LOOKING GREEN
A research for designing a green sun shading
My graduation research is about designing a controllable green sun shading. The research is part of the Dual Graduation Track Architecture & Building Technology. The architectural part is about designing a new headquarter for a new council of the United Nations in New York. The United Nations wants to create an Environmental Council and the demand is to design a new headquarter that facilitates in environmental and sustainability issues. The main program consists of collecting and distributing informations for the further developing of sustainable solutions.

The term sustainability is a wide spread of ideas, identifications and solutions. However in the architectural usage of the term sustainability isn’t always visible for most common people. Sustainable solutions in the buildings structure, organisation or installations are hidden within the building. Because of the importance of the UNEC building there should be a green icon that represents sustainability, it should just look green! So everyone understands that an Environmental Council is housing the building.

Buildings may look sustainable but it is often unclear whether this actually is the case. Plants are put in front of a building often only for the aesthetic appearance, however it would be better to be aware of the benefits that plants can offer besides giving the building a certain sustainable appearance. Plants provide shade in nature so why would you not use them as a Green Sun Shading? A green sun shading looks green but it is also performative. This is the starting point of my graduation research to prove that plants can offer more than just being used as a cladding on a building.

This report reflects on different ways of constructing a green sun shading. Such as familiarities with green façade constructions and which plants can be used in such cases.

This report aims itself at the most important parts that are needed to design a green sun shading. Which plants are suitable to use? What are the key factors of a performing green sun shading? What are the possibilities on an aesthetic and functional field?

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Preface 2
Index 3
Abstract 4

1. Introduction 5
1.1. Introduction 6
1.2. Fascination 7
1.2.1. Green in architectural designs 7
1.2.2. Green sun shading 7
1.2.3. Seasonal aesthetics 7
1.2.4. Light penetration 7
1.2.5. Biosca & Botey 7
1.3. Problem statement 8
1.3.1. Lack of knowledge 8
1.3.2. Plant species 8
1.3.3. Maintenance 8
1.3.4. Benefits 8
1.3.5. Research question 8
1.3.6. Sub questions 8
1.3.7. Examples of the SADD design development 8
1.4. Research structure 9
1.4.1. Program of requirements 9
1.4.2. Construction principles 9
1.4.3. Plants and aesthetic performance 10
1.4.4. Maintenance 10
1.4.5. Movement 10
1.4.6. Design development 10

BACKGROUND INFORMATION 11
2. History 14
2.1. Short history 15
3. Green roofs 15
3.1. Introduction 16
3.2. Benefits of green roofs 16
3.3. Conclusion 16
4. Green walls 18
4.1. Introduction 18
4.2. Façade construction principles 18
4.2.1. Framing constructions 18
4.2.2. Tensile constructions 18
4.2.3. Modular constructions 18
4.3. Benefits of a green façade 19
4.4. Benefits on a larger scale 19
5. References 21
5.1. Introduction 21
5.2. Comparison 27
5.3. Conclusion 29

TECHNICAL RESEARCH 32
6. Case Study SADD 32
6.1. Explanation 32
7. Solar study 34
7.1. Introduction 34
7.2. Implementation case study 34
7.3. Solar study summer 36
7.4. Solar study winter 37
8. Comfort 39
8.1. Introduction 39
8.2. Glare 40
8.3. Contrast 41
8.4. Sun shading demands 42
9. Sun shading 43
9.1. Introduction 43
9.2. Sun shading types 44
9.3. Green sun shading 45
9.4. Relation between daylight and solar radiation 45
9.5. Solar radiation analysis 46
9.6. Cooling and calculation 47
10. Daylight 49
10.1. Introduction 49
10.2. Calculation data 50
10.3. NEN 2057 calculation 51

CONSTRUCTIONAL RESEARCH 54
11. Plants 54
11.1. Introduction 54
11.2. Key factors for choosing plants 54
11.3. Plant types 55
11.4. Climate and plant choice 56
11.5. Plants and fruits 56
11.6. Plants for the case study 58
12. Maintenance 60
12.1. Maintenance issues 60
12.2. Irrigation systems 61
12.3. Accessibility 63
13. Construction properties 64
13.1. Introduction 64
13.2. Design weights 64
13.3. Test setup 66

MOVEMENT RESEARCH 70
14. Concept designs 70
14.1. Introduction 70
14.2. Sketch designs 71
14.3. Horizontal movement 72
14.4. Vertical movement 73
14.5. Door movement principle 74
14.6. Central turning 75
14.7. Excavator 76
14.8. Subdividing 77
14.9. Horizontal hinge 78
14.10. Interchangeable element 79
14.11. Fifty-Fifty 80
14.12. Carousel 81
14.13. Concept comparison 82
15. Design boundaries 86
15.1. Introduction 86
15.2. Program of requirements 86
15.3. Costs awareness 87
15.4. Technical boundary conditions 88
15.5. Architectural boundary conditions 89
16. Design development 90
16.1. Visual achievement 90
16.2. Sketch design 92
17. Illuminance analysis 94
17.1. Introduction 94
17.2. Design sky models 94
17.3. Setup of the analysis model 95
17.4. Summer 21st June, 14.00, clear CIE sky model 96
17.5. Winter 21st December 14.00, clear CIE sky model 97
17.6. Winter 21st of December 14.00, overcast CIE sky model 98
17.7. Summer 21st June, 14.00, sun shading test 99
17.8. Winter 21st December 14.00, sun shading test 100
17.9. Winter 21st of December 14.00, overcast CIE sky, sun shading test 102
18. Mechanical drive 104
18.1. Lifting mechanisms 104
18.2. Implementation of a mechanical drive 107
18.3. Individually or group driven 108
19. Construction and materialisation 110
19.1. Structure 110
19.2. Irrigation and drainage 112
19.3. Materialisation 113

IMPLEMENTATION 114
15. Design boundaries 114
15.1. Introduction 114
15.2. Program of requirements 114
15.3. Costs awareness 114
15.4. Technical boundary conditions 114
15.5. Architectural boundary conditions 114
16. Design development 115
16.1. Visual achievement 115
16.2. Sketch design 116
17. Illuminance analysis 117
17.1. Introduction 117
17.2. Design sky models 117
17.3. Setup of the analysis model 117
17.4. Summer 21st June, 14.00, clear CIE sky model 118
17.5. Winter 21st December 14.00, clear CIE sky model 119
17.6. Winter 21st of December 14.00, clear CIE sky, sun shading test 120
17.7. Summer 21st June, 14.00, overcast CIE sky model 121
17.8. Winter 21st December 14.00, overcast CIE sky model 122
17.9. Winter 21st of December 14.00, overcast CIE sky, sun shading test 123
18. Mechanical drive 124
18.1. Lifting mechanisms 124
18.2. Implementation of a mechanical drive 127
18.3. Individually or group driven 128
19. Construction and materialisation 130
19.1. Structure 130
19.2. Irrigation and drainage 132
19.3. Materialisation 132

CONCLUSION 133
21. Conclusion 133
21.1. Conclusion and recommendation 133
22. Epilogue 134
22.1. Epilogue 134

Sources 135
Appendix A 136
Appendix B 138
Appendix C 140
Appendix D 142
Overview
Looking Green, that is the title of this graduation research of the Dual Graduation Track of Building Technology & Architecture. What is looking green you could ask yourself. Looking green can be implemented into different things. The dual graduation track consists of three semesters. Two semesters of architecture and one semester of building technology that will be done after one semester of architecture. The architectural part of the graduation track consists of designing a new headquarter for the United Nations Environmental Council, the UNEC. The UNEC stand for a new branch of the United Nations where people can come together for learning and sharing of sustainable information, technologies or innovations. A building of importance of the United Nations that represents sustainability should act sustainable and also appear sustainable. Sustainability is a term that can be described in many ways. The term sustainability can also be described as “green”.

Unfortunately sometimes things that “look” green don’t act “green” or better said sustainable. A simple example. When a car is approved with a label “green” this don’t have to mean that the car is better than other cars. Maybe it will be less polluting than a car that doesn’t have a “green” label but it is relative. If a car with a certain sustainability label is used every day compared to the other car without the label that is used only once a week. The amount of pollution can be the same. Sometimes buildings are cladded with a green façade. Literally green by using plantations that cover a wall. This green look that literally is green can make people assume that the building looks sustainable and act sustainable. However just a green look can cover a very energy ravenous building that uses a lot of energy to keep the indoor climate comfortable.

When I look at the implementation of green in architecture most of the buildings are cladded with a closed vegetated façade or with a green roof. Green roofs were very popular two or three years ago because municipalities gave grants to the people who wanted to make their roof green. One of the benefits of green roofs was that the city water drainage was less overloaded when there was heavy rain fall because green roofs maintain a lot of water like a buffer. So this was interesting for the build environment and the people who wanted to create a green roof could afford it due to the grants.

Green walls are sometimes implemented in architecture as a vertical garden. In very dense cities it is a way to create green in the build environment where the soil is very expensive to use for just a park. Green walls also have more benefits than only looking green. For me it is unclear if an architect uses a green façade or roof because of the benefits on biodiversity scale or just for the looks of vegetated surfaces to make a building literally look green. Or to show that nature has a relation with the building. In magazines or design contests it appears to be a hype to use lots of green in designs, renderings etcetera and it affects the people one could say. This is just a feeling that not only I have when I see “green” designs but also Rem Koolhaas mentioned it in a quote during an interview.

"Designs are increasingly winning competitions because they are literally green, and because somewhere they feature a small windmill." 
(Rem Koolhaas) 7/6/1

This is literally what I mean. Green in architecture can give a building a certain sustainable “look” that can be experienced by people as a sustainable building. But what is so sustainable of the building? Are it the installations, the structure, the way of use, innovative materials, the history of the building that is refurbished and re-used again or is it just the appearance of the green façade?

Just type in “Sustainable Architecture” in the search engine Google on the internet and look what kind of images you will be facing. If no one is explained what sustainable architecture should be, a person without a architectural or technological background could think that sustainable architecture is architecture that just looks green! It shouldn’t be that way that when people look at an illustration such as I.A.3 that the first idea could be: hey is that a new sustainable airconditioning? Of course this is overreacting but just try it yourself. Typ it in Google and think about it.

Just type in “Sustainable Architecture” in the search engine Google on the internet and look what kind of images you will be facing. If no one is explained what sustainable architecture should be, a person without a architectural or technological background could think that sustainable architecture is architecture that just looks green! It shouldn’t be that way that when people look at an illustration such as I.A.3 that the first idea could be: hey is that a new sustainable airconditioning? Of course this is overreacting but just try it yourself. Typ it in Google and think about it.

Something that strikes me, is that when you look in books like the Vertical Garden from Patrick LeBlanc, Façade Greenery or DETAIL magazines that green façades are almost always based on a closed façade. There aren’t a lot of projects that use vegetation in front of a transparent façade. This conclusion gave me the idea to use a “green” façade for my UNEC design assignment of my architecture graduation project. I wanted to design a building that would function as a green icon not only being very simple in form and function but it should be very sober and calm. But a icon for the United Nations Environmental council should also literally look green. Just using the plantations to let people assume that the building is the headquarter of the Environmental Council is sustainable sot that one part is clear. It should look sustainable, and wether it is or it isn’t can be developed in many ways but the appearance has to deal with the common people on the streets who don’t know how the climate installations or the floor plans are arranged. So one of the first ideas was making a generic form applying a green grip over it to show that the building is “in grip by nature”.

However, The design consists of a lot of different functions that demand daylight for working. So a glazed façade is needed. And this is the point where this research is about. When you want to design a green façade in front of the building glazed façade how will it look? And at that point I found a project that made me think about implementing a green façade construction.

The Santiago Consorcio Building in Chile, from Enrique Brown Architects uses a green façade construction in front of a glazed façade. This façade changes colour by using annual plants and by using plants in front of a glazed façade there was no need for a sun shading. So why don’t we use plants as a sun shading device? So this was my concept for my façade design. Designing a green sun shading that not only looks green but also features the function of a sun shading. Why haven’t I seen that earlier? What are the benefits of placing a green
façade in front of a glazed façade more often? What type of plants do they use and how will you experience a green façade behind a glazed façade? I needed more information about vegetated constructions. What the demands are to make them and how I can make them to suit a system that can be used as a green sun shading. That is what this report is about.

What are the elements that are needed to make a green sun shading? Which type of plants are used? How heavy will such a system become? Will there be enough light inside a room when the green sun shading is withholding daylight due to the plants? A conventional sun shading can be controlled. For example an awning can be pulled in or out when you want shading or you don't. So is a green sun shading very nice like the reference of the Consorcio Santiago Building? Or are the looks exaggerating the function of the green sun shading?

Something that I haven't seen and heard of is a controllable green sun shading. A green sun shading like the green façade of the Consorcio Santiago building but with the capabilities to have influence on the sun shading like I can influence my awning at home. The research question for this building technology research is

How can a controllable green sun shading element be made and how can it provide enough light penetration into a building?

This report will inform about the elements that are needed to design and construct a green sun shading for a building. For the implementation the case study of my architectural graduation project will be used. And maybe this research can offer a fresh look at implementing “green” as an architectural design tool for buildings. Not just only making buildings appearing green but also benefit from the plants. So it will be aesthetics and “performance” as well. Before designing a green sun shading this report will clarify some of the following topics that are returning through the research: controllability, sight, density, dimensions, plantation function and staying in touch with the plants.

After a investigation of background information, technical research, constructional research an implantation of that knowledge will be the final step in designing a green sun shading element.
1. Introduction

This is the last time that the TU Delft offers the possibility to do a dual graduation track in architecture and building technology. The track consists of an architectural design project that starts with a masterplan and a concept design for a building. After one semester building technology will be the main program to do research on a subject that can reinforce the architectural design.

The SADD project is about designing a new headquarter for the environmental council of the United Nations in Manhattan, New York. This building has already a location and that’s beside the General Assembly of the UN. The program of requirements consists of ± 16.000m². The program contains the following functions: offices, library, horeca, workshops, auditoriums, exposition and press rooms. The largest functions are the offices and the auditoriums.

Sustainability often gets associated with a green “look”, appearance or concept. If one searches for “green” architecture, most of the buildings are cladded with green roofs or façades. Sustainability isn’t something that always have to represent green. By implementing a green roof the building can still have a high energy usage. However green is a very open and common term that everybody without architectural or technological background can understand. If a car is certified with a green logo it is considered to be good. So simple people can look at objects that suppose to be “sustainable”.

When it comes to the UN headquarter of Sustainability, one expects it to be “green”, which could consists of being energy neutral, making its own energy or even better provides the energy that is needed to maintain the building. Sustainability can be accomplished in several ways but for my research I focus on the “envelope” of the building: how will a green icon for sustainability look like and how should the façade perform?

As already mentioned, “green” in architecture is often characterized with green roofing’s or green façades that are entirely cladded with plants. The vegetation on the roofs differs from extensive sedum plantation up to intensive trees. Architects usually choose ivy or a different plant with the same rigorous features of growth and persistance. Due to these qualities the architects are insured of a green appearance of their design. Nevertheless this choice requires a lot of maintenance. A more effective option to preserve the green appearance is using a more intensive façade system like the one invented by Patrick Blanc. The system of Patrick Blanc offers more design freedom and diverse aesthetics of façades.

The use of vegetation on a building with the purpose of creating an aesthetical appearance can also offer the benefits of shading from the sun. The “green” façades will protect a building against UV-radiation. However the green sun shading idea is very simple. Instead of applying solar blinds, expensive glazing with UV reflective layers or similar shading principles, there is a natural solution available.

Wouldn’t it be nice if there is an automatic sun shading device that doesn’t need electronics to make it work. So there is shading in the summer when it’s required and lets the sun through the shading device in the winter. In summer trees have their green leaves and provide shade outdoors. In the winter a tree loses his leaves and only the branches remain. That’s exactly what is preferred. A lot of shaded surface in the summer so that we can sit in a cool area, in the winter it is very cold and we want to sit in the nice warm sun.

Green sun shading is the same concept as a green façade only the construction is different. Green sun shading works as a sun shading so there is glass behind it otherwise why bother to add sun shading in front of a closed wall. The main performance is sun shading in the summer and letting sun penetrate in the winter period. In nature this is very simple, in summer the trees are filled with green leaves and in the winter the leaves are fallen of and only the branches are left. So in summer there is a lot of shading in the streets and in the winter when it’s cold the nice and warm sun is shining along the branches of the trees. Besides providing shade or solar transmission in the summer or winter period plants also change colours during the seasons. The changing of colour during a season can also give a building an unique appearance throughout the whole year.

A very nice example of project where the architect has implemented a green sun shading on a building is from Enrique Brown Architect Association. The Consortium Building headquarters in Santiago, Chile has a green sun shading façade that also changes colour with the different seasons. So next to the air purification, relaxing environment and getting green into the cities this façade is also dynamic in its appearance. You could also say it is a dynamic sun shading façade. It changes its solar transmission through the year and even its appearance. So besides having sustainable benefits it is a very aesthetical tool as well.

Some other examples are available in Chapter 4, References.
1. INTRODUCTION

1.2 Fascination

1.2.1 Green in architectural designs
Green use in architectural designs often look very nice. There are some subsidy projects to create more green roofs for example Rotterdam has an Climate Initiative program that offers building owners to make a green roof and gives them a subsidy to make it possible. There are a lot of green roof types, the more intense ones that really go to a park on a roof of interior courtyards with large plants and trees impress me a lot also in a technical way because how deep does the layer of soil needs to be to plant a tree on a roof and how large will the forces be that the structure needs to cooperate with? The simple extensive roofs are just simple sedum plants and that's not really a challenge. The green façades however are also very nice to see, it often has a overkill appearance on the building, so you will only see green plants and the shape of the building is gone, only the windows will show some semblance of a building.

Green sun shading is an application that has some distance from the whole building. So the building will remain its own visual experience but it changes throughout the year without placing difficult electronics or moving elements.

1.2.2 Green sun shading
Green sun shading interests me because it is a very natural way that plants can provide shade in the summer and let through solar transmission in the winter. And that's exactly what we want in a building. And it also has a performance on both sides. It looks green on the outside but also on the inside. Studies have proven that a green environment will relax people and will provide a nice working area also for example offices. And that's something that green roofs or façades don't provide.

1.2.3 Seasonal aesthetics
Also the changing colours of plants through the different seasons can give a building a complete different view. A very technical building with all the HVAC machines and tubing's on the outside can look very technical in the winter but it can be hided in the summer with the use of green sun shading. Also the colour changing of leafs from green to red to brown and eventually the falling of the leafs. It could almost be if the building works like a tree that loses his leaves in the winter and grows them in the summer when it wants shade.

1.2.4 Light penetration
This subject also has some negative sides. Green sun shading grows in front of a transparent façade. But what if the plants grow very fast and they cover the entire field of view? Will people get any sunlight in when the plants are obstructing it? In the Dutch building regulations (BouwBesluit) there are regulations of how much light rooms need to have. But do these rooms provide enough light when the windows are covered with plants? Does a building needs to perform to these regulations in the summer? The earth is also heating up the last years so are people asking for the same demand of sunlight in the summer as in the winter? And also will the plants remain when they are getting "burned" by UV radiation? Maybe they need to be sprinkled with water in hot summer days?

1.2.5 Biosca & Botey
This sketch, found on the internet shows a wide amount of subjects that are important when you are designing a green sun shading, it is a pity that this sketch only remained a sketch and there wasn't any kind of text describing why Biosca & Botey (interior designers) made this sketch on a very detailled way. Because the things that are important when you think of a sun shading besides shading from the sun, for example having enough sight, how is the construction made and how can you reach the plants are visible in this sketch. This sketch was part of a workshop, i will refer to the source of the image for this. But this really shows the compexity of "just placing some plants in front of the façade".
1. INTRODUCTION

1.3 Problem Statement

1.3.1 Lack of knowledge

The green plants that are used in green façades are often ivy, because this plant is known very well in gardens everywhere. It is a plant that is almost weed that is always coming back and lives in bad conditions. However ivy also has got strong roots that can wreck building constructions. So one needs to know when to apply a ivy instead of other plant species and if one uses ivy, know the consequences of plants that will grow in a certain direction and also think about what to do after a year, some plants need to be cut to grow more. And also what do plants need to grow? I think there is a lack of knowledge when architects “just” want a green façade or a green roof. Knowing what you want, which plants, how big, what kind of construction but also know what kind of maintenance is needed and for the user of a building it has to be said that the user needs to let someone do the maintenance of the plants on a building otherwise plants will die or the demanded aesthetics will change.

1.3.2 Plant species

There are a lot of different plant species but which plants are suitable for a green sun shading? For green roofs it differs what kind of construction is used, than it works like a garden and almost everything is possible. A green façade is trickier already because plants need to grow up or down. Patrick Blanc investigated in a lot of those plants and he can use the plant properties to design special patterns in density of a green façade. But what about plants for green sun shading? Should the plants be very dense and the way a construction is made very open or should the construction be very wide and the plants very open? And how high can these plants grow? Will the plants lose their leaves from the bottom up and will they remain bald after a few years? Which plants need more cutting maintenance than other ones?

1.3.3 Maintenance

This is a very important subject, plants need maintenance. Can plants live only from water? No they need soil to grow their roots in but they also need fertilizer to grow or to let them grow better. When do the plants need to be pruned? And who is going to do that? Can a gardener stand next to the plants on a large office building or does he need a elevator like window washers have? And how will the plants get their water and fertilizers?

1.3.4 Benefits

Of course a green façade is mostly chosen for its aesthetics, "looking green". But green sun shadings also benefit from working as a barrier against UV radiation. Not only the radiation but also light is being retained by plants in a sun shading construction. All right keeping the sun out in the summer is a benefit, the building is getting less overheated but what about light penetration? Does a building perform according building regulations when there are plants growing in front of windows that are normally fully transparent? Will there be enough light and sight with a green sun shading façade? Sight could be easily solved when the green façades wouldn't be so fixated on the building but just moved away when they aren't needed for shading the sun.

1.3.5 Research question

How can a controllable green sun shading element be made and how can it provide enough light penetration into a building?

1.3.6 Sub questions

The sub questions can be divided into three subjects:

Architectonic
- How should a green sun shading look like, when functions are demanding different densities in the façade but also element sizes and constructional precedents? What can be the plants aesthetics during the seasons? Which plants can be used and what is necessary for the plants?

Technical
- Which construction principles that are known from green façades can be used for a green sun shading façade?
- Which plant species are the best for a green sun shading façade and which ones will work in a climate like New York?
- What does a green sun shading need for maintenance?
- Is it possible to integrate other functions within the green sun shading element?

Building Physics

What are the benefits of using plants as a sun shading in front of a façade? How much radiation will be transmitted through the plants? How much influence has a green sun shading to the indoor climate? Is there enough daylight with a passive green sun shading façade? Is there enough daylight according to building regulations with a green sun shading? And will users of a building with a green sun shading have enough sight to the outside environment?

1.3.7 Examples of the SADD design development

For the SADD project I have to design a new headquarters for the United Nations Environmental Council. My opinion is that a lot of buildings can be sustainable in many ways but to make it clear for common people the look of green is a very simple definition for a sustainable looking building. The UNEC building should look like a green icon for sustainability. During the designing process I already tried to design a green sun shading façade but while I was designing a sketch design a lot of questions came up. The first sketch design as shown on the right was just a fast design, it should be sun shading on the outside to prevent UV radiation from getting inside the building, and in the winter period the plants are gone so the horizontal lamellen should prevent the lower standing sun from penetrating in the building.

Questions during designing the façade:
- How large should the plant basket be? How much soil do the plants need to grow to a certain height?
- De size of the baskets also has it’s effect on the structure of the building, because it is hanging on the façade, how heavy will the element be? And how large because that effects the experience of depth in the façade in a architectural point of view.
- If the plants are bold in the summer, how are the people that are working inside the building protected to the winter sun that is shining lower inside the building? In this first design I thought about lamellen that can be lowered and maybe the area behind it can retain heat of solar radiation?
- The plants need their water and food supplements to grow and exist, what kind of installation is needed and where should that be placed? Is it possible to use a basin on the roof with rainwater?
- How far can plants grow? Can they grow over 2 stories high or isn’t this possible with certain plants? Or even with too high floor levels?
- Can there be more than just a green sun shading? Can the plants be used for other things also? Can people get in touch with the plants from the inside of the building? Maybe fruit plants can be used?
After a lot of questions and discussions I also made another design for my SADD façade. Sometimes you have to take a step backward and go back to the design of the building and dive in the research of Building Technology afterwards again. This second design is presented at the P2 SADD presentation for architecture and will be used as case study for this building technology research.

This is a view at the most southern façade, the raster is a climbing surface for the plantation and there are differentiations in density within the element sizes by the function that is behind it. The idea is that behind the elements the windows can be opened and the green sun shading could act as a second façade skin. The user can water the plants on their own, and maybe take fruits of them. But the essence is that one can put a window open and not only see the plants but also can touch it. One thing I’m still very interested in is the adaptability of this façade. How can a user decide to just put the sun shading away? Should the sun shading be dynamic so the user can just slide it sideways or downwards? For that reason I made a Program of Requirements of the green sun shading element I want to research and design. Therefore I made a research method, described in the next paragraph.

To get a clear view of what the contents of the research could be I made a small overview of topics that need to be investigated before designing or using a specific construction for the use of a green sun shading. I also think that theory isn’t enough and that a visible model of a prototype will show what a green sun shading looks like from the inside and outside and also for testing the amount of light penetration inside a room. The research is divided over three field of profession:

1.4.1 Program of requirements
What kind of requirements should a green sun shading have beside shading against UV radiation? Differences in density in the façade by using different construction precedents as caging, tensile, or hanging baskets with plants. But also different types of applying a green sun shading, outside the building, inside the building or in the cavity of a façade. Combining functions from a building with aesthetics. How should the building look like during seasonal changes? Density and appearance is important but also the type of construction, the thickness of an element, the dividing of a façade etc. What are the sun shading demands per function?

- The façade should look green in the summer and prevent against UV radiation;
- The façade should have different aesthetics during the seasonal changes of a year;
- The plants should act as a sun shading device in the summer and in the winter period;
- The plants should be easy to maintain for maintenance so getting to the plants should be done on a very easy way;
- The plants should offer more than sun shading, reduce stress while working by green surrounding (psychological), plant choice, for example fruit plants or plants with flowers so at the end of the day the employees of the building can pick a flower to take home;
- “Enough” outwards, so the façade doesn’t have to grow to dense that it isn’t semi-transparent anymore. Maybe this is a plant choice question or a question in sizes of the elements?
- Adaptivity of the elements, the user of the building should have the possibility to put the sun shading away or the sun shading should offer more benefits so the user doesn’t want to put the sun shading away on a rainy summer day.

1.4.2 Construction principles
Which construction principles are known from other green constructions? Green roofs and façades. Which kind of constructions are useful for a green sun shading façade element? What are the positive and negative points? What are the weights of a green sun shading system? What will the loads be that a structural engineer needs to calculate with? How will the structure look like? Will it be very lightweight or very heavy? What do the plants ask for construction so they can hold themselves against the wind on a high building?
1. INTRODUCTION

1.4.3 Plants and aesthetic performance
Which plants are good for a sun shading façade element? What are the properties of a specific plant that is suitable? How does the plant react during seasonal changes? An overview of plants would be very interesting for designing a green sun shading façade just like Patrick Blanc designs “closed” green façades. Can there be a combination with different plants that can support the green look in winter times when the plant that provides sun shading in the summer gets bold? What do the plants need to grow well and perform as they should? And how does a green sun shading look like? How can you make a very realistic impression that is better than the real deal in Chile, already mentioned earlier in this report. What will be the effect of green to the interior experience of the users of a building?

1.4.4 Maintenance
What kind of maintenance is needed for a green sun shading? What are the mechanical demands of the structure or construction? What do the plants need to grow and how will they get it? How can people maintain the plants like they can maintain their own garden? What are the demands of a green sun shading construction? How can they reach it? Can it be done from the inside out or from the outside of the building?

1.4.5 Movement
How can the user of a building put the sun shading away when the demand for sun shading isn’t there? Is the sun shading a passive or a dynamic element? What if the sun shading is a passive solution that can’t be slid away? Is there more than plants besides the appearance, so the user doesn’t want to slide it away because there are more benefits from this façade element.

1.4.6 Design development
Eventually there should be a good way to apply a green sun shading element into the SADD design. How will it be build? Will it be very complex and specific for the UN sustainability headquarters? Or will it be a universal element that also can be used for other buildings? How can the user have influence on the green sun shading? Is it on a natural way and do we need a backup sun shading if we use seasonal plants or can we use plants that stay green and just move them out of the way when we don’t want them. The challenge is to get as far as possible with developing the green sun shading to use the knowledge of this research in the SADD project, that will continue after this Building Technology Research. The end product of this research isn’t a full solution for the case-study but it will show the problems and questions to continue with developing the façade of the UNEC building in the architectural course of this dual graduation track.
BACKGROUND

INFORMATION
Green façades or green roofs aren’t something new. People are using this green construction for a few years now. I want to take you a few decades back to show that people during history are searching for a good relation between nature and humanity. A good example are the gardens of people during history, large mansions in France had large gardens and they weren’t just a composition of grass and plants. No, there were sidesteps to walk through the garden, parts with grass and also baskets with flowers or boxes plants shaped into animals. In the Middle Ages gardens were made for healing or meditation purpose. For example the monastery’s. The romans used ceramic pots with plants to decorate their atri.

But the most common example maybe are the hanging gardens of Babylon. The hanging gardens of Babylon are known as one of the seven world wonders. The story goes that king Nebuchadnezzar II built the gardens for his homesick wife around 600 BC. The waterworks aren’t that clear however, how did he transported the water to the higher ground where the plants where living. Some story’s go that he used an Archimedes screw to bring the water to the plants, because the gardens were higher than the water level.

However since the hanging gardens are also a mythical story, it isn’t clear if it is real. But it is good to think about these ideas that were already spoken from in the late 4th century BC by a Babylonian priest named Berossus. Later on Greek historians elaborated his story. The gardens of Babylon were made with terraces where all kinds of vegetation grew, trees, green plants and flowers. The flowers grew and grew and they eventually were hanging over the terraces and also the façades.

Growing plants on roofs and façades also need a wide knowledge and when one has the knowledge about irrigating the plants, which kind of plants will be used in which part of the world and how will the construction be made than it isn’t that difficult. Maintenance stays an issue and the way the plants are constructed on a building. Also functionality and aesthetics are an issue nowadays. The principle is as old as the gardens of Babylon but the implementation is still under trial and error. (W.2.1)
3. GREEN ROOFS

3.1 Introduction

From the green shell that buildings could get the roof is a very common implementation. It is also an easy way to give a building a “green” appearance. But next to a green appearance of a building, the building itself doesn’t have to be sustainable. It could only be a skin that is covering the building. However when a building gets a green roof it also benefits from the plants because the plants will restrict the UV radiation of the sun getting into the construction for example the construction of the roof will be less warm then when a black roof is heating up by the sun. The extra layer of soil that is irrigated with water for the plants will keep out some heat of the structural roof and also the plant benefit from the sun so they can grow.

The only thing that needs to be clear is the fact that plants need water and growing media. That’s why there are also three different kinds of green roofing systems:

<table>
<thead>
<tr>
<th>Type of vegetation</th>
<th>Depth of Substrate</th>
<th>Weight</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Herbaceous</td>
<td>40-50mm</td>
<td>120-200g/m²</td>
<td>Low/Periodic</td>
</tr>
<tr>
<td>Native Shrubs</td>
<td>150-200mm</td>
<td>120-500g/m²</td>
<td>Low/Periodic</td>
</tr>
<tr>
<td>Sedges, Grasses</td>
<td>300-500mm</td>
<td>170-1000g/m²</td>
<td>Medium/High</td>
</tr>
</tbody>
</table>

The table also shows that different kinds of vegetation need more or less substrate/soil to live on. How larger the plants the more roots they have and to let a tree grow you have to give them space to grow their roots. Also think of restricting the grow that the roots don’t crush your construction. The construction of the roof is quite simple, it is the same as a normal insulated roof with extra layers like a waterproofing membrane, drainage layer, fleece layer, soil and vegetation. This is possible on a wooden structure but preferred on a concrete structure because it can handle the loads more easily.

Example of a vegetation roof construction.

Green roof technology is becoming very popular as a component for sustainable design. It is also often called a living roof, this “green” construction has achieved much value in LEED and NAHB certification scorings and is also gaining popularity in cities. For example Rotterdam has started an Climate Initiative Program where the city gives subsidy to the people or offices that want to transform their conventional flat roofs to green roofs, mostly extensive roofs because these add-on loads can be handled easily by the existing structures of buildings. The city doesn’t just want a overview of green roofs. By applying vegetation on green roofs it also helps the city preventing the sewers to overflow when there are heavy rainfalls. And the buildings often also benefit from not overheating with the extra layer on the roof.

Some references of buildings with a green roof:

- The roof of the TU Library is a semi-intensive roof, covered with grass and walkable.

- “The U.S. Green Building Council is on course to award CAS its highest mark of sustainability, the LEED Platinum ranking. CAS is green on many levels: it’s insulated by nontoxic, second-hand blue jeans; it’s topped off with a 2.5-acre “living roof” stocked with 1.7 million native California species (which will absorb about 2 million gallons of rainwater annually).” (W.3.2)
3.2 Benefits of green roofs

Green roofs have a lot of benefits, to give a good overview a small summary:

1. **Energy Conservation**
   Green roofs provide a better thermal performance on buildings, however this also depends on the amount of water they are holding. In summer the green roof reduces the amount of energy absorption by the roof, keeping the building cooler and also reduces energy usage for air conditioning. In winter the extra layer of substrate etc. provides more insulation but this also depends how much water there is on the roof because water can freeze and ice isn’t heating the building. The heating effect of black roofs in a city is also called the Urban Heat Island Effect. By replacing the black roofs that consume heat with plants the city also benefits from a cooler living climate.

2. **Noise**
   A green roof also contributes in noise reduction, depending on the type and depth of the green roof. But a typical extensive roof already can reduce noise with 8Db.

