P2 Research Outline

Sustainable atrium design

And the effect of plants on indoor climate and energy performance


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1. Background

1.1 Context of the research project

This research is about sustainable atrium design and the integration of plants for improved thermal conditions and energy performance. It tries to shed light on the question whether plants could be used as a type of climate device for maintaining a comfortable indoor climate. Until this time, architecture and horticulture have been quite separated domains. Greenhouses have been the only building typology that combined both domains. However, the building was still only in favour of the plants and not the other way around. This research, on the other hand, tries to find out to what extend plants can be used in favour of the building.

Atriums are often a central part of a building. It is mostly used as a central part for movement through the building. There are all kinds of special designs with great architectural attraction, such as the British Museum in London and the Scheepvaartmuseum in Amsterdam. This is a well-tested strategy for refurbishments of old buildings. A courtyard, for example, with old, poorly insulated facades may be covered with a roof so that it becomes an atrium. The façade surface is then minimized, which may help bringing down energy losses. It may also be done to create extra indoor space when a building's program has to be expanded.
When atriums need more decoration, plants are often brought in to increase the appeal of the space. It is the primary function of indoor plants. However, it is researched that plants may also have a positive influence on the productivity of people and reduction of absence through illness. (Klein Hesselink, Loomans, Groot, & Kremer, 2006) This could mean that companies may save money when making sure that their offices are sufficiently planted. This knowledge is currently applied in office buildings such as the FinanzIT office in Hannover and in hospitals such as the Isala Klinieken in Zwolle.

When putting plants in a building, one has to be sure that the climate conditions are not only right for people, but also for the plants. Many studies about optimum growing conditions have already been done in agriculture and horticulture. These conditions can be maintained well in a greenhouse. Arie Taal presents an Inverse Control Strategy for the conditioning of a greenhouse for crop production. There are also studies done about conditioning with use of ground duct heat exchangers. This is all research done to find out how the properties of the building and its installations can be changed so that the ideal growing conditions for plants can be met.

There is, however, no research about how plants can contribute to the indoor climate regarding lighting conditions and temperature. This research focuses on the integration of plants in architecture and its conditioning systems. The aim is to find out how the building can help the plants to thrive and how the plants can help the building to reduce the needed amount of energy.

1.2 Basic problem analysis

Atriums are mostly the showpiece of a building. Consequently, a lot of it is often customized design. There seem to be no standard solutions or approaches for the design of an atrium roof. A prevalent roof type, however, is the saw tooth roof. It would be interesting to find out what are the most defining properties of the roof that influence the indoor climate. And the question is how this can be optimally combined with a ventilation system and indoor planting.

Planting is nowadays only used for its aesthetics and often plays an important role in entrances, lobbies etcetera. In practice however, architects tend to forget planting in the early stages of design. Corrections have to be made later on to meet the requirements of plants. This is often a compromise to the concept and the sustainability of the building. Apparently it is difficult to keep simultaneously in mind what the plants want and how the building can be made most sustainable. (Ronald Verheul, 2015)

There is a need for an integral approach that combines indoor planting with the sustainability demands of the current building practice. Ideally, it does not only contribute to the aesthetics, but also to the building performance.

But how can plants help reducing energy consumption of a building? Plants need to evaporate water to keep their metabolism going. This evaporation has a significant heat demand, which is a form of cooling. Plants need on average more light than is needed in a regular office. Lighting conditions in atriums progressively worsen with depth. Consequently, the adjacent offices at the bottom of the atrium do not always get sufficient daylight. It is also because of intentional reduced light transmittance of the roof to prevent overheating. There might be a solution for this if plants are introduced. They may cool the space by transpiration, whilst the roof is more transparent, allowing more light to come in for both plants and adjacent offices. However, the plants may not significantly block light for the offices, because that would diminish the desired effect. So, it should be researched whether the introduction of planting indoors can help to make a brighter atrium without overheating.

