# 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** | |
|---|---|
| Name | Andrea Fumagalli |
| Student number | 4736974 |
| Telephone number | |
| Private e-mail address | |

| **Studio** | | |
|---|---|---|
| Name / Theme | Building Technology / Sustainable Design Graduation Studio | |
| Main mentor | Dr. ir. Michela Turrin | Design Informatics |
| Second mentor | Dr.ir. Martin J. Tenpierik | Climate Design |
| Argumentation of choice of the studio | The selection of the topic within the master track of Building Technology matches with my desire to design and built energy-efficient buildings with passive strategies in my professional career. With this research, I would like to learn new computational skills and develop my interest in climate design. | |

| **Graduation project** | |
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| Title of the graduation project | **Energy Space Layout:**<br>Designing space layout with optimized energy performance |
| **Goal** | |
| Location: | The Netherlands |

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| The posed problem, | **Problem Statement**<br>The current situation in the Netherlands depicts the necessity to build energy-efficient residences for young people, that cope with the housing crisis and meet the *Energy Performance of Buildings Directive.* Given this purpose, sustainability needs to be addressed at early stages by a performance-driven design.<br><br>The space layout design is one of the main tasks at the beginning of the project and it involves the geometrical definition of the functions and their relationships. Its development is complex because it deals with a large number of criteria to satisfy, but it is decisive for the result of the project. For example, space layout affects the energy performance of the building, because different functions and activities require different comfort zones and energy demands. As stated in "*A Review on Automatic Generation of Architectural Space Layouts with Energy Performance Optimization" (Du, Turrin, Jansen, Dobbelsteen, & Biloria, 2018)*, studies have shown the importance of space layout for the improvement of different aspects of energy performance. However, literature depicts a lack of knowledge about the correlations between space layout and energy demand and a need for a design method, which integrates the energy performance at early stages *(Du, 2019).*<br><br>Performative Computational Architecture (PCA) is a computational approach to achieve performance-based design *(Sariyildiz, 2012)*. Following previous studies in the field of computational optimization applied to architecture, such as *"Design explorations of performance-driven geometry in architectural design using parametric modelling and genetic algorithms" (Turrin, Von Buelow, & Stouffs, 2011)*, this approach consists of 3 main steps: form generation, simulation and optimization. PCA makes use of parametric modelling and optimization algorithms to generate and explore different design options while dealing with the complexity of the project and its scarcity of information. PCA results to be not only a useful support to explore many design variants at early design stages, but also an innovative approach to investigate and generate knowledge about buildings performance. |

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| | As the problem states, only a few studies have combined the generation of space layout with energy-performance optimization (*Du et al., 2018)*. This thesis expects that the integration of Performative Computational Architecture (PCA) to the space layout design might be a promising solution to fill the gap in the field of energy-efficient design. In particular, the problem is addressed by providing **initial insights** about space layout design within a computational method and by applying the energy optimization on a **design proposal.** |
| research questions and | **Main research question**<br>• To what extent does **space layout design** affect the **energy demand** of a co-living residence for young professionals in the Netherlands, within a **computational method** that makes the knowledge explicit and available for further projects?<br><br>Computational method refers to the framework of PCA divided into 3 phases: (1) form generation via a parametric model, (2) assessment of the energy demand, (3) application of the optimization algorithm to find sub-optimal design variants and support the decision-making.<br><br>Space layout design involves the initial geometrical definition of floor plans. The process focuses on the internal functions and their relationship with the building.<br><br>The choice of the building typology needs to be in tune with the main research objective, allowing for a variety of activities and freedom in the layout. The co-living residence for young professionals is a building that provides multiple functions for young people, to let them live and work in the same place. People can decide how many modules to rent and, thus, the layout is built freely, fulfilling their needs. A representative typology for this case study is a building block with the following characteristics: a central courtyard to ensure passive strategies (such as daylight and natural ventilation), a slightly compact shape to increase the shared walls between different functions and a subdivision in modules to build the internal layout freely. |

