GRADUATION PLAN

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Background

Climate change is one of the most pressing global challenges of the 21st century, with human activities, particularly in urban areas, contributing significantly to greenhouse gas emissions. The built environment, encompassing buildings, infrastructure, and urban spaces, is a major contributor to climate change. The building sector accounts for about 30% of energy consumption worldwide and 26% of global energy-related emissions (IEA, 2023). As such, reducing energy consumption and improving the sustainability of buildings is critical for mitigating climate change.

Insulation plays a key role in reducing these energy demands by minimising heat loss during colder months and limiting heat gain during warmer months. Traditional insulation materials that do not adapt to environmental conditions are commonly used in building envelopes. However, fixed insulation materials are less effective at maintaining energy efficiency over time as they do not respond dynamically to changing temperature fluctuations and environmental conditions (Masoso & Grobler, 2008) (Pérez-Lombard et al., 2008). In contrast, switchable insulation systems, which can adjust their properties in response to external factors, have been shown to provide greater energy savings and improve indoor comfort compared to conventional fixed insulation (Cui & Overend, 2019).

Despite advancements in insulation technology, challenges remain in the long-term sustainability of building envelopes, particularly when it comes to recycling. Building materials are difficult to recycle due to the diverse and composite nature of the materials used in construction.
This problem is worsen by the fact that many building envelopes are composed of materials that cannot be easily disassembled or reused, leading to large quantities of construction and demolition waste that contribute to landfill burden (Finch et al., 2021). The lack of effective recycling methods for these materials presents a significant barrier to achieving circular economy goals and reducing the environmental footprint of the built environment.

This thesis aims to develop an easy to recycle building envelope that can enhance operational energy savings in a building. Easy recycling is achieved by making the envelope mono-material, enhanced energy savings is achieved by developing a switchable insulation. By addressing these issues, it is possible to not only reduce the environmental impact of buildings but also pave the way for more sustainable urban development in the face of ongoing climate change.

Problem statement

There is a goal to decrease the worldwide greenhouse gas emissions with 43% by 2030 ("Paris Agreement," 2016) and the building sector has a large share in the worldwide energy consumption.
Switchable insulation could be a promising solution for improving the energy efficiency of buildings. However, current building envelopes with switchable insulation are not designed with recyclability in mind and therefore are hard to recycle.

Objective

Main objective:
Developing a responsive façade element with switchable insulation that is easy to recycle

Subobjectives:
1. Define the optimal insulation range required for the switchable system

2. Identify the design requirements for the façade element

3. Determining the switching mechanism that is needed to change the thermal resistance

4. Select a suitable material that supports functionality and recyclability

5. Design the internal infill pattern to achieve the desired insulation range

6. Test if the desired performance range has been achieved

Research question

Main question

How to engineer a mono-material façade element that can adapt its thermal insulation value?

Sub-questions:

1. What is the required insulation range for the switchable system?

2. What are the design requirements for the façade element?

3. What switching mechanism is suitable for changing the thermal resistance?

4. What material supports both functionality and recyclability?

5. How should the infill pattern be designed to achieve the insulation range?

6. Has the desired performance been achieved?

Approach & Methodology

Phase 1: Literature review

In this phase knowledge is gathered on materials, requirements for façades, 3D and 4D printing techniques, mono-material façades, different patterns for infill (de Rubeis et al., 2024), and switchable insulations (Fawaier & Bokor, 2022). This knowledge serves as foundation for the design assignment of this thesis. Scopus and Google Scholar will be used to find suitable academic articles. For finding a suitable material the software ANSYS Edupack is being used.

In this phase the following sub-questions will be answered:

1. What is the required insulation range for the switchable system?

Phase 2: developing the conceptual design

In this phase the conceptual design is developed. This is done by first setting the design criteria. After that, some strategies are explored to change the thermal resistance of a facade in its application. Different strategies are explored to create flexibility. Finally, in this phase, a selection for material and actuator is made.

In this phase the following sub-question will be answered:

2. What are the design requirements for the façade element?

3. What switching mechanism is suitable for changing the thermal resistance?

4. What material supports both functionality and recyclability?

Phase 3: developing the initial design

This phase builds upon the knowledge gathered in the previous two phases. Using the conclusions from the previous phases, an different design strategies are developed.

Research by design is being done, meaning this phase is iterative in nature. It follows the following cycle: build, measure, learn by Ries (2011).

BUILD

Designing will be done through sketching and 3D modelling in Rhino3D. Prototyping will be done using a 3D printer in the LAMA Lab at the Faculty of Architecture and the Built Environment at Delft University of

Technology. The printing technique being used is Fused Deposition Modelling (FDM). The slicer software used is from Bambu Studio and Cura.
Testing the thermal conductivity will be done through a FEA simulation. For this, COMSOL Multiphysics is used.

MEASURE
After and during the building phase, the following questions will be asked:
- Does the prototype move like it was intended?
- How sensitive is it to production errors?
- What is the Rc value per 100mm?
- How long does it take to print it?
- Is there potential for a rapid production method (is it extrudable)?
- Does the design require a lot of energy in its application?

LEARN
This cycle ends with the learnings that will be taken into account in the next design iteration.

In this phase the following sub-question will be answered:
5. How should the infill pattern be designed to achieve the insulation range?
6. Has the desired performance been achieved?

