

Faculty of Mechanical Engineering  
Brno University of Technology

## Review of Doctoral Thesis

### 1. PhD candidate

Ing. Arnošt Vespalec / Arnost.Vespalec@vut.cz

### 2. Name of PhD programme

Design and Process Engineering (Mechanical Engineering Design)

### 3. Title of PhD thesis

Coarse aggregate 3D concrete printing

### 4. Principal supervisor

doc. Ing. Daniel Koutný, Ph.D. / Daniel.Koutny@vut.cz

### 5. Co-supervisor

doc. Dr.techn. Ing. Jan Podroužek/ Jan.Podrouzek@vut.cz

### 6. Reviewer

Dr. Ena Lloret-Fritschi / ena.lloret.fritschi@usi.ch

Università della Svizzera italiana

### 7. Overview of the scope of PhD thesis<sup>1</sup>

Evaluate: Very Good

The PhD thesis explores the intricate domain of 3D printing using cement composite materials, with a specific focus on the integration of 8mm aggregates. Positioned as a response to identified "white spaces" in existing literature, the research seeks to enhance understanding and address challenges associated with 3D printing technology in conjunction with cement composites. A distinctive facet involves the incorporation of large aggregates, up to 8mm, aiming to replicate real concrete structures.

The thesis outlines a comprehensive scope driven by scientific questions and associated hypotheses. Core objectives involve probing into the rheological properties of concrete mixtures, delineating layer bonding in printing mixtures with coarse aggregates, and unravelling mechanical properties in the fresh state. Methodologically, the research employs diverse approaches, encompassing the Vicat test, extrusion-based tests, interface uniaxial tensile tests, sliding pipe rheometer, and the powerful Abaqus simulation software.

Notably, integrating simulation techniques is a significant strength, circumventing the need for an iterative trial-and-error approach. This simulation aspect adds efficiency to the investigation, offering a strategic and robust means to explore material behaviour and buildability. By venturing into less-explored territories of additive manufacturing with larger aggregates, the thesis emerges as a pioneering contribution, shedding light on critical aspects of 3D printing processes with broader implications for construction applications.

---

<sup>1</sup> Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

## 8. Significance of the topic and clarity of problem statement

Evaluate: good

The thesis structure is commendable for its clear objectives and systematic approach. It meticulously addresses the behaviour of cementitious composites for 3D printing, emphasizing rheological properties, layer bonding, and mechanical characteristics. Integrating interdisciplinary elements, such as experimental stand development and parameter optimization, showcases a holistic perspective. Notably, the thesis delves into environmental sustainability by considering waste reduction, aligning with current concerns in construction technology. Scientifically rigorous, it formulates well-defined research questions and hypotheses, building upon existing literature. Overall, the structure reflects a comprehensive exploration of additive manufacturing, bridging theoretical insights with practical advancements.

## 9. Knowledge of existing literature

Evaluate: *satisfactory*

The state of the art presented in the thesis is thorough, encompassing various aspects of cementitious composites for 3D printing. However, there is a notable gap concerning recent research on 8mm aggregate printing, which has been available for over two years. The discussion introduces an intriguing perspective on Slifproming in the context of 3D printing. Still, unfortunately, this concept is not revisited or substantiated with references, despite ongoing publications in the field of 8mm aggregates. Incorporating these recent studies would enhance the current state-of-the-art analysis, providing a more comprehensive and up-to-date evaluation.

## 10. Choice of methods and technical soundness

Evaluate: Very good.

The thesis demonstrates a methodically sound and strategically structured approach to addressing gaps in 3D printing with cement composite materials, particularly incorporating 8mm aggregates. Utilizing material from previous projects, which includes Portland cement, fine and coarse aggregates, Metakaolin, and a solidification accelerator, aligns with the objective of achieving adequate strength for additive manufacturing. Measurement methods, outlined in detail, ensure transparency and replicability. For Q1/H1, an infographic illustrates Vicat tests, extrusion-based tests, and interface uniaxial tensile tests. Q2/H2 and Q3/H3 methodologies exhibit technical robustness, including rheological and mechanical behaviour, sliding pipe rheometer, and Abaqus simulation software. Results and discussions provide comprehensive insights into concrete mixtures with coarse aggregates, evaluating pumpability, extrudability, and buildability. Considerations for clogging demonstrate a holistic understanding of material properties for 3D printing processes. In summary, the thesis advances knowledge in 3D printing, showcasing a well-founded method selection and technical prowess in handling cement composites with large aggregates.

