LIVING WALL SYSTEM:
As a strategy to mitigate the Urban Heat Island effect in Damascus

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P5 presentation
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2nd mentor Dr. Ir. M. Ottele’

Board of Examiners Dr. Arch. R. Cavallo

TU Delft
BK Bouwkunde

Why ? Problem statement

Urbanization

Why ? Problem statement

Air pollution

+

Urbanization

Vegetation degradation

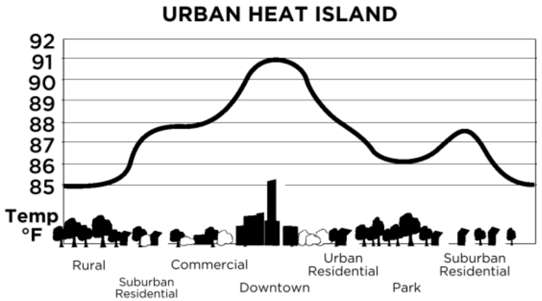
Why ? Problem statement

Urbanization

Air pollution

+

Vegetation degradation

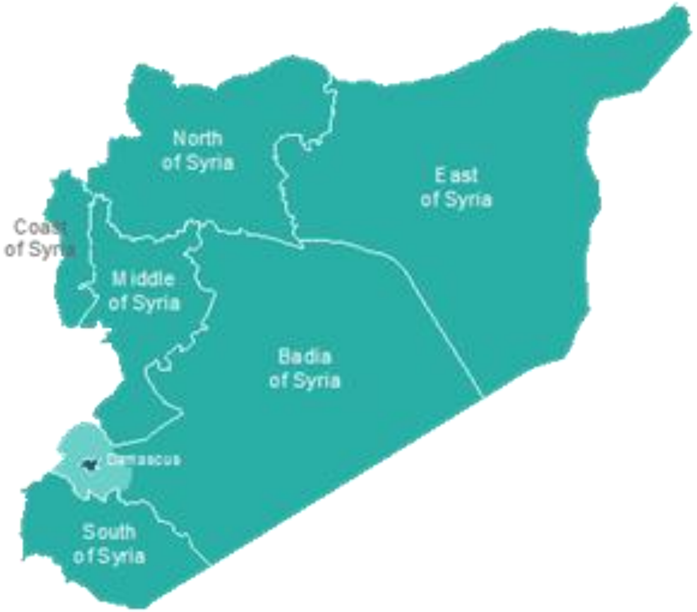


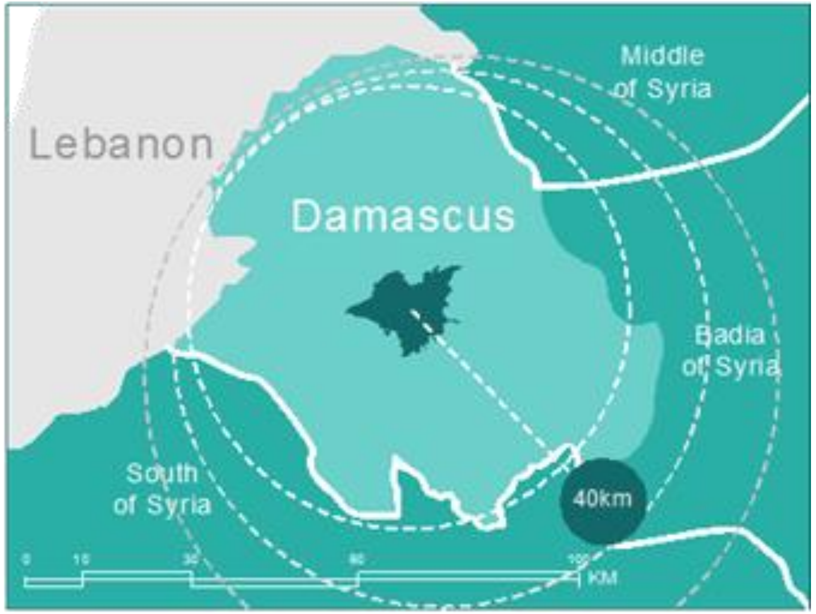
Human Health

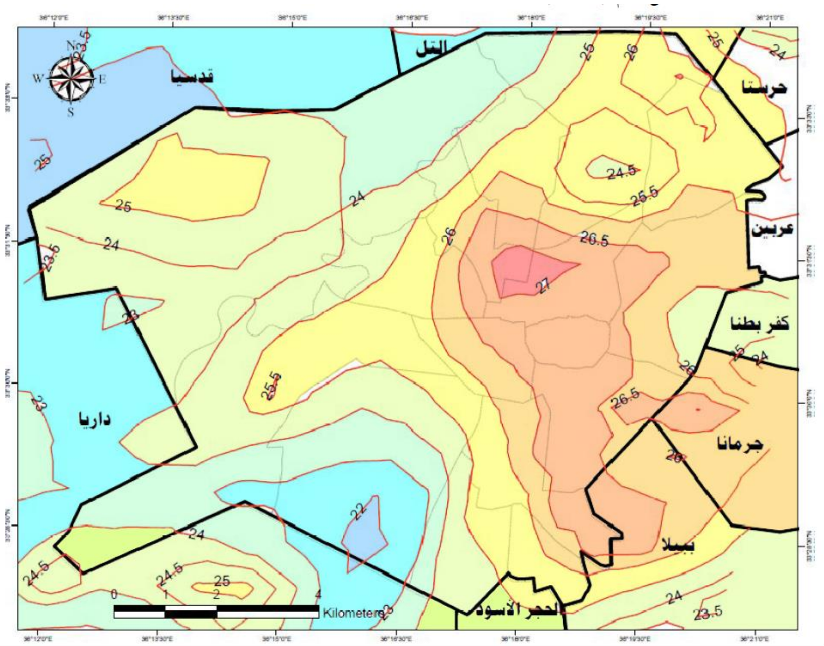
Energy

Air Quality

Why ? Problem statement







UHI in summer night

The intensity of UHI in Damascus is greater than most American and Turkish cities. It is even higher than the UHI effect in Riyad

(Al-Bakheet, 2017)

Why ? Problem statement

Implementation is limited

Due to different factors such as the **complexity, technical difficulties , feasibility** ..etc.

The efficiency of LWS in mitigating the UHI

Has not been widely studied

Increase vegetated spaces

+

High-density city

=

VGS
Living Wall System
(LWS)

Research question

*“How to design a **Living Wall System** that can be integrated into the built environment Of **Damascus** and how efficient is the proposed design as an **Urban Heat Island mitigation strategy**? “*

Research objective & sub objectives/ questions

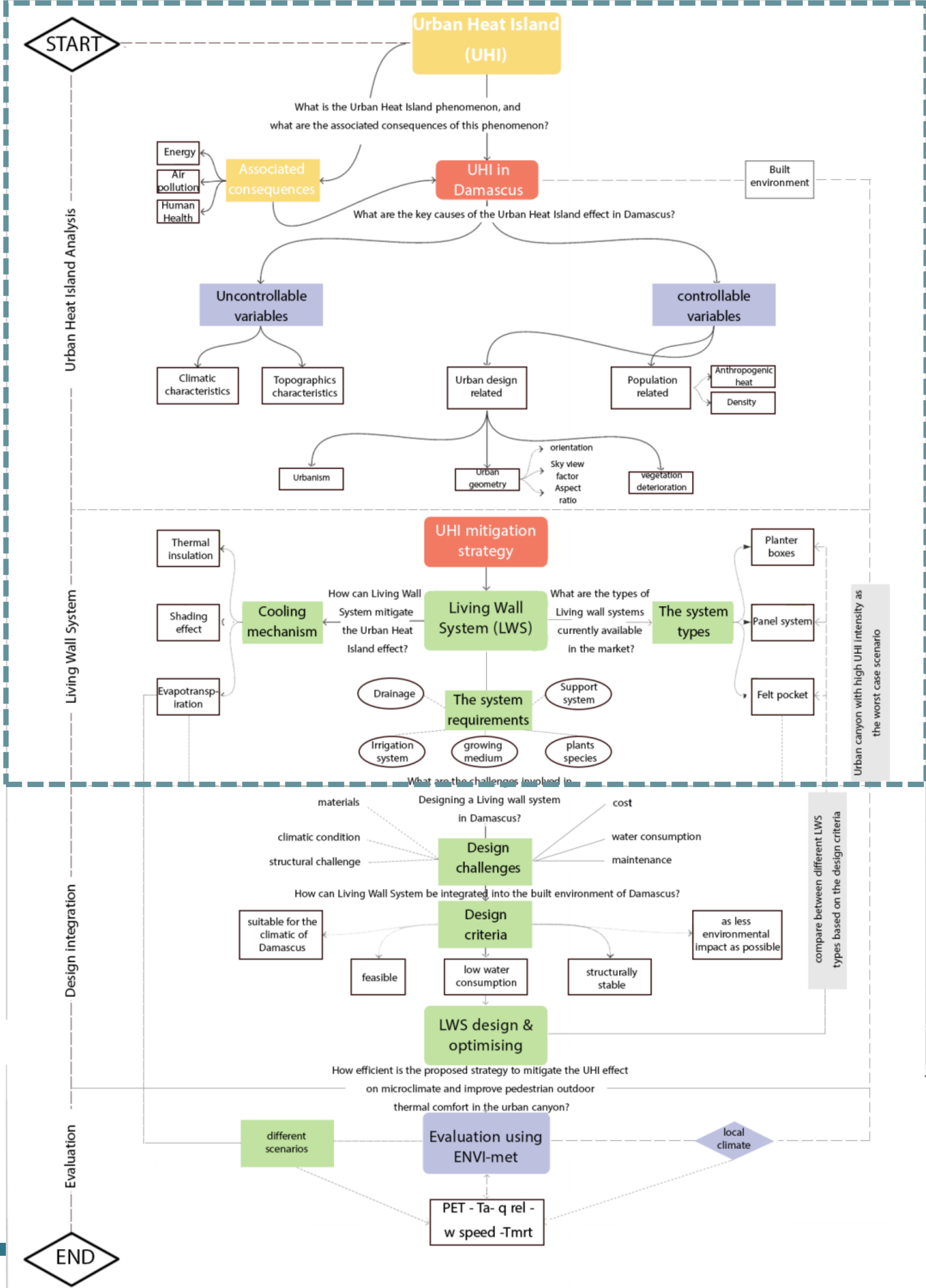
Main objective

Design a Living Wall system that can be integrated into the built environment of Damascus and evaluate the efficiency of the proposed design as an Urban Heat Island mitigation strategy.