3. **Rainwater Run-off**
   Urban areas are characterized by a large amount of paved surface. Green roofs can contribute in the water management of a city. Because of the volume of soil for the green roof that can be absorbed with rainwater, the sewer systems are less overloaded when there is heavy rainfall. It works like a large bathtub, it can fill itself until a certain level and then the water will be spilled. So instead of immediately eliminating the rainwater of the conventional roofs with rainwater drainage, the green roof collects it for its vegetation and also works as a buffer for the city sewers.

4. **Air Quality**
   Green roofs can also filter air pollution better known as smog in cities. Plants can reduce CO2 because they can extract it from the air and transform it into oxygen. However there are investigations going if an extensive green roof also filters the air, because trees do it very easy but extensive roofs are mainly covered with sedum. The green roof also cleans a large part of acid rain.

5. **Biodiversity**
   Green roofs can also contribute to keep or repair the remain of endangered species like animals and plants to stay in the city. Green roofs can also be seen as small parks connecting normal parks in the city.

6. **Aesthetic quality**
   A green roof isn’t only giving benefits for the user of the building but also for the surroundings of the building. The living climate of the build environment in cities can be nicer to live in by bringing back nature in the city. The influence from nature for relaxation and reduction of stress is proved so not only the building benefits from a green roof, also the environment benefits from it. And this quality can be achieved even more with green façades.

3.3 Conclusion

Green roofs aren’t just “looking green”, there are many benefits for making roofs green instead of having the conventional black roofs that they are painting white in the USA nowadays because of the Urban Heat Island effect. Black roofs are heating up the roofs and also the urban environment. So by applying green roofs the heating problem gets solved but also the sewer is getting less burden of heavy rainfall. So also as mentioned in the last page a lot of benefits. If one would make the benefits more visible for the inhabitants of a city there can be achieved much more. The problems of heating, heavy rainfall and dense green spaces in the cities will get visible for everyone. New green spaces can be made by making green roofs accessible and interconnecting them.

The green roof is just an constructional method of applying other layers on a roof and if one could integrate this green roof in a building in a other way the benefits of a green roof maybe can combined with passive performance for a building. An example is a study project for a green building concept where different elements of a green roof are integrated in the design. So water storage, roof garden, hanging garden for sun shading etc. Green roofs don’t have to be flat, leveling is also interesting.

1.3.4 Study project. Constructional section with the main structural shapes and layers of materials.

1.3.5 Example of the different elements, water storage for cooling the building and vegetation. Also the hanging garden that can act as natural sun shading in summer.
4. GREEN WALLS

4.1 Introduction

From green roofs to green façades, green façades or also called vertical gardens, are the same principle as green roofs one would say. However green façades also have something strange. Normally trees or plants grow out of the ground upwards towards the sun and in vertical gardens the plants are hanging on the wall. The origin of these walls are going back in nature, the rainforests as Patrick Blanc investigated are overwhelmed with plants growing on anything. The plants in a rainforest are very moist but also growing in soil, rocks, other plants, trees etc. He investigated which kind of plants grew there and if they would grow in other climate conditions. That is a very important issue because instead of the extensive vegetational roofs that are mainly covered with sedum, the green façades are looking far more intense. If one plant would grow but eventually become bald or will grow to hard, the effect of a green façade isn’t reached. But like the green roofs, the green façades have got their aesthetically function for designers but also other functions where a building and the environment can benefit from.

Green Roofs can be covered with a lot of different plants, it also demands a special construction and a good choice of plants. There are many plants that just grow as a flower in a pot bought for in house use. But the choice of plants is often underestimated. An example is the use of hedera, a climbing plant that really grows everywhere. This plant grows good under difficult conditions but it also can ruin a façade construction with his small roots that will grow in every small crack there is and they will make these cracks even bigger. Also maintenance is a big issue. You can choose for a good plant that grows really good in bad and worse conditions but the growing have to be stopped once a while, so cutting the plants has to be mentioned if one still wants to look outside like the image above of the Musée du quai Branly.

Patrick Blanc has a very good overview of the different plants and their requirements to live good on a vertical wall. By his knowledge about different plants from the rainforest he can use his knowledge to design patterns in façades of more dense and more open areas on a green façade by using different plants.

An example of a house that is covered with hedera, this can also happen when there is no maintenance on the green environment. This plant will eventually ruin the roof and leakages will appear. It looks beautiful but there are more problems probably then that it is a functional façade. Hedera better known as ivy, uses adhesive suckers/climbing roots to get grip on surfaces, even when such a plant dies, the suckers will remain on the façades.

4.2 Façade construction principles

Green façades that aren’t build up by nature as the example above need a construction just like a normal wall. This construction looks the same as a green roof but if you would put a green roof on his side the soil will fall out. So it needs a kind of reinforcement to keep the soil for the plants inside, also the plants need to grow to the outside and the plants need water but it isn’t a very nice sight if one pours water from above and by the gravity of the earth all the water will end up at floor level so that’s a problem also. Before going into the benefits of a green façade, a few different construction principles. The way of constructing a green façade also means benefits from the green façade or just a aesthetical look.

Green façades can be divided in a few constructional principles:

1. Framing constructions
2. Tensile constructions
3. Module constructions
4. Green curtain constructions

4.2.1 Framing constructions

The framing principle is very simple, just place fences, metal wire framings in eachother like a fence and grow plants in the cage or let them grow on it like ivy that will grow through and over this structure. An example of this principle is done in Rotterdam by Greenface. This company made a design to give a parking garage a new green look and they also expect that the plantings will purify the polluted air from the cars in the parking garage as shown in their diagram.

By putting a green “box” over the parking garage air can be purified by the plants. The second benefit of this design is getting more green in the dense and grey city of Rotterdam. This design is already performed and when it is fully grown in the coming years it will be the largest green façade in Europe with 5000m2.

Eventually the parking garage will look like this.
The framing principle looks like this:

It's a simple steel mesh, folded into a cage and in that cage plant buckets with soil and hedera are placed every 2-3 meters with an irrigation system that gives the plants water with a fertilizer. So it is more an add-on façade than a special construction.

A even more simple way to make a green façade is spreading tensile rods or ropes over a façade, these mostly metal wires are strained from 2 or more points and one can grow climbing plants over these metal wires. By adjusting the tensile wires there are possibilities of making different patterns or height differences. The strength and tense of the wires are depending of the plants weight but also on the windload. Because working with a tensile construction is like working with a tent, if the wind blows against it you have to hold it strongly or it will blow away.

Tensioning of the metal wires because of the weight of a plant. And the way a plant can swing when there is a strong wind on the tensile construction.

Also this construction is more an add-on construction then a fully integrated one. It can prevent heating up the outer wall by UV radiation from the sun but by the often use of climbing plants like ivy these plants bring their own problems with them.
4. GREEN WALLS

4.2.3 Modular constructions

Now it is getting interesting, like a conventional cladding, the modular construction is a framework where modules with plants can be hanged on. It is almost the same as a balcony with a hanging basket with flowers only on a larger scale. By filling the components with different plants, a designer can make a composition of a certain appearance he want to achieve. Inside these modules the growing media provides everything to let the plants grow. Irrigation is provided along these elements. The modular elements can be fixed as shown in the image on the right or hanged. The nice thing about modular elements is that you can replace elements or reshuffle them.

An example of a modular green façade system:

4.2.4 Green Curtain construction

The final construction type is a green curtain. It looks the most like a real vertical garden because the gardeners have to plant the plants on the wall on the desired places. There are also possibilities to immediately hang the vegetated mats on the façade but the principle is invented by Patrick Blanc, it is just an two layered fabric composed of two layers of synthetic fabric with pockets that physically support plants and growing media. The fabric façade is supported by a frame and backed by an waterproof membrane against the building wall because of its high moisture content. Irrigation is done from the top down.

The green façade of the Caixa Forum in Madrid is a design from Patrick Blanc, this façade holds 250 species of plants and holds 15,000 plants. The building design is from Herzog & DeMeuron.
Green façades can be used on the exterior of a building and for the interior. In the build environment green façades also have their influence on the biodiversity like the green roofs in the previous chapter. The air purification as in the Rotterdam Westblaak gebouw project is a benefit of using green façades next to green roofs also getting more green into the already dense cities is nice for just enjoying living in a city that already has less green. Green façades can also provide noise reduction because of the different wall construction, it depends on which system is used. So the real benefits are depending on the design factors of which plants there are used, which construction, how dense the plants are on the façade etc.

Instead of which system is the best the following summary is more general because different plants in façades have their own positive and negative points and also the possibilities of choosing different plants is greater than on green roofs, note that on a very intensive green roof there is also a lot of possibilities.

Benefits of green façades:

Reducing the Urban Heat Island effect
- Reducing reflective heat from building surfaces and working as a buffer for UV radiation into a wall construction.

Improving Exterior Air Quality
- Purifying the polluted air from cars and other exhausts, working as a filter for gasses and dust particlars. Creating Oxygen from CO₂.

Improving Energy Efficiency
- Improves the insulation capacity of the outer construction wall. Traps a layer of air within the plant mass. Limits movement of heat through the lay of soil for the plants. Reduces ambient temperature of the wall by shading. (L.4.1)

Building Construction/Structure protection
- Because it is a natural self-regenerating “cladding” this cladding doesn’t have needs for painting and protects the layers underneath against UV radiation.

Noise Reduction
- The plants in the green façade construction will contribute to a reduction of sound that gets absorbed in the different layers of the plants and soil.

4.4 Benefits on a larger scale

The benefits of green walls don’t only affect the building but also the environment of the building. Illustrations underneath show that green in cities is going to be a very important subject in the coming years. The use of green in a urban environment has effect on social, ecological and economics. Think of re-using building with a new green façade and the appearance of the city. Rotterdam even gives subsidy for creating more green surface on roofs or façades. Besides making new green areas and green roofs, the green walls will be the next green surface to create in dense cities that benefit from:

- decreasing the urban heat island effect I.3.14
- increasing biodiversity
- working as a stormwater overflow buffer
- filtering the air, mostly fine dust
- 155m² of plant surface area produces enough O₂ for one person for 24 hours!

These are benefits that not only the building and the user will get, but also the people and the city itself.
5. REFERENCES

There are a lot of buildings that use green as an architectural add-on to give the building a certain appearance. However there are a lot of closed green façades like the ones that Patrick Leblanc designs. When we are looking at a green façade that should be used as an green sun shading you would expect that it can be used in front of a transparent façade. There are some projects that really use plants for shading on the façade like the ones designed by Enrique Browne architects but there are also some projects that share the same “transparent” construction that could be used for shading a transparent façade. The references in this chapter have a short explanation of the project, the used construction and the plant choice that was used. After these references there is a comparison and a conclusion about the way things are constructed and where one should take care with designing a green façade that has the function of a green sun shading.

The projects were chosen random because of the lack of literature where green architecture is more associated with sustainability or green competitions than really build “green” looking architecture where the plants are placed in front of a façade in a more “transparent”way. Most of the projects were found by reading the book Façade Greenery and links from green tensile rods constructions.

The references that will get a closer look in this chapter are:

- BioPark, Paris
- Consorcio Concepcion Building, Chile
- Consorcio Santiago Building, Chile
- Europe in Bloom, Copenhagen
- Ex Ducati, Rimini
- GreenPark, Rotterdam
- MFO-Park, Zurich
- Stucki Shopping Centre, Basle
- Vilela Building, Buenos Aires
- Z58, Shanghai
5. REFERENCES

Biopark, Paris

Paris, France
Landscape Design: Raphia
Architecture: Valode et Pistre Architects
Completion: 2006
Client: Sagi
Costs: 29,000,000.

Project Information:
The Centre of Biotechnology, Biopark is a refurbishment project done by Valode & Pistre Architects in Paris. The building was an industrial hotel in the Austerlitz development zone from the 1980's. The industrial hotel now houses a centre of biotechnology. The structure of the imposing buildings remained unchanged but the façade changed due to intervention of reframing the façade with frames where metal trellis forms a support for vegetation that gives the colour to the building. Formerly industrial looks were changed into a green looking building, more suitable to the green urbanist environment. The façades are stepped into terraces, doubled by a steel waving pergola structure that is the climbing medium for roses, bellflowers, acanthuses and clematises. The main idea of using vegetation for the façade was to create a new look for the existing buildings and protecting against solar radiation, not only by using vegetation but also overhangs.

Construction:
For the Biopark, the architect used a metal grid structure that frames the smaller trellis frames where the plants can grow on. The baskets with the plants are placed on balconies. The trellis frames are made with a standardized grid, so the direction of growth isn’t applicable. The chosen plants, aren’t fully green, so the steel framing structure remains a big part of the aesthetics of the buildings.

Plants:
- Roses
- Bellflowers
- Acanthuses, (not climbing)
- Climatises

Consorcio Concepcion Building, Chile

Concepción, Chile
Architecture: Enrique Browne y Asociados Arquitectos
Completion: 2004

Project Information:
The Consorcio Concepción building is a design that has its existence from different designs, the building on the right, the final design has a strong relation with the public square it is standing on, the choice for the use of the green façade was shading from the sun, the first design of the building was a double skin façade with conventional sun shadings and one calculated that it was more expensive than this green façade where two plant baskets along the façade in combination with the construction are shading the building. The façades are orientated on the East, North and West and the south façade is a very closed façade. The lamels where the plants climb on are made of wood on the green façade and the south façade is made of metal plates, both regional products.

Construction:
The Consorcio Concepcion green façade construction is a simple construction where however in drawings the insulation isn’t clear. The baskets where the plants are placed in are made from lightweight concrete to prevent the construction getting too heavy. On the concrete baskets a metal frame is supporting the wooden lamels.

Plants:
- Star jasmine
- Plumbago
- Parthenocissus
- Bougainvillea

5. REFERENCES
Consorcio Santiago Building, Chile
Santiago, Chile
Architecture: Enrique Browne y Asociados Arquitectos
Completion: 1993
Client: Consorcio Nacional de Seguros
Project Information:
The Santiago building in Chile from Enrique Browne architects, was the first green façade that was fully inspired of looking green, making a seasonal dependend colored façade and also bringing a horizontal park vertical on a building. After this project the Consorcio Concepcion building was build with the same principles learned from this project. In the Santiago building there was a larger façade to clad with vegetation than the Concepcion building. Also maintenance was a bigger issue, a desing criteria was that the windows could be cleaned behind the green sun shading. With a normal window washer elevator on the outside of the building, not only the windows could be cleaned but also the plants could be maintained easily. However branches made it hard sometimes to lower the elevator without damaging the plants.

Construction:
Before the final design was chosen to use plants for sun shading and also different aesthetics during seasonal changes there were alternatives for making a green element as shown on the concept drawings on the right. From shading the summer sun with horizontal elements, using trees instead of climbing plants and finally the way it was made. Normal baskets of concrete filled with climbing plants that could grow on “sun shading” louvres that are also part of the construction. As seen in the previous more recent reference, the same plant choice was used, only the green façade was more exploited by reaching 4 floors instead of 2 with climbing plants.

Plants:
- Star Jasmine - Parthenocissus
- Plumbago - Bougainvillea

Europe in Bloom, Copenhagen
Copenhagen, Denmark
Architecture: Johanna Roßbach
Completion: May 2010, temporary until October 2010
Project Information:
Europe in Bloom is a green façade that shows the map of Europe on the façade of an existing building in Copenhagen. The existing building houses the headquarters of the European Environment Agency. The green façade is filled with 5,000 plants from 20 different plant species, including purple verbena, dark green sedum and delicate sutera. The façade provides benefits besides giving the headquarters a green look also an extra insulation, absorbs noise of the streets and filters a part of dust. This is very logical because the closed parts with plants work like an extra façade layer. The reason for making this green façade was to show that mimicking nature gives us the possibility to enhance green space and biodiversity in the city. This was done on 22 May, World Biodiversity Day.

Construction:
The construction is a steel grid filled with a steel mesh where felt pockets are hanged on a wooden back structure. The plants aren’t used in front of the windows, instead to keep the green aesthetics they placed plastic transparents in the frame so the view isn’t obstructed. The construction is made by the company, Green Fortune.

Plants:
From the large amount of 5,000 plants they made a schedule where which plants should be planted on the façade. Underneath this text you can see the schedule and the amount of plants. Next to the schedule you can see where there plants are placed on the façade.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Plant</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Star Jasmine</td>
<td>35</td>
</tr>
<tr>
<td>B</td>
<td>Parthenocissus</td>
<td>35</td>
</tr>
<tr>
<td>C</td>
<td>Plumbago</td>
<td>30</td>
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<tr>
<td>D</td>
<td>Bougainvillea</td>
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<td>G</td>
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<td>W</td>
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</tr>
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SUM | 6530 | 4229 |
**Ex Ducati, Rimini, Italy**

Rimini, Italy
Architecture: Mario Cucinella Architects
Façade: Façadesign snc
Completion: 2008
Client: Edile Carpentieri Srl

Project Information:
The EX Ducati building has a rounded L-shaped layout where the façade is cladded with vegetation on a diamond shaped framework. The outer façades of the L shape are cladded with vegetation and the inner façades, the rear side of the building is cladded with wooden cladding elements. The vegetation is placed around the building where the façade is creating the most heat created by the sun.

Construction:
The green façade is made from a 60 x 60 cm steel grid in a diamond pattern where the climbing plants can grow on. The plants are placed at several places, they are placed in the ground at the ground floor and they are also planted on the outside corridors. As shown on the detail on the right.

Plants:
- Star Jasmine

**GreenPark, Rotterdam, Netherlands**

Rotterdam, The Netherlands
Architecture: Greenface, part of Kuhne & Co Architects
Completion: originally build in 1976, green façade sept. 2010
Client: Christian Stadil (owner Parkeergarage Westblaak).

Project Information:
The façade of the Westblaak parking garage in Rotterdam is the largest green façade of Europe (sept. 2010). The façade should be fully green as shown in the artist impression within 3 years and will fill 5,000 m² of façade with green plants. The effect of this green façade is aimed at fine dust filtering. The amount of green façade square meters is equal to 200 fully grown trees and reduces the amount of CO₂ exhaust of the parked cars in the garage. The system also improves the biodiversity in the city and reduces the urban heat island effect. Besides the urban heat island effect it also helps the city when there is heavy rainfall by collecting the rain for the façade.

Construction:
The façade is build up as a tree that branches out over the façade. The branches are made of a steel mesh hive, that is attached on the concrete panels on the outside of the garage. In the steel mesh hive there are plastic baskets attached with an insulation blanket at the bottom of the baskets for water reserves for the plant and normal soil with pre-grown plants. Besides the simple construction of a steel mesh with plastic baskets with plants in it there is a special irrigation system that collects rainwater and uses it for the plants on the façade.

Plants:
- Hedera Helix Woender
- Pyracantha

5. REFERENCES
**MFO-Park, Zurich, Switzerland**

Zurich, Switzerland  
Architecture: planergemeinschaft MFO-Park burckhardtpartner / raderschallpartner ag  
Structural Engineering: Basler & Hofmann  
Completion: 2002  
Client: Grün Stadt Zürich

Project Information:  
The MFO-Park in Zurich is one of the four parks that are planned for the new Zurich North center. The MFO-Park is more than 100 meters long and 17 meters high. The steel structure forms a three-dimensional framework where climbing plants indulge themselves and grow in and over the whole structure. There is a inner and outer green structure where the plants grow on. In the space between there is a route consisting of steel stairs and paths. You could say that it is a multi-storey public park.

**Stücki Shopping Centre, Basle, Switzerland**

Basle, Switzerland  
Architecture: Diener & Diener, Basle  
Completion: 2009

Project Information:  
The Stücki Shopping Centre in Basle covers a lot of square meters and also has got a lot of different façades that have their own relations with their surrounding. The west side of the building has a green veil of vines and other climbing plants that is creating a visual screen opposite the housing areas. Behind this green layer are the steel escape staircases that are hidden behind the plant baskets and plants.

Construction:  
The green construction is a very simple solution where the plant baskets are placed on a canopy and tensile rods attached on the bottom of the canopies. The water drainage isn’t very nice, surplus water from the baskets just splashes on the ground underneath.

Plants:  
There is a long list of plants that are used in the green façade, this is done because the architect wanted different aesthetics during the seasons, this is a small overview.

- Jasminum nudiforum  
- Clematis montana (Mayleen)  
- Ginkgo biloba (Fastigiate Blagon)  
- Lespedeza thunbergii  
- Wisteria sinensis  
- Lavandula angustifolia  
- Fagus sylvatica (Atropunicea)  
- Hedera helix  
- Hedera colchica (Sulphur Heart)  
- Lonicera henryi (Copper Beauty)  
- Fargesia robusta

**Construction:**  
The whole MFO-Park is made of a fixed steel framework that covers six stories, combined with a tensile rod system where the plants grow on. The largest amount of plants are placed in the ground so not in baskets. It took a long time before the plants where fully grown over the entire 17 meters of the façade. By the use of a lot of plants dividing them over columns and ground connections of the steel structure.

Plants:  
The MFO Park uses 104 different vines to provide a wide range of growth and color.

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5. REFERENCES

- Lonicera pileata (Moss Green)  
- Lonicera nitida (Shrub honeysuckle)  
- Carpinus betulus (Common Hornbeam)  
- Pyracantha (Orange Glow)  
- Caryopteris clandonensis  
- Parthenocissus quinquefolia (Engelmannii)
Vilela Building, Buenos Aires

Buenos Aires, Argentina
Architecture: Joselevich Rascovsky Architects
Completion: 2008

Project Information:
The housing project holds ten apartments that are all different. The housing project has a façade that is fully filled with glass to allow a maximum exterior view while the vegetated walls create privacy, control the heat and the indoor and outdoor air quality. The plant choice also gives the building a changing façade during the seasonal changes. The main idea was that the user can cut out some parts of the plants to create their own amount of sight outside. The green façade is maintained by an irrigation system designed for the building.

Construction:
The plant baskets are resting on a concrete extension of the floors, the baskets are made of metal and are connected to a very lightweight mesh construction where the plants can grow on. The mesh construction is made of vertical small profile steel and they offer support for the horizontal aligned tensioned rods.

Plants:
Plant choice based on color, leaf density, smell and van kleur, bladdichtheid, geur, sun resistance.
- Jasmine celeste
- Thumbergia azul
- Passiflora
- Hardenbergia
- Hedera
- Jasmine azorico
- Jasmine de leche
- Jasmine solano
- Bugambilia
- Bignonia rosada

Z58, Shanghai

Shanghai, China
Architecture: Kengo Kuma & Associates
Completion: 2006
Client: Zhongtai Lighting

Project Information:
Z58 is a building consisting of a volume with a simple form that is cladded with different linings along. The front façade where the entrance is located is a façade that looks very dense and solid but hides a complete different experience from the inside. The dense façade on the outside is counterbalanced by a glazed façade on the inside. The façade is made of stainless steel plant baskets that are polished on the outside. And hold simple ivy plants in it.

Construction:
The construction is an inverted glazed façade with spider mounts that hold the glazing. The structure that holds the spider mounts is located on the outside where it also holds the polished stainless steel plant baskets. The plant baskets are simple attached to the vertical profiles of the glazed façade with two nuts at each vertical column. The plant baskets have drain holes in the bottom so excessive water can flow into the basket underneath until it reaches the ground level. At ground level the excessive water is collected in ground based plant baskets. The plant baskets aren’t folded out of one piece of steel but are panels that are cladded on a steel frame. The external dimensions of the plant baskets are 300mm high, 325 mm wide and the length is dependent on the façade columns. The plants have irrigation as shown in illustration I.5.34 from a horizontal pipe and maintenance has to be done from the outside. Cleaning the outside surface is a problem, because you need to get behind the plant baskets.

Plants:
Hedera
### Project: Biopark, Paris

- **Facade function**: Upgrading an existing building with a new look, this is combined with the function it should represent. A center for public health companies and biotechnology firms.
- **Construction**: Metal grid structure that frames smaller trellis frames where the plants can grow on. The plant baskets are integrated on the balconies behind the trellis frame.
- **Plant choice**: The facade is clad with four different plants, mostly flowering plants. These plants will lose their leaves in the autumn and winter, so the facade is only green in the summer.
- **Costs**: This could be a relatively affordable facade because of the simple steel construction and the trellis frame that is placed on the facade. Because of the rigid frame that is connected to all of the floors and is supporting on the ground floor it doesn’t have a lot of displacement forces.
- **Dimensions**: The grid structure is very open, where the trellis frame is circa 2 meters high and off centered from the building windows. The plant baskets aren’t placed over the full length of the trellis frame but are circa 800x500x800mm.
- **Maintenance**: Maintenance can be done easily from the inside out, standing on the balconies.

### Project: Ex Ducati, Rimini

- **Facade function**: Enhance the biodiversity and green space in cities.
- **Construction**: The construction of this facade is performed as a sun shading element. The choice of plants are based on their appearance in the different seasons. However, when the plants aren’t fully grown the facade structure where the plants climb in is also working as an sun shading.
- **Plant choice**: The facade will turn from freshly green in the summer to warm red in the autumn and eventually nothing in the winter.
- **Costs**: The use of plants on this facade has only got one function and that is to give the existing building a green look and the green look is representing a map of Europe. This was done to show how to mimic nature and representing a map of Europe.
- **Dimensions**: The structure where the plants climb in is a diamond shaped steel frame over the entire facade. The plant baskets are integrated in the gallery floors. The baskets are 25cm deep and 25cm wide and run along the gallery length.
- **Maintenance**: Maintenance can be done from the inside out because one can get on the plant baskets, however, when you want to prune the upper part of the two stories high planting you can’t reach it without a stair. So this could be problematic. This is the same problem if they want to clean the windows.

### Project: Consorcio Concepcion, Santiago, Chile

- **Facade function**: Enhance the biodiversity and green space in cities.
- **Construction**: The construction of this facade can be divided into two elements, the plant basket and the structure where the plants climb in. The plant basket is placed over the entire length of the facade and made of lightweight concrete and is part of the building structure. On the concrete plant basket there are metal profiles in a vertical direction that support wooden horizontal lamels.
- **Plant choice**: The architect uses four different plant types, based on their seasonal aesthetics. All are climbing plants. The facade will turn from freshly green in the summer to warm red in the autumn and eventually nothing in the winter.
- **Costs**: The construction is rather simple, however, the lightweight concrete plant basket could be a little difficult because it is in-situ concrete so they had to make a mold when they were constructing the building. But it is one integrated element that can’t be replaced or removed without breaking it.
- **Dimensions**: The plant basket has the entire length of the green facade, dimensions are circa 1 meter high and 800-900mm wide. The structure where the plants climb on span a height of two stories.
- **Maintenance**: The maintenance can be done from the inside out because the green facade construction and the trellis frame is connected to all of the floors and is supporting on the ground floor it doesn’t have a lot of displacement forces.

### Project: Consorcio Concepcion, Concepcion, Chile

- **Facade function**: Enhance the biodiversity and green space in cities.
- **Construction**: The construction of this facade is the same as the one of the Consorcio Concepcion building. The lamels however aren’t made from wood but from metal and the baskets are larger and placed every five stories.
- **Plant choice**: The architect uses four different plant types, based on their seasonal aesthetics. They all are climbing plants. The facade will turn from freshly green in the summer to warm red in the autumn and eventually nothing in the winter. The same as for the Consorcio Concepcion building.
- **Costs**: For this project it is hard to say what the costs are, maybe the amount of different plants that are used, or the construction that is made of different materials and layers. But because it was a temporary facade thing can be re-used also. But the question remains if the temporary facade was worth it. Where there are window washer lift. The plant baskets are 2 meters wide and circa 1 meter high. The plants grow over five stories instead over 2 stories.
- **Dimensions**: The construction is the same as on the Concepcion building, however the plant baskets are more wider for the window washer lift. The plant baskets are 2 meters wide and circa 1 meter high. The plants grow over five stories instead over 2 stories.
- **Maintenance**: Maintenance can be done from the inside out because the green facade construction and the trellis frame is connected to all of the floors and is supporting on the ground floor it doesn’t have a lot of displacement forces.

### Project: Europe in Bloom, Copenhagen

- **Facade function**: Enhance the biodiversity and green space in cities.
- **Construction**: The use of plants on this facade has only got one function and that is to give the existing building a green look and the green look is representing a map of Europe. This was done to show how to mimic nature and enhance the biodiversity and green space in cities.
- **Plant choice**: The construction is a steel grid made of steel profiles with a steel mesh on top of it with an wooden structure behind it. The mesh frame functions as a dividing element where modules are fitted in and nailed on to the wooden back structure. A lot of materials for a rather simple construction that could also be made with plastic modules that are fixed on the steel mesh.
- **Costs**: The designer used 5000 plants with 7 different aesthetics. The choice of plants is projected on the facade in the shape of the map of europe.
- **Dimensions**: The green facade structure covers a large part of the facade, it is hard to say exact dimensions. However the plant pockets are circa 28x28cm.
- **Maintenance**: Maintenance needs to be done from the outside, so an external platform lift is needed because the plant pockets are only accessible from the outside. The filling of the facade has been done the same way with a platform lift. There is something to say about the plan because they aren’t climbing they don’t need a lot of attention because they won’t grow very large. And it is just a temporary facade.

### Project: Ex Ducati, Rimini

- **Facade function**: Enhance the biodiversity and green space in cities.
- **Construction**: The plants are used to shade the building from the sun on the green facades.
- **Plant choice**: The facade consists of only one plant type and that is Star Jasmine that is also green in the summer when they used the winter resistant species.
- **Costs**: The construction is based on the steel diamond shaped frame on the outside of the building and the plant baskets that are integrated in the gallery floors. It could be a very affordable construction because the dimensions aren’t very large so the loads aren’t very high also. When you look at maintenance this is also easily accessible from the gallery floors.
- **Dimensions**: The diamond shaped frame is the largest component of the green facade, the gallery floor that also houses infrastructure and lighting can’t be fully calculated for the costs of the green facade because different functions also benefit from it. The plant choice and the amount of facade it needs to grow on can lower the costs because maintenance isn’t needed until the facade needs pruning or when it reaches the rooftop.
- **Maintenance**: From the gallery floors one can maintain the plant baskets and also the irrigation and fertilization. However when the plants need pruning you will need an external access with a lift. Because the gallery isn’t running along the entire facade and you can’t reach everything from the gallery.

### References

- **5.35 Comparison scheme of the references**: I.5.35 Comparison scheme of the references
5. REFERENCES

<table>
<thead>
<tr>
<th>Location</th>
<th>Function</th>
<th>Construction</th>
<th>Facade choice</th>
<th>Costs</th>
<th>Dimensions</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
<td>The green facade is applied on a existing parking garage to give the parking garage a fresh new look. Besides, the facade also is nominated by the Rotterdam Climate Initiative because it enhances the biodiversity in the city and filters the dirty exhaust gasses from the cars in the parking garage.</td>
<td>The green construction is made from a steel mesh pattern that is filled at certain points with plastic plant baskets. Also, three different plants are used along the facade. The structure is attached with steel L-profiles that hold the mesh system and the plant baskets on the existing concrete columns and structural walls. Along the structure an irrigation system is applied to give the plants the nutrients they need.</td>
<td>The facade is filled with three different plants, mainly Hedera but to prevent people climbing in the facade the structure on ground level they used Pyracantha, a plant that stings.</td>
<td>The system only uses a steel mesh that is folded into beams with plastic plant baskets placed at certain points of the steel mesh. It is an attachment to the existing facade with simple bolt on connections, because of the small plant baskets the weight isn't very high and won't demand reinforcements of the structure.</td>
<td>The plant baskets are circa 50x30x50cm and the folded mesh frame is running along the facade in a branching pattern. Plants are placed at every story on the vertical frames and the branches are left empty so the plants need to grow over the diagonal branches. The concrete panels along the facade should also be covered with hedera. The facade is entirely more of a green park. The whole facade was a existing watch factory and now it holds the new facade for the building.</td>
<td>Maintenance is not an issue for this project. They leave it growing for the first three to four years to get the green facade they want. Irrigation is done by a monitoring system that reacts on the demand of moisture in the plant baskets. When there is to much water in the baskets it just drips on the ground or along the facade.</td>
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<td>Zurich</td>
<td>The MFO-Park is entirely made of a steel structure with at certain points tensile steel rods creating a rigid whole. At certain points there are also some extra tensile rods or cables to provide more climbing resources for the plants that grow on the structure.</td>
<td>The whole structure is overgrown with 304 different vine types. These are always green in a certain way so the park keeps it's appearance in summer and winter. Most of the plants are placed in the full ground so not in baskets. It is a more natural way of planting.</td>
<td>It is a remaining structure and it only functions as a green park. So you could almost say that the structure is the &quot;building&quot;</td>
<td>It can be a very cheap solution just by using heavy plant baskets placed on the galery's with just a tensile steel rod attached to the bottom of the galery above. The weight of the baskets only ensure that you can't replace them very easily.</td>
<td>The plant baskets are circa 50cm high and wide and have a length of circa 2 meter. The length of the tensile rods is the story height minus to height of the plant baskets where the rods are attached on.</td>
<td>Maintenance can be done from the inside of the structure because you can reach the plants at every level, of course the roof is hard to reach but a green park doesn't need a lot of maintenance.</td>
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<td>Buenos Aires</td>
<td>The facade doesn't have a real function besides looking green and covering up the emergency staircases at the west side of the building complex.</td>
<td>There is a large amount of plants that are used to fill the facade to ensure that the facade will look different every season.</td>
<td>It can be a very cheap solution just by using heavy plant baskets placed on the galery's with just a tensile steel rod attached to the bottom of the galery above. The weight of the baskets only ensure that you can't replace them very easily.</td>
<td>It can be a very cheap solution just by using heavy plant baskets placed on the galery's with just a tensile steel rod attached to the bottom of the galery above. The weight of the baskets only ensure that you can't replace them very easily.</td>
<td>The entire MFO Park is more than 100 meters long and 27 meters high. Plants are placed at the ground floor.</td>
<td>Maintenance can be done very easily because this can be done from each floor. The plants aren't that high and you can easily access the areas. The maintenance of the square underneath the galery's will ask more maintenance because of the over flow of overflowing water that isn't take care of. It just splashes on the ground.</td>
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<td>Shanghai</td>
<td>The facade of the building is fully glazed, in front of the facade there is a green facade that was used for the green looks and also for privacy reasons. The idea was that the user could prune the plants themselves and have their own influence on the amount of privacy and sight.</td>
<td>The construction of the floors are continuing to the outside where the plant baskets are placed on the outer facade.</td>
<td>There are ten different plants used for the green facade, chosen for several reasons, as smell, color, leaf density. The plants are chosen for never losing their leaves completely and flowers will be present the whole year. The plants are native because they resist the climate the best.</td>
<td>Extending the floors as a cantilever is a very clever way to make supports for the plant baskets, however it will ask a special framework while constructing the concrete floors. But you don't need a lot of additional materials to fix the baskets on the facade.</td>
<td>The plants are placed on every floor of the building, only covering the facade of one story. The plant baskets are circa 28cm high and 38cm wide. The length of the basket depends on the lenght of the vertical grid that is used, but they could also be longer along the facade. They aren't very clear about it.</td>
<td>Maintenance of the facades can be done from the outside of the appartments. The windows can be opened and one has access to the plants. However it isn't clear if all the windows can be opened to reach all of the plants. Irrigation of the plants is done by a central irrigation system.</td>
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<td>The facade is used as a very dense border between the inside of the building and the build environment. The long stretched polished plant baskets give the building a strong representation of the form and between the baskets ivy is growing in the baskets. The content between inside and outside. The history of the building was a existing watch factory of concrete that isemnance. Glass, green and water are the main concepts in this building where water is represented inside the building.</td>
<td>The construction is based on a glazed facade with spider mounts that hold the plants. The spider mounts also is placed outside the building and also holds the polished stainless steel plant baskets. The plant baskets are build up out of a frame construction and cladded with polished steel panels. Within the plant baskets an extra basket is placed where the plants live in. Tensive water-flow is directed to the plant baskets underneath each other and eventually flowing into a ground based basket.</td>
<td>The facade has been implemented in the facade is a Hedera climbing plant. It is a clever construction to use a facade construction you already need for the roof, the structure is cladded with steel for two different types of construction. The green facade isn't designed to shade for the sun but for enhancing a certain experience of the building. The costs can be high because of a lot of polishing and probably coating the baskets to remain the polished surface. But by the large amount of repetitional objects it could be an affordable construction.</td>
<td>The plant baskets have a height of 300cm, a width of 40cm and a length of 70cm. The plant baskets are made of steel and is dependent of the structural columns of the glazed facade. The inside baskets for the plants could be circa 200x200x200cm high and wide. Only the entrance facade is cladded with these polished baskets with ivy in it, the other facades aren't.</td>
<td>Maintenance is an issue because of the external structure of the glazed facade that was made to be cladded with steel plant baskets. If facade isn't orientedated on heavy rainfall and wind the amount of dirt on the glazed facade could be relatively clean. When it is not, the window washer can't reach this face of the glazed facade. The plants can only be maintained from the outside and the inner glazed facade from the inside with a lift or ladder.</td>
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5.3 Conclusion

The conclusion is based on the subjects that are used to compare the references mutually.

