Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

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

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

Personal information	
Name	Aria Hassanzadeh
Student number	5443008

Studio		
Name / Theme	Building technology graduation studio – Façades and products	
Main mentor	Alessandra Luna Navarro	Architectural facades & products
Second mentor	Marc Ottelé	Materials and environment
Argumentation of choice of the studio	Facades are an important part of the built environment. A facade has a major influence on, among other things, building performance, comfort and sustainability. Improving the facade is therefore essential for the development of the built environment. This research focuses on living wall systems. Despite the proven benefits in regard to thermal, acoustical and psychological performance, there is still a lot of room for improvement when it comes to the maintenance and effectiveness of the irrigation system. This improvement is important for the realization of a green and healthy built environment.	

Graduation project	
Title of the graduation project	**Living green wall systems: A strategy to limit maintenance**
Goal	
Location:	The Netherlands
The posed problem,	The maintenance of a living wall system is seen as one of the biggest constraints for their installation. The literature review has shown that a large part of the maintenance is related to the irrigation system, such as replacing filters, unclogging the drainage, pest and disease management, weed control, fertilization, remedying leaks and removing invasive root growth into pipework. In addition to maintenance of the irrigation system, general maintenance is also necessary such as pruning, panel adjustment and panel replacement and plant replacement. The need for maintenance is often determined conservatively, namely through observation

	and experience. As a result, proper maintenance is not carried out. It would be more effective if certain factors were monitored, such as the quality of the plants, the quality of the material and the quality of the irrigation system. In this case, it would be better to determine which maintenance is necessary and when it is necessary. Despite the fact that maintenance is a major constraint, there is little literature and information available about the maintenance of living walls. This makes it difficult to compare findings from different literature. The information in the literature regarding solutions is even more limited. Apart from a number of manufacturers and researchers who are developing smart irrigation systems, there is almost no information available about this. We can say that this is a research gap with regard to maintenance of living wall systems. These maintenance issues also apply to the vertical meadow system. The water consumption of the system is monitored including the recycled water. But the question is what happens between the moment the water leaves the water tank and the moment the used water comes back into the water tank. In other words, how is the water distributed over the living wall and how much water actually reaches each plant. This is something that is not yet monitored but can be crucial for the health of the plants, as it can anticipate when a plant is getting too much or too little water. So the problem statement for the graduation research is that it is difficult to adequately anticipate the need for maintenance of living walls. This is because the quality of the plants and/or the effectiveness of the irrigation system is not monitored. If it were monitored how much water actually reaches each plant, it would be easier to estimate where too much or too little water ends up, which could lead to unnecessary maintenance.
research questions and	What is the best strategy for monitoring the water distribution of the irrigation system on a

	living green wall system that ultimately leads to more effective maintenance?
design assignment in which these result.	The research goal is to improve the effectiveness of the irrigation system by providing insight into how much water reaches each plant. For example, by mapping out how the water from the water pipes reaches the plants. When it can be made clear how much water each plant receives and whether this is an adequate amount for that one plant, maintenance can be limited. The ideal scenario is that the effect can be measured by, for example, looking at the grow time, energy use, frequency of pruning, water use and maintenance intensity. However, it is not expected that this effect can already be measured within the time frame of this thesis. That is why the research will focus purely on monitoring the water distribution of the irrigation system to the plants. Based on the literature search and discussions with vertical meadow, it is assumed that this can help to increase the effectiveness of the irrigation system and therefore limit maintenance. The end product delivered with this research will be an overview of the water distribution in the living wall system of vertical meadow. An optimal scenario is that the method of monitoring used for this is made applicable to more systems and that guidelines can be drawn up for an effective irrigation system. If the amount of water reaches each plant is monitored, so that it can be ensured that each plant receives an optimal amount of water, hypoxic stress can be prevented. In addition, the irrigation system can be used more effectively, pruning and cutting will be limited and plants need to be replaced less quickly. It can be seen below that the maintenance that is most frequently mentioned as a problem with a living wall can be limited with this.
Process	
Method description	

Various research methods will be used to answer the sub-questions. The table below provides an overview of the research methods that are applied to each sub-question and what information is attempted to be collected with them.

QUESTION	AIM	METHOD
1. Which systems exist that can be used to monitor the water distribution in a living wall?	Find different methods to experiment with when monitoring.	Interviews Desk research
2. What are the parameters that determine how much water the monitored plants need?	To know when a plant gets too much or too little water.	Desk research
3. What is the effect of different types of irrigation systems on the maintenance of a living wall system?	Finding a connection between the irrigation system and results.	Interviews
4. How does monitoring the water distribution affect maintenance?	To determine how maintenance can be limited by monitoring the water distribution.	Experimenting
5. How can the irrigation system be optimized so that each plant receives sufficient water?	To limit water consumption and maintenance.	Experimenting
6. How can the strategy, which is tested on the vertical meadow system, be made applicable to more systems?	To ensure that monitoring the water distribution has a positive effect on multiple living wall systems.	Experimenting Monitoring

Interviews

The literature research has shown that there is relatively limited information available about the maintenance of living green wall systems. The information that can be obtained from literature is often not specific enough to determine the exact cause of the maintenance. From the literature review it can be concluded that there is a research gap regarding this topic. To fill this research gap as well as possible, interviews will be held with manufacturers of living green wall systems. These are companies that maintain green facades and know a lot about this based on their experience. The aim of these interviews is to gain insight into the types of activities, their frequency, intensity, impact and costs.