Sub objectives	Sub questions	method	deliverables
To analyze the Urban Heat Island phenomenon and its associated consequences.	What is the Urban Heat Island phenomenon, and what are the associated consequences of this phenomenon?	Theoretical research, analysis and case studies evaluation	Definition of the Urban Heat Island phenomenon and its associated consequences
To define the key causes of the Urban Heat Island effect in Damascus.	What are the key causes of the Urban Heat Island effect in Damascus?		The key causes of Urban Heat Island in Damascus
To learn about the Living Wall System's cooling mechanism on the local climate.	How can Living Wall System mitigate the Urban Heat Island effect?		Learning about the Living Wall System's cooling mechanism
To learn about the Living Wall System currently available in the market and analyze the system requirements.	What are the types of Living wall systems currently available in the market?		Comparison of the different Living Wall Systems currently available and analysis the system requirements
To determine the challenges involved in designing Living Wall System in Damascus.	What are the challenges involved in Designing a Living wall system in Damascus?	Designing	Definition of the challenges involved in designing LWS in Damascus and design main criteria based on the challenges
To design a Living Wall System suitable for Damascus's context and meets the designing Criteria.	How can Living Wall System be integrated into the built environment of Damascus?		design of a Living Wall system that meet the design criteria
To evaluate the efficiency of the proposed strategy in mitigating the urban heat island effect and improving pedestrian outdoor thermal comfort on microclimate in the urban canyon.	How efficient is the proposed strategy to mitigate the UHI effect on microclimate and improve pedestrian outdoor thermal comfort in the urban canyon?	Evaluation	Evaluation of the efficiency of the proposed strategy on micro climate scale