2. Problem statement

2.1 One clear sentence stating the main problem

For retrofitting an existing atrium or transforming a former courtyard into one, it is useful to know what the correlations are between on one hand the type of roofing, properties of atrium walls and indoor planting for evaporative cooling and on the other hand daylight design, thermal comfort and energy performance. A systematic approach for atrium design has yet to be made to help architects to design more comfortable and sustainable atriums.

2.2 Possible sub-problems

Façade Design

For a standard roof such as in fig. 1 it is not yet clear what properties of the roof are most influencing the lighting quality in the atrium. Variations on the design have to be tested to find correlations between roof properties and light comfort.
It is useful to know what roofing type is the most energy efficient and most comfortable for a given atrium. Factors such as width/height ratio of the atrium and reflectance of the sidewalls are important and will have influence on the outcome.
There are no rules of thumb yet for a standard roof type, depending on e.g. atrium well index and reflectance.

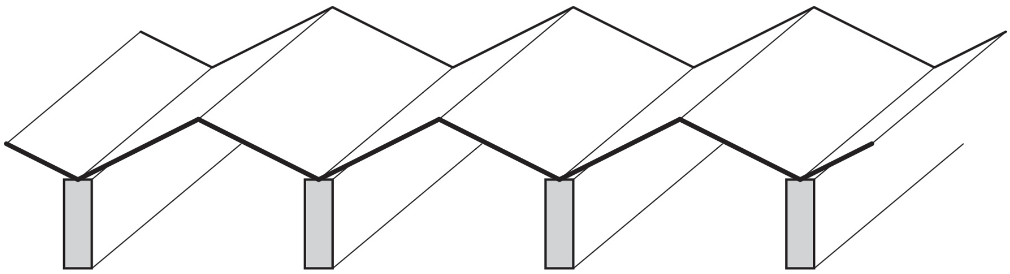


fig. 1: Scheme of standard type sawtooth roof

Light Design

Light conditions in atriums aren't always that good. The amount of light or the direction from which it is coming, are critical aspects for proper lighting conditions. A good distribution of light needs some extra attention as well. Besides lighting conditions inside the atrium, it is important to make sure that adjacent spaces are properly lit as well. The impact of the roof type on the lighting conditions and the influence of the sidewalls have to be measured and correlations have to be found.

Thermal comfort and Ventilation
Thermally, atriums are quite a challenge. They often get quickly too hot or too cold. The climate has to be adjusted to the function. It is also important to find the right ventilation system that fits the demands. Due to the large dimensions and temperature differences, atriums are prone to draft. This has to be taken into account for the design of the system. Also the function of the roof for the ventilation system should be investigated.

Indoor Plants
Generally architects are not really considering the needs of plants when designing a building. Even in day lit atria it is quickly too dark for plants. Atriums thus have to be made brighter to meet the plants' demands but it also enables more daylight for adjacent spaces. Higher light transmission may however cause overheating of the building. There is a need to find out whether this can be prevented by the evaporative cooling of plants.

Energy Performance
It has to be found out whether atriums are really an energetic improvement for a building. Relations between façade-, light- and ventilation design and the energy performance have to be found. In this way, a set of rules of thumb can be made to help architects achieve minimal heating and cooling loads. This will not only improve the energy performance of the building, but it also saves space and money for conditioning devices.

2.3 Hypotheses about the problem causes

Façade Design
There is probably not a set of rules of thumb yet, because atriums are, like most of the buildings, customized designs. There was probably not really a need to find correlations between roof type and light comfort. Besides that it is probably the wide range of factors that may influence the results and makes it harder to come to a conclusion. A lot of parameters have been fixed in this result, to make it more concrete for a certain atrium. However, the applicability of the rules, which may result from this research, is limited to similar atriums.

Light Design
Good light conditions throughout the year may be difficult to achieve, because the weather is constantly changing. Besides that, it may be extra difficult to create comfortable light conditions both inside the atrium and in the adjacent spaces. The reason for this could be that the conditions in adjacent rooms require a basic minimum light level, which is not necessarily beneficial for the climate inside the atrium.