Construction:
Most of the constructions used in the references are rigid frames where the plants grow on. The plant baskets are placed on a floor or attached on the building façade. Most of the frames are orthogonal with vertical and horizontal subdivisions. The dimensions of the constructions varies a lot. The dimensions of the baskets and the frame are depended of the surface that is overgrown with plants.

Plant choice:
There is a wide variety of plants used on the façades, some plants are used a lot like Star Jasmine. The type of plant that is used to clad a rather large surface is always a climbing plant if the used construction is based on a frame that needs to be cladded and a plant basket for the plants. The reference Europe in Bloom shows that there is a possibility to use not climbing plants but then we aren’t speaking about a “transparent” green façade construction anymore.

Function:
There is awareness of the function of implementing plants on a building. It is a pity that most of the information is written by someone different than the designer. So the question remains if an architect just used plants for creating a green appearance or for the functional benefits a vegetated façade could offer.

Costs:
Costs are hard to predict. There is almost no information about the specific costs of a project. Sometimes there is a value findable about the total construction costs of a project but without detailed element costs like the structure or the façade. Constructions can be easy to build or take a lot of effort to build. Building integration or application of a green cladding also have influence on the construction costs. A repetition or a certain simplicity can make a green sun shading cheaper but it is a relative factor what is different by the quantity of a project. Future costs awareness can be interesting. How will the system look over twenty years and can it be replaced?

Dimensions:
Almost all the systems have the same climbing structure for the plants. The amount of soil that is used in the plant baskets differs with each project based on plant choice and the demand of the plants on growth room for the plant roots. It is unclear but possible that the dimensions of the plant baskets are based on the structural needs. Sometimes the plant baskets are placed on the building like an add-on. Like a plant basket on a balcony. Or the plant baskets are part of the building structure as the Santiago Concepcion building where the structure is extended outside the building skin and is used as a plant basket. It is unclear whether the designer used only soil or a combination of different substrates to lower the amount of weight of the construction.

Maintenance:
Some projects don’t need a lot of maintenance in the first period when the plants need to grow an entire façade. Greenpark for example is a project where the whole façade supposed to be covered with ivy within three years time. Compared to Z58 the elements are much smaller and the space between the plant baskets is very dense so overgrowth of the plants could easily occur. So the façade of Z58 could expect a lot of pruning and maintenance. But the thing that lacks is the water drainage. Both Greenpark and the Stucki Centre projects just splash excess water on the site where the building is located. There is no drainage system used to transport excess water without splashing it on the ground or even worse splashing it on the façade. By not applying a drainage system one can expect a higher maintenance interval than when one uses a drainage system. Good irrigation can maintain the plant growth and aesthetics. So don’t only think about the maintenance of the green layer of the façade on itself but see it as a part of the total building. Maintenance isn’t only maintaining the plants but also maintaining the building. When a green façade is used you also have to think of the fact that windows need to be cleaned otherwise it is not nice to look outside after a while because you will see through dirty windows.
TECHNICAL RESEARCH
6. CASE STUDY SADD

6.1 Explanation

The world is very aware of the vulnerability of the earth and a lot of sustainable ideas and developments are taking place. However there isn't one large organization that takes care off the management of this knowledge and ideas. Because this concerns the whole world the United Nations want to build a new headquarter for environmental information distribution, managing and development. This new part of the UN is called the UNEC, United Nations Environmental Council. The design of the building is affected by a new to develop masterplan where there are contradictions between a strong security border and the transparency that the UN wants to have to the world.

Designing a public building that should represent the UNEC is about designing something that has a public character and it should be "sustainable". Because Sustainability is a very wide definition my opinion is that a lot of buildings can be sustainable but for common people not visible. Sustainable buildings can be sustainable with newest technology, sun energy harvesting, rainwater harvesting, a smart structure for the future etc. The UNEC building should be more like an icon for sustainability, it should look green, so that even children already recognize a sustainable headquarter of the UN.

Besides looking green, there should be a extra function on looking green. The UN Park is now filled with a temporary building that swiped the park away including the monuments given to the UN. Visitors that come to see the monuments of the park that were given to the UN can't see everything anymore. The layout is gone. To prevent this and keep the park, the new headquarters has to be a modest building, at the end of the plot so it can give the users of the building also a look over the UN Park. The green look of the façades should not only represent a "sustainability" headquarter but also use the green that is used for the footprint of the building. What goes away needs to be replaced by new green. And beside looking green it will be performing "green" by implementing the function of a green sun shading.

The shape of the building is a generic rectangular shape, one could choose to make a very compact high building but sustainability is also a functional aspect. Working in a sustainable way also asks for a functional building, freedom in changing floor plans for the future and having everything you need in reach on the same floor. Oversized old-fashioned story heights give space and the feeling of a public building. Stretched floor plans give the opportunity to have functions within reach on the same floor. So a skyscraper isn't that functional, a stretched one however is. Because functions can be connected on the same level. The ground floor exposes the interior functions as an exposition but also the workshop area so visitors of the UN park also get acquainted with the role that the UNEC has and what people are doing inside of the building. The upper stories are getting more private where research and conferences take the lead where more privacy and silence is asked. The top floor is the last layer that is filled with offices, the employees that keep the UNEC running have their own area overlooking the UN plot and surrounding UN buildings.

A building as the UNEC headquarter should be modest and sober while being very functional. The importance of the building should represent a strong and massive building, not a screaming high technological architectural folly. People should recognize an important public building with a aim on environmental issues like this.

The ground floor has a very transparent façade, that only interrupts at the entrance that is slightly pulled outwards in contrast to the rest of the ground floor façade. The façade above the ground floor that houses the more private functions of the UNEC is cladded with a caging system that could supply room for planting. These aren't filled yet with plants in the presentation because the elements aren't fully developed and after this building technology research they can change with the dimensions, construction and fillings researched in this report.
The total structure isn’t definitive yet, so there can be more columns in the façade. For the green sun shading there was a earlier design that took care of the natural sun shading. It should look green in the summer and bold in the winter. This idea wasn’t the best solution because you need a secondary system in the winter because when the plants don’t have leaves anymore they won’t shade from the sun. The clue of using the right plants at the right time is that you can achieve a different façade during the seasonal changes in a year. As shown in the impressions underneath you can see that the plants can look red/orange in the autumn instead of the fresh green look in the summer. Because there are different functions in the building there are also different demands of sun shading but when you would design a green element as the impressions below the sight is also very important. When there are plants and leaves with a high density in front of the window you will lose a lot of sight. And that is something that is important with functions that demand a lot of sight, for example the circulation space in the middle of the building that gives a nice overview over the UN park. And for example functions like a library don’t need a lot of sight outside and light inside because you want to preserve the books that can be read there. Therefore a sun shading demand overview of the functions and their demands is an interesting subject before you make the choice how the green sun shading should be made.

The most demanding function in the building is the top floor where the offices are housed and where employees of UNEC work from 9.00 o’clock till 17.00 o’clock. The main idea is that once you make a green façade that is made in front of a transparent façade that view is designed to the demands of the user and give enough horizontal and vertical sight outside. Besides sight the amount of sun shading should be optimised to be used in the summer and winter and if you use vegetation on a façade it can be very nice to have access to it. That you can really reach the plants. When the green sun shading is dense enough it could even look or act like a second façade skin so the first glazed skin can be slid open while the green façade diffuses the wind and makes the border even less with the green sun shading.
7. SOLAR STUDY

10.1 Introduction

To know what to shade for a solar study is an essential analysis that have to be made before one chooses a type of sun shading. Orientation and location of the building are two factors that are important but also the time period that one needs to shade the building and also the demands of the user. The function of the sun shading is also important. Should the sun shading be passive mounted on the façade or can the user adjust the amount of sun shading?

“The sun is the single most important factor in the lives of people and their buildings. The oxygen we breathe, the food we eat, and the fuels we burn are created by the action of sunlight on green plants. The water we drink is purified in an atmospheric distillation process powered by heat from the sun. Sunlight warms our bodies and buildings by direct radiation or through warming the air around us, sometimes encha string our comfort and other times making us uncomfortable. Sunlight illuminates the outdoors, disinfects the surfaces it touches, creates vitamin D in our skin, and has an uplifting effect on our dispositions. Sunlight also disintegrates the materials with which we build, burns our skin, and promotes skin cancer. The sun is both the giver of life and its destroyer.” (How Buildings Work - The Natural Order of Architecture)

As already explained earlier in this report the usage of plants on the façade of a building has benefits in protecting the façade because plants are using the radiation of the sun for growing and supplying the demands for photosynthesis. Normally sun shading elements are made of steel frames, plastics or fabrics that are getting bleached by the UV radiation. But for designing a sun shading with plants can be done there should be an analysis of the demands of sun shading. In the Netherlands there are no rules about sun penetration in the building regulations. For the amount of daylight there are but that is a different subject that will be explained further on in this report. But you have to prevent that there is a lot of solar radiation getting inside your building to give a nice working climate and not over-powering the demands of sun shading. In the netherlands there is no need to consider the intensity of solar radiation on the building because of the high amount of sun shading. But for the design of a sun shading with plants can be done there should be an analysis of the demands of sun shading.

The earth spins around the sun in an elliptical orbit with a mean radius of circa 150 million kilometers. It rotates also around its own axis once each day and completes an orbit every year. The half of the earth is orientated from the sun and the other half is lighted by the sun. Also the distance between the earth and the sun changes enough to cause a variation of about 7 percent in the intensity of solar radiation on the earth over a six-month period. That is the difference of the high intense solar radiation in the summer in contrast to the amount of radiation in the winter period. However this isn’t the reason that the seasons are here at our earth. The sun is in it’s closest range to the sun in June and August, but the seasons are created by a slight tilt between the axis of the earth’s rotation and a perpendicular to the plane of it’s orbit. “As the position in the earth’s orbit where the North Pole is tilted closest to the sun, the sun’s rays in the Northern Hemisphere pass through the atmosphere and strike the earth’s surface at a steep angle. The path of the rays through the atmosphere is short, so that the air absorbs and scatters relatively little sunlight before the radiation reaches the ground. Because the sun is so high with respect to the surface of the land in the northern hemisphere, solar radiation is received in a maximum concentration per unit area of the surface. The sun’s rays are then at their hottest at this orbital position, known as the summer solstice, which occurs around June 21 of each year. The total solar heat gathered by the Northern Hemisphere on June 21 is further increased by another important factor: the sun is seen for a longer period of time on this day than on any other day of the year. The sun rises to the north of east before six o’clock in the morning and sets to the north of west after six o’clock in the evening. How long before and after six o’clock sunrise and sunset occur is wholly dependent on latitude.” (L.7.1)

10.2 Implementation case study

When we look at the UNEC building the building isn’t situated perpendicular to the earth axes. The longest façade that looks over the UN park is orientated on the South-West for the largest part. The diagram underneath is showing a sun diagram that shows us where the sun is on which time of the day. The sun comes up earlier in June than in December and in September there is a equinox where the Northern and South poles is equidistant from the sun. In this equinox the sun rises exactly in the east and sets exactly twelve hours later in the west.

The diagram also shows the time that the building is in use. When we want to shade for the people that are working in the building, you should know when a sun shading should be active when we are talking about a controllable system. But when you want to shade in a passive way with an adaptive system you could also say that this isn’t a very important criteria because if you are using an adaptive system, the system will control the amount of sun shading according to the input the system is getting where the sun is shining at a certain moment. For the UNEC building the demand is that the users in some of the functions, especially the offices can control the amount of sun shading according to the input the system is getting where the sun is shining at a certain moment. For the UNEC building the demand is that the users in some of the functions, especially the offices can control the amount of sun shading according to the input the system is getting where the sun is shining at a certain moment. For the UNEC building the demand is that the users in some of the functions, especially the offices can control the amount of sun shading according to the input the system is getting where the sun is shining at a certain moment. For the UNEC building the demand is that the users in some of the functions, especially the offices can control the amount of sun shading according to the input the system is getting where the sun is shining at a certain moment.
The scheme above shows the average amount of sunhours in New York. Here you can see that July has the longest amount of sunlight hours but because of the Summer Solstice the intensity isn’t at its highest amount. In December the sun is at the lowest amount of sunlight hours. The difference is about 150 hours of sun less in winter period in contrast to the summer period.

Next to direct sunlight there is also indirect diffuse radiation. (sunlight that travels through the earth atmosphere is already a diffuse radiation), and radiation that is reflected by the ground. Direct radiation is less intense when you would compare it to diffuse radiation because diffuse is a collection of multiple direct radiation rays. When we look at a façade orientated on the south the sun is much higher middle of the day than when it sets or rises at the east or west side at the beginning of the day. The intensity of the radiation is much higher on the east and west façade in contrast to the south and north façade because of the angle of the sun at that moment. Because the UNEC building isn’t perpendicular to a direction it has to deal with a transition area where the longest façade gets the less intense radiation but also the most intense radiation on the corner with the shortest façade. The conclusion is that the façades need different types of sun shading to deal with the different angles of the sun.

Façade orientation on the west or south west are having the most problems when we are talking about overheating. The sun radiation reaches the highest values in the afternoon exactly at the moment when the exterior temperature is at its maximum. But for buildings that are used within office times for example between 9 and 17 o’clock the situation isn’t that bad because when the overheating is occurring the most users will leave the building. This means that the user isn’t getting the problem of overheating comfort but it does mean that the sun shading should be closed until the night to prevent overheating of the building. The same problem is for the east and southeast façades when the sun shading needs to be closed when the sun rises to keep the building cool before the users are entering the building. Again to prevent overheating and keeping nice comfort conditions.

The diagram below shows that the highest temperatures are reached in July and August in New York because of the earth’s capability to store energy. To give a good graphical overview of the sun that is shining on the building one should make a solar study to see what the sun does with the building. Which façade is getting most penetrated by the sun and which façade almost stays in the shadow the whole day.
The solar study from the sun diagram translated into a horizontal and vertical diagram to see the influences of the sun on the façades at a certain time. The diagrams also show on which time the sun will be perpendicular on the façades. The diagrams taken from above show the azimuth angle of the sun and the diagrams that are displaying the elevations of the building are displaying the angle of the sun.

In the summer period the sun is on its highest altitude from 12.00 until 14.00 o’clock and after that the sun intensity is losing strength until it sets. With these diagrams you can read at what time the sun is shining perpendicular on the façades of the building. When the sun is rising in the morning it will be perpendicular on the south-east façade on 11.00 o’clock and for the south-west façade the sun is perpendicular at 14.00 o’clock.

These diagrams are also very nifty to use not only for designing or choosing a sun shading type but also in an architectural design phase where passive shading techniques such as overhangs can be dimensioned with the degrees of the incident sun.

By making these simple diagrams you can have a fast and clear overview on which façade the sun is projected under a certain angle of azimuth and altitude.
The winter situation is made in the same way as the summer diagrams, now you can see the difference in amount of azimuth. The sun travels shorter along the building and the short west façade doesn’t get any sun inside. But also the South-East façade is getting less sun except for the rising sun in the morning when it is very intense. The South-West façade is getting less solar radiation, however the sun gets deeper in the chambers because of the lower altitude of the sun. So the radiation decreases but the amount of light is still getting inside the building.
The section drawing I.7.9 shows the two extremes of solar penetration into the chambers of the UNEC case study building. The section is made on the long façade so orientated on the South-West. So for the smaller façade on the South-East the sun is lower when it rises in the morning. The sun as drawn in the section above is at 14.00 o’clock when it is perpendicular to the South-West façade. It also shows that the frame that gives the façade a grid to design on also works as a sun shading element, like a overhang.
8. COMFORT

Before you just choose a sun shading or start to design a sun shading it is important to know what the demands of the user are for the sun shading. Comfort is an important subject that is hard to measure because it differs on the person. Illustration I.18.1 shows that comfort can be expressed in multiple topics. With a sun shading the topics "thermal" and "visual" are influenced. With a "green" sun shading multiple topics are addressed. Plants not only reduce the amount of radiation on the building envelope, and with reducing also the amount of direct daylight. Besides reducing radiation and daylight plants also offer multiple functions as a second façade layer that influences acoustics and air pollution. Besides building physical functions, plants also offer a relaxing relation with the people around it and how one experiences a working area. A green surrounding can offer more rest but because it also changes during the seasons, the daily rhythm is also affected. The daily rhythm gets affected because a conventional office room generally is white colored with a system ceiling and that's it. When there is a part of nature as in a green façade what you can see and even better approach or touch the whole experience of being inside is affected. So both intermediair as psychological a "green" sun shading can influence the comfort level in a building. Plantation also filters a part of the outside air and by choosing plants that smell nice in the green façade a general office chamber in the centre of a city that contends with smog the possibility to open a window can increase because of the filtering effect of the plantation and the smell it will leave in the room instead of the filthy smog.

Comfort is also about getting "enough" daylight in both comfortable and mandatory according to building laws. In the Netherlands there is a minimum demand in the Dutch building law. Mostly the minimum demands aren't really comfortable and that's why there is a new changed NEN 2057, a standardized method to calculate if you are getting enough daylight into a building chamber that is extended with a daylight ambition. For example the minimum demand of daylight is 0.5m² floor area and the ambition demand is 25% of the entire floor area what means for a chamber of 100m² that 25m² should be naturally lighted by daylight. Besides enough daylight the factor sight is also implemented in this new NEN 2057.

For sun shading there aren't real regulations that say how much you should shade from the sun and how large a sun shading should be. Because of the wide range of sun shading types and constructional options like special glazing or overhangs that are part of the entire building there are enough solutions to deal with excessive sun getting into a building. Because like the minimum demands of daylight aren't comfortable, a comfort that can be achieved by using sun shading is preventing or reducing the amount of glare in a room.

Besides minimum regulations of daylight or comfort conditions about preventing glare there are some specific demands that can be dealt with artificial lighting but it would be nice if it can be done with natural lighting to save energy. At a working area there are standardized demands of the NEN-EN 12464-1. This NEN standard there are demands on the amount of light that is illuminated on a workspace or in a room. When you are designing a green sun shading and you want to know what to shade for you can look at two different demands. A cooling demand like the cooling need calculation that will be mentioned in chapter 9. Sun shading, or how much light you want to pass through in a room. The minimum demand can be a NEN workspace lighting and the maximum a far field value. In the next paragraph these topics will be addressed more.
8.2 Glare

There are two kinds of glare: disability glare and discomfort glare. "Disability glare results when a light source reflects from or otherwise covers the visual task, like a veil, obscuring the visual target, reducing its contrast and making the viewer less able to see and discriminate what is being viewed. The problem is illustrated with the drawing below. In the example below, bright light from a ceiling light fixture or skylight is reflected from the visual task surface, and into the observer's eyes, veiling his recognition of the target visual content. Nearly as much light is reflected from the white paper as from the black ink making the letters, so that the contrast is low and the text is washed out and difficult to read. Such glare "disables" the process of reading.

Discomfort glare arises when light from the side of the task is much brighter than the light coming from the task. The eyes attempt to focus on the light from the task, but so much extra light is entering the eye from the side that the visual processes are confused and it is difficult to concentrate for long periods. The geometry is illustrated below.

In the example below, light from a window enters the reader's eyes and makes it difficult to see the lesser amount of light coming from the reading task. Prolonged exposure to such conditions can result in headaches and eye fatigue. " (W.B.1)

8.5 Sky Illuminance rates in various settings

You can measure glare or illuminance on many places, commonly illuminance is measured on the workspaces where people work, but enough lux on the workspace doesn't mean that the working area is a comfortable chamber to work in. For example if we look at the diagram above and the measured lux underneath it shows us that a comfortable working space need more illumination around the desk than on the desk. Of course this is still in combination with the dimensions of the space and the reflections of the surroundings. If one would use a glossy white wall paint the room will look brighter than painting the walls black. In theoretical terms we are speaking about "near field contrasts", the contrast that is appearing directly on the workspace and "far field contrast", the contrast that is appearing around the workspace. The image underneath shows what a comfortable amount of lux should be.

Near Field Contrasts

Far Field Contrasts

Outside Contrasts

You can measure glare or illuminance on many places, commonly illuminance is measured on the workspaces where people work, but enough lux on the workspace doesn't mean that the working area is a comfortable chamber to work in. For example if we look at the diagram above and the measured lux underneath it shows us that a comfortable working space need more illumination around the desk than on the desk. Of course this is still in combination with the dimensions of the space and the reflections of the surroundings. If one would use a glossy white wall paint the room will look brighter than painting the walls black. In theoretical terms we are speaking about "near field contrasts", the contrast that is appearing directly on the workspace and "far field contrast", the contrast that is appearing around the workspace. The image underneath shows what a comfortable amount of lux should be.

It is not just the direct sunlight that can be glaring. But the reflection of direct daylight from objects in the room can also produce serious glare, as illustrated in the drawing above. The colors of a wall or the brightness of a computer monitor also have their share on the total amount of contrast in which glare can occur.

8.3 Contrast in a room, with and without shading the windows

You can measure glare or illuminance on many places, commonly illuminance is measured on the workspaces where people work, but enough lux on the workspace doesn't mean that the working area is a comfortable chamber to work in. For example if we look at the diagram above and the measured lux underneath it shows us that a comfortable working space need more illumination around the desk than on the desk. Of course this is still in combination with the dimensions of the space and the reflections of the surroundings. If one would use a glossy white wall paint the room will look brighter than painting the walls black. In theoretical terms we are speaking about "near field contrasts", the contrast that is appearing directly on the workspace and "far field contrast", the contrast that is appearing around the workspace. The image underneath shows what a comfortable amount of lux should be.

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8.3 Contrast

Contrast is a factor of comfort that differs when you use plants in front of the façade. Because the density of leaves differs by plant choice and the amount of leaves the light that is passing through the leaves isn’t the same as when you use a conventional sunscreen. The more diffuse light that is passing through the branches and the leaves give a different contrast during the day because reflection is also appearing on the leaves.

On the right you can see a couple of photo’s that show how vegetation is interfering with the view to outside but also giving a very dense expression when you look at it. The colors are diverse, from light green, to dark green and the almost black branches lying underneath the leaves. Next to the diversity of colors the density also shows a different view outwards.

The photo above has a very high density, if one would see this in front of a window not only the view is obstructed, the contrast is also very high. Translated into a black and white picture where the saturation of colors is reduced and the contrast is increased the amount of contrast is even more visible. However the reflection of the leaves wins in an advantage because reflection can also be seen as light and turns into a lighter contrast than the darker leaves. But when we are looking outside a building and working inside a building the contrast is different.

When you are working inside a chamber the contrast outwards can be very high and only silhouettes of the green sun shading will be visible because of the high lighting outside and the lower lighting inside. When you are working inside the building the contrast of the workspace in comparison to the lighting in the chamber needs to be comfortable. For this reason it is good to know what the demands of illumination are for a honest workspace. On the next page there is a overview from functions and the demands they have on the amount of working light but also the amount of sight.
## 8.4 Sun shading demands

The schedule above shows the demands that could be asked by the functions in the building. The orientation is important for the type of sun shading and next to the type of amount of shading and sight are a more individual demand. The amount of enough daylight on a workspace or in a chamber isn’t always achievable by the sun because the sun is turning in different directions around and over the building. So in many situations the amount of lux on a workspace is achieved by using interior lighting systems. Nevertheless, it is good to use the sunlight as a natural source for enough daylight. In the schedule the demands for daylight are according to the NEN-EN 12464, Light and lighting - Lighting of work places. But as already indicated, these are values for the “near field contrast” and not for the “far field contrast”. For offices the minimum demand is 500 lux, however, for technical drawing work you will need 700-800 lux. This used to be the case in the old days but nowadays everything is going by computer so 500 lux is enough.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Function</th>
<th>Daylight demand</th>
<th>Luminance</th>
<th>Sight Demand</th>
<th>Time spent</th>
<th>In Occupation</th>
<th>Manageable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Floor</td>
<td>Entrance/Security</td>
<td>X X employees</td>
<td>very much for check</td>
<td>100</td>
<td>100%</td>
<td>8hrs</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Waiting Area</td>
<td>X X visitors</td>
<td>very much for check</td>
<td>100</td>
<td>100%</td>
<td>8hrs</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Coffee Bar</td>
<td>X X visitors</td>
<td>a lot of sight</td>
<td>-</td>
<td>100%</td>
<td>8hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Exposition Space</td>
<td>X X visitors</td>
<td>not necessary</td>
<td>-</td>
<td>100%</td>
<td>8hrs</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Unee Shop</td>
<td>X X visitors</td>
<td>view from outside</td>
<td>200</td>
<td>100%</td>
<td>8hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Workshop Shop</td>
<td>X X workshippers</td>
<td>not necessary</td>
<td>200</td>
<td>100%</td>
<td>8hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Workshop Area</td>
<td>X X workshippers</td>
<td>a lot for designing</td>
<td>500</td>
<td>100%</td>
<td>8hrs</td>
<td>30</td>
</tr>
<tr>
<td>1st Floor</td>
<td>Projects Exposition</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>100</td>
<td>60-98%</td>
<td>8hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Reading Room</td>
<td>X X researchers</td>
<td>nice readability</td>
<td>500</td>
<td>60-98%</td>
<td>15 min - 6hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Research Office</td>
<td>X X researchers</td>
<td>enough worksp.</td>
<td>500</td>
<td>30-68-98%</td>
<td>15 min - 6hrs</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Research Concentration Workspace</td>
<td>X X researchers</td>
<td>not necessarily</td>
<td>500</td>
<td>30%</td>
<td>15 min - 6hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Wardrobe</td>
<td>X X researchers</td>
<td>not necessarily</td>
<td>-</td>
<td>30%</td>
<td>15 min</td>
<td>nvt</td>
</tr>
<tr>
<td></td>
<td>Library</td>
<td>X X researchers</td>
<td>nice readability</td>
<td>200</td>
<td>30-68%</td>
<td>15 min - 6hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Meeting Room</td>
<td>X X researches</td>
<td>nice readability</td>
<td>500</td>
<td>30-68%</td>
<td>20 min - 2hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Storage</td>
<td>X facilities</td>
<td>not needed</td>
<td>-</td>
<td>0%</td>
<td>30 min - 1,5hrs</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Canteen</td>
<td>X X researches</td>
<td>both daylight - shade</td>
<td>-</td>
<td>60-98%</td>
<td>12hrs</td>
<td>80</td>
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<tr>
<td>2nd Floor</td>
<td>Lobby</td>
<td>X X visitors</td>
<td>lots of daylight</td>
<td>100</td>
<td>60-98%</td>
<td>30 min - 2hrs</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Press Room</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0-30%</td>
<td>15 min - 1,5hrs</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Meeting room</td>
<td>X X visitors</td>
<td>nice readability</td>
<td>500</td>
<td>30-68%</td>
<td>20 min - 2hrs</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Wardrobe</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>-</td>
<td>30%</td>
<td>15 min</td>
<td>nvt</td>
</tr>
<tr>
<td></td>
<td>Conference Hall</td>
<td>X X visitors</td>
<td>variable</td>
<td>0-30-68%</td>
<td>30 min - 12hrs</td>
<td>900</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Press Room</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0-30%</td>
<td>15 min - 1,5hrs</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Restaurant/Delegate Lounge</td>
<td>X X delegates</td>
<td>both daylight - shade</td>
<td>-</td>
<td>30-68%</td>
<td>2 - 6hrs</td>
<td>100</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>Brainstorm rooms</td>
<td>X X visitors</td>
<td>enough worksp.</td>
<td>500</td>
<td>30-68%</td>
<td>1 - 3 hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Auditorium 600 pers.</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0%</td>
<td>30 min - 6hrs</td>
<td>600</td>
</tr>
<tr>
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<td>Auditorium 120 pers.</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0%</td>
<td>30 min - 6hrs</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Conference Hall</td>
<td>X X visitors</td>
<td>variable</td>
<td>500</td>
<td>30-68%</td>
<td>12 hrs</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>Auditorium 300 pers.</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0%</td>
<td>30 min - 6hrs</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Brainstorm room</td>
<td>X X visitors</td>
<td>enough worksp.</td>
<td>500</td>
<td>30-68%</td>
<td>1 - 3 hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Auditorium 50 pers.</td>
<td>X X visitors</td>
<td>not necessarily</td>
<td>500</td>
<td>0%</td>
<td>30 min - 6hrs</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Meeting rooms 20 pers.</td>
<td>X X visitors</td>
<td>nice readability</td>
<td>500</td>
<td>30-68%</td>
<td>30 min - 2hrs</td>
<td>20</td>
</tr>
<tr>
<td>4th Floor</td>
<td>Office</td>
<td>X X employees</td>
<td>enough worksp.</td>
<td>500</td>
<td>30-68-98%</td>
<td>8hrs</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Concentration workspace</td>
<td>X X employees</td>
<td>enough light worksp.</td>
<td>500</td>
<td>30%</td>
<td>8hrs</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>X X employees</td>
<td>enough light worksp.</td>
<td>500</td>
<td>30-68-98%</td>
<td>8hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Video Conference</td>
<td>X X employees</td>
<td>not necessarily</td>
<td>500</td>
<td>30%</td>
<td>30 min - 2hrs</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Meeting room 50 pers.</td>
<td>X X employees</td>
<td>nice readability</td>
<td>500</td>
<td>30-68%</td>
<td>30 min - 4hrs</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>X X employees</td>
<td>enough light worksp.</td>
<td>500</td>
<td>30-68-98%</td>
<td>8hrs</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Concentration workspace</td>
<td>X X employees</td>
<td>enough light worksp.</td>
<td>500</td>
<td>30%</td>
<td>8hrs</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Office</td>
<td>X X employees</td>
<td>enough light worksp.</td>
<td>500</td>
<td>30-68-98%</td>
<td>8hrs</td>
<td>40</td>
</tr>
</tbody>
</table>
9.1 Introduction

To prevent overheating, glare or a large contrast in the indoor climate the applying of sun shading is necessary. Excessive radiation and hindrance daylight must be kept outside the building envelope to maintain a comfortable indoor climate. Sun shading is most effective on the outside of a building so that the radiation will be reflected through the sun shading therefore the burden of radiation on the building construction will be less severe. Besides shading a sun shading also has a large prevalence on the aesthetics of a building. Material choice, orientation and construction can give more depth on a simple building façade. Shading in the meaning of contrasts and depth, element dimensions and movement are examples that could make a simple generic façade very interesting. As already mentioned in chapter 1, Introduction, a green sun shading can offer an extra value to the biodiversity of the build environment besides giving different aesthetics besides shading from the sun. Next to biodiversity and shading, a green sun shading offers the possibility to change aesthetics during the seasonal changes.

Because both constructive and aesthetic considerations are addressed in the application of a system the importance is taken into account at an early design stage before choosing a certain system. For example:

- From a constructional aspect, the connections, jamb forms for applying a system, element dimensions, electricity and engineering questions can be reduced when you take notice from a certain system and the constructional demands on a building level in an early design stage. A green sun shading for example needs irrigation for the plants, so it is good to know where the hoses supposed to be placed along the green sun shading. This also applies for the demands of a sun shading construction to the place it should be mounted on.