Research methodology

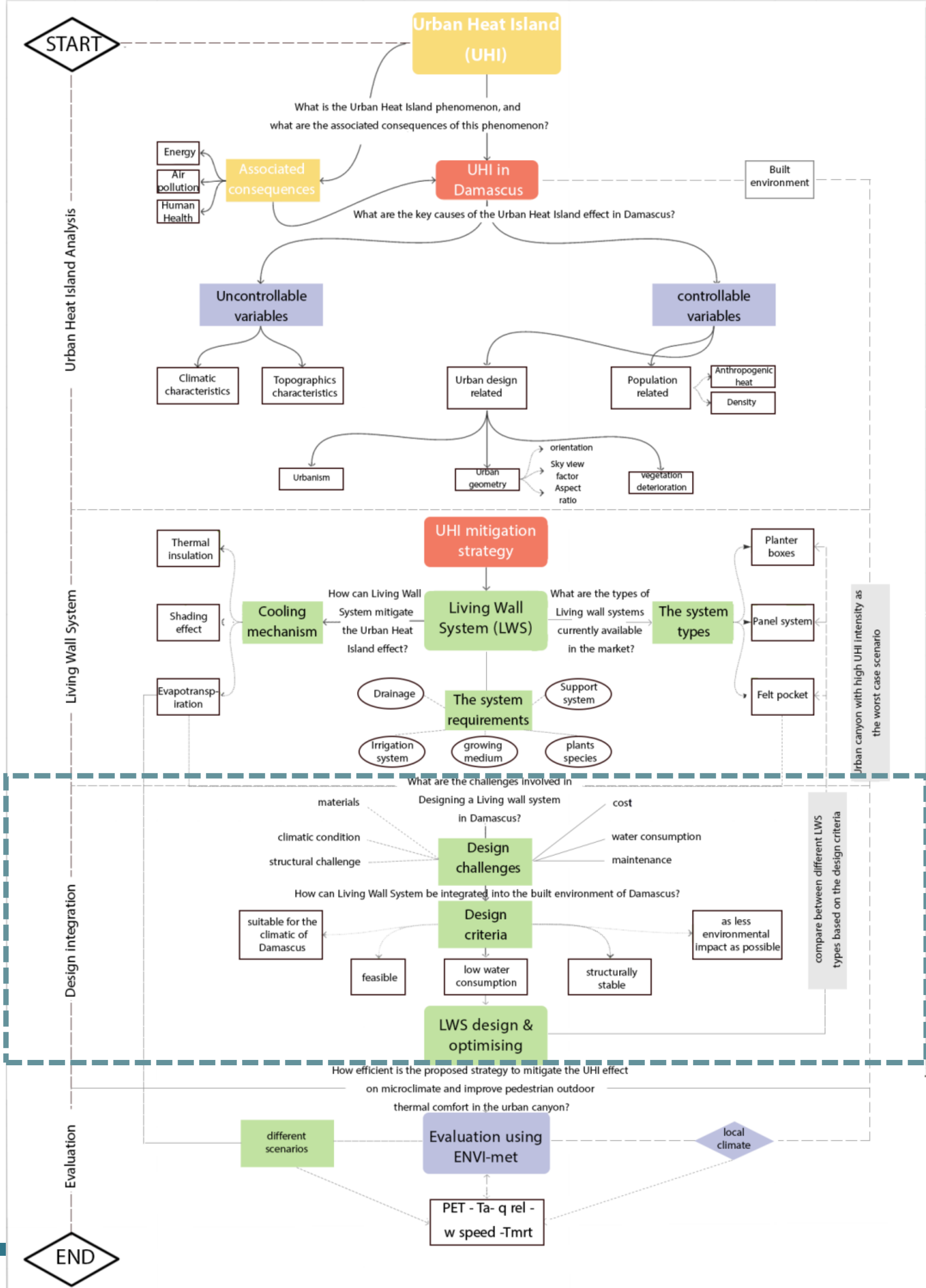
Literature review



Research methodology

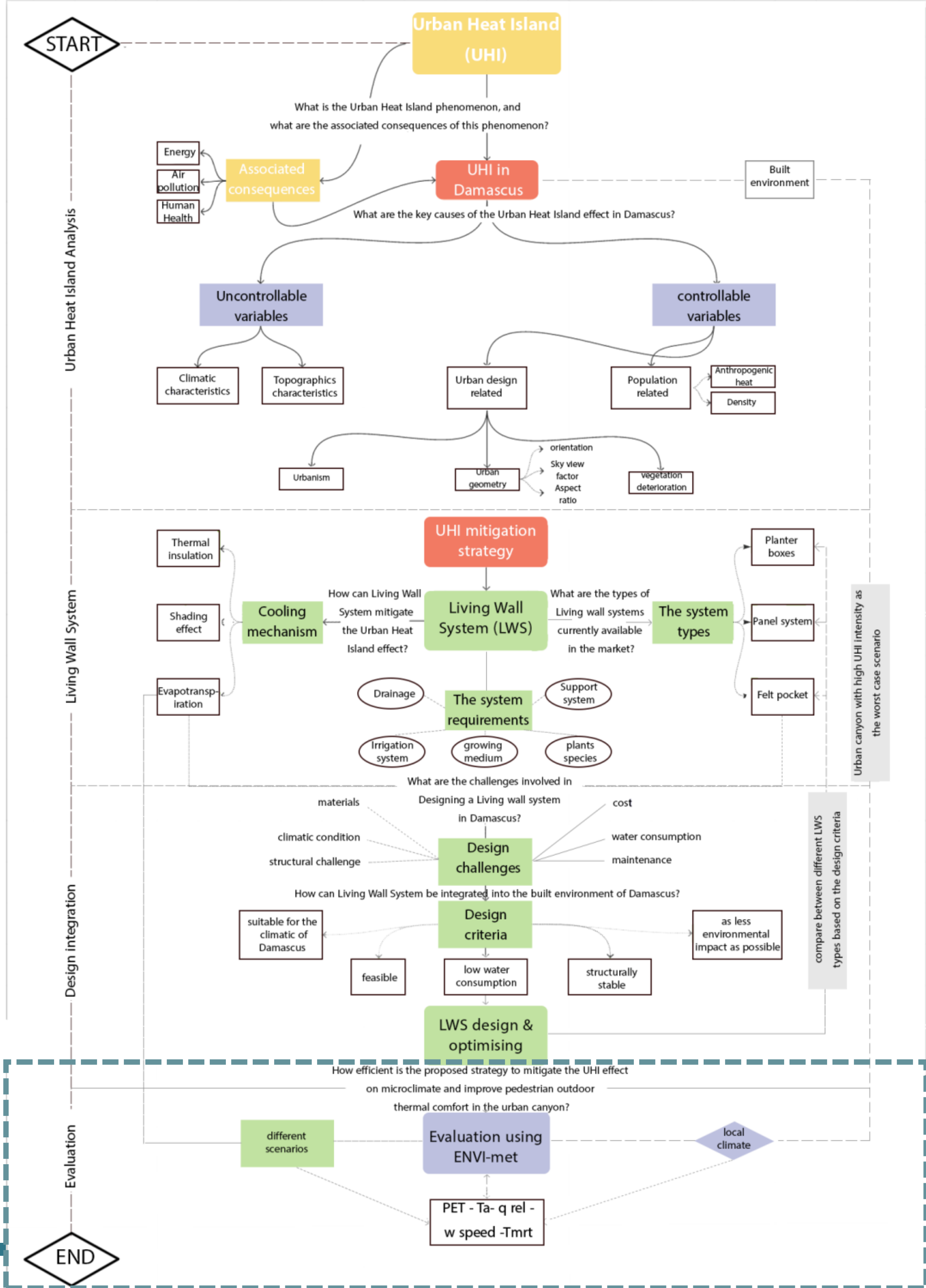
Literature review

Design & optimising



Research methodology

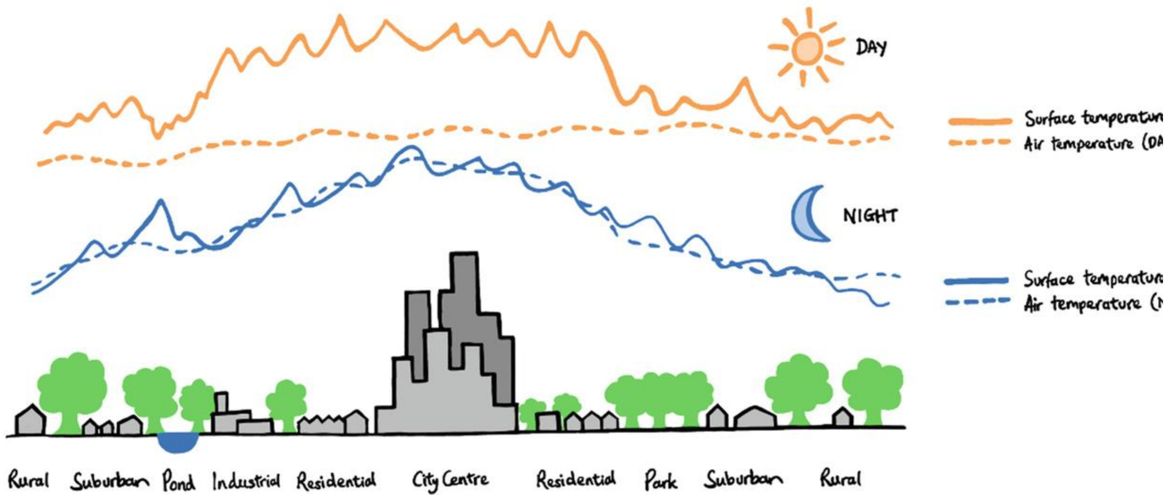
Literature review → Design & optimising → Evaluation



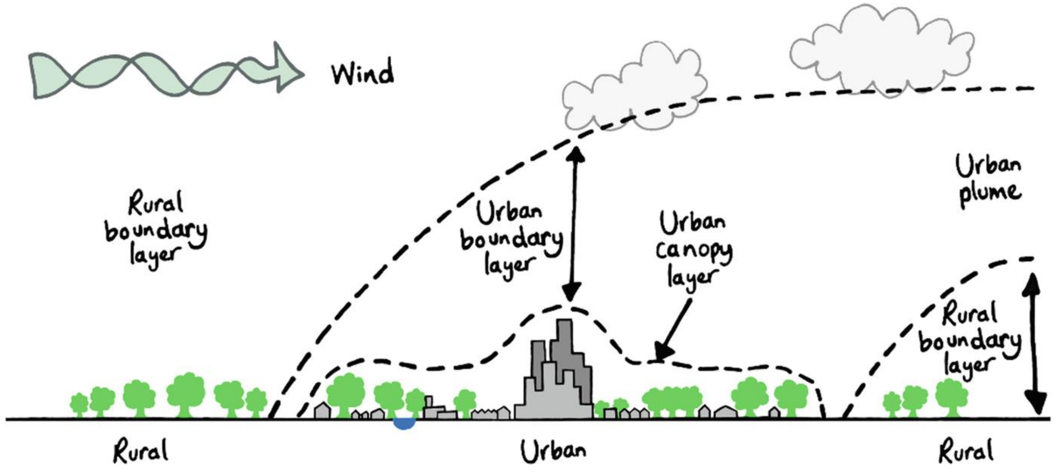
Literature Review

Phase 1

Urban Heat Island – UHI



Two types of heat island: the surface heat island
the atmosphere heat island

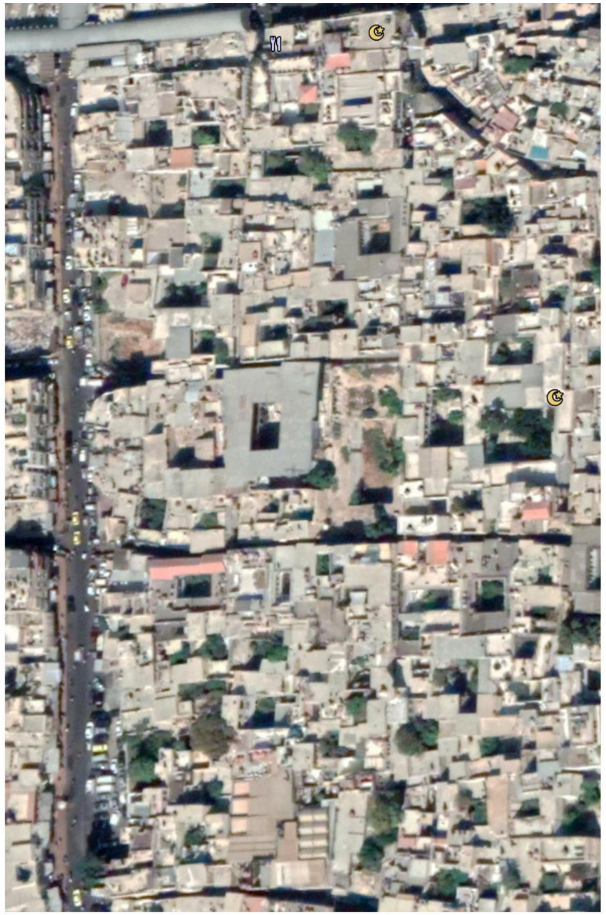


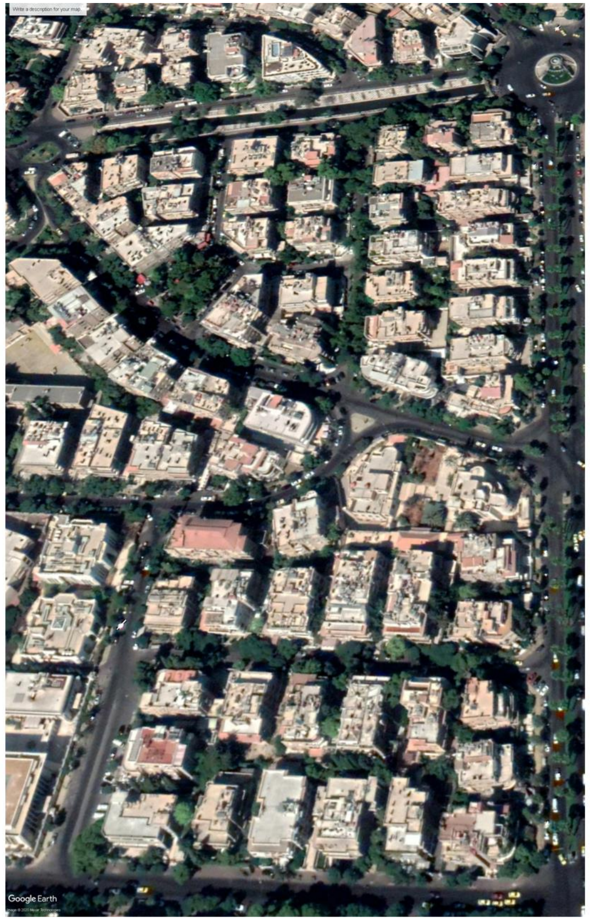
Atmospheric heat island is also classified into layers:

- Urban Canopy layer (UCL)
- Urban Boundary Layer (UBL)

(Gorse et al., 2019)

Damascus



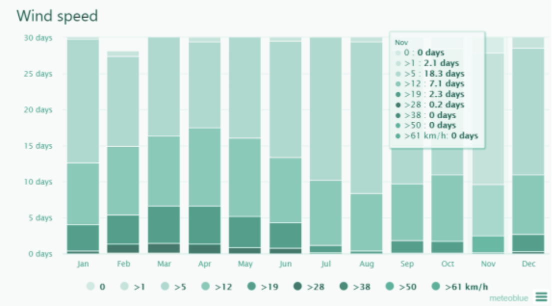


Urban environment of Damascus , from left to right , Old city, modern city , informal settlements