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| | **Research sub-questions**<br>• Which **functions** and **spatial parameters** (location, height, depth, window to wall ratio) have the highest impact on the final energy demand, with regards to space heating, space cooling, and lighting?<br><br>• Which values of **heat capacity** and **thermal insulation** distributed throughout the space layout have the highest impact on the energy with regards to space **heating** and **cooling**?<br><br>• How can the **computational method**, which assists space layout design in minimising the energy demand of buildings in the Netherlands at early stages, make the embedded knowledge explicit and available for further projects? Which **limitations** and **potentials** does it imply? |
| design assignment in which these results. | **Final assignments**<br>• General and explorative knowledge about the correlations between space layout and energy performance of a co-living residence for young professionals in the Netherlands, with the aim to reduce its energy demand.<br>• A design proposal of the space layout with optimized energy-performance, by testing the computational workflow applied on a young professional residence, selected as an instrumental case study, in the Netherlands. |
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## Process

### Method description

The thesis aims to explore the correlation between space layout and energy performance of buildings, through the application of Performative Computational Architecture. As a result, this research would like to contribute to the knowledge about energy-efficient design.

### Research Design

The methodology approach is intended to be exploratory. Through the application of computational means, it is possible to explore and test how different variables of space layout have an impact on energy demand. Hypotheses on this correlation are drawn at the end in order to provide initial insights and ideas that can be further investigated by explanatory research. Selecting a building as an instrumental case study fits the research objectives because the priority is given to the generalizations of the theory and its applicability, rather than to the real case (Groat & Wang, 2013).

For this thesis, an empirical strategy is assumed. This study carries a research-through-design methodology to extract knowledge from the application of simulations to a building case study. Within this methodology, PCA is intended as a tool of the learning process. The use of computational means plays a crucial role because it allows to generate more variables of the layout, to energetically optimize them and to analyse them systematically. The purpose is deriving possible correlations while observing the simulation results. However, to draw valid conclusions, scientific and systematic observations are needed. (Fellow & Liu, 2014) Hence, the following tactics are assumed:

- A building with a free and generic layout is selected as an instrumental case study, stating its limitations.
- The use of a parametric model allows developing design variants systematically.
- The research objectives clarify the evaluation criteria about the correlation between layout and energy performance of the building
- Literature review frames the research with theory and hypothesis on energy-efficient strategies applied to the layout.
- The computational workflow is developed and explained in order to replicate and improve the process.
- Initial insights are extracted to be further investigated.

## Process

*Figure 0.1* shows the process that this thesis follows to fulfil the research objective. The process can be subdivided into 3 phases: Background research, Performative Computational Architecture, Evaluation and Proposal.