- From an aesthetical aspect, because some systems or concepts can have a high impact on the appearance of the building. Colour, working with depth, game of lines, and density are some subjects that can be addressed during the design of a façade.

To develop a controllable green sun shading it’s good to know which sun shading types or systems already are used and how these function. Sun shadings can be considered as a passive or active element that can reduce solar radiation getting into a building. Passive systems are preferred if one needs a sun shading system for spaces with little or no interaction. An office building for example has more benefits from an active sun shading than a passive sun shading because users can have influence on the amount of shading and sun. There are also systes that are regulated by domotics. Domotics is actually an average “user pattern” that is regarded as generally comfortable.

Besides the choice for choosing a passive or an active sun shading there are also choices in aesthetics or functioning of a sun shading system. A passive sun shading can be achieved on different ways. For example with awnings, panels or by applying a certain print on a glazed façade.

The UNEC case study houses multiple functions like private and public that have different demands to a sun shading. A passive sun shading can be a good choice for a public function because of the diversity of users and the time they spent in a room not specifically needing a active sun shading. The office floor of the UNEC case study functions from 09.00 o'clock till 17.00 o'clock which is assumed that the permanent employees want to have influence on the amount of sun that radiates into a chamber. Because sun shading involves sight it’s even more interesting that the user can interfere with the amount of sight that is blocked by a sun shading.

It is good to know how long you need to shade for. “Shading devices for heat avoidance need to be designed to be effective beyond the geometry of summer solstice when the sun is highest in the sky. Depending on the local climate conditions, cooling may be a priority from the mid spring to early fall seasons. The length of the south facing shading devise should be sized for the extended season.” (W.9.1)
9. Sun shading

9.2 Sun shading types

Some examples of sun shadings and adequate orientations are shown in illustration 9.2. The diagrams are clear about the way a horizontal sun shading is desired on a south façade and a vertical sun shading on a north façade. The choice for different orientation types is because of the movement of the sun’s altitude and azimuth during the day. When one looks at the view restriction it is immediately clear that a horizontal sun shading offers more panoramic sight than a vertical sun shading because of the funnelling effect between sun shading elements.

With a green sun shading it is rather difficult to make a vertical or horizontal direction with plants because plants rather grow upwards than horizontal. It is possible but the mutual dimensions need to be wide enough so the branches can’t get grip on each other. The largest façade of the UNEC case study is 140 meters long and mostly orientated on the South-West where the sun is at its highest altitude. So a horizontal sun shading is desired based on the types mentioned earlier. A vertical system is also possible with taking notice that the panoramic sight or the entire sight can be blocked by using a closed vegetated element. Some types like eggcrates offer shade for both azimuth and altitude changing sun slalges and have a certain distinguished appearance but lack in sight when the dimensions are very small.
9.3 Green sun shading

An experimental investigation of the effect of shading with plants in front of a façade has been done by the Centre de Tecnologic de Transferencia de Calor, The Polytechnical University of Catalunya in Spain. A nice feature of the investigation beside text and temperature readings was the fact that they made a time-based film that shows the growth of two plants during the seasonal changes. These plants are very nice because of the production of fruits by a Vitis Vinifera, a grape plant and a Parthenocissus quinquefolia, both climbing plants, where the Parthenocissus will give a rich red color in the transition from autumn to winter. However one can also see in figure I.9.2 that in the winter period both plants lose almost all of their leaves so in the winter one can't shade from the sun.

A lot of awareness is necessary to choose a good plant for a green sun shading but where can you find these plants? Well instead of making a long list with possibilities of plants it isn't possible to summarize the best there are because of the climate issues. However Jakob (W.9.3) has made a nice overview of climate zones and climbing plants that can be used in the climate zones. You can find this brochure in the attachment of this report. But this issue will also be further explained in chapter 11.

9.4 Relation between daylight and solar radiation

As already mentioned and shown in the diagrams in chapter 7, Solar Study, the façade isn't only lightened by the sun but also heated by the solar radiation. The radiation is important to shade from to keep the indoor climate comfortable without getting large heat loads that need to be covered with large cooling needs. To compare different sun shading systems on effectiveness there is a solar factor, in Dutch abbreviated with ZTA value. The ZTA value is the relation between the total solar radiation and the amount of solar transmittance. The ZTA value than stands for the layer that reduces the amount of solar radiation. In case of a green sun shading the ZTA value will stands for the both the layer of plants and the glazed façade.

Gernot Minke and Gottfried Winter did research in shading possibilities in 1983. Plants can shade from the sun because they transform solar radiation into different components. From 100% solar radiation only 5-30% will pass through the leaves of a plant. This is shown in illustration I.9.5 and translated by M. Ottelé at a building level in 2011 on illustration I.9.6.

Because sun altitude and azimuth are changing during the day it is impossible to get a precise ZTA value because the total solar radiation differs with the sun and sky properties. When it is very cloudy the radiation is lower than on a clear day. Because of the sun's changing values of intensity you should use extreme values like winter and summer to give a good general value for the total sun radiation.

Orientation based systems are chosen or developed to achieve a high as possible efficiency. Take note that for choosing a system that there should be taking care of orientation, sight and the cooling need that is desired. Sun shading can be very simple by just placing a cloth or a panel in front of a window. But you won't have any sight anymore. Placing a panel in front of a window for just the time that the shading is needed already takes care of the sight problem. Maybe a South-West façade just needs to be shaded for 4 hours a day, instead of 8 hours when someone is working in a building. The relation sight and shading is very important, otherwise what would be the reason to keep a window on a façade if the window needs to be fully shaded because it is placed at the worst orientation?

To give an idea how much radiation is radiated on a building façade i made a simulation for the UNEC case study. The two extremes that are used are the summer and winter period of June and December. In June the radiation is expected to be higher than in the summer because the sun takes travels longer from rising until setting down than in the winter as already mentioned in chapter 7.
9. Sun shading

9.5 Solar radiation analysis

So with the basic conclusion of the period of maximum solar radiation and minimum as mentioned in chapter 7, I made an analysis of the amount of Wh/m² that is projected on the building façade.

When we want to shade from the sun we also are dealing with shading solar radiation. With Autodesk Vasari or another program you can make a simulation analysis of how much solar radiation in Wh/m² there is projected on the façade by the sun during a certain time line. For example on this page there are two different analyses. The two images above show the peak values of the amount of solar radiation over one day in June and December. This is the highest amount of radiation during the whole day. One thing that is very interesting is when we look at the amount of radiation, the winter period is higher than the summer period.

What also is visible is that the smallest façade on the south-east is getting the most radiation, and the longest façade on the south-west is second in line. But when you don't look at the complete package, the whole amount of solar radiation during the day, the winter period in December would emerge as the most negative period where you should shade a lot in contrast to the summer period. However, when you make a cumulative analysis as the images shown below this text, the amount of solar radiation during the day will be summed up to a total amount of radiation per square meters for the whole day.

For the UNEC building this was done also in the summer and winter period. Now it is more clear that the intensity of the sun is much higher in contrast to the amount of solar radiation in the winter. Roughly said, the difference is around the 1000Wh/m² more that the façade needs to deal with in June compare to December.

The simulated values in this radiation analysis are only the radiation values that occur during one day in June or December on the façade. The actual transmitted radiation is determined by the ZTA value of the façade construction.

With the design of the green sun shading element the amount of radiation on the plants of the element will stay the same but the façade that is behind the sun shading will decrease because of the thermal properties that plants offer.

To get a feeling what the plants offer as a sun shading I made a cooling need calculation to see what the difference will be when a green sun shading is applied in front of a glazed façade. This calculation will be shown in the next paragraph.
### 9.6 Cooling need calculation

The cooling need calculation is based on just a small part of an office area of the UNEC case study. The perspective illustration below shows the office area where the free height is 3.5 meters high from floor to ceiling and has a floor area of 123 square meters. The calculation method that is used is according to the method described in the Climate Installations reader (I.9.1) of Delft University of Technology. The glazed surface is calculated without the white frame to measure without external obstructions. So only a room with an entire glazed façade is calculated.

The total assumed cooling need for this small part of an office area is 217 W/m² when there is no sun shading in front of the window or a glazing with a lower ZTA value. This calculation is just an approximated value to show the difference without a green sun shading and with a green sun shading.

Excluded free cooling, like nighttime ventilation with cooling of building mass (less power is needed circa 20-30 W/m²).
9. Sun shading

Calculation sheet for the cooling need of a chamber of a building

Steps

1. United Nations Environmental Council
   With green sun shading ZTA

2. Calculate the net floor area
   - Length: 13.56 m
   - Width: 9.04 m
   - Net floor area: 123 m²

3. Calculate the room volume (between floor and ceiling)
   - Average free height between floor and ceiling: 3.5 m
   - Room volume: 425 m³

4. Choose the design indoor air temperature and outdoor air temperature
   - Tindoor = 25°C
   - Toutdoor = 28°C

5. Determine the external heat load
   Surface area light-transmitting part of the building skin (excluding frame)
   - Alighting = 47.46 m²
   - Average ZTA-Value
   - ZTA = 0.8
   - Green sun shading ZTA
   - ZTA = 0.3
   - Qsun = 600 W/m²
   - External heat load = Alighting * ZTA * Qsun = 683.4 W

6. Determine internal heat load
   - Amount of people: 12
   - Lighting asset: 10 W/m²
   - Computers asset: 0 W/m²
   - Internal heat load = 126.0 W

7. Calculate ventilation cooling loss
   - Ventilation rate
     - n = 1
   - Ventilation volume flow Qvent
   - Heat recovery rate (feebale heat) hrv
   - 506
   - Infiltrationvoid
     - n = 0.2
   - Infiltration volume flow Qin
   - Air density p
   - 1.2 kg/m³ depending on outdoor temperature
   - Ventilation cooling loss = (Qvent * (1 - hrv) + Qin) * ρ * c * (Toutdoor - Tindoor)
   - 300 W
   - Including dehumidificator
   - 163.5 W
   - 28°C, 54%RH indoor; 20°C, 60%RH outside

8. Determine total cooling need
   - excluding dehumidificator
   - 932.0 W
   - including dehumidificator
   - 1865.5 W

Excluded from calculation:
- Heat transmission through building envelope (more power is needed)
- Heat transmission through neighbours (sometimes more power is needed)
- Excluded free cooling, like nighttime ventilation with cooling
- of building mass (less power is needed circa 20-30W/m²)

The value of the cooling need with an external shading element is much lower than without. Of course this can also be achieved with conventional sun shading types but than you won't have the extra benefits of a green sun shading as mentioned earlier in this report. The difference between shading with a green sun shading and no shading is 130 W/m².
10. DAYLIGHT

For designing a sun shading element you will need to know how much sun you will have to shade from but also the amount of light that you are decreasing. If you would make a very dense sun shading, no light can get in the chamber and there are some regulations about getting enough daylight into a chamber of a building. For dwellings these demands are higher than public buildings, and of course in Europe or other parts of the world there are different regulations.

In Europe there is a standard calculation method to determine if you are getting enough daylight in a chamber of a building. This goes hand in hand with the building regulations of a country. The Dutch building law gives a minimum requirement for the amount of daylight in a building. This is a minimum of 0.5 m² or 10% of the floor area, for dwellings, for offices this is 0.5 m² or 2.5% of the floor area. The 0.5m² or 2.5% of the floor area is depending on the amount of square meters of floor area in total. When it is larger than 150m² you will need to use the percentage demand. The NEN 2075 offers calculation standards. The NEN 2057 calculates the equivalent daylight surface. This size of the daylight area that enters a room in accordance with obstructions, light transmission and angles.

The equivalent daylight surface is calculated with the following formula:

\[ A_{e,i} = A_{d} \times C_{b} \times C_{u} \]

Where:

- \( A_{e,i} \) = equivalent daylight surface
- \( A_{d} \) = light passage area
- \( C_{b} \) = obstruction factor
- \( C_{u} \) = passage reduction factor

When you want to know how dense or how large or small your sun shading can be to let ‘enough’ light in your building chamber, you can determine the minimum required area of transparent façade surfaces with the NEN 2057 calculation standard. Normally you would use it to check the amount of equivalent daylight surface that comes in the building chamber, but you could also say, I start with a entire glass façade and see how much equivalent daylight surface is getting inside the chamber so you can determine the amount of façade that you could close without losing the minimum amount of equivalent daylight surface according to the building laws.

Determining the minimum required area of transparent façade surfaces can be done in several ways. By determining the total façade as transparent surface in the NEN calculation, the maximum possible light transmission can be calculated. The transparent area can be reduced until the desired value is reached. The NEN calculation does not calculate with the total façade surface, a strip of 600 mm height is not included in the calculation. This strip / parapet (shown in orange in illustration I.12.1) is not used, because the possible light that enters through this surfaces does not enter the space of the chamber far enough. This makes the area of façade surface in the calculation smaller than in reality.

The Dutch building code requirement of 0.5 m² per space and the increased requirement of 10% of the floor space will probably not meet the needs and wishes of the users, to have a comfortable working condition, you could increase the demand for daylight. The NEN 2057 describes different comfort classes. In this project Class B is the ambition for the offices. Class B requires a day of 25% of the floor area and an outside view on the environment from at least 50% of the user areas. To meet the required view, the whole façade surface can be used including the 600 mm strip. For the UNEC building there are large offices and concentration workspace offices, to make a more general calculation the boundaries are shrunk to a part of the office floor and lightfall from the backside of the offices is coming from the atrium (I.12.1) isn’t calculated so the only light that was coming in was from the colored façade where the parapet area is reduced from the entire glass surface.

When you are designing an external sun shading like a plant basket hanging outside the façade, you are also creating an extra factor to calculate with. This overhang how you could call it is shading light, especially in the summer period when the sun is higher than in the winter period. The NEN 2057 describes an overhang as an external obstruction. So this will be a extra factor in the daylight calculation standard.

The length of the overhang will decrease the amount of transparent surface in the façade for the calculation. This is done with a obstruction factor \( C_{b} \) that can be translated from a scheme in the NEN 2057.

But first before you can start calculating you will need an overview of square meters of the office area, the daylight surface, parapet surface and the length and obstruction of the overhang. This is explained in the following two paragraphs.
For calculating the amount of equivalent daylight surface the drawings on this page are used for the calculation. The green sun shading as drawn isn’t calculated as a external obstruction in this calculation, only the full transparent façade and the amount of overhang of the plant basket.

As shown on the section above based on chapter 10, the summer sun is shaded for a large part already by a small overhang. So this is interesting because when you make a large overhang, you are shading from the sun, so you don’t need difficult constructions or controllable green sun shadings. You only need a overhang in the summer. However, you will need some light in the building according to the building regulations so it is good to know how large the overhang can become when you are designing a green sun shading.

For the NEN 2507 Calculation there is some basic input needed like floor and façade area. This is shown in scheme I.10.5. To show the amount of façade that can be closed both NEN calculated surface with the abstraction of the parapet surface and the entire glazed surface are shown. The light green values are the input dimensions and the dark green values are the calculated surface areas.
10.3 NEN 2057 calculation

So with the basic input of square meters the next calculations are made:
- determine the amount of horizontal obstruction;
- determine the amount of vertical obstruction caused by the overhang.

For the horizontal obstruction the value is 20 degrees because there isn’t a real obstruction. For a specific calculation you can put in account the framing construction of the green sun shading but this can be neglected because the climbing structure can be very thin.

The vertical obstruction needs to be read out of a scheme in the NEN 2057. To read the amount of obstruction you will have to calculate angle beta. With angle beta you can look up obstruction factor Cb. This is shown in illustration I.10.6.

Next is using the equivalent daylight formula to calculate how much daylight surface is reaching the floor surface. The amount of entered daylight is almost 30 m². This amount of entered equivalent daylight surface can be compared with the demanded requirement according to the building law and the ambition demand. The building law demand of 3,08 m² is easily reached. The ambition demand of 25% equivalent daylight surface however isn’t. And this is only occurring already by the use of a overhang. However this calculation is based on a office chamber with only one daylight surface. In the UNEC case-study the office areas will be facing both the external façade and also a atrium to get more light into the chambers. Than the ambition demand can get achieved. However if this isn’t the case it is hard to reach this ambition demand.

The values in illustration I.10.7 also show the percentages of closed and open façade surface to get an idea how much surface of the façade needs to be open to reach the demanded equivalent daylight surface. This is shown in both calculated parapet façade surface and the entire glazed façade surface.

<table>
<thead>
<tr>
<th>Function</th>
<th>Room/Area</th>
<th>Project</th>
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<tbody>
<tr>
<td>NEN 2057 Daylight calculation</td>
<td>10.3</td>
<td>10.4</td>
</tr>
<tr>
<td>Ambition demand 25% of the total floor area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Law, offices 2,5% of the total floor area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Ae,i, equivalent daylight surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total glazed facade surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Ae,i, equivalent daylight surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Based on parapet</td>
<td>Based on total glazed surface</td>
<td></td>
</tr>
<tr>
<td>Percentage open</td>
<td>Percentage closed</td>
<td>Percentage open</td>
</tr>
<tr>
<td>76%</td>
<td>24%</td>
<td>8%</td>
</tr>
<tr>
<td>7%</td>
<td>93%</td>
<td>6%</td>
</tr>
<tr>
<td>30,73 m²</td>
<td>30,73 m²</td>
<td>Based on NEN 2057 scheme</td>
</tr>
</tbody>
</table>

Calculation of the vertical obstruction factor Cb

Based on parapet Based on total glazed surface

| Based on parapet | Based on total glazed surface |
| Percentage open | Percentage closed | Percentage open | Percentage closed |
| 76% | 24% | 7% | 93% |
| 7% | 93% | 6% | 94% |
| 30,73 m² | 30,73 m² | Based on NEN 2057 scheme |

I.10.6 Calculation of the vertical obstruction factor Cb

<table>
<thead>
<tr>
<th>Obstacles</th>
<th>α</th>
<th>β</th>
<th>Cu</th>
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</thead>
<tbody>
<tr>
<td>a. no obstacle</td>
<td>20°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. even obstruction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. overhang</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. combination from b. &amp; c.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. external reduction factor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Determine Cb for any other obstacle, Cu=1 with no obstacles

Based on parapet Based on total glazed surface

| Total Ae,i, equivalent daylight surface | | |
| 29,89 m² | | |
| 30,75 m² | | |
| 0,76 m² | | |
| 39,32 m² | | |
| 47,46 m² | | |
| 24° | | |
| 37° | | |

I.10.7 Final results NEN 2507 calculation
CONSTRUCTIONAL RESEARCH
11. Key factors for choosing plants

11.1 Introduction

The planting of a green sun shading is an integral part that is both aesthetically and constructively issue before one can proceed to design a sun shading or completing a final design concept. The concept of the green sun shading for the UNEC building was that the plants have a natural shading in the summer and let through enough sun in the winter. This idea is used very good in the two projects of Enrique Brown architects, however it is used as an aesthetic element that is passive in its use. Because of the different climate zones over the world a green sun shading like that of Enrique Brown isn’t usable in a country like the Netherlands or New York. One could say, ok I want to use a green façade as a sun shading for my building and when it is a cloudy rainy summer day I can’t move the sun shading to have a clear view outside. That could be one of the design arguments to just use a passive green sun shading. Or just to have a green façade that is visible from the inside and the outside, other than the projects of Patrick Leblanc, because he makes a solid wall with on one side the plants.

However the plants that Patrick Leblanc uses are very different compared to plants that are used in tensile more open green façades. This is because of the difference in growing medium, but also if one would make a green façade with just plants and baskets that grow 60cm, one needs a lot of baskets to fill the entire façade with green. The tensile constructions use climbing plants, but which climbing plant should you use, and why shouldn’t you use hanging plants?

Plants for a green sun shading must be attuned to various criteria, published in "Gevels in ‘t groen from the SBR(L.11.1). The publication is about choosing the right plants that suit the location and the building. For a green sun shading there are some criteria that you can use to select the right plants but there is more emphasis on the demands that the user of the sun shading wants to have.

For example a conventional sun shading can be twisted or slid away, when it’s a awning it can be reeled in when the user doesn’t want to shade sun anymore. If one has a passive sun shading that is fixed to the façade, for example solid louvres of sheetmetal or another material, the user is excluded from having influence on his individual comfort demands of having sun inside his room or shading the sun. So as a conclusion one could say that different types of users ask for different types of sun shading. A public building like a theatre asks less individual demands of a sun shading than an office or a dwelling. In reflection on the SADD case-study, the UNEC building in New York has a large area that has got a public function used by multiple users and where rather production is been made than that there are people looking outside all the time. However the top floor is filled with mostly an office function. These users would rather use the opportunity to draw the blinds open or close them than that people are looking outside the public areas. Here one can also speak of a passive and active part of the building when discussing the use of sun shading. An fully electronic (home automation) controlled sun shading is also possible, that not only gives the sun shading an adaptive functionality but also gives the façade a more dynamic appearance. However, when you are using plants as a sun shading, you will have to know which plants you should choose, or that will work as a sun shading. You don’t want a plant falling of his construction because too used a standing plant instead of a climbing plant. Because choosing a plant for sun shading isn’t an easy decision, one could use a list with points of attention beside deciding which aesthetics and function the plants need to have beside keeping of solar radiation.

11.2 Key factors for choosing plants

Essential parts for a green sun shading (L.11.2):

Plant species:

One needs to know what purpose or function the façade will fulfill. Is it an aesthetic purpose, sun shading or thermal control. The density of the plants, so the amount of leaves is a variable depending on various conditions, but the color of the plants, the smell or whether there are of ain’t growing flowers on the the plants can be selected in advance. How and when plants grow, always green or lose their leaves, fruits or are they attractive for pests are fundamental considerations, but above all of effect on the performance and maintenance of the green sun shading.

Façade design:

After selecting the plant species one can design the façade, the looks of the façade depend of the density and colors etc. of the plants. You could compare it with designing a urban landscape on a vertical plane. You can start in two directions, already with a system where you put the plants in or with the plants and choose or design a construction afterwards. It is good to have a look at the demanded construction while designing the vertical green façade. For example a tree will need more soil than a blade of grass, and this in turn has an affect on the constructive principles of the building or the green element. How much space does a plant need? How far should the plants stay away from the façade to remain growing on their own construction instead of on the building. What are the growth patterns of the plant? Does the plant grow up or down? How much will the plant load be after it is fully climbed and grown in the construction? How dense will the plant grow and is the plant resistant to strong winds? All this has influence on the construction where the plant comes to stand in or attaches to.

Climate:

When one talks about a green awnings are the prevention of sun and ascension of light and sight outside the important factors where it is all about. The availability of sunlight and the possible overbeschaduwen with a passive green awnings are difficult to calculate because it depends on the nature, the plant does the job. In addition, factors such as urban warming also affects the performance of a plant. The plant must in some extremes can also well against extreme heat or cold or requires a constructive or installatietechnische solution be devised. How does, for example, the planters on a façade frost-free?

Some criteria for choosing plants could be:

• What kind of plants are there used? Climbing, hanging or standing plants?
• How high can the climbingplant grow?
• How often is maintenance scheduled and needed?
• How much asks a plant of maintenance?
• Is the plant winter resistant or does it only last for one year?
• How does the plant climb? Hechters, slingerplanten, steunklimmers or rankplant?
• Do the plants have a seasonal changing in appearance or are they always green?
• How wide will the plant grow?
• How fast will the plant grow?
• What are the light and heat demands of the plant?
• How sensitive is the plant against diseases and lice or other vermin?
• How much defoliation do the plants have and when does it occur?
• How does the plant smell?
The types of plants also have their advantages and disadvantages. Applying climbing plants compared with hanging plants, for example, is that climbers can be led to a specific point, the frame or rods can be placed vertically but also slanting or horizontal. A hanging plant, however, has only 1 direction and that is hanging down. Because climbing plants can be influenced in the direction they need to grow they are preferred in the application in a green sun shading. To go deeper into the different plants and the growth and the performance of the plants you could say that there are actually 4 different types of plants that need a different construction.

For example:

- **Planting as shown illustration I.6.4 in baskets can also be applied into direct ground,** it should be said that the soil should have sufficient nutrients to meet the requirements of the user or designer how the plants should grow and can grow. Is a green façade or green sun shading desired only as an aesthetic product and should it just crawl over the façade without having high demands of diversity in flowers or heights and density land-based plants can also be an option. In comparison to plants that are planted into baskets for a façade, land-based plants require less attention on maintenance concerning irrigation, nutrients and they don’t ask for a lot of structural measures because the most of the weight of plants on a façade is based on the soil of the plant baskets. When you use land-based plants the soil is on the ground floor, just in the land, so you will reduce the amount of loads on the façade.

However, the disadvantages could be that the façade appearance of the whole building is influenced by the plant species that are planted on the ground floor. In addition, it can take a very long time before the plants have covered the entire façade, while smaller elements have the advantage of quickly overgrowing a surface but these also require more attention on maintenance earlier than a plant that should provide an entire façade of green.

The difference should be there and that is why basically a green sun shading also can be divided into a passive and active sun shading. An active sun shading will be directed more to the user with the possibility of control of the amount of sun shading and sight while the passive sun shading is a better alternative for public buildings because there are less individual demands.

For example the MFO Park in Zurich.

The choice of plants one must keep in mind that plants can’t grow on every construction. Climbing plants distinguish themselves in different groups where there are climbers who have tentacles and wrap themselves around a construction, or have very sticky branches that stick on a more closed construction like a wall or plate, or plants that have suction cups that have no grip on a steel wire or mesh work. For these climbing plants a flat background is necessary where they are able to attach to.

The tense steel constructions of “Jakob” lend themselves very well here. Jacob has a brochure with guidelines for choosing the right plants for the correct dimensions of a climbing construction. This is mainly targeted for closed façades, but offers many guidelines for other green constructions. Dimensions of a grid or tense cables are tuned on plant species and also additional adjustments such as re-tensioning of the cables on the weight of the plants that are on their way to hang out in combination with wind loads are clearly explained. With a little bit of creativity you can also translate the tensile steel rods to a more rigid framework with similar dimensions.
**11. PLANTS**

### 11.4 Climate and plant choice

When you want to make a green sun shading for a building you can use different plants and constructions as explained in the previous chapters, with climbing plants there are a lot of possibilities to make different patterns with frames or tensile rods. So the construction for the plants isn’t that hard to make. So when you would optimise the frame you will have the optimum shading performance right?

However, an investigation of the Polytechnical University of Catalunya mentioned earlier in chapter 9, shows a different view of using plants for shading on building. In a time based video made with photos it is visible that the plants can’t keep up with the fast adaptations of the sun in the different seasons, this means that in spring and summer when the sun is very hot and intense that the sun shading isn’t fully grown yet. This is depended by which plant is used of course but it also kicks the concept a little bit because what good is a sun shading if you can’t use it to shade yourself from the sun?

This also means that you can’t just use plants that are fully green in the summer and bold in the winter period. Because the green sun shading isn’t that performative as we hope it would be.

So the plant choice should be more diverse and depending on different climate zones to work during the whole year. In the summer period you want to shade for 90% and in the winter period you are happy with 30% or 60% of shading? That is a performance question one should ask the users of the building. Maybe like in the UNEC building there is a possibility to slide it to the middle of the façade where there is a more open atrium but that is getting a lot of sun in the winter because the sun angle is lower than in the summer. And that the users in the offices don’t lose their demands if 100% sun shading just by placing elements in a open area that has other demands for sun shading.

So for designing a green sun shading it is inevitable to make a general green sun shading that can be used around the world. This isn’t possible because different climate zones ask for different plants and they ask for different constructions. Also for the demands one ask of a green sun shading. A controllable green sun shading isn’t used yet, and the UNEC building could be a nice opportunity to show what is possible with plants used as a sun shading.

### 11.5 Plants and fruits

When you are thinking of using plants for your façade or building don’t only think in green, flowers and colors, also think of fruits. There are also some plants that will grow fruit and then the green sun shading isn’t only providing shade but also nice fruits to pick. One could think of grapes, kiwi’s, passion fruit etc. And maybe if the space is there and there is enough soil and nutrients one could think of using “leifruit” trees that can be grown in different shapes with different kind of fruits. Trellis fruit harvest was formerly applied in monasteries, as façade greening. However, this is not often applied to façades because these plants require more maintenance to properly grow and fruit.

Fruit trees also demand a very fertile soil and a lot more ground than climbing plants for a façade, on the other hand, grapevines or blackberries are less demanding on the amount of land as long as the roots get enough nutrients and are distributed through a good irrigation and fertilizing system, this will be more explained in chapter 7. Maintenance. Vegetables and fruit are therefore a beautiful concept thought to apply in a building as “sustainable” solution or add-on, but when we want to make a green sun shading it is nice to have more control and less maintenance of the plants. Vegetables like tomatoes and peas or sprouts are possible but they need a lot of attention and they don’t last very long compared to kiwi’s and grapes.

Returning to designing a green façade for the UNEC building of the case-study, for which a green sun shading must be manageable is not desired to create an entire heavy construction, trellis fruit harvest is therefore rather difficult to realize, as well as fruit trees. There must therefore be demands to the aesthetics and functions that the plants must have and give. The concept idea was applying a green sun shading that changes color during the seasons. So the color is an important fact, in addition, it would be nice if the plants offer an additional factor so that it not only looks green but also offer something. The smell or the appearance of beautiful flowers in the summer would be a desired side effect for the experience of the building. In addition, some plants also grow fruit that can be picked by the users. You can also think of a more playful way of fruit, grapes for wine or hop for beer, for example, UNEC for brewing of “sustainability” beer.

**Warsteiner Brewery, an example of plant choice, you could make “UNEC” beer from the UNEC façade**

[Image references: 11.7 Different kinds of possibilities to make a pattern or optimisation of the green element. Frames or rods can give the possibilities to work in larger densities in comparison to a fencework with fixed distances like the second illustration. 11.8 Plant overview, Jakob Line 11.9 Trellis fruit harvest 11.10 Warsteiner Brewery, an example of plant choice, you could make “UNEC” beer from the UNEC façade]
So it is clear that plants can grow fruits, you can think of trellis fruit or climbing plants with fruits or small shrubs. But the disadvantage of plants that can grow fruits are the demands of the plants on the amount of soil and room to grow their roots. They need more maintenance against pests and need more nutrients. As an example as shown in figure I.6.16 a fruit plant requires a lot of space in the ground. If you would translate those demands to a façade you could also say that the roots can grow sideways and decrease the amount of depth but give it back in the width as shown in figure I.6.15. The main reason of the depth in full ground is that there are the main nutrients for the plants and in a green façade with baskets you will need to ensure the amount of nutrients for the plants with an irrigation system.

On the next page you will find a list of plants with some properties concerning color, fruit giving, flowering, seasonal greening. This list is tailored to the UNEC case study. The list gives a nice summary of certain aspects that are nice to know when you are designing a vertical garden.
11. PLANTS

11.6 Plants for the case study

For the UNEC building I will summarise a few plants that are suitable for the New York climate. For the architectural point of view I already made some subjects next to these plants to give a more visual feeling of how the plants look, if they are growing fruits or if they are getting bald in the winter or always green. After this building technology research this scheme can be used to make a vertical garden design of the façade based on, color, fruit giving, smelling, flowering. Because I want a different aesthetic in the façade during the seasons, it would be nice if one can pick some fruits of it in the summer.

11.15 Impression of seasonal aesthetics

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<th>Nr.</th>
<th>Plants</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
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<th>Red</th>
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11.16 Overview of suitable plants for the UNEC Case Study
12. MAINTENANCE

12.1 Maintenance issues

All green constructions require some degree of maintenance because they are living systems. The amount of maintenance a client is willing to provide is an important design factor that also has an impact on the selection of the type of system and plants that are used. Green façades generally use plants that grow from ground soil or from plant baskets.

Each plant choice may require a different irrigation and nutrient requirement. Site location and climate conditions may require that a normally robust or non-dependent plant species be given additional irrigation and nutrients. Some plants will be deciduous and some provide fruits or flowers that may require additional care and maintenance. Most plants need pruning and respond in a better grow and leaf creation. Tensile constructions may require periodic checking of the cable tensions to ensure that the elements are properly in place as the plants are growing and are getting more heavier. When you choose for a more rigid frame instead of tensile rods this checkup isn’t necessary. Plants require regular irrigation and the intervals of maintenance will depend on the consistancy of the soil and the plant choice. Plants with high nutrient requirements will normally require a greater amount of care than those that normally grow in poor nutrient environments. The amount of maintenance can also be influenced by the wishes of the client and of the aesthetic qualities that the green sun shading needs to have. Maintenance issues should be discussed with the client in the early stages of design to know what kind of expectations the client has when one is thinking about green sun shading.

By thinking on maintenance systems, one definitely has to think of a suitable irrigation system that both delivers enough nutrients and water but also can discharge amounts of water so the plants don’t get too much water what could mean that rotting of the plant roots can occur. Another point of interest is the re-use of rain water like in the reference project Green Park Rotterdam. With precipitation data as shown in figure 1.12.3 one could calculate how much water falls in a certain month and how much you can store in a bassin or on the roof etcetera. This water can be re-used for the plants.

An irrigation system isn’t that complicated, the installation room isn’t that large either. In the sketch below you can see that within 1m x 1m x 1,5 meter everything can be installed to pump water through the lines of the irrigation system. When you are combining storm water re-use with this system the installation room stays the same size only the pump and the pipelines will change, of course this is depending on the size of the green system that needs to be irrigated.

![Schematic view of the minimum dimensions of a technical space for irrigation](image1)

![Waterbuffer system of GreenPark where they store 400,000 m3 of rainwater and re-use it after filtration for the plants](image2)

![Average amount of precipitation based on rain and snow in New York, results of a monitoring of 2009](image3)
12. MAINTENANCE

The irrigation system of the Greenpark project is designed by Mastop Totaaltechniek. The system that is shown in illustration I.12.4 shows how these planes are divided again. The sensors are placed in a bottom part of the façade and a top part. The reason for placing sensors in the top part is that the sun has more influence on the top part of the plants than the plants that are located more at ground level. The top part needs more water in the summer than the bottom part so there is a second irrigation hose running along the façade. For example the South façade counts 4 sensors and will feature 4 distribution pipes where secondary hoses connect to provide water to each plant basket. The bottom part of the illustration shows the more mechanical part of the irrigation system.