Thermal comfort and Ventilation
The required amount of lighting might cause overheating of the atrium. Decreasing light transmission might hinder natural heating of the atrium in wintertime. A proper balance has to be found because sometimes the requirements can be contradictory. Furthermore measures should be taken to prevent draft.

Indoor Plants

Plants are not yet to be seen as an integral part of buildings. The evaporative cooling potential of planted areas has not been considered yet as a conditioning device. This is probably because it is a relatively incontrollable factor. The climate conditioning is less direct than with electronic devices. Another reason is that it is a living organism and it needs regular care to keep it performing well.

Energy Performance
It might be difficult to find rules of thumb for correlations between roof and ventilation design and energy performance. This is due to the many factors that are involved in this. A set of rules might be too difficult, but at least a comparison between the solutions could be made.

3. Objective

3.1 General objective (directly connected to main problem)

The consequences of the several roofing solutions have to be made more insightful. Making the relation between the effect of the roofing system and other atrium aspects, such as lighting and thermal comfort, more clear, may help architects to find more sustainable and more comfortable solutions. This could be useful when designing a new building, but also when refurbishing an old one. Paramount is the improved comfort and energy performance. Projected innovation is the use of indoor plants for evaporative cooling to be able to bring more daylight into the atrium without overheating.

3.2 Sub objectives (directly connected to sub problems)

Façade design
The first objective is to find out what the influence is of the aspects of roof design on the light conditions in the atrium. Variations will be made with the amount, size and position of roof openings. The effects of the shape of the roof and the type of glazing have to be assessed. Also the effect of the type of opaque material (i.e. reflectance) should be measured. The main focus is on the roof, because the properties of the atrium are already known, since an existing building is taken as starting point for the design. The aim is to find a working roof type based on synchronized variables.

Light Design
The effect of the roof variants on indoor light conditions should be tested for the following aspects: colour, intensity, duration and distribution. The roof design should be verified based on minimum luminance on several places in the atrium. As a rough design guideline, some formulas for daylight factors will be used.

Thermal comfort and Ventilation
After validation of the roof with lighting design as measure, it is necessary to apply a ventilation system that fits the requirements. The effect on air movement, temperature and refreshment rate should be measured. Those aspects of thermal comfort should be within the norms regarding the function of the atrium. Aim of the design is to come up with a natural ventilation system that minimizes the energy demand.

Indoor Plants
After thermal validation of the atrium design, plants should be brought into the design to check in what way they affect the lighting conditions and the thermal behaviour of the atrium. The objective is to find out how many plants can be applied whilst maintaining proper lighting conditions. It is necessary to define what plants are suitable in the atrium climate. After investigating their effect on the indoor climate it should be researched to what extend they can contribute to a better energy performance.

Energy Performance
The corresponding energy performance of the roof of the atrium with the roof design should be calculated with a computer model. Several design alternatives should be evaluated to be able to compare them for energy performance.

3.3 Final products

1: Report: description of literature, process etcetera.
2: One design elaboration on the best performing atrium design as an intervention in an existing building.
3: Rules of thumb (for architects) about how to design a sustainable atrium.
4: Lighting condition, Thermal climate and Sustainability comparison between atrium designs.

3.4 Hypotheses about direction of solutions

Façade Design
The design for the atrium roof will probably consist of an open structure that allows maximum indirect light so that even adjacent spaces have sufficient daylight. Direct light will be blocked most of the time to prevent overheating of the atrium. A roof structure like a shed-roof might be the best option for this purpose. The glazing will be insulated to prevent condensation and excessive heat loss during cold winter nights. It also helps minimizing cold downward airflows.

Lighting Design
The properties of the walls of the atrium are given, but the roof is optimized for proper daylight conditions. It will be a system that creates a lot of diffuse light and minimizing glare. Most likely, the windows of the atrium walls will have individual shading so that every occupant can control the light conditions for the adjacent room.