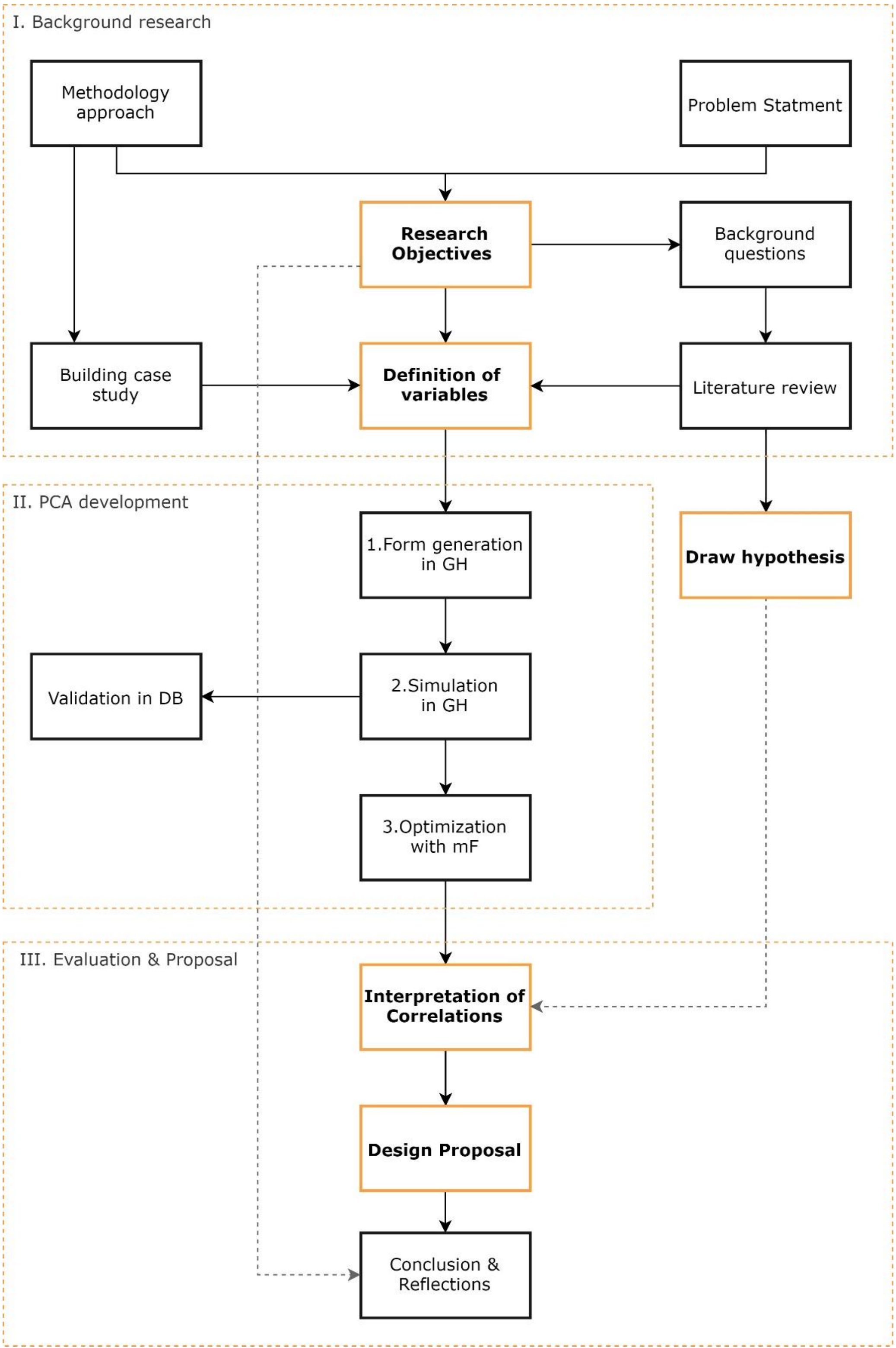


*Figure 0.1: Methodology process. Source: Author.*

*Background research*

The two starting points are the problem statement and the methodology approach. The first one points out Performative Computational Architecture as a possible solution to the lack of research about energy optimization of space layout. The latter defines the methodology as research through design with an exploratory intent. Research objectives and questions are drawn consequently, focusing on the influence of space layout to the energy performance within a computational workflow. Afterwards, a literature review is carried on to build a theory and to draw consistent hypotheses. In parallel, a building is selected as a case study and analysed. These two steps define the variables of space layout to explore and provide the boundary conditions.

*Performative Computational Architecture*

Successively, the PCA process is implemented with the related computational tools. The parametric model is built in Grasshopper to generate more design options, Ladybug and Honeybee simulate their energy performances, and ModeFrontier applies the optimization algorithm. As a result, the algorithm finds the combinations of variables with the minimum energy demands, in respects of heating, cooling and lighting.

Since the layout depends on the envelope's performance and on the HVAC system, four reference models are built, respectively with low or high thermal properties and with mechanical or mixed ventilation. Later on, the following variables are investigated:

- Plot's size and orientation, Courtyard's dimensions and overhangs' extensions as passive strategies affecting the internal layout.
- location, height, width, depth and window-to-wall ratio of the functions as spatial parameters.
- heat capacity, thermal insulation as thermal parameters of the partition walls, ceilings and floors.

Finally, the models will be optimized in respects of three objectives contemporary: heating, cooling and lighting demands. Taking into consideration all three demands, the multiple-objectives optimization is expected to find not only the optimal solutions for each of them, but also for the total energy demand. The total energy demand results to be the common ground to compare different design variants.

*Evaluation & Proposal*

Through the comparison with the theory and the hypotheses from the literature review, the data is critically interpreted to explore the impact of space layout to the energy demand. ModeFrontier makes use of data analytics tools to establish correlations coefficients between the variables and the objectives. A series of computational components in Grasshopper is intended to visualize and represent the findings in geometrical diagrams.