## 11. Quality, originality and significance of the results

Evaluate: Good

The thesis demonstrates a commendable presentation of results, especially through peer-reviewed papers, highlighting a significant and commendable aspect deserving further recognition in the research domain. Including well-described results in peer-reviewed publications adds credibility to the findings and contributes valuable insights to the broader academic community. This positive characteristic showcases a commitment to rigorous scholarly communication and dissemination of knowledge, reflecting positively on the overall impact of the research in the field. It reflects the researcher's dedication to enhancing the collective understanding of cementitious composites for 3D printing, fostering collaboration and knowledge exchange within the scientific community.

## 12. Quality of attached papers

Evaluate: Good

The papers are very clear and well-written, demonstrating transparency and a rigorous methodology.

## 13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

Evaluate: GOOD

The overall assessment of the thesis is positive, with notable strengths and a few weaknesses. The research addresses critical gaps in 3D printing with cement composite materials, specifically incorporating 8mm aggregates. The strategic and methodically sound approach and the utilization of relevant materials align with the objective of achieving strength for additive manufacturing.

Strengths:

**Methodological Soundness:** The thesis demonstrates a robust methodology, ensuring transparency and replicability in measurement methods. **Comprehensive Insights:** Results and discussions provide comprehensive insights into concrete mixtures with coarse aggregates, covering pumpability, extrudability, and buildability.

**Holistic Understanding:** Considerations for potential issues like clogging showcase a holistic understanding of material properties for 3D printing processes.

Weaknesses:

**Literature Gap:** While the state of the art is well-covered, the absence of references to the latest research on 8mm aggregate printing, particularly in the last two years, is a notable weakness.

**Unexplored Reference:** The introduction of "Slifproming" in relation to 3D printing is opened up but not further used as a reference, creating a potential gap in support of ongoing work on 8mm aggregates.

In conclusion, the thesis substantially contributes to advancing knowledge in 3D printing, showcasing well-founded methods and technical prowess. Addressing the mentioned minor weaknesses would further enhance the overall quality of the research.

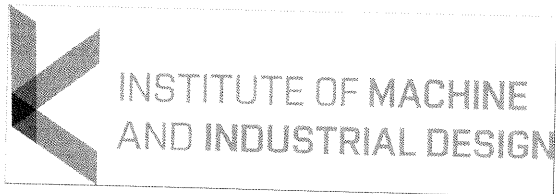
## 14. Questions and comments

## 15. Conclusion

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.

Yes

## 16. Date and signature

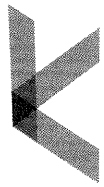


Faculty of Mechanical Engineering  
Brno University of Technology

Date: 07/03/2024

Please note

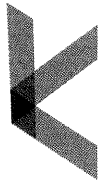
- A. Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.
- B. E-mail the completed form to: [Klara.Javorcekkova@vut.cz](mailto:Klara.Javorcekkova@vut.cz)