Thermal comfort and Ventilation
The thermal comfort in the atrium will be slightly rougher than the climate in the adjacent rooms. This is the consequence of the size, insulation, and conditioning of the space. It may be a bit too rough to work in the atrium, but it will be a good place for a reception and short meetings.
The space will probably be ventilated with use of natural stack effect and overpressure inlet at the bottom of the atrium.

Indoor Plants
The layout of maximum amount of indoor planting will be like a pyramid with the top in the middle at half the height of the atrium. It will then never block any direct light in the atrium. Plants will however affect the lighting conditions, because indirect lighting accounts for a large part of the available light in atriums. Plants and the soil will have a cooling effect and consequently keep the air humidity within acceptable regions. However, a high amount of plants would be needed to have a significant effect. Plants may also improve the room acoustically.

Energy Performance
The energy performance of an atrium with least direct lighting is likely to be the best, because it will probably have the least cooling load. The heating load is probably not such a problem, because office buildings often have to be cooled. The atrium can make use of the rest heat of the offices.

3.5 Boundary conditions (what and what not): Starting points, constraints and assumptions

The starting point of this research is an existing atrium. A lot of parameters for this research are thus already fixed. The Deltion College in Zwolle is the building that is going to be investigated. The building is located in a temperate climate in The Netherlands. It is an elongated atrium stretching about 300 metres from southwest to northeast. It is varying in width but on average about 25 metres wide. The function of the atrium is mostly movement and organisation. However, people are starting to use it as study places as well. The reflectance of sidewalls is a property that still has to be measured.

fig 2: Pictures of atrium and schematic plan of Deltion College

This atrium is an apt case, because it already has a saw tooth roof. The existing configuration is thus suitable comparison material. Moreover, this space is not designed as a study space. There is an actual need to fit the indoor climate to the new function. This atrium is also applicable due to its three to four layer height. In a study about the energy efficiency of atriums it is found that an atrium is more energy efficient from a height of approximately 4 storeys onwards. (Aldawoud & Clark, 2008)

The aforementioned aspects are all constraints of the research. The focus and the variation in this research, is about the design of the roof, the ventilation system and the planting inside the atrium.

It is assumed that suitable climatic target values for the function can be found in literature. Also assumed is that the saw tooth roof is in practise a prevalent standard solution for covering large spaces and therefore a valid starting point. The standard spanning beams combined with the pitched roofs make an interesting roof type on which variations can be made. Another assumption is that plants have a cooling effect, but it needs to be found out if it is large enough to be useful.

4. Research questions

4.1 Main research question

What is the effect of variations on a standard atrium roof on indoor light- and thermal comfort and the energy efficiency of the atrium and to what extend can plants contribute to this?

4.2 Sub-questions

Facade

Which aspects of a roof are most influential on light conditions and thermal comfort in an atrium?
Which configurations of aspects of a roof are good to combine to create a comfortable and sustainable roof design?
Which rules of thumb for atrium roof design can be deducted from the results?

Light design

What is the effect of the roof design on the aspects of light quality?
What is the best way to distribute light in the atrium configuration that is being researched?
How can light quality be optimized for spaces adjacent to the atrium?

Thermal comfort and ventilation

Which ventilation system is applicable for an atrium with the properties of the researched atrium?
What are the norms regarding the indoor climate of the program in the atrium.
How can the ventilation and heating/cooling system be realised in cooperation with the roof?

Indoor Plants

How many and what type of plants could be put into an atrium?
What is the effect of plants on the light conditions?
What is the effect of plants on the thermal climate and air humidity in the atrium?
To what extend can plants help making brighter atriums?

Energy Performance

Is the proposed design an improvement compared to the existing?
Which design variants are energy-efficient?
What is the relation (rule of thumb) between design of the roof and energy performance?
To what extend can plants contribute to a better energy performance?