The Greenpark parking garage uses rainwater for irrigating the plants. Because of the quality of the rain water (acid rain) the water will be fertilized after it has been filtered through the filtering system. This is also done because the rainwater is collected from the entire parking garage, and cars can leak oil and other substances that plants don’t like in their water.

The irrigation system further consists of a water pump that has a certain amount of pressure according to the building height, how high the water should be transported. But the amount of bar of pressure is very low because of the use of small hoses with drippers at the end that literally drip water in the baskets. These drippers can be adjusted to drip fast or slow. An extra feature of the system to prevent ice damage to the hoses and drippers is a conventional air compressor.

Besides the moisture sensors there are also temperature sensors that react to the system when the temperature outside the parking garage is below three degrees celcius. When this temperature occurs, the water pump is stopped and the air compressor blows out all excessive water to prevent the water from expanding in the irrigation hoses.

Besides rainwater re-use, moisture sensors, temperature sensors and a tangling installation of hoses the most important part of this system is the monitoring done by a computer of Mastop Totaaltechniek that keeps an eye on the system. The monitoring program sounds the alarm when there are leakages in the system or when the plants are getting too dry. And by the use of an irrigation system with a monitoring the water delivery on the plants is based on question and demand measured by the sensors so the water pump isn’t always producing pressure and water to the plants. This saves energy and don’t give excess water to the plants. By monitoring not only the maintenance and performance of the plants is insured but also the irrigation system.
The system of the Greenpark garage was very complex despite the simple construction and working of the system. This is mostly the result of the green façade construction that consisted of small plant baskets and the rainwater re-use. A different system that is also made by Mastop Totaal Techniek is a green wall from Sempergreen. This is a closed green wall construction so the delivery of irrigation is a little easier than that of the Greenpark project. The monitoring screenshot I.12.5 already shows that there are just three divisions in the façade where the water supply is from the topside of the divisions. This is because of using gravity. Water will always run down a façade and in a system like this it's easy to use it. In illustration I.12.5 you can also see that the top part is demanding water and the other two divisions have no water demand. So a system can be very simple but also very complex. This is a system for just a small green wall in contrast to the entire GreenPark parking garage.
12.3 Accessibility

An example of a maintenance issue as shown in the sketch is how can you reach the plants? Do you want a balcony so the user can do it by himself or does the user want a system without a balcony, just mounted in front of the façade? In that case you will need to think about maintenance from the outside that can be done with a window washer installation from the roof or with a lifting mechanism from the ground. This depends on the height of the building, but also on the way the windows should be cleaned.

Maybe a combination of both principles is necessary when the plants grow very good and can’t be maintained from the inside balcony anymore.

Integration of accessibility in the design itself can be an option also during the design process. Ken Yeang with his Bioclimatic skyscrapers focuses on the use of green in highrise building, not immediately focussed on green sun shading but more on the biodiversity. But as shown in the drawing on the right one can see that the users benefit from the integration in the design. They can reach the plants and it is also easy to go to a next level with a stair of the maintenance workers because this is also facilitated outside the building.

This is a integrated solution more focussed on the architectural point of view, so this could also be a architectural starting point that a green sun shading or green element is placed on the building as an add-on or as a part of the whole building.

By choosing the right choice and demands of the user of the building you will know if there will be a lifting mechanism in front of the building every month or not.
Besides taking notice of the fact that maintenance is an important fact to maintain the aesthetics and performance of a green sun shading the construction of the green sun shading is also important to achieve a certain density of plantings to shade from the sun. A green sun shading can be split up in two parts where the upper part needs to be filled with leaves in both summer and winter period. As already mentioned in chapter 10, plants, there is a wide range of plants to choose from. There are many combinations possible to create different densities in leaf structures, flowers, smells etcetera.

The choice for making an active or passive sun shading also reflects on the plant choice and element dimensions. By splitting up one story high element into two elements the plants don’t have to overgrow an entire story height what can take a long time. Smaller elements ask less time to grow what also is tested in a test setup I did last summer that will be mentioned in paragraph 12.3. Besides choosing a passive green sun shading compared to an active sun shading the construction also takes care of making the decision of choosing one of the two. A controllable active sun shading can be nice to adapt to the sun angles and possibility to have influence on the amount of shading and sight.

A green sun shading can be divided in the structure where the plants need to climb in and the “basket” with the growing medium for the plants. The structure where the plants need to climb in can be designed in different materials, dimensions and principles. Tensile rods, fixed rods or framings are examples but to be very honest this isn’t a very hard part to design.

Minimum distances of the framing will be made depending on the plant choice and varies from 300mm till 600mm between each other. Using a framing, for example what is used in concrete reinforcements is a little more dense but offers a plant the possibility to grow very dense. For shading from the sun an element should be very dense to prevent glare that could occur through open areas in the plants overgrown surface. When a part of a façade is only for creating a green appearance the choice for density or a certain structure as shown in illustration I.12.2 could be used because the density can be a designers choice when for example the bottom part of a green sun shading doesn’t have to deal with shading from the sun.

The second part of a green sun shading, the basket where the plants live in is the heaviest part of the entire element. The dimensions but also the materialisation is important. The basket only is filled with a growing medium for the plants to grow in. The soil is almost always moist what means that you have wet soil that is heavier than dry soil and the construction of the basket needs to be watertight to prevent excess water dripping over the building façade. Excess water is a conclusion that already is mentioned in chapter 4 of the references. Generally when you have a plant basket at home you will just puncture a hole in it and put a dish underneath it. On a façade that solution is rather difficult so a buffer in the basket or a drainage pipe can be suggested for handling excess water dripping out of the basket. Or you will have to protect the top part of the basket against rain water with a cap so only the irrigation supplies the demanded water for the plants.

Still many questions last. For example how heavy will a green sun shading be? Which forces will react on a green sun shading. And how can you save weight by choosing different materials? For these questions the next paragraph will introduce a test setup of an element based on the references of chapter 4. The element is designed very simple but already created a lot of awareness for designing such an element.

**13.2 Design weights**

When you are designing a green sun shading you will need to know the weight of the sun shading system otherwise your façade could fall of because it can be very heavy. A conventional sun shading is only about the type of sun shading, the material and the way it is applied. When you use passive solar fins these are fastened to the façade on two or multiple points. If they should move there is another factor and that is how the rotation unit at the end of the sun shading is detailed, it should be thicker and more solid than a normal unit that only holds the fins.

But before going in to details to fast we have to deal with main forces that react on the sun shading:

1. **Gravity**;
2. **Weight of the construction**
   a. Materialisation, basket and frame
   b. Plants;
   c. Irrigation system;
   d. Growing Medium, soil or substrates;
   e. Water, that is in the irrigation and growing medium;
3. **Wind forces**;
4. **Snow**;

The way these forces are transferred on the façade or structure of the building are design questions, the same way one can use a passive solution, so fixed baskets with plants or one wants a more controllable unit one can decide to shade sun yes or no. The weight of a green sun shading element isn’t the same the whole year, because of the plants, rain, snow and other factors shown above. In the summer the growing medium is getting just enough water to let the plants grow and vaporize water. So the soil weight as shown underneath in the scheme is a dry-weight. When the soil is wet it can be twice as heavy. So when you are choosing a growing medium you will have to discuss what growing medium fits the plants best. Is it normal soil or can we use clay substrates or other substrates like Perlite (W.13.1), that can be a little less heavy when they are wet. For designing the baskets for the growing medium we have to look which material we want to use for aesthetic reasons and if it needs to be water tight, or should the water tightness be solved in the construction of the baskets? A basket should retain the growing medium and it shouldn’t leak water that is the main idea when designing a plant basket for a façade.

Besides the weights of the baskets with the growing medium there is the irrigation system that is filled with water and the weight of the water pipes. However these aren’t the heaviest of them all. The weight of a basket filled with wet soil and plants can easily way over 100kg/ m³. The weight of the test setup is build up with normal cheap materials only for testing a quick and fast grow of plants.
The materials that are used are:

Concrete Multiplex (for formwork): 2,4 m²
Plastic pond foil: 1,85 m²
Normal plant soil: 104 kg
Wooden frame (40x40mm): 12,6 m¹
Steel framing (rigid): 13 kg
Plant weights and mounting bolts etc. are not calculated in the total sum of weights.

This leads to the following weight:
Multiplex: 36 kg
Pond Foil: 1,7 kg
Wooden frame: 10 4kg
Wooden frame: 9,3 kg
Steel framing grid: 13 kg
Total: + 164 kg

The materials that are used are:

Concrete Multiplex (for formwork): 2,4 m²
Plastic pond foil: 1,85 m²
Normal plant soil: 104 kg
Wooden frame (40x40mm): 12,6 m¹
Steel framing (rigid): 13 kg
Plant weights and mounting bolts etc. are not calculated in the total sum of weights.

For a more developed design of the green sun shading this amount of weight will be enlarged with insulation materials and more weather proof materials instead of multiplex. So the soil is more protected from freezing and resisting the weather influences.

<table>
<thead>
<tr>
<th>Description</th>
<th>Thickness</th>
<th>Mass</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Multiplex</td>
<td>2,4</td>
<td>kg/m²</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Plastic pond foil</td>
<td>1,85</td>
<td>kg/m²</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Normal plant soil</td>
<td>104</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Wooden frame</td>
<td>12,6</td>
<td>m¹</td>
<td></td>
</tr>
<tr>
<td>Steel framing</td>
<td>13</td>
<td>kg</td>
<td></td>
</tr>
</tbody>
</table>

Next to the way of designing the sub construction or the size of the elements or the baskets the wind takes care of another weight that can be very high at certain orientations. For the UNEC building one can make a wind analysis with the Autodesk program Vasari or Ecotect.

Here you can see how much wind speed there will be on the façades. Because the wind is turning around the building the amount of speed differs a lot. This diagram shows that the southern and west part of the building have a lot of wind pressure. However the west part should't have a lot of pressure because of adjacent buildings. The southern part, so the largest façade does because it is in a more open space.

When you would translate all these forces to diagrams you will end up with some kind of structural system that can manage it's own load, and the wind load but also the load of the user that is standing on it. And maybe if you make a very stiff connection you don't need the entire framework. That is just a structural design question.

One can see that the weight of substrate is decreasing the total weight very much. From 2000kg/m³ to 800 or even 260kg/m³. So for the design of the construction of the sun shading one can choose a lot of materials. Next to this amount of materials the weight of the sub-construction isn't mentioned yet. This is the construction/structure that connects the sun shading element to the structure of the building. This construction need to be calculated with the weight of the element and the other factors that have an influence on the façade element. The construction can be made in different ways so as shown in the references as an basket on a balcony or GALERIJPLAAT. However for a more controllable system the way of moving of the element and if it is rotating horizontally or vertically or sliding has its influence on the entire weight of the sub-construction.
13. CONSTRUCTION PROPERTIES

13.3 Test setup

Because of the time this research is done (autumn/winter 2011) it wasn't possible to make a mockup scale 1:1 with real plants because plants grow in spring and summer and not in the autumn or winter. So in June I started to make two mockups with two different types of constructions, this before I knew all the information that I put in this report.

The plants grew very good in the summer period, in only a month time, the hupulus, or hop how it is normally called was grown to the top part of the frame on the tensile rods. The second construction with a steel mesh didn't grow so good. The red Parthenocissus didn't grow very good so that plant failed a little bit. But that also shows that the time the plants are planted into the soil need to be done at the right time. And there are many kinds of Parthenocissus, as already explained in the chapter Plants, there are different types of plants, in this basket there were two kinds of Parthenocissus, one that can climb in a mesh and there was one that needed a closed surface to climb on. That is an adhesive sucker climber.

But for a simple and fast construction made of wood and steel climbing structures it worked out well to experience the problems of designing a green façade. The loads are very heavy, these baskets are 1 meter and 20 centimeter wide but filled with normal soil you can't carry them on your own. With two people you will manage but not for a very long time. So I put wheels underneath the baskets to transport them.

Next up is that the plants grow very good, the different kind of structures work as expected, the tensile one worked very good and also the aesthetic part is very well visible. When you would think of a façade made with tensile rods, you can look along the plants, within a certain distance, but when you look at it from the side it is hard to look right through it.

The tensile system asked reinforcements in the corners because of pre-tensioning the rods made the wooden structure bend. So by using a most common way of leading climbing plants this isn't really a good construction for making elements that are dependent on theirselves. You could better make it from stiff rods or a steel or wooden framework.

To prevent failure of plants that die or don't grow very fast it is good to make the choice to pre-grow plants already in elements so they have good circumstances to grow to a certain amount of virtue. By pre-growing plants in the elements the plants are stronger to withstand weather influences than when they are very young. Also the other benefit of already growing the plants in elements is that when you apply the plants on a building the green look is already achieved more than when the plants take months to fully overgrow an element. The choice of pre-growing plants is depended of the plant choice.

For example, the hupulus in the test setup I.13.11 & I.13.15 grows very fast. However it was required to help the plant's branches leading around the steel tensile rods to get the plant growing in the desired direction. After a month the hupulus already covered the test setup and seeks an own way over the element structure.

Points of comment that are worth mentioning are:
- Tensile rods ask for a rigid frame where they can be tensioned in. This could be better carried out with a rigid frame instead of tensile rods with lots of clamps, nuts and bolts;
- Water drainage isn't placed in the test setup. For a green sun shading it will be necessary to be able to discharge excess water during a heavy rainfall. Another option can also be designing a second water storage in the plant basket that works as a reservoir before discharging the excessive water;
- The distances from the plants themselves could have been optimised to the amount of surface one plants needs to cover. The test setup with hupulus worked very well but also could have worked with two plants instead of three;
- The plant baskets were very heavy. They are hard to displace because the simple basket already weighs over 160kg, mainly because of the wet soil. A combination with substrate could decrease the amount of weight. However soil will be needed to prevent ice damage to the plant roots;
- Material choice and durability are an issue, it is good to eather make a choice for a durable material that lasts. Or make a construction that can be easily replaced for example a framing structure with panels attached on it.
I.13.1 Detail of the tensile construction clamps.
I.13.14 Hupulus climbing around the tensile rods.
I.13.15 The tensile construction with hupulus already covers the entire tensile construction, 04-09-2011.
I.13.16 Side view of the tensile construction test setup, from the side it already looks very dense, 04-09-2011.
I.13.17 From the front at a close distance you can hardly look through the plants, 04-09-2011.
I.13.18 From a distance you can clearly see that the free dimension between the tensile rods is wide enough to look along the plants.
I.13.19 The second test setup with Parthenocissus didn’t grow very well, this was because it were two different species, one was appropriate to climb on a frame the other for a wall.
I.13.20 Close-up of the Parthenocissus that didn’t grow very fast compared to the Hupulus.
MOVEMENT RESEARCH
When there is need to control a sun shading it mainly depends on the way the sun shading moves when we are talking about conventional sun shading types. This could be done electrical or by hand. In the NEN-EN 12216 there are some basic sun shading systems and their basic movements.

This is a European standard that shows how the commonly used solar blinds or awnings should work and how they will be fixed on the building. If one would design a green sun shading element the basics of sun shading types are nicely explained in this document. Especially the basic movements that you can think of while designing a movable sun shading. Why a movable sun shading? Well fixed sun shading elements are nice, sometimes. Most of the times it will give a building a unique appearance because fixed sun shadings can be very important in the way a façade looks. However fixed sun shadings can be nice in summer or winter but most of the times they don’t offer a lot of sight outwards. This all depends on the orientation of a façade of course. The choice for a more passive type of sun shading can easily be used for public buildings where there are less demands on sun shading than in dwellings.

Nevertheless when you want to have a sun shading that can adapt to the demands of the user or a shading that is constantly blocking the sun the most obvious way to achieve that is by making the sun shading movable. Just compare it to your own awning at home. When the sun shines and it is getting annoying you will turn the sun shading down. The length of the awning is the variable between shading 100% sun and how much sight you will have outwards. For example the orange awnings on the right show how much a sun shading does for the aesthetics of a building but also shows that when some are fully extended until they reach the railing of the balcony the sight from inside the dwellings is gone. So it is not only about shading enough sun radiation with a sun shading but also having enough sight outwards.

The projects that I refer to in chapter 5 all use vegetation to create a green appearance to a building. Or maybe to create a veil that says it is sustainable. Some constructions are doubtable of sustainability. For example the Consorcio Santiago building where wide lamellae are applied as a structure where the plants can climb in and also shade against the sun. Why would you use two sun shading constructions if you can do it with one construction also? Was it a aesthetic reason to give the building a green appearance and when the plants don’t work we can always fall back on the other sun shading to keep the building “working”?

In principle the projects don’t differ a lot among each other. Often a basket with soil is applied that is or applied as an add-on on the façade or cast with the building structure. Actually it is the same principle of hanging flower baskets on a balcony. The key question remains if one would make a green sun shading that remains green in the winter or turns red but remains its density, what will become of the amount of sight from the inside to the outside environment?

Illustration 14.4 shows that the sun shading of the Consorcio Santiago Building isn’t fully grown at the time when the photo was taken. The picture also shows that the sight to the outside environment is still blocked not only by the plants but also by the construction of the green façade. The distance from where the picture is taken is also important, perhaps the sight is better when the picture was taken more closer to the façade? This is a factor that is also of influence on the UN case study. The main idea was that you could always have sight on the UN park when you are inside the building. With a green façade construction like the Consorcio Santiago Building that mostly blocks the sight there is less connection to the outdoor environment. But if the green façade can be moved or lifted away from point of sight the problem could be easily be solved.

With this thought I sketched some movement concepts for a green sun shading. Some of the concepts can be directly derived from the NEN-EN 12216. Some are based on orientation. Generally south façades are shaded by a horizontal sun shading type and head façades with a vertical sun shading type depending on the façades orientation. The reason for choosing between a vertical or horizontal type are mentioned in chapter 9. With a green sun shading you could say that you either choose for a vertical type and have less sight when the entire façade is closed. This is also the same option with a horizontal type. Choosing the right type is based on the users demands of sight and also the accessibility to do maintenance on both the green sun shading as on the glazed façade.
14.2 Sketch Designs

As already short explained in paragraph 14.1 I made some sketches of movement concepts to design a controllable sun shading. A controllable sun shading is a sun shading that you can move out of sight so the user can have more or less sight and shading. On this page you see ten different sketches that are sketched very simple but only describe the way a green sun shading should move or function.

The sketches already show that the green sun shading is considered as a green surface that slides, turns or just moves in a direction. There are no concepts that have a base for example where the plants only get moved independent of the structure where the plants are attached to, like a curtain that hangs on a rail. This is because most of the plants can break when you want to bend the branches. So the base of the element, the basket with the soil and the plants needs to be connected to each other. In the next paragraphs all of the sketch designs of this page are developed slightly further with the possible place of a plant basket in a bottom position or in a higher position indicated with a dashed line. Because of the choice for a climbing plant instead of a hanging plant as mentioned in chapter 13, the position of the plant basket will likely be at the bottom of a green sun shading element. Because of the inextricability of the plants, the basket on the structure where the plants climb in the green sun shading will be described as an element. The possibility to subdivide a large surface in smaller surfaces thus smaller elements is possible so the position of multiple baskets in one element is variable. The sketch designs that are shown on this page will be explained in the next paragraphs.
14. CONCEPT DESIGNS

14.3 Horizontal movement

The first concept is a horizontal movement, you could compare it with a curtain that you want to slide away when you want to look outside. It could be a very simple concept by making a rail where the element is hanging on or standing in. But when you are sliding something there has to be a free space like in a slide puzzle or elements need to overlap each other. And also when you want to have a free field of view, or a panoramic view from the inside of the building outwards, the elements should be stacked somewhere at the end of the building or somewhere else.

In the drawing you can see that this is a very minimal sketch, the element height isn’t fixed yet because it also depends on the length the plants will grow or climb. Also a second basket is drawn in a dashed line, this is supposed that there could also be two plant baskets in the element. For example when the plants grow four meters high to divide the plants over the element height or to use different plants for example fruit and flowers.

But a very simple way of shading like horizontally moving the elements like a sliding puzzle or stacking louvres doors maybe does the trick. One could even investigate how much of the façade should be closed for the daylight demands and use that amount of m2 to design the dimensions of the element. According to the closed stacking area where the elements are being parked when there is no need for sun shading.

The 3d model I.14.9 shows that a horizontal way of sliding the elements can be stacked behind each other. The negative point of this concept is that there will be multiple rail structures where the elements move in. For just three elements it could be just 60cm of rails but when a larger amount of elements need to be stacked in a parking position the amount of rails will increase. The 3d model also shows a possibility to work with two smaller elements instead of one.

Perhaps the height demand of the sun shading can be a factor to make smaller elements that overlap each other in a vertical direction to get the same large element with two elements.
14. CONCEPT DESIGNS

14.4. Vertical movement

This concept is the opposite of the horizontal movement, the vertical movement. Instead of moving elements horizontally on the same floor, you could also slide them along a rail downwards or upwards. When you are sliding the elements halfway they work as a small overhang, maybe not shading from all the sun but you will get a more panoramic view than with the horizontal movement concept. The direction of the movement is a tricky part. When you are sliding the elements downwards, the floor that is underneath will see a green sun shading element lowering, this depends on the height of the floor levels of course but when you slide something it will travel from point A to point B. And where is point B you could ask yourself. And for which orientation is this element shading from the sun? Maybe the element needs to pivot a little bit so the length is less long but in a pivotted way it could also function as a shading element, almost as a conventional awning.

But the most important criticism is do you want to slide the element upwards or downwards, because the top floor won’t have a sun shading when it is slided down and the underlaying floors do have it in a certain way because the elements work like an overhang.

Other points of interest are the sliding mechanism that needs to be covered so the plants can’t get stuck in it. This could mean malfunctioning of the movement. Plants can get stuck or you will have to make some kind of barrier that the plants can’t reach the sliding mechanism. And how should the sliding mechanism work? Will it be hanged on a steel cable? or should one use a chain that carry’s the whole element? How much load can a chain carry? Maybe it can be a element that is hanging on sprockets? Maybe it works like an elevator?

So beside questioning how should one make this concept, the idea behind this movement is that the view isn’t obstructed in a horizontal way. It could function as a overhang in a lowered or pivoted position on a south façade, so repelling the higher altitude angles of the sun. But in a raised position like the horizontal concept, it could also react as a fully closed element for the east and west orientations.
14. CONCEPT DESIGNS

14.5 Door movement principle

The third concept is a different type of movement, sliding is an option but it needs a lot of sliding framework where the elements can slide in. If you want to slide an element over a façade of 140 meters, one needs a rail of 140 meters long. That is a lot of material. And rails can easily get dirty because of the falling leaves or air pollution and dust etc. Well you can also turn an element like a door. This has been done in the façade of the Bibliotheque Nationale in Paris. The library gets a very diverse façade because of the different opening, different contrasts because the sun falls on the elements in a different angle. And some parts are turned by a computer system to let enough sun in for the pre-heating of the installation or when the elements are closed they are preventing the sun to get in. The doors in the façade of the Bibliotheque Nationale are on the inside of the building, so there is a glass façade in front of the doors that is heating up by the sun. For the UNEC building the elements should be placed outdoors because this is the best place to decrease the amount of solar radiation that is penetrating the building.

The movement of the element could be more easy than the sliding concepts, however when the horizontal elements are slid away or stacked over each other there is a more or less clear panoramic view. With this concept the amount of panoramic view is depending on the size of the elements because you will be looking along two walls of elements.

So dimensions are important again, but also the weight of the element will probably cause some calculations and a strong hinge that needs to carry the large momentum of the construction. In the horizontal concept the weight of the element could rest on a rails, hanging or standing, but in this concept the whole weight of the element will hang on the hinge that is attached to the building. Also when it needs to be controlled by an electrical motor the engine will need some capacity to get the element turning because it works from a momentum arm.

Another point of interest is when the façade is dealing with a lot of wind forces, the hinge again will get lot of strain because the plants will function like a kite that is catching the wind.
This central turning concept is a variant of the door movement concept. Instead of creating large momentum forces on the hinges where the element is hanging on, the central turning element is driven from the centre of the element. By using an axle in the centre of the element the weight is evenly transferred and can be transferred to the axle as well when it is a continuing rod that covers all floors until it ends on the ground floor I.14.21. The type of construction differs because of the distance that the elements are placed from the building.

The door concept could be fixed on the façade and the central turning concept is fixed in the middle of the element. By turning the element you can see that half of the diameter of the total movement needs to be the minimum distance towards the façade to let the element turn. The construction where the elements stand in at some distance from the façade should be very rigid.

The amount of sight that remains can be smaller than the amount of sight when the door concept is used. The door concept can turn in 1 direction. However when you have two elements you can let them turn in opposite direction. Which results in two elements width of sight. With the central turning concept you can turn elements in the opposite direction but by turning them in the centre of the element the amount of sight remains to a horizontal sight of just one element wide. The positive side of this concept is that you can also rotate the elements with the sun. By rotating them with the sun an optimal sun shading can be achieved.

The dimensions of the green sun shading element are inextricably with the distance they are placed from the façade and how much mechanical servos are needed. The amount of servos is also based on either one element that can be turned separately from the rest or that for example five elements turn at the same time.
14.7 Excavator

The excavator concept is almost the same as the vertical movement concept. The element displaces in a vertical way, the movement however is done by rotating a arm that is attached to the sun shading element. The idea was that when you are placing an element in front of the façade it should be aligned but you don't want to look the entire day to plants that are placed against the glazed façade. When the plants are just a little bit further away from the façade it can still work as a sun shading but it also can give more sight when they aren't at the same position on each floor. This concept however is hard to realise, the weight in the arms of the construction can be very high. The test setup of chapter 13 was already over 160 kg for a relatively small element. Compared to a sliding concept that is hanging between two rails this Excavator construction will demand some more structural calculations and a calculated amount of transmissions to easily lift the element up and down.
6. Subdividing a large element into two or more elements is already mentioned at the first concept. However, when you would subdivide an element you can also make the choice for making a permanent sun shading that has enough horizontal view by using different plants. The top part can be evergreen and the bottom part can be affected by seasonal changes. This means that the aesthetic view of the façade will change during the seasons and also that you can place evergreen elements at a certain height where it can shade from the sun.

For façades that have to deal with lower standing sun angles this concept is a little bit harder to realise because than an entire green façade should be made in front of the glazed façade to withstand the sun. This could be a choice or design question. Nevertheless by applying a more passive way of shading there aren’t any mechanical driven servos or movable constructions needed. In case of the UNEC case study this option could be implemented on façade parts where a public function is housed. And where there is a more private function where there are more demands of a sun shading there could be a controllable element. Illustration 1.14.26 illustrates that a subdivided passive green sun shading also can be implemented as a double balcony when the floor heights permit it. Access to the plant baskets is easy for maintenance like the Stucki Shopping Centre reference in chapter 5 and also the window washer can easily access the glazed façade.
14. CONCEPT DESIGNS

14.9 Horizontal hinge

A different concept is a horizontal hinge. Instead of making a vertical hinge like the door concept or making an arm that is turning from the centre of a green sun shading element a horizontal hinge can also function as a movement concept for a green sun shading. Of course when large elements are made the loads are heavy on the hinge and the device that delivers the mechanical transmission. However by thinking out of the box or flat green sun shading surface the experience of the green sun shading is different compared to the concepts mentioned earlier. The problem of turning a plantbasket horizontal is that the soil needs to stay in place. By designing multiple hinges on the sides of the plant baskets the baskets can remain in a vertical position.

The basket form can be different than it is drawn in the principle drawing I.14.27 that the weight is more in the middle and in the bottom of the basket. The form of the baskets are always designable in any form. Why not? Everything is possible only why would you make a round or triangular plant basket? It is more a design question for architecture or a product development question to know how you would design a plant basket. However design development could work to make this concept possible.

The main idea behind this concept is shown in the sketch design I.14.28 that shows that a flat façade like the Z58 reference of chapter 5, can also be transformed into a less lined façade with only one plant basket in sight. So from for example three horizontal baskets to one basket and with showing the plants sticking out.

The aesthetics of a façade could appear completely different at a certain point of the day. When the element is aligned vertically to the façade it can shade from every angle of sun and when it is in opened it can still work as a overhang. Maintenance is an issue, the green sun shading can be accessed from the inside of the building or the outside. The window washer however can’t reach the façade without a lift that can work around the green sun shading when it is in a horizontal position.
14. CONCEPT DESIGNS

14.10 Interchangeable element

A different kind of view on a green sun shading is subdividing the green sun shading element in a summer and winter part where the summer part is transported into the building in the winter to survive the cold winter. This offers the opportunity to use annual plants and also use plants inside the building. The movement of the element can be done in many ways, a door hinge or extended door hinge could turn the element towards the façade where someone can pull the element into the building. Through a air lock or just by opening a door. However the test setup from chapter 13, already weigh over 160kg. Even placed on wheels this is hard to move. Substrates and other options can lighten the basket but there is another problem.

The structure where climbing plants climb in shouldn’t be higher than the free height inside the building and has to pass the opening in the façade. A door frame is mostly smaller than the free height of a room. So that is a design specification one needs to deal with. Instead of turning the element and transporting an entire element in the building an other option is subdividing the plant basket instead of the entire green sun sun shading element.

When annual plants are used, they will lose their leaves in the winter and also their strength in their branches which mostly only leaves a small plant. Subdividing the plant baskets could offer the possibility to put own plants in the green sun shading or replacing plants that didn’t survive a hot summer or cold winter. The structure where the plants climb in can be a problem but also plants in pots like small fruit trees can be placed into such elements. So maybe a large element is too heavy to transport inside the building after a while but the concept of moving plants inwards or outwards is possible on different ways. You only need to have access to the plants or smaller baskets to get them out and the weight has to be manageable.
This concept fifty-fifty is a completely different concept than the 8 concepts mentioned earlier. Moving an element in a direction demands a certain distance that needs to be passed. If an element is closed most of the concepts lack in sight because a fully cladded green surface is in front of the glazed façade. What if you can influence the density of the green surface? With just a small amount of displacement the density of a green sun shading element can be changed from 100% sun shading and 100% sight obstruction to 50% sun shading and 50% sight obstruction.

This concept can also be implemented into other concepts but the main idea is that by displacing two elements in opposite directions in a vertical, horizontal or diagonal way you can switch the amount of density of the sun shading. The space between the structures where the plants climb in has to be 400-600 mm or wider to prevent overgrowing of the plants. Horizontal growth is tricky but possible with enough maintenance because plants want to grow upwards. However, by making two elements that are stacked you only have to slide the elements a small distance to look through the green surface. This concept is explained in illustration I.14.34, where the green spheres represent the horizontal structure with the plants. In a shifted position across each other the sun shading element is in a 100% shading position and when the two elements are at the same height the 50% shading position is reached.

Maintenance is depended on the place where the element is placed. When the element could turn like the concept of a door with hinges, the window washer can easily reach the glazed surface. This also applies for the maintenance of the green sun shading because this has to be done from two directions because of the use of two elements.
14.12 Carousel

A concept that is based on the variable density of the fifty-fifty concept is the carousel concept. This concept goes deeper in the possibility to change the amount of sight and sun shading by adjusting the amount of density of the green sun shading. A carousel is one element where smaller elements are rotated on a track. You can compare it with a carousel on a fun fair. By using more smaller plant baskets with their own climbing structure for the plants, these elements can be replaced easily but also offer the opportunity to make open spaces in between plant baskets.

By using the same principle as the fifty-fifty concept two layers could be used to make one closed green sun shading layer. When there is a demand for sight the possibility is there to just slide away one layer of plants until they are parked in the end of the element as shown in illustration 14.35. Because of the smaller plant baskets en thus smaller elements in one large element that only functions as a guidance the smaller elements can be parked at the end of the element. Not only making more than 50% of sight but the variety of sight and sun shading is much larger. The ratio of density could be around 25-50-100% of sun shading or sight. The possible problem of using smaller elements that can be very high is that they can easily fall over. So both top and bottom of the smaller elements need to be guided in the larger element.