## Review of Doctoral Thesis

<b>1. PhD candidate</b>
Ing. Arnošt Vespalec / Arnost.Vespalec@vut.cz
<b>2. Name of PhD programme</b>
Design and Process Engineering (Mechanical Engineering Design)
<b>3. Title of PhD thesis</b>
3D CONSTRUCTION PRINTING OF COARSE AGGREGATE CEMENTITIOUS COMPOSITE
<b>4. Principal supervisor</b>
doc. Ing. Daniel Koutný, Ph.D. / Daniel.Koutny@vut.cz
<b>5. Co-supervisor</b>
doc. Dr.techn. Ing. Jan Podroužek/ Jan.Podrouzek@vut.cz
<b>6. Reviewer</b>
dr inż. Sławomir Czarnecki/ slawomir.czarnecki@pwr.edu.pl
Politechnika Wroclawska
<b>7. Overview of the scope of PhD thesis<sup>1</sup></b>
<b>Very good</b>
The chosen topic for the PhD thesis offers an exploration of 3D printing and sustainable construction materials processes. Those two dynamically relevant and contemporarily significant subjects. The research is focused on technological innovation and environmental responsibility. The connection between 3D printing techniques and sustainable practices in construction, presents a rich landscape for exploration, with potential for groundbreaking insights. The timeliness of this investigation is underscored by the current emphasis on sustainable solutions in the construction industry in the transformative capabilities of 3D printing. The intersection of these two hot-topic issues amplifies the research's importance, promising not only to contribute to the academic society but also to offer practical implications. The thesis, aims to make a meaningful contribution to the scholar discussion and address real-world challenges within the context of contemporary technological and environmental imperatives.
<b>8. Significance of the topic and clarity of problem statement</b>
<b>Very good</b>
The addressed issue is novel, representing a natural progression derived from the ongoing global research findings. The Author has adeptly identified gaps and limitations in existing studies, establishing a

<sup>1</sup> Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.



rational foundation for his research objectives. The clarity with which the researcher delineates the deficiencies of prior work contributes to a well-defined problem statement. This precision not only underscores the significance of the chosen topic but also enables a transition into the delineation of research goals. By systematically acknowledging the constraints of previous achievements, the Author not only enhances the scholarly dialogue but also sets a clear trajectory for their investigation. The strategic articulation of these aspects attests to the researcher's acumen in presenting a focused and relevant problem statement, aligning the study with the forefront of contemporary research in a coherent form.

### 9. Knowledge of existing literature

#### Very good

The author of the dissertation demonstrated a well understanding of the literature, skillfully incorporating a brief historical overview while analyzing the latest technological advancements. The depth of their knowledge is evident throughout the papers, as they navigate various literary sources with finesse, establishing a strong foundation for their arguments. The historical context provided adds richness to the overall narrative, enhancing the reader's understanding of the subject matter. Moreover, the author exhibits a keen awareness of recent technological developments, offering insightful analyses and critiques. The synthesis of historical perspectives and contemporary insights reflect the author's comprehensive understanding of the topic. Moreover stated research hypothesis are the reasonable extension of previously conducted research by previous scientists.

### 10. Choice of methods and technical soundness

#### Very good

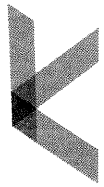
The selection of scientific methods in this research aligns with the stated objectives, showcasing a thoughtful and deliberate approach. The methods chosen are well-suited to address the research goals set forth in the dissertation, and the execution of these methods has proven effective in attaining the intended outcomes. The results obtained have been analyzed, demonstrating a commitment to technical rigor and a thorough understanding of the data. The researcher's proficiency in navigating the chosen methodologies is evident, as the analysis contributes meaningfully to the overarching goals of the study. The technical soundness exhibited throughout the research process underscores the reliability and validity of the findings.

### 11. Quality, originality and significance of the results

#### Very good

The experimental inquiries undertaken in this study are notably enriched by complementary numerical analyses, reinforcing the high quality of the obtained results. This integration of experimental and numerical methodologies not only substantiates the credibility of the findings but also attests to the thoroughness of the research approach. The commitment to incorporating diverse analytical techniques enhances the robustness and reliability of the results, contributing to the overall quality of the study. Moreover, the work stands out for its originality. This originality not only distinguishes the study within its field but also suggests a valuable contribution to advancing the broader scientific discourse. In essence, the research not only achieves high-quality results but also sets itself apart through its inventive and pioneering nature, signifying a commendable and impactful scholarly endeavor.

### 12. Quality of attached papers



#### Very good

The author of the dissertation has significantly bolstered the scholarly merit of his work by incorporating three notable publications into the research. Notably, one of these publications graces the pages of the esteemed journal *Construction and Building Materials*, widely recognized and respected within the academic community. The inclusion of a publication in such a prestigious journal attests to the author's commitment to engaging with high-impact academic platforms, indicative of the substantive quality of their work. Furthermore, the author fortifies his research by featuring two additional publications in the journal *Materials*, a periodical that comfortably resides within the second quartile (Q2) of scientific journals. This strategic selection of journals demonstrates the author's discerning approach to disseminating their findings, ensuring their work reaches a broad academic audience while maintaining a high standard of peer review. Altogether, the incorporation of these publications underscores the author's dedication to contributing valuable insights to the field, leveraging reputable platforms to enhance the credibility and impact of their research.