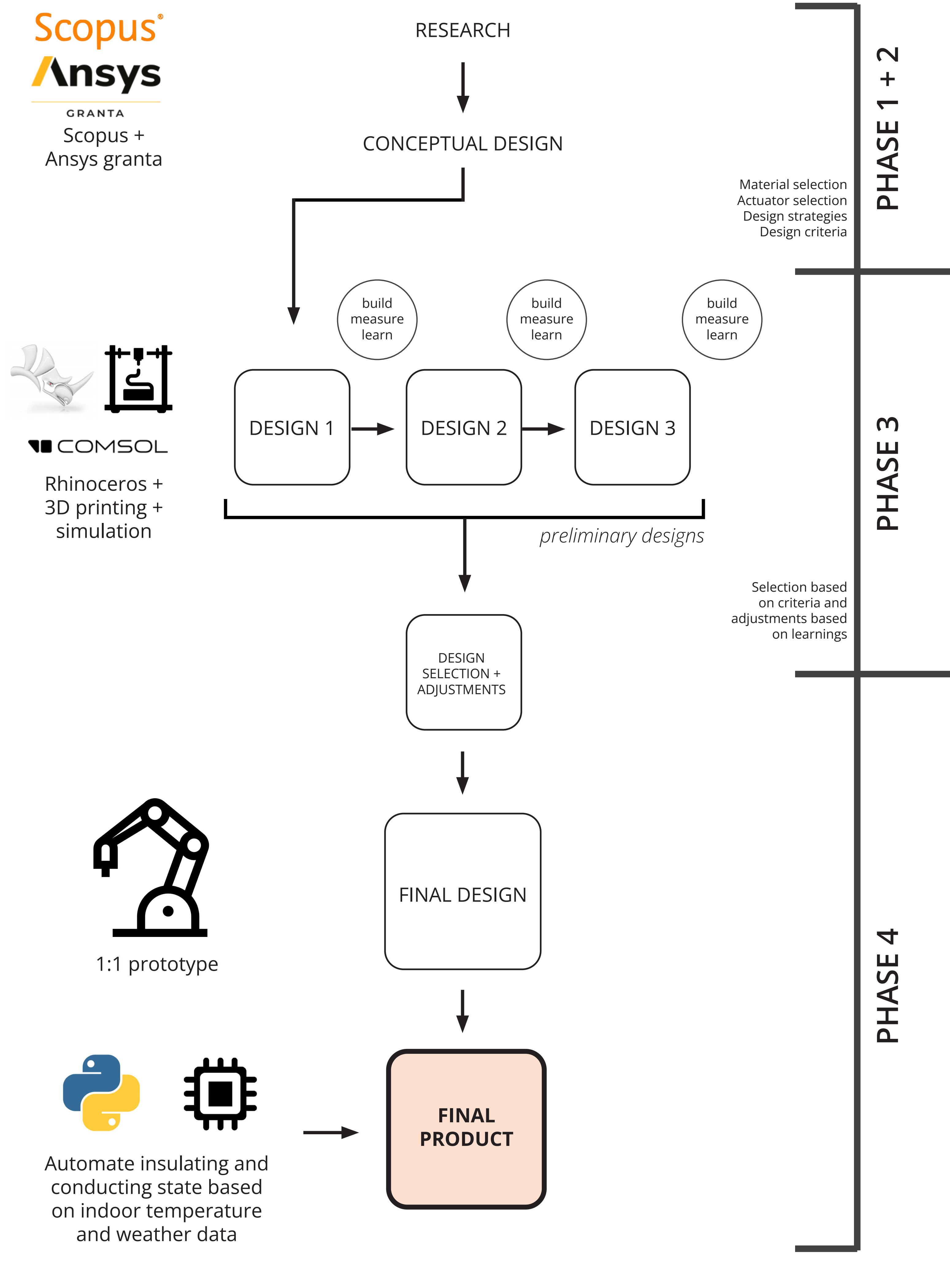
Phase 4: Final design
In this phase a selection is made from the developed design directions from the initial design phase. The selected design is further developed into a proof of concept.

This phase ends with a conclusion, reflection and recommendations for further research. The aim of this is to bring closure to the research project, while offering insights and directions for continued exploration and improvement in the subject matter.

Relevance
Society
The developed product in this graduation work aims to contribute to lowering CO_2-emission by reducing energy usage in buildings. This is in line with the Paris Agreement to limit the temperature increase to 1.5°C above pre-industrial levels by decreasing the greenhouse gas emissions with 43% by 2030 compared to 2015 ("Paris Agreement," 2016). In addition, the product is easy to recycle, which is increasingly important in a circular economy. The societal impact has the potential to be great since the product developed is scalable in nature.

Science
Furthermore, this work introduces a novel way to create switchable insulation suitable to the circular economy by using auxetic structures. Therefore, a new application of auxetic structures is also shown. Additionally, the mistakes made in developing the product are valuable lessons for anyone working on a similar design task.

Industry
To conclude, this work introduces a new façade for the industry and shines light on the potential and advantages of switchable insulation for the built environment. Architects get a new tool to achieve sustainable buildings and comfortable indoor environments for the buildings they design.



Scopus
Ansys
GRANTA
Scopus +
Ansys granta
RESEARCH
CONCEPTUAL DESIGN
Material selection
Actuator selection
Design strategies
Design criteria
PHASE 1 + 2
build
measure
learn
DESIGN 1
DESIGN 2
DESIGN 3
COMSOL
Rhinoceros +
3D printing +
simulation
preliminary designs
PHASE 3
Selection based
on criteria and
adjustments based
on learnings
DESIGN SELECTION + ADJUSTMENTS
FINAL DESIGN
1:1 prototype
FINAL PRODUCT
Automate insulating and
conducting state based
on indoor temperature
and weather data
PHASE 4

PRELIMINARY DESIGN

DESIGN X