A construction as used in the Greenspark reference of chapter 5 could easily be adapted to be used in this carousel concept.
### 14. Concept Designs

#### 14.13 Concept comparison

<table>
<thead>
<tr>
<th>Concept</th>
<th>Movement</th>
<th>Structural</th>
<th>Maintenance</th>
<th>Sight</th>
<th>Positive points</th>
<th>Negative points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal sliding movement over a rail or hanging in a rail profile.</td>
<td>Inclined between two rails, where top and bottom are fixed and momental forces are only working on the bottom rail.</td>
<td>Maintenance can be accessed from the inside or the outside. If the elements are next to each other the window washers can have some problems but when the elements are parked at the end of the façade, the façade should be clear and easy accessible.</td>
<td>Depending on the amount of layers and element width the sight can increase or decrease, the vertical sight however isn't blocked by the green sun shading, maybe only by a rail system where the elements slide in.</td>
<td>The sliding concept is a easy concept to realise. The amount of profiles will increase when you want to slide away more than 3 stacked elements, for example to get a more panoramic view outside. In shaded position you will always look against a full green sun shading façade.</td>
<td>Sight is blocked when the sun shading is in shaded position. The façade can be very crowded when there are a lot of rails and profiles where the elements slide in.</td>
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<tr>
<td>Vertical sliding instead of horizontal sliding. The end of the sliding element could be sliding a little outwards to decrease the amount of hight of the element to improve the amount of sight.</td>
<td>In hanging position the load will be in the bottom of the element because of the heavy plant baskets. So the momentum will be around bottom of the element. The momentum can be decreased by fixing the top but the displacement can be divided to top and bottom in the sliding frame.</td>
<td>The elements can be accessed from the inside of the building or with an external construction like a canopy. The question is if the elements are very high if this isn't detrimental to the amount of sight by placing the elements further away from the façade. Window washers have a problem with stand out elements.</td>
<td>Panoramic sight is present by lowering the elements. Vertical sight is obstructed in the view looking upwards out of the building. Downwards however is obstructed a little bit because of the stand out of the elements.</td>
<td>Panoramic sight is available, vertical sight is obstructed a little bit downwards but still available, depending on the element height. Recognizable concept looking like a conventional awning.</td>
<td>The view is blocked when the element is getting too high. The amount of standing out has a maximum to prevent the plants and soil from falling out. Plants want to grow upwards, so the façade can't remain in a diagonal position.</td>
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<tr>
<td>Turning from the end of the element. Like the hinge of a door. It could turn into two directions when other elements are “smart” and don’t hit each other in fully closed position. Possibility to turn 180 degrees or 90 degrees of freedom. Or other degrees of course.</td>
<td>There is a large weight that reacts in a momentum on the hinges where the element is attached to. It should be smooth for a mechanical drive application and don’t turn rough.</td>
<td>When sun shading element is in closed position maintenance can be done with a lift from the outside or simple from the inside of the building. However window washers will have a difficult time with a lift when the elements are in openended position the lift can only get between two elements.</td>
<td>Vertical sight is without hindrance. Horizontal sight is depending on the element width and directions it turns. When two elements turn to the opposite directions of each other, you will have more horizontal sight than when both elements turn the same direction. Than it is more funneled</td>
<td>Recognizable movement like a door. You can turn the element in the direction you want to shade. Development is also possible to use 2 elements instead of one.</td>
<td>When the sun is high you will have a closed façade which means no sight through the plants. Maintenance can be a problem for the window washers because of the elements that form a horizontal obstruction.</td>
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<tr>
<td>Turning from the centre instead of from the end of the element. The elements can turn 360 degrees without obstructions. Instead of heavy hinges</td>
<td>By placing the turning axle in the middle of the element, the amount of momentum is decreased compared to the previous concept. The construction that holds the element however needs to be tougher but you could also continue the axle over the entire façade and make it load bearing.</td>
<td>Maintenance issues are almost the same as in the previous concept, however this time it is getting even more harder to reach the glass surface with a lift. The most obvious way is applying a slatted floor or decrease, the vertical sight however isn’s detrimental to the amount of sight by placing the elements further away from the façade. Window washers have a problem with stand out elements.</td>
<td>Vertical sight is obstructed when the elements are in parallel position to the façade. Panoramic sight is less than in the previous concept but depending on the size of the elements.</td>
<td>Better weight distribution of the elements. Structural solutions from hanging the elements from the façade or a continueusing axle.</td>
<td>Maintenance is an issue because of the length the elements need to be placed from the façade, the wider the element the longer the distance towards the façade. Maintenance can best be done with a balcony outside that is obstructing vertical sight.</td>
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<tr>
<td>Dumping movement like a excavator. Instead of sliding a element vertically it can also travel in a vertical direction with a turning movement by applying arms.</td>
<td>Structural loads will concentrate on the two turning points in the arm of the construction. At the façade and at the element construction. You could make a counterweight or spring that catches a part of the load, especially when it needs to lift the element back up. Or preventing it from falling down.</td>
<td>Maintenance is possible from the inside or outside when the element is parallel to the façade, so when the arms are vertically holding the element. The window washers have a problem because they have to move between the arms holding the element.</td>
<td>Sight is hard to determine because of the place of the elements panoramic sight is present but vertical is relative.</td>
<td>Vertical sight is depending on the place of the element. Variety in depth of the façade is interesting because the element will be at the most extended length when it is perpendicular to the façade and getting closer when the arms are holding them under an angle.</td>
<td>A lot of momentum loads on the arms that are holding the element. Also restriction in movement is tough because elements can have interference with each other.</td>
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<tr>
<td>Concept</td>
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<td>Subdividing the element what could be implemented into a passive or active sun shading. When the passive solution is used only the top element should remain leaves and look “green” and the bottom part can be folded according to the season. This concept could also be an option for the other concepts.</td>
<td>In a passive manner the construction could be a rigid frame attached to the building or standing on it’s own. When it is active you will have less loads and momentum than the already explained concepts. Because you will divide the load in two or more elements.</td>
<td>Maintenance can be done from the rigid frame made as a balcony. This frame could also be the area where window washers can work on. Compare it to a gallery with an extra level between the building floors. In the active variant it depends on the way it moves.</td>
<td>Sight depends on the dimensions of the elements. When we talk about a passive sun shading you could also say that the upper part is starting from 2 meters height counting from floor level, so view will be panoramic and because of the gallery floor the vertical sight can be achieved when you stand outside on it.</td>
<td>Splitting elements into two or more elements can make structural issues less heavy. A passive concept instead of an active one saves energy that normally should be used for moving the elements. Sight can be optimised by researching the demanded height for sun shading the façade.</td>
<td>Dividing the elements into more elements will lead to more material usage. The user doesn't have influence on the amount of shading with a passive construction.</td>
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<td>Horizontal hinge at top side of the element. By making smaller elements the plants don’t need to cover a large surface. Smaller plants or normal standing plants can be used.</td>
<td>The load of the construction is divided over the entire element instead of at the bottom of the element. The momentum needed to lift the element in a horizontal way and keep it there can be rather heavy on the mechanism that holds it.</td>
<td>The plants can be maintained from the inside or outside. Window washing normally will be done with a lift, this is not possible because the elements should be open to access the glazed façade. So a external construction like a balcony is needed with security measures so workers aren’t pushed of it.</td>
<td>Horizontal and vertical sight is available. Vertical sight is only available until the element upwards and downwards also by the element that is applied for the story beneath.</td>
<td>Possibility to use different plants instead of climbing plants for a large surface. More aesthetic possibilities by using three or more plant baskets. In opened horizontal position the baskets will maintain their upright position and have a certain aesthetic height that could be interesting.</td>
<td>The axle that turns need to contend with the load of the element needs to be very solid to withstand the momental forces. Maintenance is an issue because you will need a balcony and because of the moving elements they can sweep a worker outside of the balcony, so safety measures are needed like harnesses.</td>
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<td>Interchangeable elements provide the possibility to use seasonal or temporary plants that can be transported inside the building for use on the office floor. A sliding window or airlock is needed to transfer the element inside.</td>
<td>Structural it is comparable with the concept based on the hinge of a door. The construction that holds two elements. The restriction also is that the elements shouldn’t be wider than floorheight otherwise they will jam against the ceiling. The elements shouldnt be very heavy to get them inside.</td>
<td>Maintenance can be done inside when the elements can be transported from the “frame” into the building. Other comments are the same as in the third concept based on the movement of a door.</td>
<td>Sight is limited in width in panoramic view angle because of the angle the elements can turn to get the outer or inner element inside. Vertical it depends wheter the element is perpendicular or parallel to the façade.</td>
<td>Plants can also be used inside the building. Possibility to use different plants that only grow a certain season and can’t withstand winter. Maintenance can be done partly inside the building.</td>
<td>Elements are very easy heavy when you use soil instead of substrate. Element height is according to the free story height. The interchangeable element can’t be used as sun shading in the winter so the second element should provide enough shading in winter and summer.</td>
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<td>50% Density by vertical or horizontal movement. Sight can be adjusted from 0% to 50% looking between the horizontal or vertical foliage lines. Density of sun shading also decreases with this movement. The whole element needs to shift in a small direction.</td>
<td>The shifting construction only has to travel the distance of the heart to heart dimensions of the horizontal foliage construction.</td>
<td>Maintenance is an issue considering the space between the tow elements. You need to have enough space to stand between those two elements or do maintenance from the inside and outside of the element.</td>
<td>Sight is based on the density of the element construction. But you will always look at a green sun shading element. Vertically the sight is blocked the most. Horizontally the sight is funnelled between the horizontal foliage lines. And vice versa.</td>
<td>The possibility to change the density of the green sun shading. Not only the sight but also the amount of shading from 0% to 50% sight and 50% to 100% of shading density.</td>
<td>Plants normally want to grow vertical but with a wide horizontal construction you can navigate the plants a little. There should be a distance between the 2 layers to prevent growing from the plants in each other. Sight is obstructed more than other concepts.</td>
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<td>The carousel concept is based on the 50% density concept only in smaller way of elements. The amount of density can be arranged by sliding elements. Compared to other concepts these elements are very small so they can have a very high density but also a very small density depending on their position.</td>
<td>The concept could be placed in a rigid frame where the smaller elements can move horizontally next to each other. Because of the movement, there has to be some guidance at the top of the small elements to prevent the elements from falling over.</td>
<td>Maintenance can easily be done when the elements are really working within a carousel system so you can turn the outside elements inwards so you can do maintenance on them.</td>
<td>Sight can be varied by placing more or less elements next to each other or stacking behind eachother. Sight can be varied in horizontal and vertical way.</td>
<td>Wide variety of sight and density. Small easy to change elements. Maintenance can be done from the inside of the building or from a balcony, this depends on the way it is placed in front of the façade.</td>
<td>Smaller baskets are less stable when they move so they have to be fixed to the bottom of the carousel system or with an guidance at the top of the elements that moves with the plants.</td>
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**14. CONCEPT DESIGNS**

14.14 Evaluation

After making concepts and comparing concepts the next step is to choose a concept or use the concepts to design a green sun shading element. Nevertheless, some of the concepts are simple and already can be assumed to be feasible. Some concepts haven’t got that simple idea and look rather difficult to create. Besides choosing between ten different concepts an other choice is combining concepts into a new one that benefits from different features. For example the concept of dividing a large element into smaller feasible elements, where the plants don’t have to grow very high can be combined with a simple concept of horizontal movement.

The choice between sight and sunshading is hard to decide standing from certain point of view. A user could appreciate that there is a green sun shading with benefits of fruits or nice smells and functions as a sun shading also. However when the façade is in front of the window the whole day one could get annoyed because sight can be blocked. Than there is the choice between horizontal ans vertical sight. What is preferred? Do the employees of the UNEC building prefer a vertical view over the park and over the UN assembly building or do they prefer a view over the skyline of New York. One thing that is inevitable is that the relation sight and sun shading are inextricably. A decision could also be based on the way a sun shading is used. When there is sun and when it is producing glare you want to shade because you are annoyed about the glare. Sight isn't that important at that point. When sight is important you will stand a little closer to the façade to look outside. It is a way of experiencing sight. You can experience sight from the chair at the desk you are working on or you can experience sight while standing in front of a window.

Sun shading element dimensions can help in having control over sight and sun shading. Development of a concept like the central turning concept can also lead to a horizontal sliding movement where two elements are combined. The difference is already visible in illustration 14.36. Both sight and mechanical drive are different. Sight can be enlarged in a horizontal point of view and the mechanical drive can be reduced to one servo that is pulling on two elements instead of one element if one chooses to influence one element at a time.

Basically you can choose for a certain concept or a combination or develop one concept to make a total new one. However a good design isn’t only based on pros and cons. A good design is based on evaluation criteria such as shown in illustration 14.37 and the demands of the user of the sun shading. Form, shape, density, material usage, aesthetics, mechanical drive, domotics, durability and much more topics can be investigated for designing a green sun shading that also needs to be tested and calculated on it’s way of functioning and to withstand the external weather influences. For the green sun shading of the UNEC case study I won’t choose a concept what is explained in this chapter. I will use small parts of these concepts because by making concepts you discover things to pay attention to. Development of a concept green sun shading that is the important factor of this research. How can a user of the UNEC building be able to have influence on the amount of sight and sun shading without losing direct contact with the plants and still can reach out and pick a kiwi out the green sun shading? To make a good decision the next chapter will continue by starting with the demands that were summed up in the beginning of this research and adapted with new knowledge gained from this research.
IMPLEMENTATION
15. DESIGN BOUNDARIES

15.1 Introduction

As already mentioned in the evaluation of chapter 14, designing a green sun shading isn’t only about choosing between different design concepts. Controllability of a green sun shading can be done in several ways, the most obvious one is making a movable sun shading. A controllable sun shading can be nice on a building when the user demands some influence on the amount of sight and shading. Public buildings however can choose for a domotic or passive sun shading without individual influences because of the large amount of people and different comfort conditions of those people. During this research some topics always return:

- Controllability
- Horizontal sight
- Vertical sight
- Density
- Element dimensions
- Plant choice and function
- Staying in touch with the plants

These topics are important for designing a green sun shading for the UNEC case study. Probably these topics can be used as a guidance for other projects also if the choice is to make a green sun shading that offers more than just sun shading itself. In paragraph 15.2 there is a summed program of requirements for the green sun shading of the UNEC case study. The demands of this program of requirements are developed during this research. Some requirements are hard to achieve, some are rather open and not very clear. The UNEC building will probably will use different kinds of green sun shading systems according to the functions that are located behind the façade. For the further implementation the office function will be used to design a green sun shading that can be influenced by the users of the office space.

The sun shading should be optimized for the orientation where it is positioned. The preference goes to the largest façade of the case study, orientated partly on the South-East but mainly on the South-West. As already mentioned in chapter 9, a cooling need can be calculated with a ZTA value of the plantation of a green sun shading. The element dimensions of the green sun shading should be made according to the already used grid system of the UNEC case study. Plant choice and function should be made according to the scheme I.6.18 of chapter 6. The combination of flowering and fruit bearing plants give a different experience of a green sun shading and the user should always be able to get in touch with the plants. Beside these topics of demands a little paragraph is added in this chapter that will reflect on the costs aspect. Designing a green sun shading should not only look and work sustainable but is should also be durable.

15.2 Program of requirements

To create a minimum demand of the green sun shading the following program of requirements is made:

1. The sun shading needs to be controllable;
   - The shading variety can be varied between 50% and 100% of sun shading;
   - The shading variety can be varied between 30%, 60% and 100% of sun shading;
2. The green sun shading should be optimized for the orientation of a building façade;
3. The green sun shading should transmit a minimal illuminance of 400 lux on the desks of the office area to use as much natural lighting before using artificial lighting. And according to NEN-EN 12464-1, Light and lighting – Lighting of work places, Part 1: Indoor work places minimal lux demands according to scheme I.8.7 from chapter 8.
4. Maintenance should be easily be done from the inside of the building, so that there is no need for a window washer elevator. Also the plants should be easily accessed for pruning and maintenance of the irrigation system;
5. Plant choice should be based on the following minimal demands:
   - colour  flowers  carrying fruits smelling
     - Autumn  green/yellow  no  no  no
     - Winter  red/brown  no  no  yes
     - Lente  fresh green  yes  yes  yes
     - Zomer  full green  yes  yes  yes
6. The plants need a fertilized irrigation system that makes use of collected rainwater;
7. The sun shading needs to be accessed from the inside (5), and equipped with a fall protection for the users and to create the opportunity to slide open the glazed façade and use the green façade as a second façade in the summer.

15.1 Plants like hupulus for usage in a green sun shading

15.2 Fruits like grapes can be used in a green sun shading
15.3 Costs awareness

Not very sun shading will be the same as is the building where a green sun shading is applied on. The costs of a green sun shading or a green façade as already mentioned in chapter 4 is hard to evaluate on the costs just by looking at a project or system. Producing a green sun shading can cost a lot but if it is done in a simple way or with a lot of repetition the costs can be feasible within a building budget. Nevertheless no building is the same and also a green sun shading can differ in the way it is designed or functioning. So each of the green sun shading implementations have associated costs and benefits that should be calculated individually. Some of the most important variables that influence the capital and maintenance costs of green sun shading systems include the following:

**Project size:**
How large is the building, what are the demands and what is the budget for the whole building or only the building envelope that withholds the sun shading also.

**Design team costs:**
What are the costs on the architect, the structural engineer, the project manager? Is there a special façade engineer for the project? Who will design the façade?

**System type:**
Which kind of green sun shading system will be used? Is there a demand for a active or a passive green sun shading? Which movement type is desired and do the elements need to be influenced individually or in groups? Does the user wishes domotics?

**Support structure requirements:**
What does the green sun shading demands to the building structure? Does it need reinforcements or will there be a extra structure for the green sun shading?

**Building location:**
Where is the building located? What are the orientations? Which façade needs a green sun shading and are there also different solutions instead? Do the functions need a green sun shading and what are the demands?

**Complexity of design, use of standard or custom components:**
How is the green sun shading constructed? Are there lots of small loose components or is the green sun shading one element that only needs to be filled with soil and plants and connected on an irrigation system?

**Site conditions and access:**
How are the site conditions of the building? Are the façades dealing with high wind pressures or a lot of precipitation on a certain orientation? Are there precaution measures necessary to protect the green sun shading against severe weather conditions?

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**Cost of irrigation installation:**
How will the irrigation system be implemented? Will it be implemented with or without a monitoring system and where should the sensors be placed to maintain a good performance of the plantations? How many sensors will there be needed and how much maintenance intervals will be required to check and keep the system up to date?

**Local availability of materials:**
Maybe there can be saved on costs by using materials from the local environment?

**Type of plants used:**
Which plants are used for the climate where the building is located? What are the demands of the plants on irrigation and growing space, for example the depth of a plant basket. Do the plants need a lot of pruning and maintenance or when does maintenance occur? Are the plants sensitive for pests?

**Short and long term maintenance:**
When does maintenance for the plants is planned? Who will doe the maintenance? And how will the system be over 20 years by the use of durable materials or replacing plants when they don’t grow that good anymore?

**Conclusion:**
Green façades and maybe also green sun shading are a key component of “looking green” architecture and they will become increasingly important instruments in architecture in our cities in the years to come. Green sun shading technology will provide a wide range of options for designers who are interested in using the building envelope to accomplish multiple functions and to provide design features on the interior and exterior experience of buildings.
The UNEC case study has a rather heavy structure consisting of a 450mm concrete floor including pressure and finishing layers and 600mm high edge beams that span a large distance.

The structure however is not final because the design will be changed in the second semester of the Dual Graduation track of architecture. Nevertheless section 1.15.4 shows the technical boundary conditions for the design of a green sun shading element. The external framing that is both visible in illustration 1.15.3 and 1.15.4 is a design element that can be used for supporting the green sun shading, however the façade design of the UNEC case study may change due to the design of the green sun shading.

So effacing the frame is allowed during the green sun shading design process. The sun shading can be designed as an integral part of the building by for example continueing the building floors outwards. It can also be a add-on construction that can be placed after the floors and the glazed wall is applied.

Besides the structural boundaries of the floors and edge beams the free height from floor to ceiling is 3,5 meter. The area above the 3,5 meters is reserved for the climate installation. So the building has a very high free height that also means that a lot of light can be transmitted into the chambers that are 9 meters deep. For easy maintenance of both green sun shading and the glazed façade a gallery or balcony will be needed. So the green sun shading will be placed at some distance from the façade.

This subscribes the technical boundary for applying the green sun shading on the building.
15.5 Architectural boundary conditions

As already mentioned in paragraph 15.4 the way of constructing a green sun shading with an outside area like a balcony or gallery can be done in different ways of constructing. By extending the floors of the building outwards and isolate them. Or with a thermal interruption with a so called iso-korf system. But designing an add-on system is also possible that can be mounted on the façade afterwards as shown in illustration I.15.5. From an architectural point of view this raises the question if a sun shading that is already based on the climate and dimensions that are needed for a specific building should be considered as a part of the building or an add-on on the building.

Generally sun shading systems like awnings, louvres etcetera are placed afterwards on the building. So a generally it are add-on systems. However when a sun shading can be achieved with a overhang this can also be an extended floor or balcony. This is more a integrated design of the building. For example the Eco Skyscraper of Ken Yeang of illustration I.15.6 and I.15.7 is an integral design where the floors continue outside the building and function as a balcony and also have the opportunity to reach different levels from the outside of the building what can be useful for maintenance but also troublesome for creating borders where visitors of the building can come.

The choice of creating a add-on sun shading or an integral part of the building design is an important question that needs to be investigated in the design part of the dual graduation track in the last semester of architecture. How will people experience the green sun shading and how will the maintenance be done on a 140 meter long façade? How should the green sun shading be constructed?

The assumptions for the building design were, designing a sober and functional building that can be reclassified after for example twenty years. So division and appearance can change. When a sun shading is an integral part of the building it is good to know what will remain if a façade gets restyled after maybe twenty or forty years. An add-on construction should be easier to replace or substituted for a different sun shading. For the implementation and further design of the green sun shading the concept of making an add-on construction will be used.
While designing a green sun shading element for a building you need to have a certain image in mind how the façade should look like from the inside and how it will shade the amount of sun from entering the building. Also what the effect would be when you are using plants instead of using simple screens or awnings as a sun shading.

The best way to make a thought visible is making a artist impression or how many people name it a rendering of a 3d model. When you have a large amount of textures that show a certain material it is easy to make a rendering, but when you want to achieve a specific feeling or impression you will need to make the textures yourself.

For simulating the amount of shading that was expected to be diffuse when you are using plants. The textures used to make the plants were made of a picture made from the trees around the Delft University of Technology. These trees give a nice amount of transparency in the tops with the sky behind it.

The 3d model of the UNEC case study is made in a program called Autodesk Revit. The textures are applied later on within a modelled mass. When you make a picture from plants and you want to use this picture in a rendering you will need to make 3 different images with Photoshop or other editing software to get transparency in the areas that you don’t want to render and to give the plants a certain amount of depth so the rendering program can simulate the shade of the plants.

The better the texture the better the rendering and simulation of the light will be.

Rendering I.16.1 show the effect of plants used in the lowest part of the façade, the sun that is entering the building is very bright and direct.
On rendering I.16.4 the visual achievement is accomplished, this impression shows the effect of using vegetation as a sun shading. The amount of light is shaded from the chamber and the light that is entering the chamber is more diffuse at certain points.

You can also see that there are spots in the façade where the sun is very bright, and that this reflects on the floor also. Here we are getting a certain amount of glare, a very bright amount of light that isn’t comfortable but what can occur when you are using plants.

So the density of the construction but also the chosen plants are the critical detail when glare appears. In the digital model it depends on the picture where the texture is made from.

This model is made with the assumptions of a green façade where the top part is shading the sun and the bottom part is used as a parapet where grapes or kiwis or other fruits can grow on. So this part is always accessible for the users of the chamber.

But now the question remains of what are the dimensions of the sun shading and how large should it be to prevent from getting too much sun inside?

For the amount of sun shading I refer to chapter 8. Comfort, where there is an explanation about glare and near and far field contrast with NEN-EN demands of lux in a working space.

To determine the dimensions of the sun shading element it is good to know how much light is entering the building without a sun shading and with a sun shading. However the design of the green sun shading is important also before designing element heights.
The sketch on the left is a translation of the renderings that already showed that a green sun shading is needed at the top of the chamber. The sketch also shows that the top part of the sun shading is the most important in shading from the sun in the winter and summer period. You can also see that with the use of a overhang or a small plant basket in this case the amount of sun that is getting into the chamber isn’t very much compared to the winter period. However the intensity in summer is much higher and longer than in the winter. So you could say that you can make a green sun shading like a overhang with enough width to prevent the sun from getting into the building in the winter and add a second vertical element for shading enough from the sun in the winter period.

Sight is very important. The user should be able to look outside. Turning concepts could be desired if there is a demand in a lot of vertical sight but they are less optimal in a horizontal panoramic point of view. This surely depends on the dimensions of the elements but if you look at the renderings from the previous page you can already see that there is a large panoramic sight, without large obstructions other than the curtain wall framings.

The horizontal sight is also limited when the green sun shading is made as shown in the sketch when the sun shading element is grown to story height. When you make green sun shadings that will have the height of an entire story of the building the top part needs to be fully grown to work as a proper sun shading but the problem of sight is that you will have to look through the plants of the green sun shading. So subdividing the element in two elements to maintain a nice horizontal view is an option to maintain a good performance and keeping a nice panoramic point of view. The rendering already showed that you need some kind of hanging plants or a element with plants to shade from the sun. The disadvantage of hanging plants is that when it is windy and especially on higher buildings the plants don't stay at one spot. They will sway because of the wind. So climbing plants aren't just easy to cladd a large area because they can grow over structures they also resist an amount of wind because they attach themselves in the framing where they are climbing in.

A green sun shading can be very simple, a metal frame that holds a plant basket with plants at some distance parallel to the façade working as an overhang and possibly also like a french balcony where the users can also reach the plants. And a second element or combined into the same element a plant basket that is at a lower place to prevent the lower radiating sun from getting in the building. The added value of the overhang is that it isn't just a overhang but also gives another function as a parapet and the opportunity to use fruit plants for more interaction from the plants to the users. The experience can be even more enhanced with flowers and smells of the flowers that are one could smell in the building when there are some windows or doors open. So there is much more to achieve besides shading from the sun.

When we look at the maintenance of this sketch you could definitely say that is shouldn't be done from the outside of the building. The baskets at floor height can be accessed from the french balcony perhaps but in winter time it isn’t nice to have doors open just for maintenance and getting the cold inside. Doing maintenance with a lift is an option but the window washer also needs to have access to the windows of the buildings so an external area like a gallery or balcony are necessary. Besides by making a balcony or gallery this isn’t a bad idea, it is again a value that can be added to the building. You will get an outdoor area that can be nice in the summer and because of the plantings that work like a parapet the sight is blocked in a vertical point of view this isn’t an issue when you look at it from standing on the balcony. Standing from the inside of the chamber you can’t fully look down but when you stand on the balcony you can, without the obstructions of underlaying green sun shadings for the storys underneath. Usage and sight are a combined parameter that needs to be dealt with.
So by making use of a balcony the point of sight can be assumed as moved because of the extra function it already offers. The vertical sight from the workspace is still obstructed by the external parapet. However when you are standing on the balcony the vertical sight is still there. Only the way of usage and experience is different. Besides the choice of designing a balcony for easy maintenance of the plantation and the glazed façade there is also a structural connection needed to prevent the balcony from displacement or bending down by the loads of the green sun shading element. There are different possibilities to design a balcony. For example with a reinforced system that is cast into the in situ-concrete. A so called “iso-korf” system, that is just set of steel reinforcement bars with a insulation block to prevent cold bridges. A balcony can also be made with consoles, so another “add-on” construction to the building. A different option is making a external structure like a steel frame that stands on its own or like in the references making the floors stick outside the building and insulate these overhanging floors. A lot of options for designing a balcony on its own, even without a green sun shading element.

In sketch I.16.7 I draw some wind bracings that reduce the downwards displacement that could also be used as a green sun shading coping with the changing azimuth angle of the sun. Because when the sun turns around the building, the sun can also get inside under an angle in the horizontal field. By using vertical elements you can shade from this angle of sun also. The structural braces can take care of some load of the entire green sun shading and also be used to be overgrown with plantation. The panoramic sight will be less wide than when you don't use vertical elements but in combination with a wide dimension between those vertical elements you can play with the amount of panoramic sight. In the example below one element for the UNEC case study is circa 13 meters, the side aisles where the bracings are also located in are circa 1 meter wide, so that is also the width of the balcony. Because of the elements that is needed to change the amount of sun shading in the vertical field there is a second layer of plant baskets. The second row of plants is the sun shading for the story above. When the sun shading isn't used it will be at the same height as the fixed parapet baskets for an easy maintenance access.

The choice as shown in sketch I.16.7 to use two steal columns with a wind bracing probable isn't needed but could be handy for montage of the green sun shading. A balcony with a wind bracing connected to the buildings structure could also cope with the loads of the sun shading element. However when you have four floors both balcony fixing and wind bracing fixing will be at the same spot for fixation. A secondary structure to lean on asks less demands on the building structure. A structural calculation could offer a choosing answer but an architectural demand of aesthetics also.

The green sketched element with a question mark inside is the part of the sun shading that mainly will need to shade from the lower standing sun when it rises and sets down in the summer and during the day in the winter. The dimensions of that question mark element can be determined by the demand of amount of daylight for a comfortable working space. This can be done with an illuminance analysis what will be discussed in the following chapter.
17. ILLUMINANCE ANALYSIS

17.1 Introduction

To determine the dimensions of a sun shading element as mentioned in chapter 16 you can dimension it by drawing the sun angles on a section and determine how low the sun needs to be shaded from. Or you can determine the dimensions based on a light simulation. A light simulation can be made in many ways. For the UNEC case study an illuminance analysis can offer support to measure illuminance values in lux. These values can be compared with the minimal demanded values as mentioned in paragraph 8.4 Sun Shading demands.

When you are making a illuminance analysis you are using a lot of input before you can measure the amount of lux on a surface in a room. For making this lux analysis there are two programmuses used in this research. Autodesk 3DS Max Design 2012 for the final lux analysis and for deciding how large the sun shading element should be to give a comfortable amount of natural light inside the office chambers. As before this final analysis is calculated in 3DS Max, there was a test without a sun shading with Velux Daylight visualiser. Velux made a program to measure the amount of lux that is entering a 3d model. The Velux program is more simple in use but also limited. You can’t use your own materials and that immediately deletes the option of rendering and measuring the amount of lux with the made plant textures in Revit. For closed elements like overhangs Velux offers an easy work around in the program and isn’t hard to learn.

3DS Max Design however works with the same radience engine and can calculate the amount of lux on a more precise way by using more user defined measuring points. However before we use the program we need to understand the input that we need before we can do a calculation of the illuminance in lux in the office chamber. In this chapter a illuminance analysis is made. There is a difference in illuminance and luminance. Illuminance is the amount of light coming from the sun in this case that lands on a surface. Luminance is the amount of light leaving a surface in a particular direction, for example our eyes. Luminance can also be described as the amount of brightness of a surface experienced by our eyes. A typical office workspace has 300-500 lux of horizontal illuminance. What means that 300-500 lux normally is produced by artificial lighting on a desk in an office chamber.

The illustrations I.17.1 beside this text shows some examples of illuminance values to get a feel of the amount of illuminance in lux. Illuminance can also be described as footcandles but in the metric system it is expressed in lux.

The amount of illuminance differs over the earth can be considered as a design sky. Design skies are made of statistical analyses of dynamic outdoor sky illuminance levels. The amount of illuminance values of a design sky are also depended as a function of latitude. For design skies there are different calculation methods to calculate the values on your own but a better solution to use is to use a standardized design sky that already has been calculated and tested before. The next paragraph will go a little bit deeper into the subject design sky because it will be used in the illuminance analysis.

17.2 Design sky models

"The main source of light in the sky is obviously the Sun itself. However, as a result of atmospheric scattering and reflection off clouds, the entire sky dome also emits light. The overall distribution of light over the sky dome therefore depends on current environmental conditions. Illustration I.17.3 below illustrates a range of different sky conditions showing just how variant this lighting distribution can be. These images are the result of taking photographs using a fish-eye lens. Such images capture the full hemisphere of the sky, with the horizon around the perimeter and the zenith in the centre.

As clouds form and move through the sky, the distribution of light can change almost minute by minute. This means that we cannot really design for any specific distribution, but must rely on ‘average’ conditions. The Commission International de l’Eclairage (CIE) has developed a series of mathematical models of ideal luminous distributions under different sky conditions of which the three most common are clear, uniform and overcast. As shown in illustration I.14.4. However, there are many different types of sky and many different mathematical models used to describe them. Each of these models assume the entire sky dome has some level of luminance, varying with angle from the horizon to the zenith, and with the relative angle from the current sun position.

The sky gets this luminance from sunlight that is scattered by air molecules or suspended particulates and reflected around by moisture vapour and clouds. As a worst-case, the overcast sky condition is usually used” (W.17.1) The overcast sky with it’s cloudy sky dome will give a almost white light because of the breaking of the light due to the diffuse surrounding. You shouldn’t always use one model for measuring the amount of illuminance but it is good to work with two or three models to get a good overview of extremes. Not every country uses the CIE sky models. England for example uses its own UK sky model based on own research (W.17.2) But the CIE sky is a standardized sky model that is proven to give good results, so for this analysis we will use the CIE sky models. (T.17.1)

The overcast sky is used for simulating the worst daylight conditions. Comparing it to the clear and intermediate sky the overcast sky will give the smallest amount of daylight inside the building because of the “cloudy” sky. So for the simulation and analysis it is very good to do both worst case scenarios. The sky that give the most realistic effect is the intermediate sky, where the sky has some haze in the sky that diffuses the light and passes more daylight through than the overcast sky. But the clear sky will give the most extreme effect of light. The expected result will be, that when there is an overcast sky, you need less sun shading in contrast to a clear sky. For designing a sun shading element both extremes are interesting, but when you are designing a controllable sun shading element you could say that you only shade for the times that the sun is very intense. When it is very cloudy you won’t shade for it to get enough daylight inside the chambers of a building. So for a passive sun shading both overcast and clear sky models are interesting. However for a controllable sun shading the clear sky model is more interesting because you should be able to move away the sun shading in an overcast situation when you don’t want a sun shading the whole time. Nevertheless for this analysis both clear and overcast skies are used to investigate what the difference of illuminance will be in a modelled office chamber.
17.3 Setup of the analysis model

For making an illuminance analysis model you need a good closed 3d model to avoid light leakages from seams at floor and wall connections. The materialisation of the floors, walls and ceiling should be textured with a generic material that doesn’t reflect or have a colour. A generic white/grey color will give the best results.

After setting up the model from in this case Autodesk Revit to 3ds Max Design, the location doesn’t have to be configured because I already did this in the Revit model. Otherwise it is rather simple to change or create a location and sun in 3ds Max Design. To set up the rendering quality that goes hand in hand with the light analysis some trial and error is needed to maintain a good visual image.

After producing just a nice lighted image, the following step is creating light meters in the 3d model. Light meters are made with a surface where metering points are attached to. The amount of light meters can be adjusted to the desired amount of meters. The more meters are applied the more specific the readings will be.

For the following analysis to show what the difference will be between a clear CIE sky and an overcast CIE sky in illuminance the light metering surface will be placed on the floor to show a relation between the 3d view and the plan view. At the final design for the green sun shading a measurement of illuminance will be done at the height of the workspaces. To check the setup of 3ds Max Design it is good to make a second analysis with a other program as Velux Daylight Visualizer. By making a comparison between two programs the data is checked. If a Haze Driven sky model is used in 3dsMax Design the image can be visually nice as shown in image I.17.8 however the lux values are very high and not realistic. So it is good to check if the values are the same in a different certified program. Also for making a illuminance rendering it isn’t needed to use the entire 3d model of the building of the case study to prevent long calculations. 3ds Max Design will calculate the whole 3d model so the best way of making an analysis is by making just the a part what need to be analysed.

