzzle that is build upon years of work to deliver an industrially relevant thesis. While there are some scientific aspects that could be further elaborated in the sections about rheology, mix design, machinery, pumping and nozzle technologies, the overall picture of the research work that has been carried out is satisfactory.

Final assessment of the doctoral thesis
Ing. Kovarik proves the functionality of the 3DCP on the basis of several prints and a very well elaborated research and engineering work, which is a rare case. The presented research work combines science and engineering, and this is exactly what 3DCP researchers need to take into account to support the development of the technology for the benefit of a more sustainable built environment. From my scientific, practical and educational experience on 3DCP, I support that the Czech Technical University grants Ing. Kovarik a Ph.D. degree.

Following a successful defence of the doctoral thesis I recommend the granting of the Ph.D. degree		
	yes ☒	***no*** ☐

Date: 27.09.2023

Opponent's signature. .....