4.3 Background questions

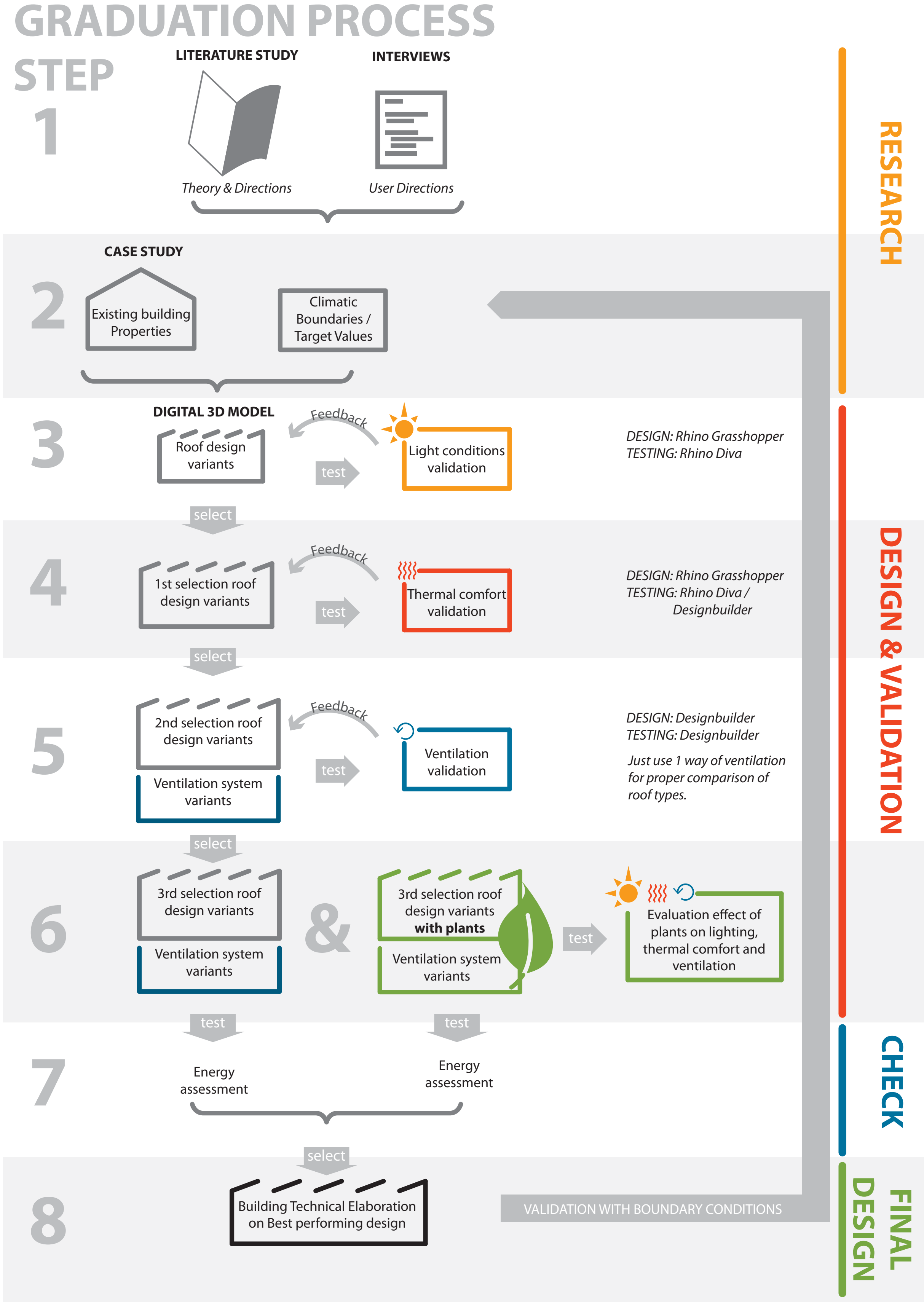
What is the existing structure of the building on which the new atrium roof has to be built?
What are optimal lighting conditions for workplaces in an atrium and in adjacent spaces?
How rough may the climate be in the atrium, depending on function and duration?
How should plants be accommodated, considering growing medium, irrigation, maintenance and placement?
On what factors depends the water evaporation of a plant?
Can plants improve the building acoustically?