Urban Heat Island in Damascus- Key causes -

Key causes of Urban Heat Island in Damascus

Urban Heat Island in Damascus- Key causes -



Climatic Characteristics

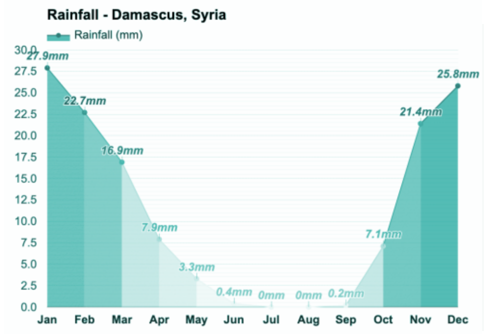
Population related

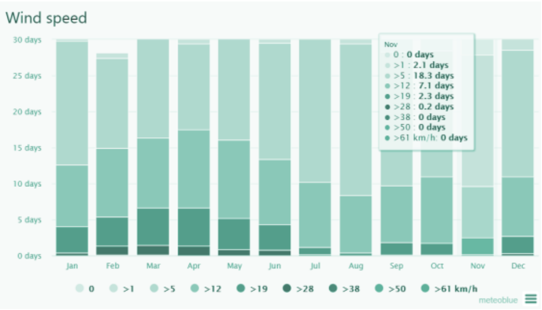
Topographic Characteristics

Urban Design & structure related

(meteoblue,2020)

Urban Heat Island in Damascus- Key causes -





Climatic Characteristics

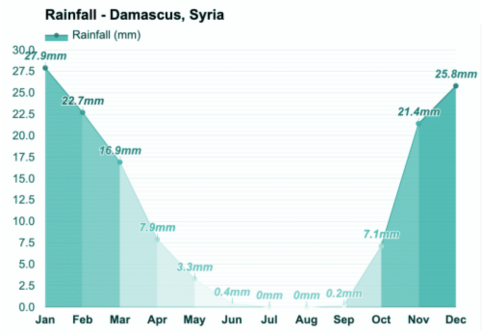
Population related

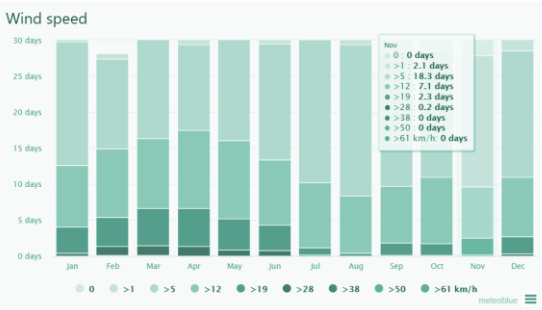
Topographic Characteristics

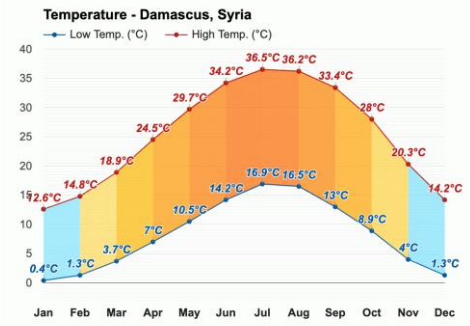
Urban Design & structure related

(weather atlas, n.d.)

Urban Heat Island in Damascus- Key causes -







(weather atlas, n.d.)

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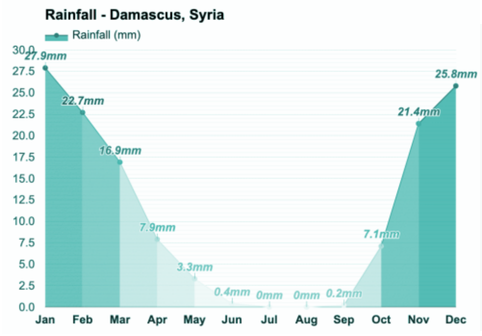
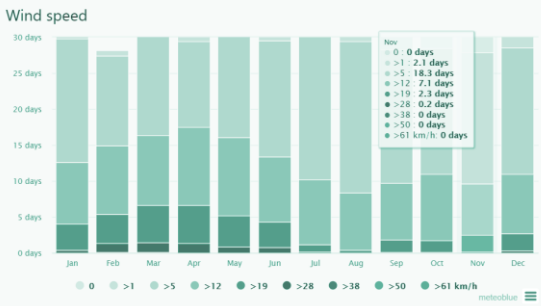
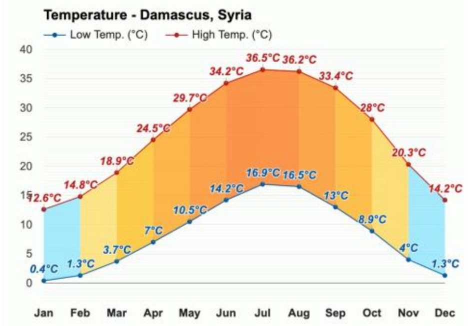
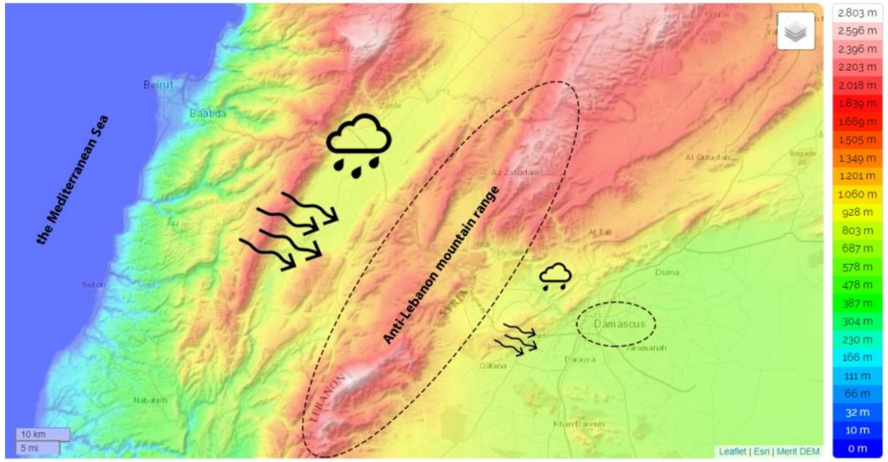




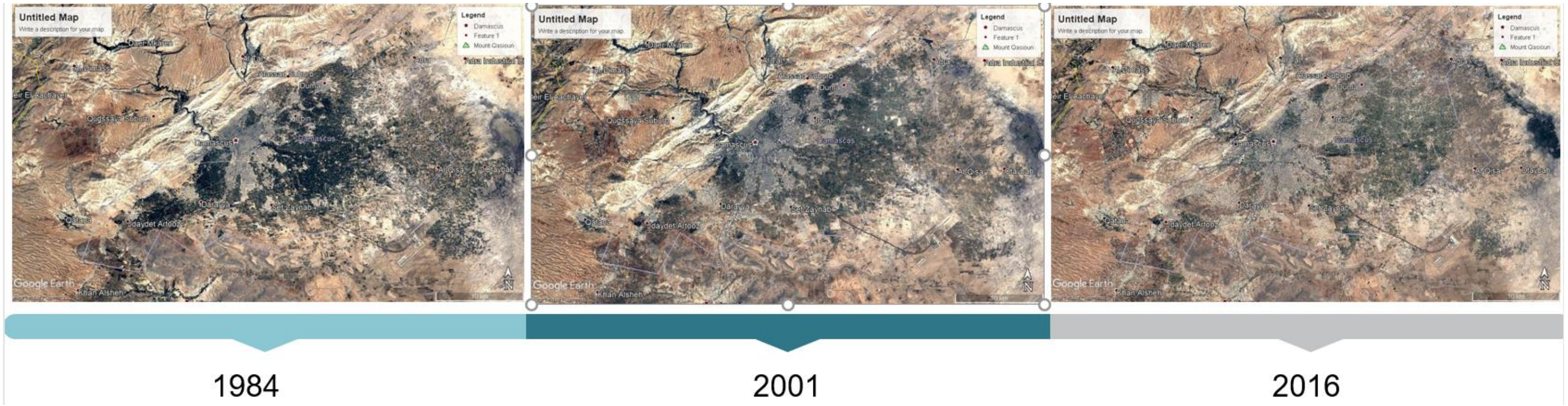




Damascus, 2277 دمشق, Syrië (33.51307 36.30958)

(topographic-map.com, n.d.)