Monitoring

Monitoring is all about measuring and observing certain factors. During this research, the water distribution is monitored. So we look at where the water from the irrigation system ends up in the living wall system. The method and technique used for this is still unknown. This becomes clear after answering sub-question 1. These would, for example, be techniques that emerged from chapter 2.5, such as thermal imaging. The location is also still unknown, this will be discussed in consultation with the mentor and the parties involved (vertical meadow).

Desk research

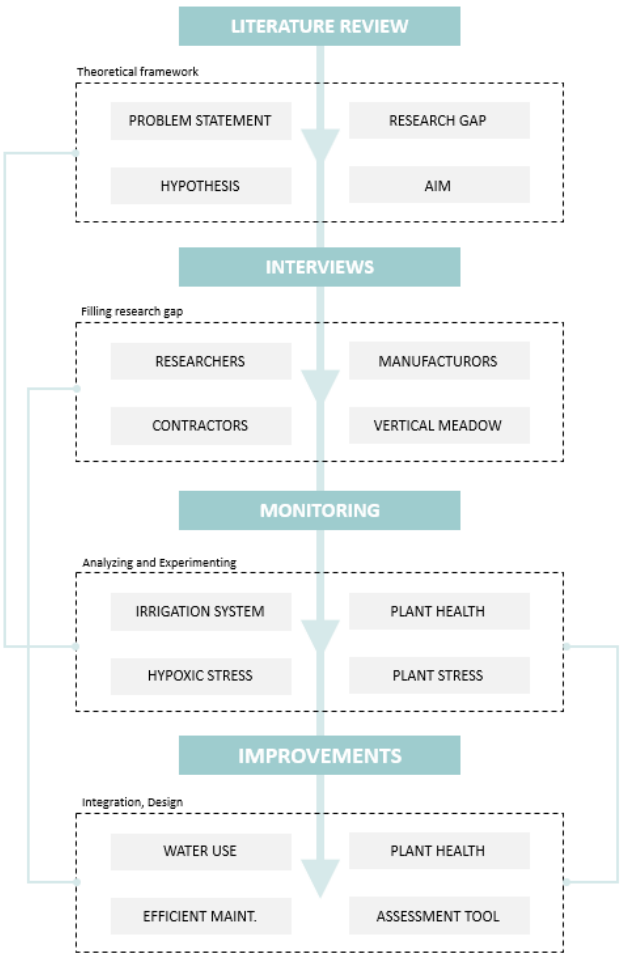
During the desk research I collect existing information, for example from literature, studies or other available data. During the research I will come up with new findings and results that will create a new research gap and new questions. As a result, I will have to take a step back to the literature or other available information to supplement this information before continuing the research.

Experimenting

Experimenting and monitoring are closely related. While monitoring involves measuring and observing certain factors, experimentation attempts to influence these factors. The aim is to find out how the results of monitoring can be positively influenced. When the water distribution is monitored, it is interesting, for example, to influence the water distribution through experimentation in such a way that each plant receives sufficient water. In addition, various ways of mapping the water distribution will be tried, to see which technique is best suited for this. This can also be seen as experimentation.

Research process

The research is an iterative process. During the research, findings are made based on the interviews, experiments, literature research and analyses. Based on this, the research objective and the research question are refined during the research. Figure 21 shows roughly how the order of the research will be. The basis of the research is a literature review. This forms a starting point for determining the objective and problem statement. It is important to determine what the research gap is during the literature review. thereafter, an attempt is made to fill this gap as much as possible by means of interviews. In this phase it will be clear with which techniques the water distribution of the irrigation system will be monitored. If the results are not satisfactory, they will be analysed and another attempt will be made at monitoring. If the analyses show that too much information is still missing, a step will be taken back to the literature. If the monitoring yields good results, these will be further tested in order to arrive at a final recommendation.



Literature and general practical preference

Fadli, F., Zaina, S., Bahrami, P. (2019). *Smart biofacades; An innovative living construction technology.*

Grazuleviciute-Vilenske, I., Daugelaite, A., Viliunas, G. (2022). *Classification of biophilic buildings as sustainable environments.*

Gunawardena, K.C., Steemers, K. (2020). *Urban living walls: reporting on maintenance challenges from a review of European installations.*

Haggag, M.A. (2010). *The use of green walls in sustainable urban context: with reference to Dubai, UAE.*

Joye, Y., van den Berg, A. (2011). *Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research.*

Manso, M., Castro-Gomes, J.P. (2015). *Green wall systems: A review of their characteristics.*

Mendonca, P. (2017). *Advantages and constraints of living green façade systems.*

Murphy, M. (2006). *Sick building syndrome and the problem of uncertainty*. Durham, NC: Duke University Press.