The model of the office chamber is slightly adjusted to give a simulation of only the façade that transmits light into the building. To be sure that the height of the sun shading can be determined with the green texture that was made for creating a realistic view of a plantation as sun shading element. The problem with making an analysis in Velux Daylight visualiser was that you can’t load your own textures otherwise the analysis could also be made in Velux. A notice for working with 3ds Max Design is that the export of data can be done with a 3d rendering with an overlay of the measured lux values measured by 3ds Max. A fast and graphic representation like Velux needs to be done with a screenshot because when you want to export the plan views the value numbers will decrease in size.
17. ILLUMINANCE ANALYSIS

17.4 Summer 21st June, 14.00, clear CIE sky model

Lux measurement in the summer, without an external obstruction.

The lux values differ from very high values in the green area as shown in the plan view to less high illuminance in the 9 meter deep office chamber.

Lux measurement in the summer with the concept green façade texture as a sun shading 1 meter in front of the façade.

The lux values of the office chamber are already very low by implementing the concept green façade of paragraph 16.1. This means that with only this concept that there will be too much shading because the demanded lux values of 400-500 lux on the workspaces are around 200-300 lux. This is because of the high altitude of the sun in the summer that can shaded with a simple overhang.
17. ILLUMINANCE ANALYSIS

17.5 Winter 21st December 14.00, clear CIE sky model

Lux measurement in the winter, without an external obstruction.

The lux values of the winter period are much higher because of the lower altitude of the sun. Nevertheless note that the sun will be shining shorter than in the summer but will have a large amount of glare if no sun shading is used.

Lux measurement in the winter with the concept green façade texture as a sun shading 1 meter in front of the façade.

By implementing the same green façade concept in the winter the values of illuminance are still very high to prevent from glare. Also the demanded illuminance value at the workspaces will be higher than demanded.
17.6 Winter 21st of December 14.00, clear CIE sky, sun shading test

Lux measurement in the winter, with a closed obstruction 1 meter in front of the façade
Height level 1 bottomside measured, +/- 2.5 meters from the floor level.

Because of the large values of the winter period, the following analysis is continued with the winter period to determine the height of the sun shading element in comparison with the demanded illuminance values for the workspaces and the measured amount of illuminance from the analysis.

The analysis will be done with four different stages:
- sun shading level 1 without the green façade concept
- sun shading level 1 with the green façade concept
- sun shading level 2 with the green façade concept
- sun shading level 3 with a realistic plant basket
17. ILLUMINANCE ANALYSIS

Lux measurement in the winter, without an external obstruction.
Height level 2 bottomside measured, +- 1.4 meters from the floor level.

Lux measurement in the winter with the concept green façade texture as a sun shading 1 meter in front of the façade.
Height level 3 bottomside measured, 2 meters from the floor level.
17. ILLUMINANCE ANALYSIS

17.7 Summer 21st June, 14.00, overcast CIE sky model

Lux measurement in the summer, without an external obstruction.

Lux measurement in the summer with the concept green façade texture as a sun shading 1 meter in front of the façade.

The analysis of the clear sky model came up with a green sun shading element with a height underneath the green sun shading of 2 meters. This was measured with a clear sky model. The next analysis is the same as with the clear sky model only this time with an overcast sky model to see the difference in illuminance values.
17.8 Winter 21st December 14.00, overcast CIE sky model

Lux measurement in the winter, without an external obstruction.

Lux measurement in the winter with the concept green façade texture as a sun shading 1 meter in front of the façade.

As expected the values are less high with an overcast sky model than with the clear sky model. The illuminance values differ from 200-300 lux to the first desk standing closest to the glazed façade.
The same procedure will follow for the analysis of the green sun shading element only now with an overcast sky model. The first illuminance analysis with the sun shading in level 1 still has to high illuminance values that are around 1100 lux where 500 lux is demanded.

Lux measurement in the winter, with a closed obstruction 1 meter in front of the façade and concept green texture. Height level 1 bottomside measured, +/− 2,5 meters from the floor level.

Lux measurement in the winter, with a closed obstruction 1 meter in front of the façade.

Height level 1 bottomside measured, +/− 2,5 meters from the floor level.
Lux measurement in the winter, without an external obstruction. Height level 2 bottomside measured, ± 1.4 meters from the floor level.

Lux measurement in the winter with the concept green façade texture as a sun shading 1 meter in front of the façade. Height level 3 bottomside measured, 2 meters from the floor level.

The values of illuminance with an overcast sky model are too low to achieve the demanded amount of illuminance on the workspaces. The sun shading element needs to be higher to let more light in the room. However, with these analysis it is also clear that the bottom part of the green façade works as a sun shading element. This could be appearing because of the placement 1 meter in front of the façade. At the end of this research the final design will be tested with both clear and overcast sky to see if the developed façade can achieve the demanded illuminance values.
18. MECHANICAL DRIVE

18.1 Lifting mechanisms

With the lux analysis of the previous chapter 17, the height of the bottom side of the element is determined at 2 meters from the floor level. The height of the element should be high enough to maintain a dense surface of plantation. The plants will be placed in a plant baskets where the plants can grow upwards over a framing structure as explained in chapters 11 and 13. The structure where the plants climb in will be a rigid frame with minimal distances of 200-400mm wide gaps. So almost the same as a concrete reinforcement frame. This is chosen for creating a very dense surface where the plants have enough grip and directions to grow on. However when the frame will be overgrown with plants this will not be very visible any more after a while because of the use of evergreen plants. The moving element however needs to be rigid enough to move it up and down. There are a different possibilities to lift a green sun shading element up and down. For designing the green sun shading I made some different solutions. In this chapter some principles will be explained.

The first principle is that of a conventional lifting mechanism with a pulley and a rope as shown in illustration I.18.2. The green sun shading element can be lifted upwards by winding the cable that is connected to the green sun shading element. Illustration I.18.2 also shows that there will be some kind of guidance at the sides of the baskets to prevent the element swinging like a pendulum due to wind forces. A nice feature of this concept is that there is no mechanism in sight when the elements are placed in a parked position on the story above. The lifting mechanism can easily be placed underneath the balcony. However when the basket needs to be at the same level as the fixed plant baskets that function as a balustrade the lifting mechanism need to be higher than the basket. So small boxes with the pulley and winding mechanism will be in sight on the balcony.

The second concept instead of using a steel cable that needs to be winded is using a rigid rod with windings. By using two rods with a winding as used in window openers the element already has a certain amount of rigidity. A winding mechanism can be placed in the bottom of the plant basket that winds itself on thus also the green sun shading element up or down as in the window opener mechanism as shown in illustration I.18.5. Because of the path the green sun shading needs to follow to change from a shaded to a parked position the length of the steel rods will be rather long. Depending on the width of an element you can get a lot of steel rods hanging or standing as in illustration I.18.6 in front of the horizontal field of view. A worst case critic could be that you can experience the façade as a prison with steel bars in sight. Placing the bars in a downwards position offers the possibility to make the winding mechanism in the bottom part of the element or a nut in the bottom part and by turning the rod with windings the element will lift. The other option is placing the rods above the balcony the sight will be less blocked upwards so you can’t bump your head against it. The placement of the nut is also different in the “standing” concept it should be placed in the top part of the element what means that the element should be a rigid frame and hangs on the rods. Where the hanging system rather is standing on the restriction. However without precautions you can fall over the rods also. So a simple rigid mechanism like the window opener has a lot of side issues.

The third option is using the balcony or the frame where the green sun shading element is moving between as the movement mechanism instead of placing a winding mechanism on the balcony or using rods that have a lot of side issues. The third concept consists of a rack and a pinion in the frame where the elements move. In there could be a pinion that drives the rack of the element. The benefit of using a rack and pinion is that the balcony structure is becoming the guidance and drive for the green sun shading element. This mechanical drive is also generally used in green houses as shown in illustration I.18.9. This mechanism could be very simple to apply on the frame of the sun shading element.
Because of the interest in making a mechanical drive from the balcony frame that could function as a guidance and drive at the same time this design is developed a little step further. In sectional drawing I.18.10 the top element is worked out with a rack that is moving between the two guidances, the fixed plant basket and the architectural framing. The problem that occurred while drawing the section is that the green sun shading element needs to remain between the guidance of the balcony construction. That means that the element height of the sun shading needs to be 3 meters high. This also means that when the element is in a parked position that you can’t look outside anymore because the element will be higher than the fixed plant basket. The green sun shading will act like a green wall. So this concept isn’t really feasible.
The last and also used concept is based on thinking of a different lifting mechanism than the pulley with a steel rope. The lifting mechanism should have some rigidity to withstand the wind forces but also needs to be out of sight when the green sun shading is in parked position. The concept of a scissor lift caught my attention because it can be folded into a small dimension and also have some rigidity in horizontal movement. However the amount of movement in a horizontal position depends on the angle of the scissors. When the scissors are opened larger than 45 degrees the amount of rigidity will decrease. The mechanical drive concept based on retractable scissors needs a parking element where the scissors are folded into each other like the space that was needed for the conventional lifting concept. Also the scissors can be placed within a telescopic box that moves with the scissors to decrease the amount of horizontal movement and to protect the scissors against weather influences. To maintain the scissors working correctly the placement of a box where the scissors are folded on balcony level it makes maintenance easy accessible. The question that last is how much elements do the scissors consist of and what will be the length of the folded scissors when the green sun shading element is in a parked position.

For checking the height and length of the scissors I made a parametric model of the green sun shading design with the mechanical scissor drive. By using parameters to set up the height of an element the scissors are folding with the element and eventually will stick above the balcony floor. The position of the green sun shading element in shaded position and parked position determines the length and amount of scissors. Thus also the maintenance element that is placed on the balcony.

The parametric illustration I.18.13 shows that there is a diversity of element positions when each element is driven by a separate servo. The mechanism that will fold the scissors is based on the working of the window opener mechanism of illustration I.18.5. However because of the amount of scissors and the way they interact which eachother only one scissors needs to be winded open or closed. A chain reaction within the scissor construction will act as the lifting movement. For stability and reliability two or three scissors should be connected to the rod with windigs. This part could be accessed in the box on the balcony for maintenance.
18. MECHANICAL DRIVE

By using the mechanical scissor drive mechanism for lifting the green sun shading element the following implementation of the green sun shading element is made as shown in illustration I.18.14. In this drawing the elements are described. The 3d section is taken over a parked green sun shading element showing the folded position of the scissors in the maintenance box and behind it a extended position of a green sun shading. Besides the scissor construction this drawing already shows more details about the way the plant basket is constructed and the way the balcony is fixed. The construction of the basket and the structure of the balcony will be explained in chapter 19. Construction and Materialisation.

18.2 Implementation of a mechanical drive

I.18.13 Parametric drawing of the different positions one element could have and the influence on the scissor position

I.18.14 Fragment of the UNEC case study façade with the green sun shading applied
18. MECHANICAL DRIVE

18.3 Individually or group driven

The mechanical scissor drive offers a possibility to make individually driven green sun shading elements. When this isn’t desired a different drive train should be designed to combine multiple scissors on one servo. Also the choice can be to make one large sun shading element with the disadvantage of large loads of a large green sun shading. However combining six or more smaller elements on one drive train offers the choice to use less electronics. Nevertheless when green sun shading elements are driven individually the amount of influence on sun shading is larger than when all the elements move at the same time. For example a green sun shading element can also be in front of an empty space in an office room or in front of a pantry where it can be nice to have some sun inside but still keep the possibility to keep other elements down that are located at working spaces.

Besides having influence on the position of the green sun shading elements the appearance of the façade can also get very dynamic by the input of the users demands on the sun shading as illustrated in illustrations I.18.16 - I.18.19. There is also an interesting conclusion by using the controllable green sun shading elements at the top floor. That is that the elements will be standing above the roof edge in parked position. So an architectural design question is how will the roof edge be designed and will there also be a fixed annual element?

Plant choice and a possible design of a “vertical green sun shading garden” can have influence on the appearance of the façade from both inside and outside experience. Illustration I.18.20 shows a impression of the indoor experience of the use of the developed green sun shading element.

I.18.15 Movement of sun shading elements in front of the glazed façade.
I.18.16 Green sun shading in shaded position
I.18.17 Green sun shading in parked/non shading position
18. MECHANICAL DRIVE

18.18 Green sun shading in a position influenced by the user

18.19 Green sun shading in a random position and with use of different plant fillings

18.20 Impression of the green sun shading from the inside of an office chamber

18.21 Green sun shading fragment implemented on the UNEC case study
19. CONSTRUCTION AND MATERIALISATION

19.1 Structure

As already mentioned in paragraph 18.2, the construction of the green sun shading isn’t explained yet in this report. The construction of the green sun shading has to be applied to the technical boundary conditions of the UNEC case study, described in paragraph 15.4. These boundary conditions aren’t final yet because the building will develop in the second part of the architecture track of this dual graduation track.

Designing a structural solution for a balcony can be done one several ways. As already mentioned with a structure attached to the building structure or a structure for the balcony alone. Because of the weights that the green sun shading has, circa 500 kg per controllable green sun shading element based on the test setup and the dimensions of the green sun shading element. The total amount of weight of the balcony frame with the green sun shading on it and the annual plant baskets that are fixed the total weight can be around 7000 kg for the entire unit that is fixed within the architectural framing in front of the façade. It isn’t clear yet how the architectural framing that devises the elements of the façade will remain in the development of the façade design in the second half of the architecture track. And it isn’t clear now if the frame is attached to the floors of each story or that it is loading on the massive table structure at the ground floor.

For the construction of the green sun shading the entire unit will be attached to the façade like the principles that are drawn in illustration I.19.1 and I.19.2 A steel construction will be attached to the floors to fix one side of the green sun shading to the building and the part of the overhang will be hung on a bracing also fixed on the building but to spare the structure of the building, the architectural frame will also be used to support the balcony of the green sun shading element.

Illustration I.19.3 shows a framing structure that is placed at the same level as the floor. This means that the annual plant baskets will be hung on the outside grillages and in the back of the illustration between the grey balcony floor and the white profile the controllable green sun shading will move. The structural frame of the building is also visible in illustration I.19.4.
Illustration I.19.6 shows an attempt of a sectional drawing of the green sun shading element connected to the façade of the UNEC case study building. There are a lot of attention points for further development like the thermal line that isn’t connected now by the location of the curtain wall. Also the connection of the architectural frame is still unclear and also the edge beam could be smaller in the end of the architectural design development. All these factors have influence on the detailing of the green sun shading element. This have to be designed further before detailing the green sun shading element. Nevertheless the dimensions of the green sun shading are already known so the development of the buildings façade also consists on not only architectural demands of the building design but also the technical demands of the green sun shading. For the next paragraph the placement of the irrigation and water management are explained. So there aren’t technical demands but also maintenance demands for a further development of the buildings façade.
The irrigation system as explained in chapter 12, Maintenance consist of two different pipe lines. The first one is for the annual plants that remain at the same place on the end of the balcony. And a second pipeline for the moving green sun shading elements. The supply of fertilized water will be transported from the technical room of the building where the pump and filtering system uses rain water for watering the plants. This supply is transported vertically along the vertical sun shading elements of the whole sun shading unit. There could be 4 vertical lines or even more depending on the division and pressure in the system along each vertical element or hidden behind the architectural framing. From the vertical supply line there are branches for the fixed plant baskets and one for the controllable sun shading elements. The horizontal supply line again will be branched with flexible hoses that run along the scissor construction for supplying nutrients to the plants.

For dealing with excessive water the plant baskets are divided into two chambers. The top part is a basket with the soil and the plant in it and the lower part of the basket is a excessive water retaining basket. This basket can hold a large amount of excessive water due to heavy rainfall or too much irrigation. The problem of creating a water retaining basket in the green sun shading element is that elements can have different heights so losing the water is a problem that can be solved with different solutions. One option like the references in chapter 5 use is a excessive water overflow. However this isn’t the best choice because the excessive water can hold dirty soil and can splash on people at ground level and on the building. A option is to use a excessive water overflow that aims at the annual plant baskets. Nevertheless the running water has to splash in those annual baskets. An other option is retaining the water until green sun shading reaches the parked position and than convey the amount of retained water to the water drainage that is located in the bottom of the fixed annual plant baskets. This can be done with a lid that opens when the green sun shading is in a parked condition. Illustration I.19.9 shows that the dark blue colors annual plant baskets have a connected system that conveys the excessive water to a vertical drainage. the lighter transparent colored rectangles are the movable elements that need to lose the excessive water when they are in a parked position.
The materialisation of the green sun shading consists of the plantation that has a wide range of plants that can be used. The construction of the frame and especially the baskets can be designed also. Materials as plastic, metal, wood or composites can be used for the plant baskets to make it from one piece or as drawn in illustration I.19.21 as a cladding on a frame. The plant basket where the soil is situated and the plants can easily be made with a thermoforming procedure to make a plastic element out of one piece. This also counts for the water reservoir underneath.

The appearance of the green sun shading beside the plantation consists of a horizontal lining of the plant baskets. Different options for cladding the plant baskets are cladding them with a closed green wall construction for example with the modules mentioned in paragraph 4.2.3. This will demand some space in the frame but it is possible.

The maintenance of these vegetated modules have to be done from the outside so maybe that could be a decision for don’t implementing a closed green construction on the plant baskets. An other option for creating a “green” look to the materials to stay in the same “looking green” concept is by making materials appear like a plant or vegetated surface.

An example of making a certain leaf pattern on a balcony parapet is shown on illustration I.19.20. This perforation of a leaf in a steel parapet cladding is designed by 24-H Architects. The illustrations I.29.21 and I.19.22 show that there are also two options in the way the plant baskets can be materialised. The elements can look very closed in whatever form is desired, in this case the shape is rectangular. But as mentioned the basket can be made out of a frame like the Z58 building in chapter 5. The feature of making a frame with a cladding is that different materials are possible to apply and the materials can be changed after a while or when a new look is desired without changing the whole green sun shading element. A material choice can also be applying a transparent material instead of a perforated or closed material.
20. ILLUMINANCE CHECK

20.1 Illuminance analysis of the designed green sun shading

The final check if the green sun shading is working is the illuminance analysis for the designed green sun shading. Impressions I.20.1 and I.20.4 show that the amount of light differs from the sun altitude as already mentioned in chapter 17. The illuminance values are measured on the height of the desks in the office chamber. The illuminance values differ because of the densities of the plantation textures from the rendering. Nevertheless the difference of the winter and summer are clear.

The analysis is done with both a clear CIE sky and a overcast CIE sky. In the summer the sun shading should be a little bit higher to get more daylight deeper in the room. The values start at circa 700 lux and fade away till 244 lux in the middle of the room with a clear sky on the 21st of June. The values for the winter period is much higher at the border of the building façade on a clear day.

The values on the 21st of December with a clear sky start at the glazed façade with 4500 lux and fade of to 400-600 lux in the middle of the office chamber. Again this is also depending on the textures that is used but the demanded values of 500 lux at a near contrast area at the desks of the UNEC employees is achieved. The overcast situation is also simulated and gives values that are circa 100-200 lux lower in the summer and 1200-400 lux lower in the winter.
21.1 Conclusion and recommendation

The end product of this green sun shading research isn’t a sun shading element that is finished yet. The detailing and the final implementation needs an architectural design that is worked out on a more detailed level. However with the gained information of this research and the designed dimensions of the elements this can be a good handle to hold on while developing the UNEC building. So for the structural part of this research the connections and also the structure on its own can change according to the architectural design. One other point of criticism is that the way the movable green elements discharge the excessive amount of water isn’t fully designed yet.

The implementation of this controllable green sun shading is designed for the largest façade of the UNEC case study. It would be good to test this green sun shading element also on the South-East façade where the sun will rise in a lower altitude and will be much more intense than the winter sun on the South-West façade. So probably there is a need for different green sun shading implementations over the entire façade of the UNEC building. Also the question for further development is, do the public functions also need a controllable sun shading element or is it only needed in office rooms, conference rooms and the horeca function for example? This could be a variety in the façade where both active and passive elements can be used or a domotic system that has influence over the whole façade to get the best cooling needs for the building. Where some functions have the possibility to override the domotic system and influence the sun shading elements individually.

Nevertheless there are some factors that can make a green sun shading “successful”.

Design, installation and maintenance considerations for green sun shading systems will vary by designed concept and the conditions of the built and natural environment. Green façade constructions require that the designers, installers, manufacturers and maintenance managers should consider the following points:

- The attachment to the building envelope. How will the green sun shading be attached to the building or on a freestanding structure?

- Calculation of the structural loads is inevitable for larger systems, resulting with extra loads as snow, wind and excessive water.

- Plant selection for wind and light exposure, and climate zone.

- Realistic expectations related to plant aesthetics and growth. Choose to grow plants in the green sun shading elements before applying them to the façade construction. This will ensure that the plants can withstand weather influences better than when they are very small and need to grow a lot.

- Plant maintenance and/or long term maintenance needs to be planned and monitored by a maintenance company specialized in maintaining plants. Not only the plants but also the irrigation system and the quality of the soil and the moving parts of the green sun shading.

So these are just some points of interest that need to be kept in mind while designing a green sun shading.
22. Epilogue

22.1 Epilogue

The research of designing a green sun shading was very interesting to do. It is a pity that there isn’t a fully worked out green sun shading design element yet. Nevertheless by doing research on the way a green sun shading should work and which subjects are needed to design a green sun shading a lot of questions for my architectural design appeared. I think I can use almost everything of my research to develop my façade for my building design. The first thing after this research is making a clear overview of the aspects that need more attention also demanded by the green sun shading element. The plant overview that can be used for the UNEC building can be used to design a diverse building façade with the same green sun shading element. Also the possibility to research the materialisation and shape of the baskets is still not final. By making framing constructions, the frame can be cladded with different materials for this design process but also with the idea of changing the looks of the green sun shading in the future. So the research did not only give some answers of how to make a green sun shading and where attention should be paid. This research also created more questions of how the building façade would look like while using a controllable green sun shading at certain areas in the building façade where individual influences of the sun shading are demanded or combined with a domotic system.

I enjoyed the research very much because sometimes the question is should I pay that much attention to a plant that just moves around over the façade to have control over the sun shading of a building? However it is much more than just an element moving over a façade. Compared to the introduction where I mention about Google and searching on the keyword “Sustainable Architecture” I hope to see more “transparent” green constructions where plants are used for their functions of growing fruit, flowers, smell and sun shading besides just for the green appearance.

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4025644

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121
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I.13.3 Design drawing of the two test setup baskets.
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I.17.17 3D view light analysis, winter clear CIE sky, sun shading level 1, C.A. Slui, 2011

I.17.18 Section light analysis, winter clear CIE sky, sun shading level 1, C.A. Slui, 2011

I.17.19 Plan view light analysis, winter clear CIE sky, sun shading level 1 + green façade, C.A. Slui, 2011

I.17.20 3D view light analysis, winter clear CIE sky, sun shading level 1 + green façade, C.A. Slui, 2011

I.17.21 Section light analysis, winter clear CIE sky, sun shading level 2 + green façade, C.A. Slui, 2011

I.17.22 Plan view light analysis, winter clear CIE sky, sun shading level 2 + green façade, C.A. Slui, 2011

I.17.23 3D view light analysis, winter clear CIE sky, sun shading level 2 + green façade, C.A. Slui, 2011

I.17.24 Plan view light analysis, winter clear CIE sky, sun shading level 3 + green façade, C.A. Slui, 2011

I.17.25 3D view light analysis, winter clear CIE sky, shaded level 3 + green façade, C.A. Slui, 2011

I.17.26 Section light analysis, winter clear CIE sky, sun shading level 3 + green façade, C.A. Slui, 2011

I.17.27 3D view light analysis, summer overcast CIE sky, green façade, C.A. Slui, 2011

I.17.28 Plan view light analysis, summer overcast CIE sky, no obstructions, C.A. Slui, 2011

I.17.29 3D view light analysis, winter overcast CIE sky, no obstructions, C.A. Slui, 2011

18. Mechanical drive

Illustration credits

I.18.1 A conventional lifting mechanism, knowledgepublications.com

I.18.2 A conventional lifting mechanism can be placed underneath the balcony and doesn’t obstruct the sight, C.A. Slui, 2011

I.18.3 A conventional window opener with a rope to turn the nut, http://www.ac sisling.com/acatalog/lg/W1030.jpg

I.18.4 A mechanical drive concept with hanging rods with windings, C.A. Slui, 2011

I.18.5 An example of the winding mechanism placed in the top or bottom of the green sun shading element, C.A. Slui, 2011

I.18.6 The variant of the hanging rods with windings now in a standing position, C.A. Slui, 2011

I.18.7 The concept based on a rack and pinion drive mechanism, C.A. Slui, 2011


I.18.9 A pinion and rack mechanism used in green houses, http://www.redpathhort.com/accessories/rackandpinions1.jpg

I.18.10 Sectional drawing of the pinion and rack concept, C.A. Slui, 2011

I.18.11 Concept drawing of the scissor mechanical drive, C.A. Slui, 2011


I.18.13 Parametric drawing of the different positions one element could have and the influence on the scissors position, C.A. Slui, 2011

I.18.13 Parametric drawing of the different positions one element could have and the
influence on the scissor position, C.A. Slui, 2011

I.18.14 Fragment of the UNEC case study façade with the green sun shading applied, C.A. Slui, 2011

I.18.15 Movement of sun shading elements in front of the glazed façade, C.A. Slui, 2011

I.18.16 Green sun shading in shaded position, C.A. Slui, 2011

I.18.17 Green sun shading in parked/non shading position, C.A. Slui, 2011

I.18.18 Green sun shading in a position influenced by the user, C.A. Slui, 2011

I.18.19 Green sun shading in a random position and with use of different plant fillings, C.A. Slui, 2011

I.18.20 Impression of the green sun shading from the inside of an office chamber, C.A. Slui, 2011

I.18.21 Green sun shading fragment implemented on the UNEC case study, C.A. Slui, 2011

I.19. Construction and materialisation

Illustration credits

I.19.1 Principle of a balcony detail where a vertical profile is mounted on a concrete structure of the building. On the vertical profile the balcony can attached on a horizontal tube profile, C.A. Slui, 2011


I.19.3 Principle of the steel framing that rests on the architectural frame and is connected on the building structure, C.A. Slui, 2011

I.19.4 Detail showing the frame of the green sun shading attached to the structure of the building, C.A. Slui, 2011

I.19.5 Impression of the balcony and the structure of the green sun shading elements, the bracings are placed in the end of the balcony in the vertical sun shading elements, C.A. Slui, 2011

I.19.6 Sectional drawing of the green sun shading applied to the UNEC building, C.A. Slui, 2011

I.19.7 Schematic overview of the irrigation system, C.A. Slui, 2011

I.19.8 Principle of excessive water flow of the controllable green sun shading, C.A. Slui, 2011

I.19.9 Schematic overview of the excessive water drainage of the green sun shading element, C.A. Slui, 2011


I.19.21 Example of closed plant baskets, C.A. Slui, 2011

I.19.21 Example of the plant baskets with a transparent material, C.A. Slui, 2011

I.20. Impression of the green sun shading in shaded position on 21st of June with a clear CIE sky model at 14.00 o’clock, C.A. Slui, 2011

I.20.2 Illuminance analysis of a clear CIE sky on 21st of June, C.A. Slui, 2011

I.20.4 Impression of the green sun shading in shaded position on 21st of December with a clear CIE sky model at 14.00 o’clock, C.A. Slui, 2011

I.20.5 Illuminance analysis of a clear CIE sky on 21st of December, C.A. Slui, 2011

I.20.6 Illuminance analysis of a clear CIE sky on 21st of June, C.A. Slui, 2011
Fountain Park - Playa Vista, CA

Custom **greenscreen** installation with four sided column covers and tapered horizontal panels mounted to a structural steel frame.
Franklin Avenue Beautification
Garden City, NY
These sculptural, multi-layered greenscreen® elements mount to custom planters to create a series of unique pedestrian portals along a revitalized shopping street.
Park Wilshire - Los Angeles, CA

Cut to curve greenscreen® panels are mounted top and bottom to separate the garage from the pool area at this condominium project.
Rooftop Gardens - New York, NY
These rooftop gardens adapt custom *greenscreen*® panels to a variety of planter systems for screening and softening in this hardscape environment.
Second Floor Terrace,
Graduate School of Business
Stanford University, Palo Alto, CA

Layers of green screen® panels dropped into a steel perimeter frame and wrapping the center post to create a custom “tree-like” trellis structure.

1743 S. LA CIENEGA BLVD. LOS ANGELES, CA. 90035  T - 800.450.3494  www.greenscreen.com
Fountain Park - Playa Vista, CA
Custom column surrounds + tapered horizontal greenscreen® panels are used to create a curved, shady pergola in a park setting.
Plant recommendations for greenscreen® from the Monrovia Growers Catalog

Choosing the appropriate plant materials for greenscreen® requires careful consideration of climate zone, sun and wind exposure, soil type, size of container, water and nutrient needs, adjacent plant materials and desired visual effect.

greenscreen® is well suited for vines that grow by twining, climbing, curling or tendrils. Trumpet Creeper (Campsis radicans), Virgin’s Bower (Clematis virginiana) and Cape Honeysuckle (Tecoma capensis) are all good examples of vines that grow this way. Plants that grow by suckers or aerial roots may be just as suitable, but require additional maintenance and installation consideration. Examples of this type of vine are English Ivy (Hedera helix ‘Thorndale’), Virginia Creeper (Parthenocissus quinquefolia) and Climbing Fig (Ficus pumila). These plants can be used in freestanding applications and/or projects with significant maintenance resources so that there is no possibility of the plants attaching themselves to the building envelope in a wall mounted application.

greenscreen® also recommends that all plant material receive regular maintenance according to standard horticultural practices. Specific maintenance specifications regarding vine plant material should be part of the best management practices. Heavy and aggressive plants, such as Wisteria (Wisteria chinensis) and Bougainvillea (Bougainvillea varieties) can quickly dominate or overtake a site if proper maintenance is not performed.

Designing and mixing vines on the same panel can be very successful. Using evergreen vines, in combination, with deciduous vines is a great way to make sure that there are four seasons of interest on the panels. Also, there may be design opportunities to grow vines from the top down with cascading plants, such as the Begonia Vine (Cissus discolor) and Sweet Potato Vine (Ipomoea batatas). greenscreen® recommends that a landscape architect, landscape designer or horticulturist be consulted for specific applications.