Urban Heat Island in Damascus- Key causes -



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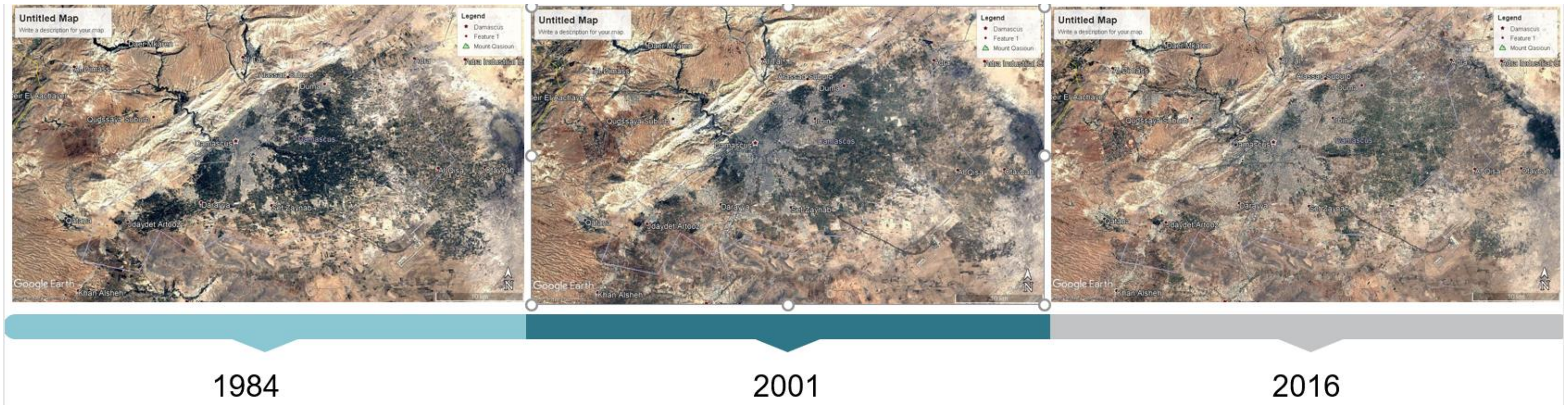
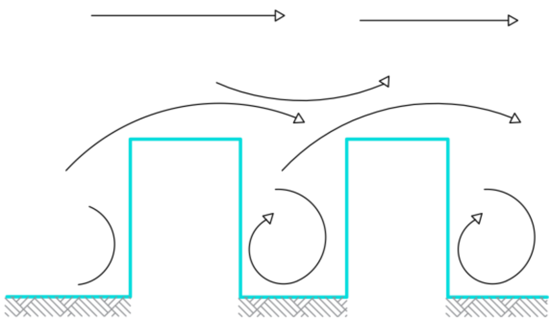
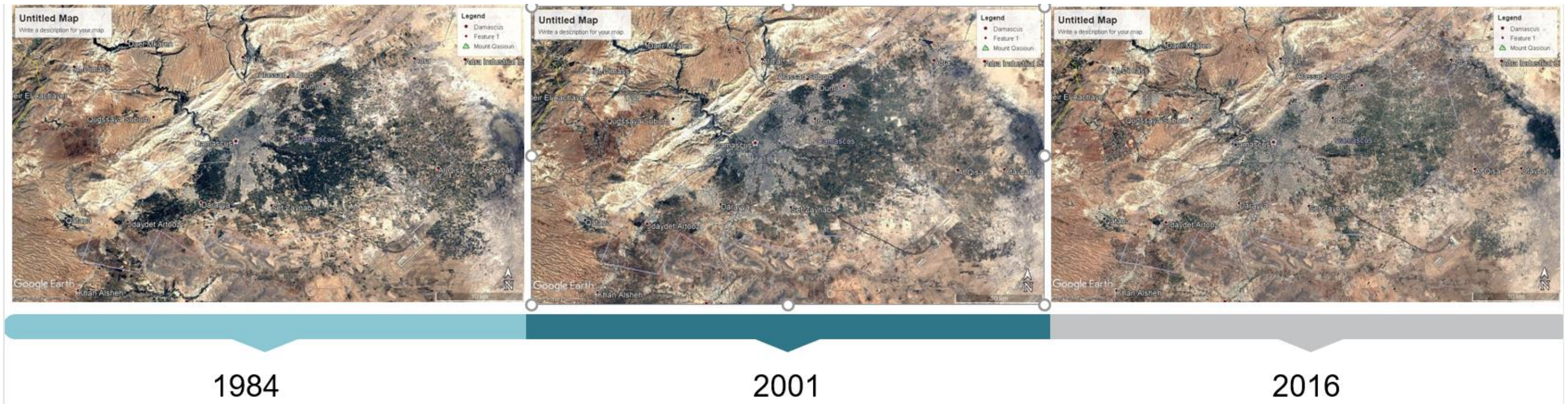


(Pinterest, 2018)

Urban Heat Island in Damascus- Key causes -





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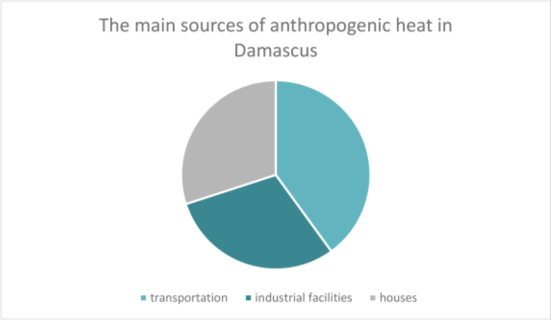
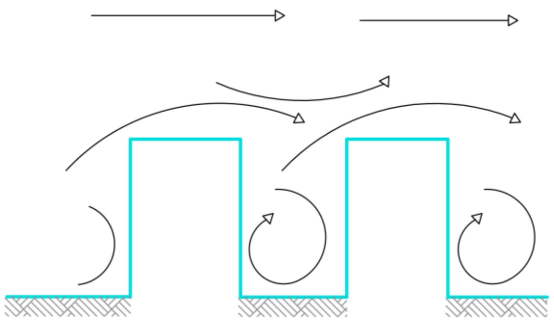
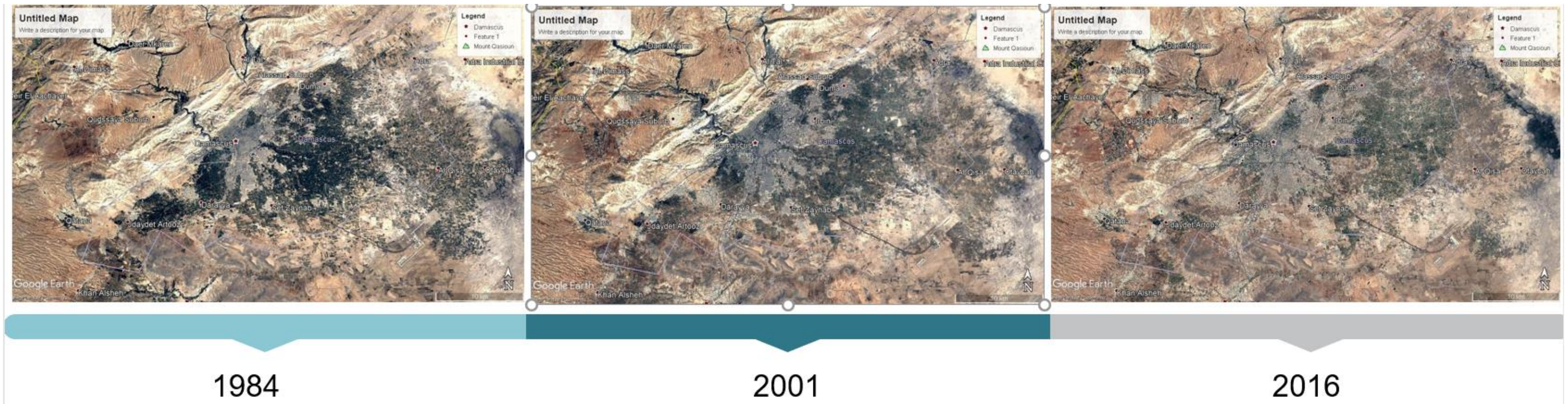
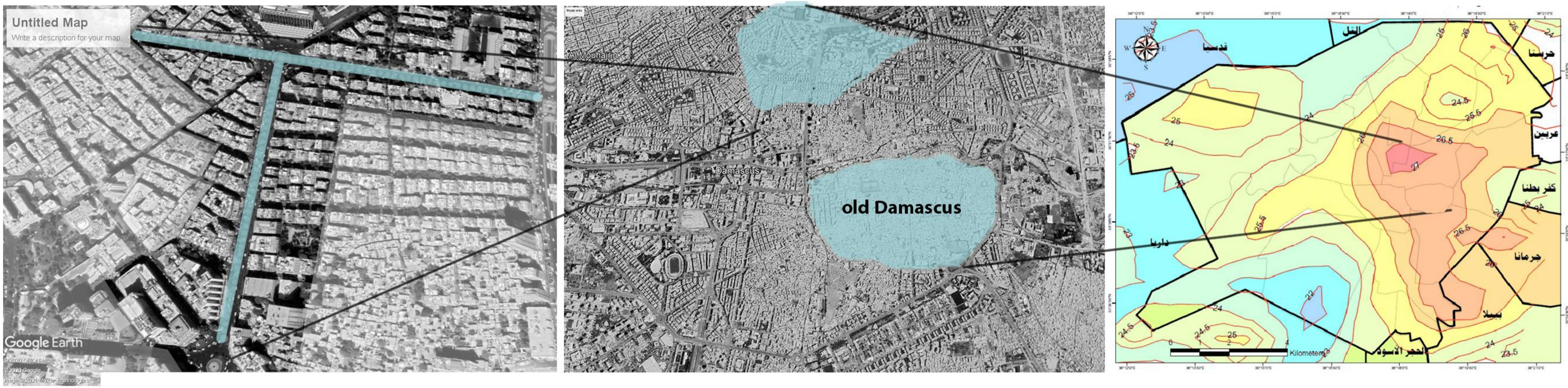