After post-processing the data, initial correlations are established and applied on the building case-study. Consequently, the thesis carries on a design proposal of a space layout with optimized energy-performance for a co-living residence. Finally, given the research objectives, conclusions and reflections are drawn.

## Literature and general practical preference

The references listed below are used for the problem statement, the research methodology and the literature review:


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## Reflection

This thesis explores the impact of space layout on the energy demand of the building in order to achieve performance-based design. The topic is related to the master program in *Architecture* because it contributes to energy-efficient and future-proof houses. Indeed, the aim is providing initial insights to understand which spatial parameters of the internal configuration are effective in reducing the building energy consumption. The topic is then related to *the Building Technology* track because it explores the application of innovative techniques for a more sustainable building sector. Indeed, Performative Computational Architecture (PCA) is applied and investigated as a computational framework. When combined, parametric modelling and optimization algorithms show potentials to support and explore performance-driven design.

### Societal relevance

This graduation research contributes to the sake of society because it tackles to need for designing energy-efficient houses for young professionals. The built environment plays a significant role in mitigating climate changes, due to its high energy use and carbon emissions (Global Alliance for Buildings and Construction et al., 2018). For this reason, the European Union has established norms to force energy-efficient constructions and renovations from 2020 onwards. Moreover, the housing market in the Netherlands depicts a need for new residential buildings. As stated in the report from the Dutch Association of Estate Agents *(NVM, 2018)*, most of young and older people cannot afford new houses. Therefore, designing buildings, where people can live together, might cope with the housing crisis in the Netherlands.

### Scientific relevance

This study has a scientific relevance because it explores the gap of knowledge about designing energy-efficient layouts. Studies have proven the influence of spatial configuration on the energy demand of the building, but only a few of them has applied energy-optimizations (*Du et al., 2018)*. More specifically, computational methods have been utilized to generate functional layouts, whereas energy optimizations have been explored in façade design. Literature depicts a lack of understanding the correlation between space layout and energy performance and a need for a proper design workflow *(Du, 2019).* Therefore, the application of energy-optimization methods to space layout is promising to fill this gap in the field of research. This thesis aims not only to provide theoretical insights for further investigations, but also to make this knowledge available to other designers via a computational workflow

## Time planning

The image below presents the expected workflow over the following semester for the development of the thesis.

| | | |
|---|---|---|
| **Master Thesis** | **0h** | **28%** |
| **Introduction** | **0h** | **100%** |
| Problem Statment | 0 | 100% |
| Methodology | 0 | 100% |
| Research Questions | 0 | 100% |
| **P1** | **0h** | **100%** |
| **Literature Review** | **0h** | **100%** |
| Energy & Comfort regulati... | 0 | 100% |
| Energy efficient stretegies | 0 | 100% |
| **Optioneering** | **0h** | **100%** |
| Form Generation | 0 | 100% |
| Simulation | 0 | 100% |
| Optimization | 0 | 100% |
| Hypothesis | 0 | 100% |
| Definition of Variables | 0 | 100% |
| **P2** | **0h** | **0%** |
| **Building Case Study** | **0h** | **0%** |
| Building functions | 0 | 0% |
| Climate Analysis | 0 | 0% |
| Drawings | 0 | 0% |
| **Form Generation** | **0h** | **0%** |
| Form Generation | 0 | 0% |
| **Simulation** | **0h** | **0%** |
| Simulation | 0 | 0% |
| **Validation in DB** | **0h** | **0%** |
| Set up model | 0 | 0% |
| Simulate | 0 | 0% |
| Compare | 0 | 0% |
| **Optimization** | **0h** | **0%** |
| Optimization | 0 | 0% |
| **P3** | **0h** | **0%** |
| **Intrepretation** | **0h** | **0%** |
| Analysis Data | 0 | 0% |
| Correlations | 0 | 0% |
| **Design Proposal** | **0h** | **0%** |
| Concept | 0 | 0% |
| Simulation | 0 | 0% |
| Representation | 0 | 0% |
| **P4** | **0h** | **0%** |
| **Conclusion** | **0h** | **0%** |
| Conclusion | 0 | 0% |
| Reflections | 0 | 0% |
| **P5** | **0h** | **0%** |