ZONE | AVG. ANNUAL MIN.
--- | ---
2a | -50°F through -45°F
2b | -45°F through -40°F
3a | -40°F through -35°F
3b | -35°F through -30°F
4a | -30°F through -25°F
4b | -25°F through -20°F
5a | -20°F through -15°F
5b | -15°F through -10°F
6a | -10°F through -5°F
6b | -5°F through 0°F
7a | 0°F through 5°F
7b | 5°F through 10°F
8a | 10°F through 15°F
8b | 15°F through 20°F
9a | 20°F through 25°F
9b | 25°F through 30°F
10a | 30°F through 35°F
10b | 35°F through 40°F
11 | above 40°F
### Zone 3

<table>
<thead>
<tr>
<th>Plant</th>
<th>Variety</th>
<th>Growth Habit</th>
<th>USDA Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinidia arguta 'Issai'</td>
<td>Hardy Kiwi Vine</td>
<td>Deciduous</td>
<td>3-8</td>
</tr>
<tr>
<td>Clematis integrifolia ‘Caerulea’</td>
<td>Bushy Blue Bell Clematis</td>
<td>Deciduous</td>
<td>3-7</td>
</tr>
<tr>
<td>Clematis alpina ‘Constance’</td>
<td>Constance Alpine Clematis</td>
<td>Deciduous</td>
<td>3-9</td>
</tr>
<tr>
<td>'Pamela Jackman'</td>
<td>Pamela Jackman Clematis</td>
<td>Deciduous</td>
<td>3-9</td>
</tr>
<tr>
<td>'Ruby'</td>
<td>Ruby Alpine Clematis</td>
<td>Deciduous</td>
<td>3-9</td>
</tr>
<tr>
<td>'Stolwijk Gold' P.P.#18648</td>
<td>Stolwijk Gold Alpine Clematis</td>
<td>Deciduous</td>
<td>3-9</td>
</tr>
<tr>
<td>Trachelospermum asiaticum ‘Ogon Nishiki’</td>
<td>Japanese Star Jasmine</td>
<td>Deciduous</td>
<td>3-9</td>
</tr>
</tbody>
</table>

### Zone 4

<table>
<thead>
<tr>
<th>Plant</th>
<th>Variety</th>
<th>Growth Habit</th>
<th>USDA Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinida Kolomikta</td>
<td>Ornamental Kiwi</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>Campsis radicans ‘Monbal’</td>
<td>Balboa Trumpet Creeper</td>
<td>Deciduous</td>
<td>4-11</td>
</tr>
<tr>
<td>‘Flava’</td>
<td>Yellow Trumpet Creeper</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Campsis x tagliabuana 'Madame Galen'</td>
<td>Trumpet Creeper</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Clematis lanuginosa ‘Candida’</td>
<td>White Flowering Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Clematis paniculata</td>
<td>SweetAutumn Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Clematis viticella ‘Alba Luxurians’</td>
<td>Alba Luxurians Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>‘Blue Angel’</td>
<td>Blue Angel Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>‘Etoile Violette’</td>
<td>Etoile Violette Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Clematis x. ‘Jackmanii’</td>
<td>Jackman Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Clematis x. ‘Nelly Moser’</td>
<td>Nelly Moser Clematis</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Hydrangea anomala petiolaris ‘Miranda’</td>
<td>Varieg. Climbing Hydrangea</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>Lonicera japonica ‘Halliana’</td>
<td>Hall's Japanese Honeysuckle</td>
<td>Deciduous</td>
<td>4-11</td>
</tr>
<tr>
<td>‘Purpurea’</td>
<td>Purple Leaf Honeysuckle</td>
<td>Deciduous</td>
<td>4-11</td>
</tr>
<tr>
<td>Lonicera sempervirens ‘Magnifica’</td>
<td>Trumpet Honeysuckle</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Lonicera x brownii ‘Dropmore Scarlet’</td>
<td>Trumpet Honeysuckle</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Lonicera x heckrottii ‘Goldflame’</td>
<td>Goldflame Honeysuckle</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Lonicera x ‘Mandarin’ P.P.# 11083 (COPF)</td>
<td>Mandarin Honeysuckle</td>
<td>Deciduous</td>
<td>4-9</td>
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<tr>
<td>Parthenocissus quinquefolia</td>
<td>Virginia Creeper</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>‘Monham’</td>
<td>Star Showers Virginia Creeper</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Parthenocissus tricuspidata ‘Green Showers’</td>
<td>Green Showers Boston Ivy</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>‘Veitchii’</td>
<td>Boston Ivy</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Rosa x ‘Cecile Brunner’ (Climbing Type)</td>
<td>Cecile Brunner Climbing Rose</td>
<td>Deciduous</td>
<td>4-11</td>
</tr>
<tr>
<td>Rubus idaeus ‘Canby Red’</td>
<td>Candy Red Raspberry</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>‘Heritage’</td>
<td>Heritage Raspberry</td>
<td>Deciduous</td>
<td>4-8</td>
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<tr>
<td>‘Indian Summer’</td>
<td>Indian Summer Raspberry</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>‘Williamette’</td>
<td>Williamette Raspberry</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>Vitis labrusca ‘Catawba’</td>
<td>Catawba Grape</td>
<td>Deciduous</td>
<td>4-8</td>
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<tr>
<td>‘Delaware’</td>
<td>Delaware Grape</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>‘Eastern Concord’</td>
<td>Eastern Concord Grape</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>‘Niagara’</td>
<td>Niagara Green Grape</td>
<td>Deciduous</td>
<td>4-8</td>
</tr>
<tr>
<td>Wisteria macrostachya ‘Aunt Dee’</td>
<td>Aunt Dee Kentucky Wisteria</td>
<td>Deciduous</td>
<td>4-9</td>
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<tr>
<td>‘Blue Moon’</td>
<td>Blue Moon Kentucky Wisteria</td>
<td>Deciduous</td>
<td>4-9</td>
</tr>
<tr>
<td>Zone 5</td>
<td>Zone 6</td>
<td>Zone 7</td>
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<tr>
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<tr>
<td><strong>Akebia quinata</strong>&lt;br&gt;‘Shirobana’</td>
<td><strong>Bignonia capreolata ‘Tangerine Beauty’</strong>&lt;br&gt;Tangerine Cross Vine</td>
<td><strong>Actinidia chinensis ‘Tomuri’</strong>&lt;br&gt;Kiwi Vine</td>
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<tr>
<td><strong>Clematis texensis ‘Princess Diana’</strong>&lt;br&gt;‘Monul’</td>
<td><strong>Clematis montana ‘Freda’</strong>&lt;br&gt;Freda Anemone Clematis</td>
<td><strong>Clematis armandii</strong>&lt;br&gt;Evergreen Clematis</td>
<td></td>
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<tr>
<td><strong>Hedera helix</strong>&lt;br&gt;‘Thomdale’</td>
<td><strong>Hedera helix ‘Silverdust’</strong>&lt;br&gt;Silverdust English Ivy</td>
<td><strong>Clematis × cartmanii ‘Blaaval’</strong>&lt;br&gt;Avalanche Evergreen Clematis</td>
<td></td>
</tr>
<tr>
<td><strong>Hydrangea anomala petiolaris</strong>&lt;br&gt;‘Thomless Boysen’</td>
<td><strong>Rosa banksiae ‘Lutea’</strong>&lt;br&gt;Yellow Lady Bank’s Rose</td>
<td><strong>Decemaria barbara ‘Chauga’</strong>&lt;br&gt;Chauga Wild Hydrangea Vine</td>
<td></td>
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<tr>
<td><strong>Lonicer a periclymenum</strong>&lt;br&gt;‘Winchester’</td>
<td><strong>Schizophragma hydrangeoides ‘Moonlight’</strong>&lt;br&gt;Moonlight Hydrangea Vine</td>
<td><strong>Gelsemium rankinii</strong>&lt;br&gt;Swamp Jessamine</td>
<td></td>
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<tr>
<td><strong>Polygonum aubertii</strong>&lt;br&gt;‘Black Satin’&lt;br&gt;Thornless Boysenberry</td>
<td><strong>Wisteria floribunda ‘Issai Perfect’</strong>&lt;br&gt;White Japanese Wisteria</td>
<td><strong>Gelsemium sempervirens</strong>&lt;br&gt;Carolina Jessamine</td>
<td></td>
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<tr>
<td><strong>Rubus ursinus ‘Black Satin’</strong>&lt;br&gt;‘Rosea’&lt;br&gt;Pink Japanese Wisteria</td>
<td><strong>Wisteria floribunda ‘Rosea’</strong>&lt;br&gt;Amethyst Falls Wisteria</td>
<td><strong>Gelsemium sempervirens &amp; G. rankinii</strong>&lt;br&gt;Double Shot Jessamine</td>
<td></td>
</tr>
<tr>
<td><strong>Wisteria frutescens &amp; ‘Amethyst Falls’</strong>&lt;br&gt;Chinese Wisteria</td>
<td><strong>Wisteria frutescens &amp; ‘Amethyst Falls’</strong>&lt;br&gt;Chinese Wisteria</td>
<td><strong>Trachelospermum asiaticum</strong>&lt;br&gt;Asian Star Jasmine</td>
<td></td>
</tr>
<tr>
<td><strong>Wisteria sinensis Chinese Wisteria</strong>&lt;br&gt;‘Shirobana’</td>
<td><strong>Wisteria sinensis Chinese Wisteria</strong>&lt;br&gt;‘Shirobana’</td>
<td><strong>‘First Snow’</strong>&lt;br&gt;First Snow Asian Jasmine</td>
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<tr>
<td><strong>Wisteria frutescens ‘Tomuri’</strong>&lt;br&gt;‘Pink’&lt;br&gt;Madison Jasmine</td>
<td><strong>Wisteria frutescens ‘Tomuri’</strong>&lt;br&gt;‘Pink’&lt;br&gt;Madison Jasmine</td>
<td><strong>Trachelospermum jasminoides ‘Madison’</strong>&lt;br&gt;Madison Jasmine</td>
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<tr>
<td><strong>‘Winchester’</strong>&lt;br&gt;‘Shubert’&lt;br&gt;‘White Snow’&lt;br&gt;‘Shepherd’s’</td>
<td><strong>Wisteria frutescens ‘Tomuri’</strong>&lt;br&gt;‘Pink’&lt;br&gt;Madison Jasmine</td>
<td><strong>Vitis vinifera ‘Ruby Seedless’</strong>&lt;br&gt;Ruby Seedless Grape</td>
<td></td>
</tr>
</tbody>
</table>

**Zone 5**<br>Deciduous, Evergreen, Semi-Evergreen<br>5-9<br>1743 S. LA CIENEGA BLVD. LOS ANGELES, CA. 90035 T - 800.450.3494 www.greenscreen.com

**Zone 6**<br>Evergreen, Semi-Evergreen<br>6-9<br>3 OF 4

**Zone 7**<br>Deciduous, Evergreen, Semi-Evergreen<br>7-9
## Zone 8

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Recommended Name</th>
<th>Zone</th>
<th>Hardiness</th>
<th>Evergreen/Semi-Evergreen/Deciduous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinidia chinensis ‘Vincent’</td>
<td>Vincent Kiwi Vine (Female)</td>
<td>8-9</td>
<td>Deciduous</td>
<td></td>
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<tr>
<td>Antigonon leptopus</td>
<td>Mexican Coral Vine</td>
<td>8-11</td>
<td>Semi-Evergreen</td>
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<tr>
<td>Jasminum polyanthum</td>
<td>Pink Jasmine</td>
<td>8-10</td>
<td>Evergreen</td>
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<tr>
<td>Masciiagnia macroptera</td>
<td>Yellow Butterfly Vine</td>
<td>8-10</td>
<td>Evergreen</td>
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<tr>
<td>Trachelospermum asiaticum ‘Angyo’</td>
<td>Angyo Asian Jasmine</td>
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<tr>
<td>‘Ogon Nishiki’</td>
<td>Japanese Star Jasmine</td>
<td>8-11</td>
<td>Evergreen</td>
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<tr>
<td>Trachelospermum Jasminoides ‘Variegata’</td>
<td>Variegated Star Jasmine</td>
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<td>Evergreen</td>
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<tr>
<td>Macfadyena unguis-cati</td>
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<td>Pandorea jasminoides ‘Charisma’</td>
<td>Charisma Bower Vine</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
<td>‘Lady Di’</td>
<td>White Bower Vine</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
<td>Passiflora jamesonii ‘Coral Seas’</td>
<td>Coral Seas Passion Flower</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
<td>Passiflora x ‘Lavender Lady’</td>
<td>Lavender Lady Passion Flower</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
<td>Solanum jasminoides ‘Variegata’</td>
<td>Variegated Potato Vine</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
<td>Tecomaria capensis</td>
<td>Orange Cape Honeysuckle</td>
<td>9-11</td>
<td>Evergreen</td>
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</table>

## Zone 9

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Recommended Name</th>
<th>Zone</th>
<th>Hardiness</th>
<th>Evergreen/Semi-Evergreen/Deciduous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bougainvillea ‘Delta Dawn’</td>
<td>Delta Dawn Bougainvillea</td>
<td>9-11</td>
<td>Evergreen</td>
<td></td>
</tr>
<tr>
<td>Clytostoma callistegioides</td>
<td>Lavender Trumpet Vine</td>
<td>9-11</td>
<td>Evergreen</td>
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<tr>
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<td>Blue Dawn Morning Glory</td>
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## Zone 10

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APPENDIX B
BUILDING GREENING IN THE WORLD'S VEGETATION AND CLIMATE ZONES

The greening of building meets all the requirements for consideration as an important element in contemporary housing estate planning.

Main advantages:
- Occupies very little ground space but nevertheless has many uses.

Examples:
- Energy saving: Large amounts of energy and considerable sums of money can be saved by greening buildings with climbing plants, particularly in climatic zones where inner rooms are cooled at certain times (e.g., in the Mediterranean countries, Southern USA, Japan, Australia, etc.).
- Well-being: Improved ambient conditions, a better quality of life, easing the ecological burden – all these benefits are readily attainable by covering buildings with greenery.

CLIMBERS AT A GLANCE
1. This zone is characterized by its continental type climate of short, warm summers and long, severe winters. Evergreen climbing shrubs such as hydrangea are well-suited for the climate.

2. Precipitation is evenly distributed throughout the year. The summers are warm, the winters moderately cold — the climate typical of Central and Western Europe. Temperatures lower than −18°C (1°F) to −30°C (−22°F) are not uncommon in the north of the USA.

3. The deciduous forest zone is well-suited to a wide range of plants. Climbers, vines, and climbing roses are popular in this zone. The hardy Peoniflora species, Delphinium sp., and Narcissus sp. are popular in the company of plants representative of the colder zones.

4. Many plants that thrive in Mediterranean regions do well in the mild-winter regions of the deciduous forest zone.

5. Climbing roses combined with Clematis sp. and grape-wine shoots are popular in this zone.
MEDITERRANEAN HARDLEAF EVERGREEN ZONE WITH WINTER RAINFALL

This zone is found around the Mediterranean Sea, in California, on the Cape and in South Australia. It's characterized by hot, dry summers and mild, humid winters. Light frosts are exceptional. Many astringent climbers and wall shrubs flourish here in all their splendor. These include Bougainvillea and many Passiflora (Passiflora corinna, amethysta, multijuga, actinophyllum), Datisca cannabina, Vincetoxicum hirundinaria and many others. Many species grow satisfactorily in warm temperate climates, such as those in the coastal regions of New Zealand and other parts of the world. However, they require the humid heat of equatorial regions (e.g., Strophanthus macrophyllus).

TROPICAL TO WARM TEMperate FOREST

The hot, frost-free humid or variably humid climate supports lush vegetation consisting of a wide range of plants. Many of these are familiar to us Mediterranean gardens (such as Bougainvillea) grow well in this zone, including those that require considerable warmth such as Thunbergia grandiflora and many Passiflora (Passiflora corinna, amethysta, multijuga, actinophyllum). Datisca cannabina, Vincetoxicum hirundinaria and many others. Many species grow satisfactorily in warm temperate climates, such as those in the coastal regions of New Zealand and other parts of the world. However, they require the humid heat of equatorial regions (e.g., Strophanthus macrophyllus).

SAVANNAH AND DESERT SHRUB ZONES

Most of the climbers that are used in zone 4 will grow well in zone 5 when the microclimatic conditions are observed. Water management is satisfactory.

HOT DESERTS AND SEMI-DESERTS

Provided that an efficient watering system is available, buildings in these hot, dry regions can be greened to contribute significantly to a pleasant home environment. Combination with reliable desert plants (Kalospora, Tamarix, Cereus, etc.) is good practice because the resulting litter often dries and aids in the overall aesthetics of the area. Climbers and ramshackle plants from the gardens of the newly emerging Mediterranean hard-leaf zone such as Nertera coccinea, Podocarpus macrophylla or even Pyrrhogyne species will grow on buildings with considerable vigor when they are well tended and watered.

COLD-WINTER STEPPE, TEMPERATE SEMI-DESERT AND DESERT ZONES

The zone of opposites. Hot summers are followed by severe winters. The hardy plants listed under the preceding desert zone such as Clematis tangutica, alpina and iberica can be used here. Watering is always essential. The climbers Biscutis argenteus and composites are suitable for use as windbreaks.

HIGH ALPINE (I), TUNDRA AND POLAR DESERT REGIONS (I)

The short vegetation period makes it difficult for plants that want to climb. However, with careful attention paid to the microclimate (exposure, wind, altitude, topography), the climbers from the coniferous forest zone can have a chance of successing. Greening buildings with climbing plants in this vegetation zone is virtually impossible.
APPENDIX C
An experimental investigation of the effect of shading with plants for solar control of buildings

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Abstract

An experimental investigation was carried out to analyse the effect of using trees for solar control of buildings by shading. Several physical parameters were measured in two areas, on the same façade, of a building at the Agricultural University of Athens; high trees shaded one area, while the other was clear from any shadow. Comparisons were made for a hot summer period between the physical parameters measured in the shaded and the unshaded areas regarding the air and wall surface temperatures, the heat exchanges between the wall surface and the surrounding environment, the wind speed and the humidity of the air. The results showed that plants constitute an excellent passive system for solar control of buildings offering significant advantages over conventional artificial sunscreens.

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Keywords: Solar control; Passive cooling; Energy saving

1. Introduction

Summer thermal comfort in buildings is very important, especially in big cities, where the temperatures are becoming higher and higher due to the increased activities (e.g. traffic) and the lack of green. At the same time, there is a strong need of satisfactory thermal conditions, especially in working areas where people spend the most of their daytime. Today there is a tendency to use air conditioning systems to improve summer thermal comfort in buildings. Nevertheless, the air conditioning systems increase energy consumption, but they especially increase the peak in electricity power demand. The consideration of green spaces is an important constituent of city planning since plants improve aesthetically the surrounding spaces of buildings and building blocks and also decrease ambient air temperature.

According to Ca et al. [1] a nearby park can reduce the air temperature by up to 2°C in the surrounding area.

The application of plants around buildings and especially on the south façades, offer the possibility of reducing the undesirable effect of high solar radiation and thus reduce peak power consumption [2,3]. The applied plants can be deciduous, which means that in summer their foliage shade the building, while in winter when the leaves have fallen, plants let solar radiation to be freely absorbed by the building. This is a method of passive temperature control, which results in a less use of air conditioning systems and in a smoother energy load profile. The load profile is usually highly seasonal and daily and monthly load peaks may be four to five times the corresponding average consumption [4]. Consequently, the application of plants in buildings provides a great potential for energy savings, because apart from their aesthetic presence they are capable of reducing the electricity demand peaks.

In this paper, a study is presented on the influence of trees on the heat transfer between a building façade and the environment. An experiment was set up on a SE orientated façade of a building at the campus of the Agricultural University of Athens. One set of instruments was installed under the shade of trees and another on a clear part of the same façade. Comparisons were made between the physical parameters measured in the shaded and the unshaded areas regarding the air and wall temperatures, the heat transfer towards the wall, wind speed and the humidity of the air.

2. Materials and methods

For the experiment two sets of instruments were used; one at a shaded area by deciduous trees (area 1, see Fig. 1) and the other at an unshaded area (area 2, see Fig. 2). Areas 1
and 2, located on a SE orientated wall of a building in the campus of the Agricultural University of Athens (see Fig. 3). These areas covered a wall surface of about 1.5 m × 1.5 m, at a height of about 3 m above the soil surface and 7 m apart from each other. The wall were made of concrete of thickness of 20 cm. The outside wall surface was painted light yellow at both areas. Behind the walls of the two areas offices were located, where thermal conditions were similar. Because the wall construction at both areas was identical, it is considered that the optical and thermal properties of the inside and outside wall surface were the same.

Each set of instruments consisted of:

- a **pyranometer** measuring the solar irradiance on the wall at a vertical level (vertical wall level), which results from the direct solar radiation and from the diffuse solar radiation incident from the sky above;

- a **net radiometer** measuring the solar and the long wave radiation balance at a vertical level (vertical wall level), i.e., the net radiation balance in the spectrum between 0.2 and 100 μm;

- an **anemometer** measuring the wind velocity near the vertical wall surface at a distance of about 20 cm;

- a **heat flux meter** mounted on the surface of the wall measuring the incoming or outgoing flow;

- a **combined air temperature and air humidity meter** installed at a distance of about 15 cm from the wall surface;

- three copper-constantan thermocouples mounted on the wall surface measuring the wall surface temperature. These three thermocouples were under the ‘viewing’ area of the net radiometer.

All these instruments were connected to a data logger, where data is collected and the average of a 3 min period was stored as the mean value. These three readings were used so as to calculate the average wall surface temperature.

In order to compare net thermal energy gains in areas 1 and 2, the integrals of the values of net radiation ($N_1$ and $N_2$) and the values of thermal flux ($F_1$ and $F_2$) were calculated over 24 h as follows.

$$ N_j = \sum_{i=1}^{480} N_{ji} t $$

$$ F_j = \sum_{i=1}^{480} F_{ji} t $$

where $j = 1, 2$ (areas 1 and 2), $N_{ji}$, $F_{ji}$ the values of net radiation and thermal flux recorded every 3 min, respectively, $i = 1, 2, 3, \ldots, 480$ (480 being the number of the non-dimensional time units).
3 min periods over the day) and the 3 min period of time in seconds (t = 180 s).

3. Results and discussion

Comparisons of the physical parameters measured at the shaded and unshaded areas were made so as to analyse the influence of the presence of plants on the heat exchange between the wall surface and the environment. A hot 4-day period (from 7/8/1999 to 10/8/1999) was chosen to present intense thermal exchange phenomena.

By observing Fig. 4, the importance of shading the wall can be noticed. The tree leaves block the solar radiation and in the shaded area, the pyranometer measures the most of the time, diffuse irradiation. Peak values that can be seen in Figs. 4 and 5 on the curves of the shaded areas, during daytime, are caused from ‘windows’, i.e. small areas where the foliage does not cover the façade letting direct solar radiation to fall on the pyranometer or the net radiometer. As it can easily be seen on Fig. 4, the peak in the non-shaded area reaches almost 600 W/m² thought at the same time the corresponding value for the shaded area is under 100 W/m². Only by mid-day, the solar radiation on the shaded wall exceeds 100 W/m² and reaches 180 W/m², this is caused because the sun in very high in the horizon and the shade from the trees does not fall on the wall.

In Fig. 5, the net radiation on the wall can be seen for both areas 1 and 2. Net radiation can be interpreted as the radiative energy absorbed by the wall surface. The net radiation on the wall in area 2 is greater than in area 1 during most of the daytime. In Fig. 5 can also be seen that the net radiation during the night in the shaded area is larger (less negative) than the one in area 2. This can be explained
by the presence of the trees that act as barriers and block thermal radiation emitted by the wall surface.

During the daytime the air temperature in the shaded area is lower than the corresponding one in the unshaded area as seen in Fig. 6. This is in agreement with the findings of Parker [5] and can be explained as following. During daytime in the shaded area, the air temperature is higher than the wall surface temperature (compare Figs. 6 and 7), thus the air loses heat by convection to the wall surface. At normal climatic conditions, i.e., conditions without very extreme air temperatures and high wind velocities, the leaves of the plants manage to keep their own temperature lower than the surrounding air through transpiration, i.e., by evaporating great amounts of water [6,7].

Although direct temperature measurements of the tree leaves at the experimental site were not taken, the fact that the measured relative humidity in area 1 kept constantly higher than the one measured in area 2 (up to 7%), support the hypothesis that tree leaves during daytime had a lower temperature than that of the air. After converting relative humidity in absolute humidity (Fig. 8), it is clearly seen that the evaporated water from the trees caused an increase of

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**Fig. 5.** Net radiation in the shaded area (thin line) and in the unshaded area (thick line).

**Fig. 6.** Air temperature in the shaded area (thin line) and in the unshaded area (thick line).

**Fig. 7.** Wall surface temperature in the shaded area (thin line) and in the unshaded area (thick line).
absolute humidity of about 1–2 kg water per m³ dry air. Thus, the air between the wall and the trees in area 1 loses energy by convection during daytime to both the wall surface and the leaves of the trees and because its refresh rate is low, its equilibrium temperature becomes lower than in area 2 (Fig. 6).

The refresh rate of the air between the wall and the trees is expected to be lower than in area 2, because the trees ‘block’ the air movement. This hypothesis is supported by the measured lower values of air velocity in area 1 relative to area 2, as presented in Fig. 9.

It must be mentioned also that when a conventional sunscreen is used to shade a wall, its temperature during daytime usually becomes several degrees higher than the surrounding air and thus an additional thermal radiation load originating from the sunscreen would burden the wall. In the case of using plants there will be no such consequence. The described effects of plants reveal the significant difference of the use of plants as solar control tools relative to the conventional sunscreens.

In Fig. 7, the effect of tree shading on the wall surface temperature is demonstrated. During daytime the solar radiation absorbed by the wall surface in area 2 increases its temperature several degrees above that in area 1, while during night-time both temperatures come close together. It is seen in Fig. 7 that the minimum wall surface temperatures (of all days) in the shaded area 1 are slightly higher than the corresponding ones in the unshaded area 2 are. This could be explained by the fact that the trees inhibit the radiative cooling of the wall during the night. However this effect, as can be seen in Fig. 7, may not be considered as very important.

The analysis of thermal flux (Fig. 10) leads to similar results as previously. During daytime more thermal energy flows into the wall in area 2 than in area 1 due to direct exposure to the sun and the resulting higher surface wall temperature in area 2. The energy absorbed by the wall surface will advance to inner wall layers and will reach the inner wall surface, which in turn will result in elevation of its temperature.

Taking into consideration that the sense of thermal comfort in a room is the outcome of a combined effect of radiated energy from the walls and the air temperature, the room behind the trees would provide better thermal comfort than the unshaded one. In addition, when an air conditioning system is used to cool the room air, more energy will be consumed by the system in the unshaded room, because the room air will gain heat by convection from the walls which in case they have high thermal inertia will remain at high temperature for long time. When an air conditioning system
is used, the sense of thermal comfort in the unshaded room would be lower than the shaded one because of the increased radiation emitted by the warmer walls of the unshaded room.

Table 1 shows the daily energy integrals of net radiation and thermal flux in areas 1 and 2 as they have been calculated by Eq. (1). It can be seen in Table 1 that the radiative energy and heat flow gains in area 1 are much lower than in area 2, however as the air temperature increases during the presented 4-day period (see Fig. 6), both ratios $N_2/N_1$ and $F_2/F_1$ tend to decrease. This could be attributed to the fact that as the air temperature increases during this hot 4-day period, the wall temperature increases too and the cooling effect of the plants tends to decrease. That is, during this 4-day period as the air temperature increases, both measured values of net radiation and thermal flux in the shaded area increase at a higher rate than in the unshaded area which results in a decrease of both ratios $N_2/N_1$ and $F_2/F_1$. This means that during periods of prolonged hot air conditions the cooling effect of the trees tends to decrease, however both ratios $N_2/N_1$ and $F_2/F_1$ remain higher than 2.

4. Conclusions

The application of plants to shading buildings proved to be an efficient passive method of solar control. The radiative and thermal loads in the shaded area proved to be significantly lower relative to the unshaded one. In addition, the evaporative cooling effect of the plants resulted in lower air temperature around the shaded wall. Apart from the energy savings that can be achieved from the use of trees as shading devices, one should also consider the overall benefits for the environment which will result from the reduced emissions due to the energy saving and the aesthetic influence of trees to the urban landscape.

References

De ruwe Perlite grondstof is een anorganisch glazig gesteente, dat tijdens vulkanische uitbarstingen is ontstaan. Perlite-gesteente omvat tal van kleine celletjes, waarin water is opgesloten. Perlite-gesteente wordt eerst gezuiverd en vervolgens tot een soort grof zand gemalen en dan in speciale ovens blootgesteld aan zeer hoge temperaturen. Het water gaat over in dampvorm, waardoor Perlite expandeert.

Uit de gesmolten gesteente ontstaat een witte, glasachtige, korrelige massa met een laag volumegewicht. Perlite-korrels hebben een ruig oppervlak en in de korrel bevinden zich vele capillairen. Het gevolg van deze structuur is dat de geëxpandeerde Perlite-korrel een betrekkelijk grote hoeveelheid water kan vasthouden. Een gedeelte van dit water bevindt zich op de ruige buitenzijde en is direct beschikbaar voor de plant. Een ander gedeelte dringt in de capillairen en blijft daar ter beschikking van de plant totdat deze het nodig heeft.

**Voordelen**

- Anorganisch, onvergankelijk, inert en steriel
- Vrijwel neutraal, pH tussen 6,5 en 7,5
- Vrij van ziektekiemen, zaden en insecten
- Niet toxisch, onbrandbaar
- Stimuleert wortelzetting en krachtige groei
- Voorkomt dichtslaan van de grond
- Uitstekende isolerende werking
- Verkleint temperatuurschommelingen tot een minimum
- Kan voor hergebruik worden gesteriliseerd door stoom, vlam of chemicalien

### Chemische analyse

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<tr>
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### Eigenschappen

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### Gradatie

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### Toepassingen

Agra Perlite wordt in de tuinbouw voor diverse doeleinden gebruikt: in potgrond, capillaire bewatering (eb- en vloed systemen), substraatteelt, lichtreflectie, het zaaien, persblokken/potten, bewortelen van stekken en microvermeerdering.

In potgrond wordt Agra Perlite geheel of ten dele gebruikt in plaats van zand of steengruis waarbij het de beluchting, de waterdoorlatendheid en ook het wateropnamevermogen bevordert. Agra Perlite kan worden gebruikt om de kant en klaar gemengde potgrond, bestaande uit leem of turf, luchtiger maken.

Gebruik bij capillarie watervoorziening tenminste een dikte van 25 mm. Agra Perlite in plaats van zand of fijn grind in bijvoorbeeld bakken of tafels. Gebruik de Agra Perlite voor hydrocultuursystemen ten behoeve van een maximum drainage en luchtdoorlaatbaarheid.

Bij de substraatteelt van diverse groentegewassen onder glas in steenwolpotten of steenwolmatten, kan Agra Perlite worden aangebracht om zodoende de wortels voldoende lucht te geven en ertoe bij te dragen schimmelaantastingen te verminderen.

Agra Perlite brengt meer licht in de kassen om de jonge planten gedwongen op te kweken. Perlite is vulkanisch glas, daardoor wordt het zonlicht zo voortreffelijk gereflecteerd.

Agra Perlite doet zaden sneller ontkiemen, verbetert de groei van het zaaisel en biedt minder weerstand bij het uitkiemen of oppotten. De gelijkmatige middelgrote korrels voorkomen het te snel uitdrogen van de oppervlakte en reduceren het bewateringsprobleem.
Het zaaien met Agra Perlite

Agra Perlite doet zaden sneller ontkiemmen, verbetert de groei van het zaaisel en biedt minder weerstand bij het uittrekken van de planten. Zaai op een goed vochtig mengsel van gelijke volumedelen Agra Perlite en hoogveenturfmolm of voeg 1 volumedeel Agra Perlite toe aan 2 volumedelen goed gemengde potgrond.

Er kan ook alleen Agra Perlite worden gebruikt, vooropgesteld dat het zo goed als mogelijk wordt vochtig gehouden door capillaire vochtaanvoer of door, bij tussenpozen werkende verneveling.

Struoi fijne hoogveenturfmolm over de zaden en dek af met een glasplaat of plastic, zodat het vocht wordt vastgehouden. Agra Perlite 2 en 3 is geschikt voor algemeen gebruik bij zaai van grote en middelgrote zaden, al of niet gemengd met potgrond. Agra Perlite 2 wordt aanbevolen voor fijne zaden en voor commerciële productie. De gelijkmatige middelgrote korrels voorkomen het te snel uitdrogen van de oppervlakte en reduceren het bewateringsprobleem.

Beworteling van stekken

Agra Perlite versnelt de beworteling, reduceert het risico van verstikkingsproblemen, veroorzaakt een optimale balans van lucht, licht en water.


Gebruik voor harde stekken en tere planten een mengsel van 4 volumedelen en 1 volumedeel hoogveenturfmolm.


Persblokken of potten

Onze kwaliteit Agra Perlite 1 is de juiste gradatie om gemengd met fijne turf of potgrond tot potjes of blokjes te persen.

Meng ongeveer 15 volume procenten Agra Perlite 1 in de fijne turf of potgrond voor een betere samenstelling en een betere werking. De luchtigheid wordt bevorderd waardoor een betere beworteling wordt bereikt. Zou het blokje te droog worden, dan helpt Agra Perlite 1 bij het snel opnemen van water.

Bedek de blokjes met een dikke laag van 2 - 4 mm Agra Perlite 1. Het gebruik van Agra Perlite als afdekking van het blokje heeft de volgende voordelen:
- Beschermt het zaad tegen overmatig zonlicht, waardoor het ontkiemt wordt bevorderd.
- Houdt het water vast en voorkomt uitdroging van de zaden en het oppervlak van het blokje.
- Reflecteert het licht naar de onderzijde van de groeiende zaailing en bevordert snellere groei.

Microvermeerdering

Agra Perlite 1 is om zijn steriliteit en om zijn unieke bewortelingseigenschap ideaal voor de kritische momenten bij het opvoeden van plantjes op groeiende microvermeerderingstechnieken, zoals doekcultuur en weefselkweek.

Agra Perlite 1 gemengd met AgarGel of puur gebruikt met een voedingsoplossing is een bij uitstek geschikt bewortelingsmedium voor plantjes.

Ongemende Agra Perlite of half gemengd met hoogveenturfmolm en voedingsstoffen, is een ideaal groeibestek omdat het de beworteling bevordert en verplanten vergemakkelijkt.

Agra Perlite 1 en 2 is ook een ideaal inert groeimedium om de effecten te demonstreren van voedingsstoffenvariaties en toxische chemicalien.
**Potgrond**

In potgrond wordt Agra Perlite geheel of ten dele gebruikt in plaats van zand of steengruis waarbij het de beluchting, de waterdoorlatendheid en ook het wateropnamevermogen bevordert.

Agra Perlite kan worden gebruikt om de kant-en-klare gemengde potgrond bestaande uit leem of turf luchtiger te maken.

Meng 3 of 4 volumedelen hoogveenturfmolm met 1 volumedeel Agra Perlite plus kalk en voedingstoffen om een “potgrond zonder aarde” te verkrijgen.

Meng gelijke volumedelen van gesteriliseerde leem, hoogveenturfmolm en Agra Perlite. Voeg hier kalk en voedingstoffen aan toe om een op leem gebaseerde potgrond te verkrijgen.

Als alternatief is een mengsel van 1: 2 te gebruiken. Meng zorgvuldig en geef voldoende water na het planten. Voeg voedingsstoffen toe al naar gelang de behoefte.

**Capillaire bewatering**

Gebruik bij capillaire watervoorziening tenminste een dikte van 25 mm Agra Perlite in plaats van zand of fijn grind in bijvoorbeeld bakken of tafels.

Gebruik bij elektrische verwarming een mengsel van half zand en half Agra Perlite om oververhitting van de kabels te voorkomen.

Gebruik de Agra Perlite voor hydrocultuursystemen ten behoeve van een maximum drainage en luchtdoorlatendheid. Tevens wordt Agra Perlite 3 geadviseerd voor drainage onder steenwolblokken.

**Eb- en vloedsystemen**

Bij het eb- en vloedsysteem is het onontbeerlijk in de grondmengsels Agra Perlite 3 te gebruiken. De doorluchting is dan min of meer verzekerd, terwijl ook de waterhuishouding in het mengsel verbetert. Gebruik ten minste 25% Agra Perlite.

**Substraatteelt**

Bij de teelt van diverse groentegewassen onder glas in steenwolpotten of op steenwolmatten, verdient het aanbeveling onder de steenwol een laagje Agra Perlite 3 te gebruiken om zodoende de wortels voldoende lucht te geven. In de praktijk noemt men dit “het stempen met Agra Perlite” van de steenwolpotten. Agra Perlite kan ertoe bijdragen schimmeltransformeringen te verminderen.

**Lichtreflectie**

Vooral in de sombere wintermaanden is er vaak gebrek aan voldoende licht in de kassen om de jonge planten gedrongen op te kweken. Agra Perlite brengt meer licht in de kas, indien u de perskluiten, zaai- en steenwol, en dergelijke bedekt met een laagje Agra Perlite.

Agra Perlite is vulkanisch glas, daardoor wordt het zonlicht zo goed gereflecteerd.


Ook bij de teelt van sla, andijvie en dergelijke in de volle grond in de kas biedt Agra Perlite meer licht in de donkere dagen. Agra Perlite is een natuurproduct en kan na de teelt zonder enig bezwaar door de grond worden gefreesd.