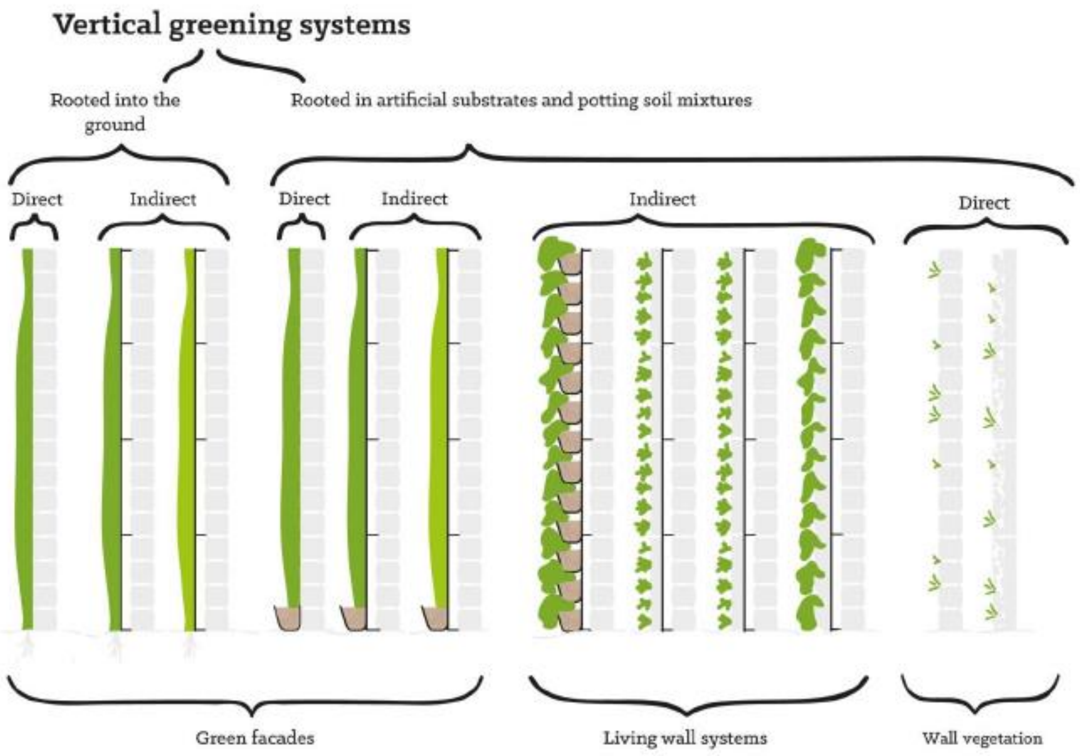
Urban Heat Island – Damascus



(Al-Bakheet, 2017)

Living Wall System as mitigation strategy

Living Wall System as a cooling strategy



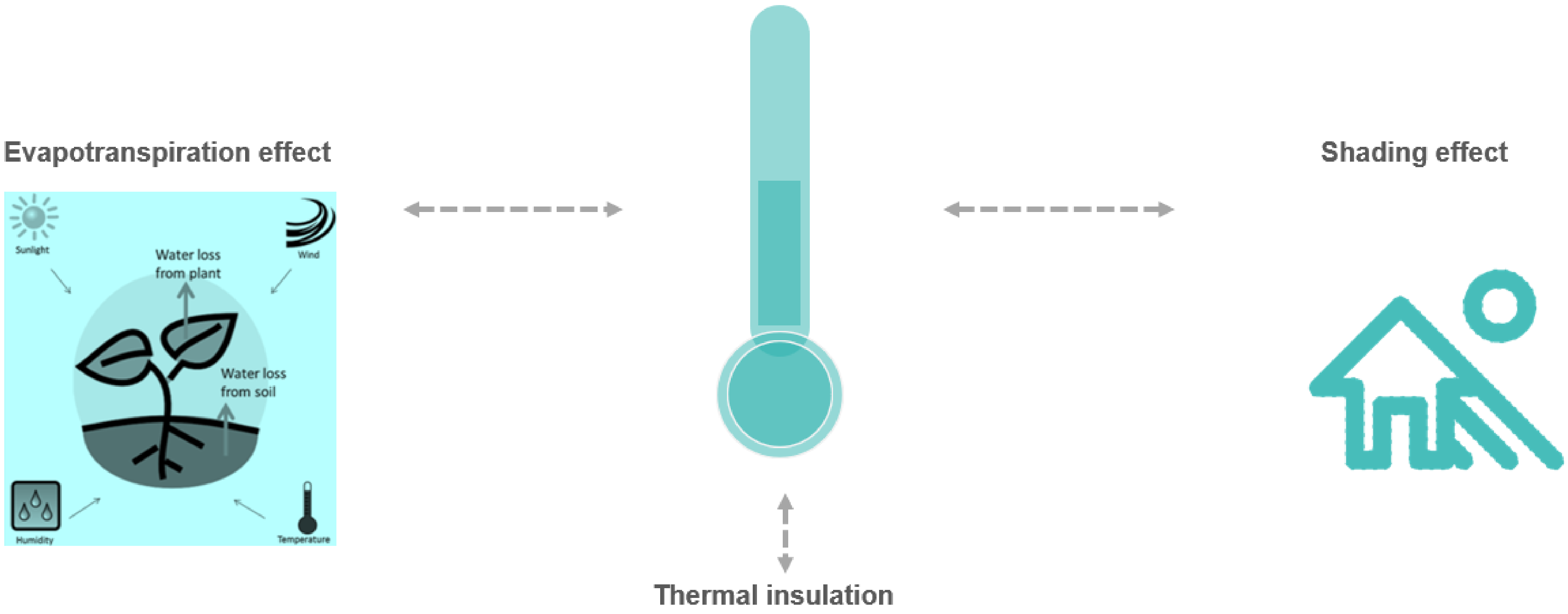
Vertical Greenery System

Vertical green type		Rooted into the ground			Rooted in artificial substrates and potting soil mixtures							
type		**Green façade**						**Living wall system**				V
direct or indirect		direct	indirect	indirect	direct	indirect	indirect	indirect	indirect	indirect	indirect	d
Effects	Can be optimized for modular desing (Y/N)	1	2	3	4	5	6	7	8	9	10	
Reduce the urban heat island effect	N	+	+	+	+	+	+	++	++	++	++	
External shading	Y	+	+	+	+	+	+	++	++	++	++	
Create a microclimate	N	+	+	+	+	+	+	+	+	+	+	
Improve insulation properties	Y	-	-	-	-	-	-	+	+	+	+	
Improving air quality	Y	+	+	+	+	+	+	++	++	++	++	
Provide sound insulation	Y	+	+	+	+	+	+	++	++	++	++	
Increase biodiversity	Y	+	+	+	+	+	+	+	+	+	+	
Aestetical effects	N	+	+	+	+	+	+	+	++	++	++	
Social and psychological benefits	N	+	+	+	+	+	+	+	++	++	++	

Comparison between Vertical Greenery System

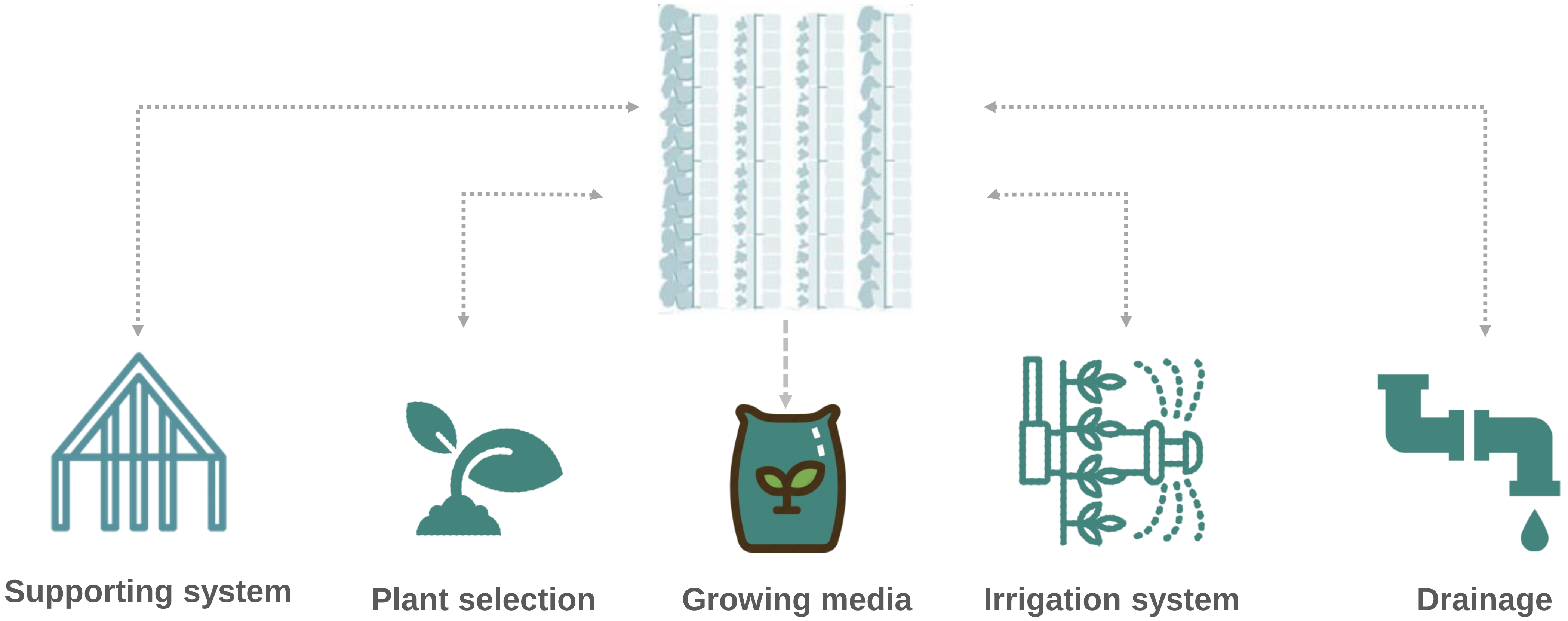
(Wegemans,2016)