Ottelé, M., Perini, K., Fraaij, A.L.A., Haas, E.M., Raiteri,R. (2011). *Comparative life cycle analysis for green facades and living wall systems.*

Özyavuz, M., Madrigal, J.P., Arisoy, N., Akten, M. (2013). *Advances in landscape architecture.*

Pérez-Urrestarazu, L., Egea, G., Franco-Salas, A., Fernández-Canero, R. (2013). *Irrigation systems evaluation for living walls.*

Pérez-Urrestarazu, L., Urrestarazu, M. (2018). *Vertical greening systems: Irrigation and maintenance.*

Perini, K., Rosasco, P. (2013). *Cost-benefit analysis for green facades and living wall systems.*

Radic, M., Dodig, M.B., Auer, T. (2019). *Green facades and living walls – A Review establishing the classification of construction types and mapping the benefits.*

Rakhshandehroo, M., Najd, M.D., Yusof, M.J.M. (2015). *Green Façade (Vertical greening): Benefits and Threats.*

Samudro, H., Samudro, G., Mangkoedihardjo, S. (2022). *Prevention of indoor air pollution through design and construction certification: A review of the sick building syndrome conditions.*

Schemel, S., Simunich, J., Luebkeman, C., Ozinsky, A., McCullough, R., Bushnell, L. (2019). *2050 Scenarios.* Arup London.

Sheweka, S., Magdy, N. (2011). *The living wall as an approach for a healthy urban environment.*

Sheweka, S.M., Mohamed, N.M. (2012). *Green facades as a new sustainable approach towards climate change.*

Vertical meadow. (n.d.). *221115 vertical meadow cladding.*

Wilson, E. (1984). *Biophilia*. Cambridge, MA: Harvard university press.

Yuan, X., Laakso, K., Davis, C.D., Guzmán, J.A., Meng, Q., Sanchez-Azofeifa, A. (2020). *Monitoring the water stress of an indoor living wall system using the ''triangle method''.*

Reflection

This graduation plan helps to achieve the goal of this research step by step. Despite the fact that there is relatively little literature available on the subject, an attempt has been made to extract as much information as possible from it. Nevertheless, the research gap is large, which means that a lot of information and knowledge is missing to show in detail what the problem is. This means that additional research is needed in the form of interviews and desk research after this P2 report. The interviews and additional desk research allows me to collect targeted information to narrow the research gap and formulate an even more concrete problem. I would have preferred to be able to describe in this report exactly what I am going to monitor, with what devices, how I am going to monitor and where I am going to monitor. But since there are no official measurement techniques for monitoring the water distribution in a living wall system, this needs to be investigated in more depth. That makes sense, because this is the research gap I want to solve. Despite the fact that there are many uncertainties and a lot of

information is still missing, I think we have succeeded in setting up a stable research methodology. I expect that this research methodology will lead me to be able to achieve the goal by simply trying. The research will mainly be based on testing things and failing, which will give me new insights and information. This makes the research an iterative process. This means that during the research I come back to the problem statement and objective in order to sharpen it or to improve it after the process.

In short, there are many uncertainties and a lot of information is missing, which means that the research gap is large. But at the same time I expect that I can get far by filling the research gap as much as possible with interviews with people who have experience in the maintenance of living wall systems and then do a lot of testing to see what works and what doesn't. A logical consequence of this is that the problem statement and research objective will be further refined during the research.

Scientific

This problem statement touches on various themes in the context of building technology. This problem statement revolves around sustainability, technology and facade design. As described in chapter 2.1, as a society we are becoming increasingly aware of the essential role of nature in our environment. For example, in chapter 2.3 it is described what the contribution of a living wall can be in the built environment. Nevertheless, a living wall system is relatively rare in the built environment compared to more traditional facade cladding such as masonry. An important reason for this is the required maintenance and attention for living wall systems as described in chapter 2.4. If a way is found with this research in which the effectiveness of the irrigation system can be increased, a step can be taken in the right direction to limit maintenance. Because the effectiveness of the irrigation system influences the quality of the plants and therefore the maintenance. With this research, a large research gap can also be filled that concerns the maintenance of living wall systems. This in turn can form an important basis for follow-up research.

Societal

When the aforementioned maintenance problems of a living wall system can be reduced, it will become more attractive to use it more often in the built environment. This helps to restore the link between people and nature. Where hard materials are taking over the built environment, nature will now reclaim our living environment. This can even lead to the expansion of cities without this having to be at the expense of nature. Because where nature reserves are sacrificed for the expansion of cities, the sacrificed nature returns to the built environment. This is done in the form of parks, trees, water and now also in the form of green buildings or green facades.