#### 13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

##### Excellent

The doctoral thesis excels on multiple fronts, demonstrating a comprehensive understanding of the research process. The identification and definition of the research problem are commendable, providing a solid foundation for the study. The selection of research methods aligns seamlessly with the research objectives, resulting in a robust and well-executed investigation. The achievement of the stated research goals is reflected in the high-quality results, analyzed and published in respected journals. The incorporation of both theoretical and practical dimensions, exemplified by the utility pattern, underscores the researcher's holistic grasp of the problem. The work stands out as an excellent embodiment of scholarly endeavors, with each criterion fulfilled at the very high level. The commitment to excellence is evident at every level, making this thesis an outstanding contribution to the academic field. While the strengths are abundant, it's crucial to acknowledge that, like any scholarly work, potential areas for refinement could be identified through ongoing discussion and iterative feedback.

#### 14. Questions and comments

1. It is known that in various cementitious composites the adhesion of the layers is assured by the chemical and physical behaviour. The Author mainly focused on setting time and the wet-to-wet cementitious material application. However by evaluating also the layer surface morphology it can be predicted the potential adhesion within the layers of old-to-new (hardened already with fresh mixture) concrete. Has the Author tried to evaluate the properties of such behaviour, fresh mixture applied on hardened already layer. And Has the author analyse the properties of the surface in terms of morphological parameters, not only the surface area but also the others?
2. Does the Author see the potential of expanding this technology in this shape to make it usable for ordinary concretes containing 16mm or even 32 mm coarse aggregates? What should be done to make it possible?
3. What future of 3D printing of cementitious composites does the Author expect? Is it going to be a still and constant improvement in devices/machines or rather modification of composites mixtures leading to be more prone to printing instead to traditional casting into the moulds.

#### 15. Conclusion

Faculty of Mechanical Engineering  
Brno University of Technology

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.

YES

**16. Date and signature**

06/03/2024

Please note

- A. Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.
- B. E-mail the completed form to: [Klara.Javorcekova@vut.cz](mailto:Klara.Javorcekova@vut.cz)

## Principal supervisor's final report on the PhD study

<b>1. PhD candidate</b>
Name of PhD candidate / E-mail: Ing. Arnošt Vespalec / Arnost.Vespalec@vut.cz
<b>2. Name of PhD programme</b>
Name: Machines and Equipment
<b>3. Title of PhD thesis</b>
Title: 3D Construction Printing of Coarse Aggregate Cementitious Composite
<b>4. Principal supervisor</b>
Title and name of principal supervisor / E-mail: doc. Ing. Daniel Koutný, Ph.D./ Daniel.Koutny@vut.cz
<b>5. Co-supervisor</b>
Title and name of co-supervisor / E-mail: doc. Dr.techn. Ing. Jan Podroužek / Jan.Podrouzek@vut.cz / Ing. David Škaroupka, Ph.D./ skaroupka@fme.vutbr.cz
<b>6. Stays at other institutions (min. 7 days)</b>
Institution / Country / From / To
<b>7. Teaching activities</b>
Course name / Total number of hours CAD – Basis (3CD) / 156 Design project (ZIP) / 26 Plastic prototypes (ZPP) / 78 Computer Modelling - Alias Design (YPA) / 39 Design and CAD (4KC) / 78 Team project (ZKP) / 13 CAD Modelling (ZM1) / 32
<b>8. List of main publications</b>
Bibliography references cited according to the norm ISO 690. If appropriate, impact factor must be specified.  VESPALÉC, A.; PODROUŽEK, J.; BOŠTÍK, J.; MIČA, L.; KOUTNÝ, D. Experimental study on time dependent behaviour of coarse aggregate concrete mixture for 3D construction printing. <i>Construction and building materials</i> , 2023, 376 (5), pp. 1-12. ISSN: 0950-0618. Journal impact factor = 7.4, Quartile Q1, Citations = 2.