Living Wall System as a cooling strategy

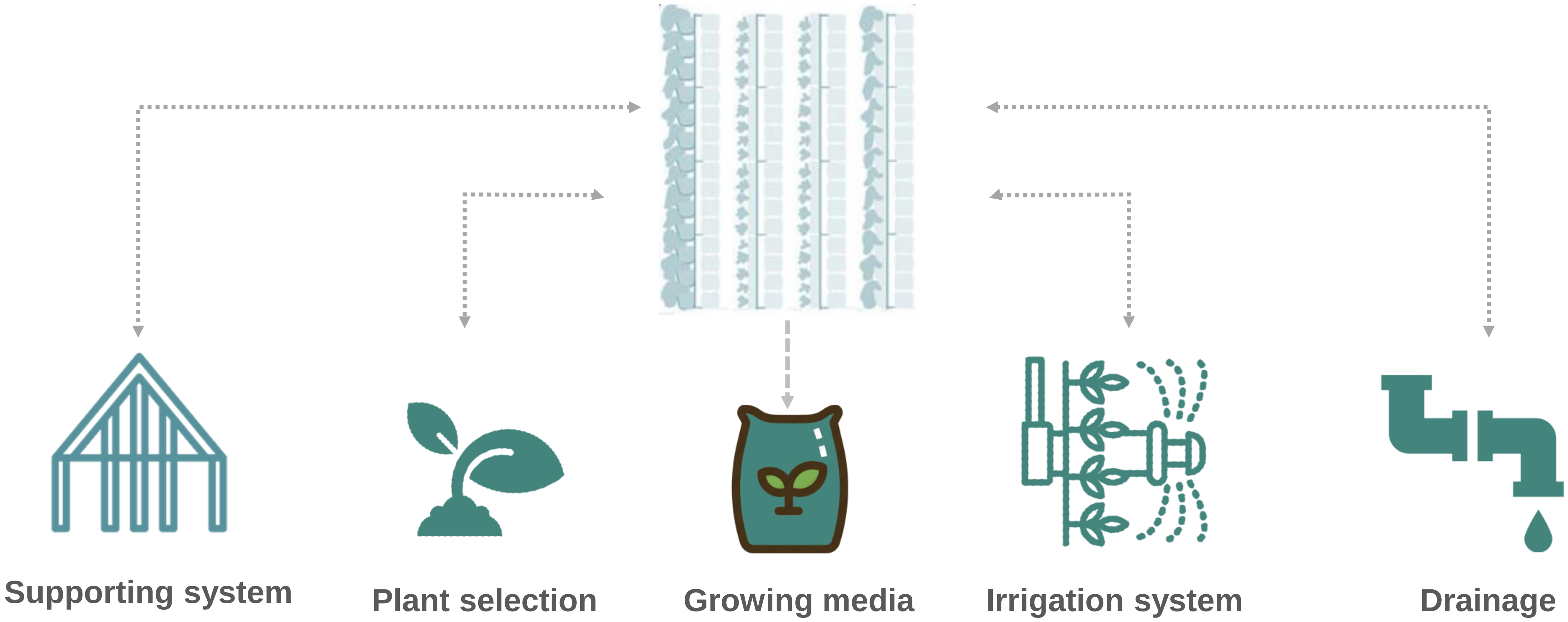


Cooling mechanism of LWS

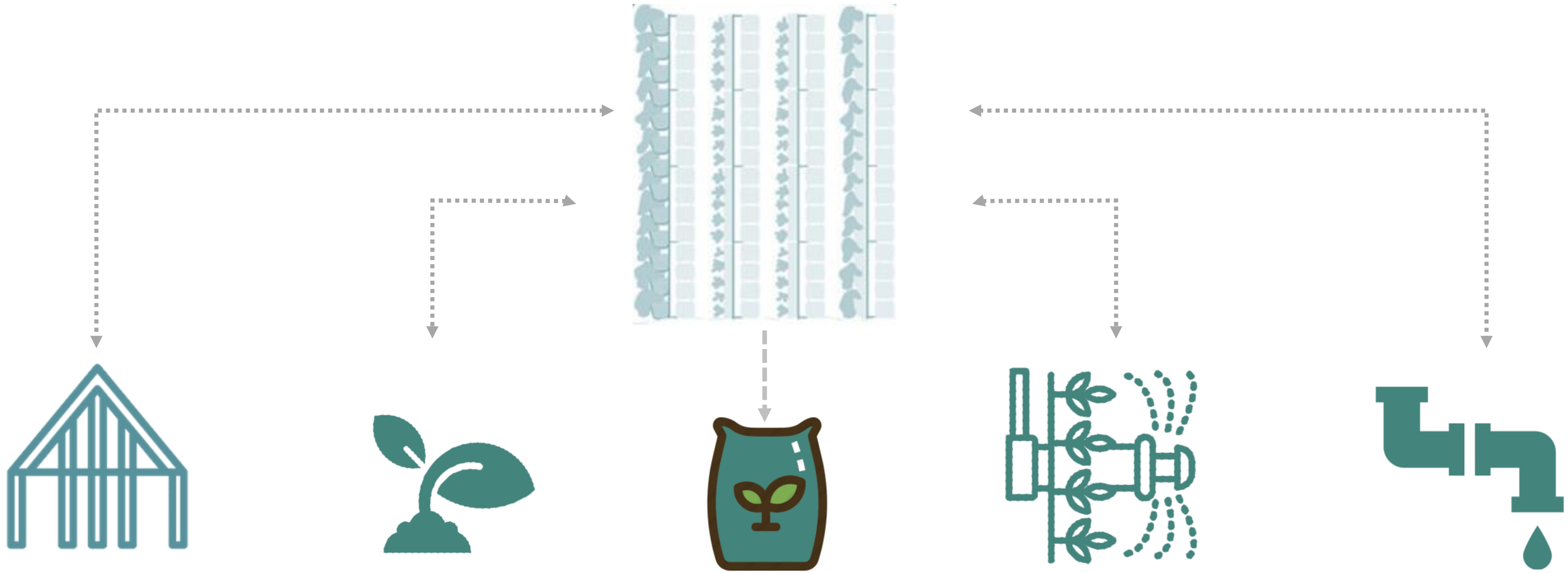
Living Wall System – System requirements -



Living Wall System – System requirements -



Vertical and horizontal structural elements



Supporting system

Vertical and horizontal structural elements

Plant selection

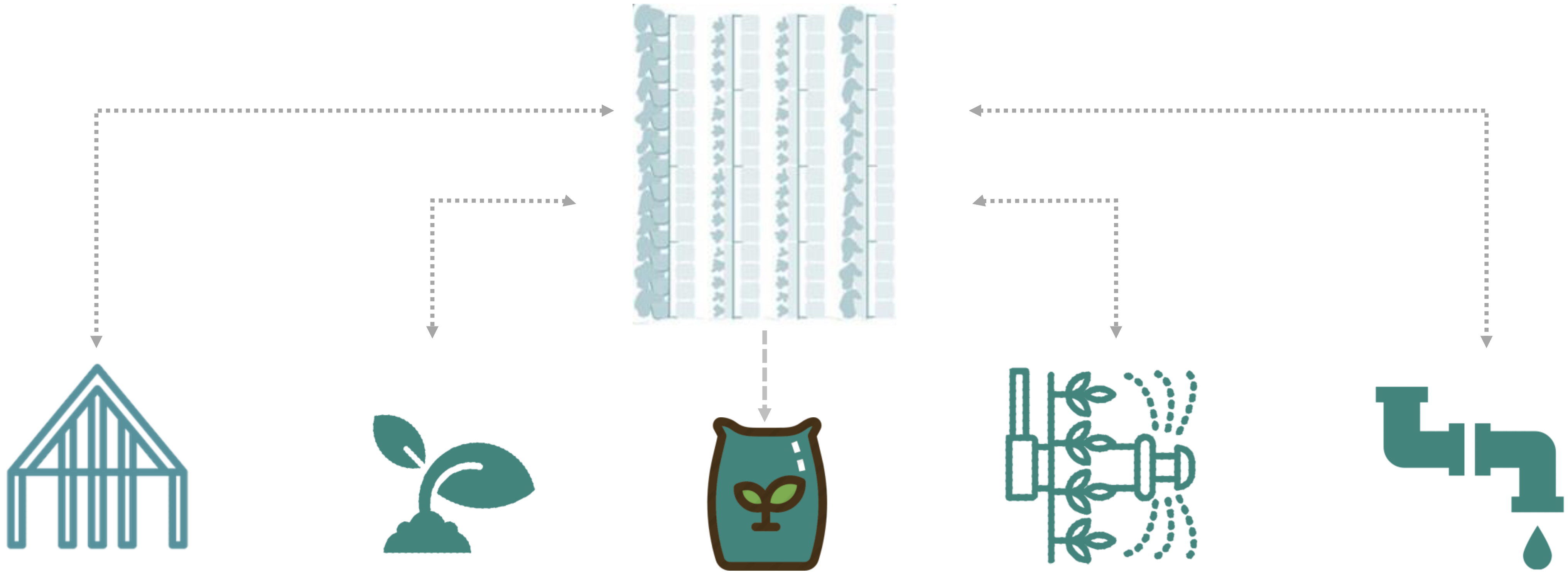
Evergreen native plants

Growing media

Irrigation system

Drainage

Living Wall System – System requirements -

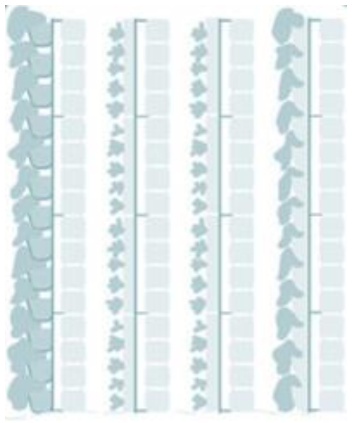


Supporting system | **Plant selection** | **Growing media** | **Irrigation system** | **Drainage**