5. Approach and methodology

5.1 Research questions into report parts or chapters (directly connected to research questions)

Title page

5.2 Step-by-step approach or logical organisation (scheme)



5.3 Methodology of research: surveys, case studies, enquiries, evaluative loops, etc.

Literature study: Literature will be used to find information about the status quo of planted atrium design. It will be used to find target values for the indoor climate and more information about precedents and techniques.

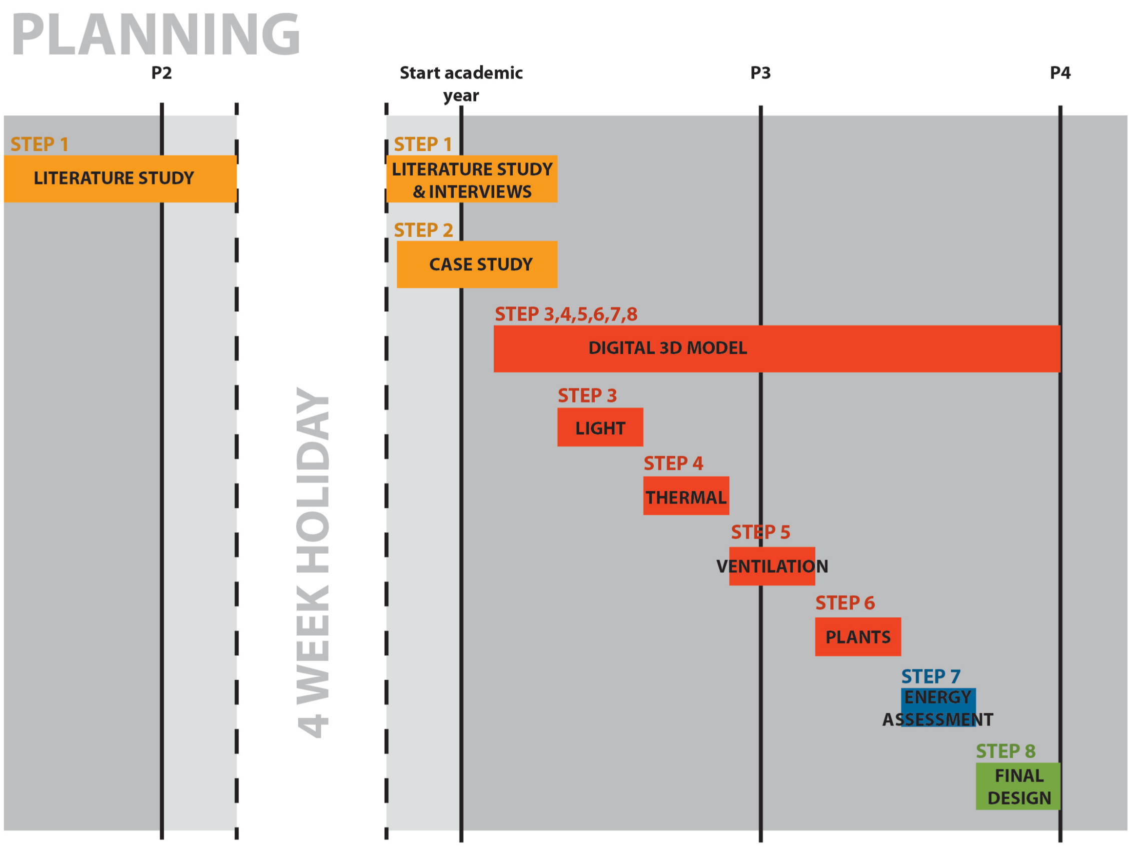
Case study: The research will have the Deltion College as location. It could thus be considered a case study for an improvement of that specific building.

