# Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

# Graduation Plan: All tracks

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| Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest. |

The graduation plan consists of at least the following data/segments:

| **Personal information** | |
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| Name | Jordy van Eijk |
| Student number | 4566297 |

| **Studio** | | |
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| Name / Theme | Compuational Design: Acoustics by additive manufacturing | |
| Main mentor | Martin Tenpierik | Climate design |
| Second mentor | Michela Turrin | Computational Design |
| Argumentation of choice of the studio | Acoustics is something that fascinated me during the Bachelors and Masters. It is something I would like to specialize in. Besides the acoustical part I really like to work with parametric design. This seemed like a good project in which the two could be combined. | |

| **Graduation project** | |
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| Title of the graduation project | Reduction of the geometrical complexity of Helmholtz resonators |
| **Goal** | |
| Location: | The case study for this thesis will be a small meeting room in the faculty of architecture at the TU Delft. This case study is mainly chosen for convenience. The location is easily accessible and the small size of the room makes it so that only a small amount of the resonant absorber is needed in order to perform the in situ tests with. |
| The posed problem, | Due to the rise of additive manufacturing the production of complex geometries has become more available. In room acoustics this has resulted in the research of resonant absorption trough additive manufacturing. Resonant absorbers are very effective at absorbing low |

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| | frequencies and can do so with a much thinner material compared to porous absorbers. These resonant absorbers are very reliant on their geometry. The use of additive manufacturing in acoustics made it possible to make these resonators very precise and increase the geometric complexity to improve the performance.<br><br>This increase in complexity ties efficient resonant absorption to additive manufacturing because most other manufacturing techniques are not able to produce this type of geometry while also meeting the other requirements set by the resonator. The increased complexity of the elements and the associated production techniques make resonant absorbers more of a niche product and not widely available. Additive manufacturing is rapidly increasing its suitability for large scale production but at this moment is has the downside that it does not scale very well to larger scale production. If a product would be mass produced additive manufacturing does not increase in speed. Other production methods do benefit from mass production resulting in the decrease of cost for the absorbers and therefore a wider availability. |
| research questions and | The main research question of this thesis will be: How can an acoustic panel based on cavity resonators be designed with reduced geometrical complexity while retaining a broadband high absorption coefficient for low frequencies? |

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| | Sub questions regarding background knowledge:<br><br>- Which room acoustic variables can be used to decide upon the acoustic quality of an office?<br>- What are the main types of acoustic absorbers available for single material broadband acoustic absorption?<br>- What type of production techniques are available and practical to use when manufacturing resonant absorbers?<br>- In recent years, What research has already been done into resonant absorbers for room acoustics aimed at high absorption over multiple octave bands?<br>- What computer controlled manufacturing techniques are suitable for the production of resonant absorbers?<br>- What processes are needed to be included in a digital design workflow for the design of resonant absorbers?<br><br>Sub questions regarding the development of the design:<br><br>- What frequency range needs to be absorbed?<br>- What level of absorption coefficient can be seen as sufficient?<br>- Where can the complexity of the geometry be reduced and where is the complexity a necessity for the functioning of the resonator?<br>- How can the location of the resonator orifices be optimized? |

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| | Sub questions regarding the assessment of the design:<br><br>- How do the internal boundaries of the cavities affect the performance of the resonators?<br>- Does the reduction of the geometry result in a sufficient increase of the absorption?<br>- Has the reduction in geometrical complexity resulted in availability of additional production techniques? |
| design assignment in which these result. | The aim of this thesis is to see if there is a possibility to reduce the geometrical complexity of a panel based on Helmholtz resonators providing broadband absorption for low frequencies. Production of large panels by the use of additive manufacturing allows for a lot of freedom in geometry but increases the price and reduces the availability. If the complexity of the geometry is reduced more production techniques become available. Therefore research needs to be done to see which techniques become available and if they can outperform additive manufacturing. In order to be able to design this absorber a good understanding of the possible absorbers is needed.<br><br>The end goal of this thesis is to produce a workflow for the design of an acoustic absorber with reduced geometrical complexity compared to current examples. The inputs will be the targeted frequency or frequency band. The output is the geometry that can serve as the input for the chosen production technique. |
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## Process