VESPALEC, A.; PODROUŽEK, J.; KOUTNÝ, D. DoE Approach to Setting Input Parameters for Digital 3D Printing of Concrete for Coarse Aggregates up to 8 mm. *Materials*, 2023, 16 (9), pp. 1-17. ISSN: 1996-1944.

Journal impact factor = 3.4, Quartile Q3.

VESPALEC, A. NOVÁK, J. KOHOUTKOVÁ, A. VOSYNEK, P. PODROUŽEK, J. ŠKAROUPKA, D. ZIKMUND, T. KAISER, J. PALOUŠEK, D. Interface Behavior and Interface Tensile Strength of a Hardened Concrete Mixture with a Coarse Aggregate for Additive Manufacturing. *Materials*, 2020, 13 (22), pp. 1-20. ISSN: 1996-1944.

Journal impact factor = 3.623, Quartile Q2, Citations = 11.

#### **9. Assessment of the supervision process**

##### **Very good**

Justification for evaluation: Basic communication with the student focused on the course of doctoral studies took place on a regular weekly basis. More detailed discussions of the topic of the dissertation, including planned experiments, partial results and proposals for further steps, then took place approximately every four to six weeks. In addition to regular meetings, internal reviews of prepared publications and discussions on additional evaluation of results and text modifications took place. The student also actively discussed specific topics of prepared studies with supervisor specialists and other experts in the field of material sciences. Throughout the study, communication went smoothly, and certain disruptions and slowdowns in activities only occurred during the COVID-19 pandemic. The extension of the study beyond the standard time was also due to the effort to publish the results in first-quartile journals, which involved a demanding and lengthy review process in one of the journals.

#### **10. Assessment of the candidate's ability to work independently**

##### **Very good**

Justification for evaluation: The doctoral student worked actively and independently while solving the thesis topic. From the beginning of his studies, he was successively involved in three applied research projects. During the study, he showed that he can independently plan experiments, evaluate the results and prepare research papers. Within his dissertation, he also demonstrated that he is able to identify the research gaps, establish hypotheses, realize appropriate verification methodology and discuss achieved results.

#### **11. Assessment of the contribution that the research makes to knowledge in the field**

##### **Very good**

Justification for evaluation: The doctoral student focused the research on the three-dimensional concrete printing (3DCP) and enhancing its effectivity by use of cementitious composite with larger aggregates of 8 mm. The focus was on three aspects, intra-layer strength, green strength and optimization of controllable parameters for buildability. Three studies were published describing the effects of larger aggregates on individual aspects. First study showed that intra-layer strength decreases with the rising time delay between layer deposition, while larger aggregates does not influence intra-layer strength. Shorter times between 5-10 minutes allows intra-layer pore and moisture migration leading to higher strength, and larger aggregates influence crack propagation. The second study reveals unexpected negative cohesion slope for early stage mixture with coarse aggregates and that the mixture with coarse

aggregates cannot be reliably pumped in the early stage up to 5 min. The third study describes the computational model for buildability prediction based on controllable parameters. Within the simulated range of parameters showed that extrusion width is the most influencing factor in achieving higher buildability with coarse aggregates cementitious composites. Such simulation can highly reduce material waste in comparison to the widely used trial-error approach.

#### 12. Other comments

Project on which student participated or led during his PhD studies:  
 2018 – 2021, TAČR EPSILON TH03010172, Research and development of a 3D printer for use in the construction industry, team member  
 2023 – 2025, TAČR TREND FW06010034, Multicomponent mixture and application technology for 3D printing in the construction industry, team member  
 2022 – 2025, TAČR TRANSPORT CK03000240, Development of cement composites and process parameters for 3D printing of elements meeting the requirements of transport structures, team member

#### 13. Conclusion

PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.

YES

#### 14. Date and signature

04/03/2024

Please note

- A. Evaluate categories 9 to 11 using the terms: *poor, acceptable, satisfactory, good, very good, excellent.*
- B. In each category 9 to 11 explain reasons for evaluation using between 100–200 words.
- C. E-mail the completed form to: [Klara.Javorcekova@vut.cz](mailto:Klara.Javorcekova@vut.cz)