Interview: An interview has already been conducted with Indoor Planting Office Copijn to obtain information about plant management in atriums. More interviews may be useful to get to know how the climate is experienced in the atrium of Deltion College. Both students and facility management should be interviewed. It is also useful to interview a person working in a garden centre to find out how they maintain a comfortable climate whilst letting in enough light for the plants. How does the climate remain so comfortable and what has water to do with that?

Digital model with evaluative design loops: a 3D model will be optimized according to lighting, thermal and ventilation conditions. The model will be tested for these aspects and energy performance. Programs such as Rhino, Grasshopper, Diva and Designbuilder will be used.

6. Planning and organisation

6.1 Research approach into planning with timelines (directly connected to approach)



6.2 Research team: execution, supervision, advisory board

Execution: Borris Boschman (student)
Supervision: Peter van den Engel (mentor climate design), Frank Schnater (mentor façade design), Truus Hordijk (mentor lighting design)
Advisory board/ other contacts: Raymond Verheul (Copijn landscape architects)

6.3 Financial framework: costs and funding, funding parties

Funding is not really necessary for this project. There is no development of a physical prototype or so that would need sufficient funding.

7. Relevance

7.1 societal relevance

It appears to be an architectural trend to incorporate large amounts of plants in buildings. They are used as ornaments and space dividers in atriums and other large spaces. What yet hasn't been researched is how they can contribute to a better energy performance. This research tries to find out to what extend plants are suitable as a tool to create better sustainable buildings. If it turns out to be sufficiently beneficial, it can give architects another reason to put plants in buildings apart from their positive, psychological effects.

7.2 scientific relevance

It is not yet researched in a comparative way how planting in atriums can contribute to the energetic performance of buildings. This research should clarify whether the transpiration of plants can help to maintain a comfortable climate in atriums by means of evaporative cooling. This may reduce the cooling loads significantly and consequently contributes to the sustainability of a building.

7.3 projected innovation

The projected innovation of this research is a set of guidelines/parameters with which a sustainable, planted atrium for a regular office building can be designed. It tries to find out whether plants can fulfil a cooling function that is beneficial for the building. The extra cooling may enable extra light transmittance, which enhances natural lighting of the atrium and adjacent spaces.

7.4 Embedding in research programmes and relationship with other research projects

This research is related to research done by Littlefair about Daylight prediction in atrium buildings.(Littlefair, 2002) It is also related to a study by Du and Sharples about daylight distribution in atrium buildings.(Du & Sharples, 2010) Those two studies researched the influence of well geometries and wall reflectance on light conditions. This research is in the same research field, but focuses more on the influence of roof types on light conditions. Considering the thermal and energy efficiency, this research is related to research done by Wageningen University and Haagse Hogeschool about climate in greenhouses. This research uses findings from these projects, but the focus is on atrium buildings. Atriums may have plants in them, just like the greenhouse, so the type of challenges that the plants cause may be similar to those in the Wageningen study.

8. References

8.1 Literature already studied and to be studied (status)

Lighting: Literature about lighting in atriums has been studied. Formulas about daylight factors have been found already. Those can be used as a quick design aid.
Thermal: Literature about thermal comfort has been studied yet, considering atrium geometry. More literature needs to be found about thermally efficient ventilation strategies.
Energy: Literature on energy efficiency and atrium geometry has already been studied. More studies are required on the effects of roof design on energy efficiency.
Plants: Literature on the psychological benefits, evaporative cooling properties and maintenance has already been found. Consultation of Copijn may be needed in the future to ask for practical advice considering the planting design.

8.2 Persons and institutions already consulted and to be contacted (status)

Already consulted: Copijn (indoor planting office)
To be consulted: Facility management Deltion College, students of Deltion College

8.3 Personal Publications (published and planned)

There are no personal publications considering atrium design and indoor planting. There are also no planned publications.

8.4 Literature used in this report

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8.5 Collected literature as basis for research

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