### Method description

The first part of this thesis will consist of a literature review. In this part the main principles of room acoustics will be discussed to gain a solid theoretical background for the rest of the project. The second part of the literature review looks at the possible resonators that can be used in a panel for acoustic absorption. Sound measuring techniques are discussed in the third part of the first chapter. The fourth part of the literature review consist of work from other authors already done regarding resonant absorption and additive manufacturing. The fifth part of this report is concerned with an overview of manufacturing techniques able to make the resonator panels. The last part of the literature review consist of an overview of the possible processes of the computational workflow produced in the second part of this thesis.

After the P2 presentation a workflow will be developed for the design of the resonant panels. The softwares Rhino and Grasshopper will be used for the generation of the geometry. The simulations will be performed within COMSOL. An attempt will be made to connect the softwares to create a seamless design workflow from problem frequencies to geometry for the resonant absorber.

When the simulations give the desired results the step will be made to physical tests. The designed workflow will produce the geometry which can be made by the chosen production method. The simulated results will be verified with impedance tube tests.

If there is sufficient time left and the panels perform well in both the simulation and the impedance tube an attempt will be made to produce a full scale model which can be tested in situ. This test can be a proof of concept and can validate the results produced form the workflow designed within Grasshopper and COMSOL.

### Literature and general practical preference

Wortmann, T. (2018, July). *Efficient, Visual, and Interactive Architectural Design Optimization with Model-based Methods* (Thesis). Singapore University of Technology and Design. https://doi.org/10.13140/RG.2.2.15380.55685

van der Eerden, F. (2000, November). *Noice reduction with coupled prismatic tubes* (Thesis). University of Twente. https://research.utwente.nl/en/publications/noise-reduction-with-coupled-prismatic-tubes

Kinsler, L. E., Frey, A. R., Coppens, A. B., & Sanders, J. V. (2000). *Fundamentals of Acoustics*. Wiley.

Groover, M. P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes and Systems* (4th ed.). Wiley.

Godbold, O. (2008, April). *Investigating broadband acoustic adsorption using rapid manufacturing* (Thesis). Loughborough University. https://repository.lboro.ac.uk/articles/thesis/Investigating_broadband_acoustic_adsorption_using_rapid_manufacturing/9517877

Ermann, M. (2015). *Architectural Acoustics Illustrated*. Wiley.

Cox, T. J., & D'Antonio, P. (2009). *Acoustic Absorbers and Diffusers* (2nd ed.). Taylor & Francis.

Hudson, R. (2010). *Strategies for parametric design in architecture. An application of practice led research* (Thesis). University of Bath.

## Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The relation between my topic and the master track building technology is: Room acoustics are a essential part of a comfortable indoor climate. Creating more accessible options for designers can increase the number of project for which a suitable option is available. This project can be linked to two of the four pillars of building technology: Climate design for the room acoustics and the resonator principles. Computational design for the production techniques and the workflow that will be the result of this Thesis.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

The societal and professional relevance of this thesis can be seen in the workflow produced. This workflow can make resonant panel absorbers more accessible for a wider audience. The reduction of the geometrical complexity makes way for a wider variety of production methods. This includes production methods that could produce the product faster and cheaper.

The scientific relevance of this thesis can be seen in the reduction of geometrical complexity. A lot of research has been done investigating how to increase the performance of existing resonators (Godbold, 2008)( Gommer, 2016). This generally leads to an increase in complexity of the resonator geometry. The reduction of the panel thickness is also a large topic within the field of acoustic by additive manufacturing (Cai, 2014)(Setaki, 2014). Again the complexity is increased. Increasing the complexity binds the product to a specific production method. By looking into the reduction of the geometrical complexity a wider array of production techniques become available.

A second scientifically relevant part this Thesis is the aims to investigate is the influence of the partition walls that separate the cavities of two Helmholtz resonators on the performance of those resonators. If the partitions between the cavities of the resonators are deemed unnecessary the geometrical complexity of the panels could be reduced significantly.