Vertical and horizontal structural elements

Evergreen native plants

Living Wall System – System requirements -



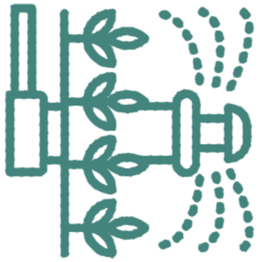
Supporting system

Vertical and horizontal structural elements

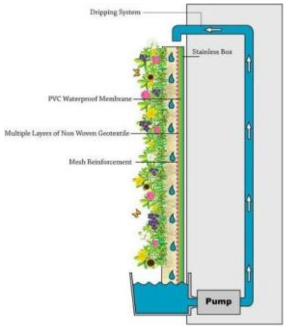
Plant selection

Evergreen native plants

Growing media

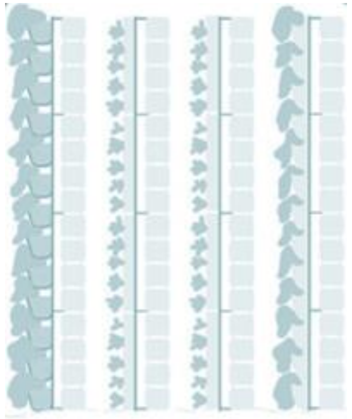


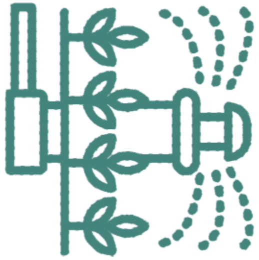
Irrigation system



Drainage

Living Wall System – System requirements -

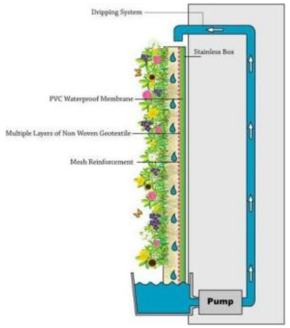




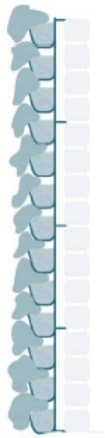
Supporting system | **Plant selection** | **Growing media** | **Irrigation system** | **Drainage**

Vertical and horizontal structural elements

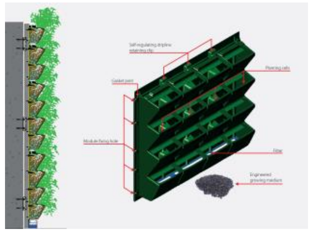
Evergreen native plants



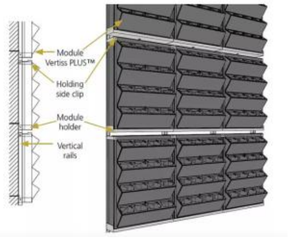
Living Wall System – Types of LWS -



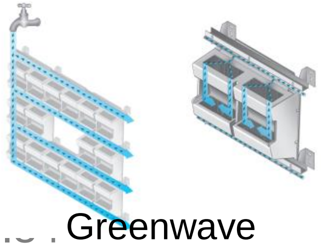
Living wall system
based on planter boxes
The life expectancy of this system is over 15 years



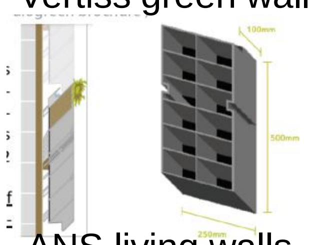
Modulogreen



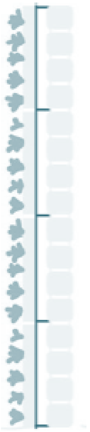
Vertiss green wall



Greenwave



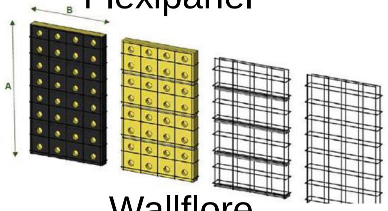
ANS living walls



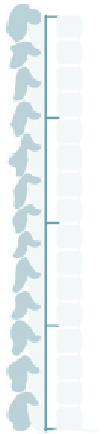
Living wall system
based on panels
The life expectancy of this system is over 10 years

Flexipanel

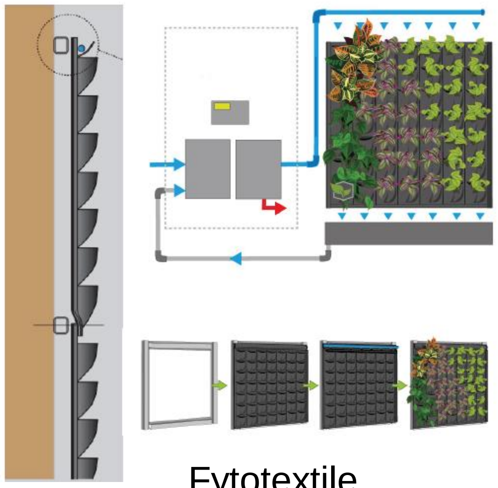
LivePanel



Wallflore



Living Wall System
based on felt pockets
The life expectancy of this system is over 10 years



Fytotextile

Living Wall System – Types of LWS -

Analysis of current living wall system

General information					vegetation	growing medium		Panel		mounting system			Irrigation	
system	type	weight kg/m^2	cost €/m^2	life expectancy	Plants per unit	growing medium	hydroponic	Material	Panel size cm	material	fixation	insulation	irrigation system	water consumption l/day/m^2
Modulogreen	based on planter boxes	29-39 (dry)-69 (saturant)	500-600	30 years	16-32 plants wide range of plants	Soil mixture	no	ABS Plastic	90*90,4*17,8	Aluminium brackets Aluminium profile T80 *52	anchoring bolts Gasket EPDM	possible	close loop irrigation system	1
Flexipanel	based on rock wool	20-25 (dry) - 40-45 (saturant)	650	10 years	25 plants plants with short roots	Rockwool- soil	yes	Thermoplastic Polyolefin backing waterproof layer	62*52*16	Aluminium profile	anchoring bolts clips	possible	close loop system	1,5-2,5
Fytotextile	based on felt layers	25 (dry) - 41 (saturant)	800	10 years	42-45 plants with short roots	Rockwool - soil	no	FYT-RCF waterproof layer FYT-DRA irrigation distributor FYT-AIR evapotranspiration	100*100*13	aluminium profile	anchoring bolts	possible	close loop system	1,4
ANS	based on planter boxes	72 (saturant)	500-600	20 years	12 wide range of plants	Soil mixture	no	recycled Plastic Water proof layer	50*25*30	Steel frame fixing rail	anchoring bolts	possible	close loop system	1,5
Vertiss plus	based on planter boxes	32 (dry) - 53 (saturant)	600-700	15years	16 wide range of plants	Organo-mineral medium	no	High Density Expanded Polypropylene	80*60*19	galvanised steel	stainless steel securing Stainless steel holder Stainless bolts	not possible	open system	2,5
LivePanel	based On rockwool	35-40 (saturant)	550	20 years	9 plants with short roots	Rockwool - soil	yes	Expanded Polypropylene pressed rock wool slabs	40*40*5,65	Aluminium profiles	anchoring bolts clips	possible	close loop system	3
Greenwave	based on planter boxes	120(saturant)	400	n.d	4-6 plants wide range of plants	Soil mixture	no	polypropylene (HDPP)	51,5 *60	Steel trail Steel brackets	anchoring bolts	possible	open system	n.d.
wallflore	based on rockwall	50(saturant)	550	n.d.	20 plants with short roots	Rockwool	yes	galvanized steel wire -epoxy powder coating -HDPE film -Stone wool	100*60*30	Steel vertical trail	anchoring bolts	not possible	close loop system	n.d.

Design Integration

Phase 2

Challenges – Design criteria

Challenges – Design criteria

Low water consumption

Challenges – Design criteria

Water Consumption | **Cost** | **Environmental Performance** | **Structural Stability** | **Maintenance**

Low water consumption

Feasibility

Challenges – Design criteria

Low water consumption

Feasibility

Less environmental impact

Challenges – Design criteria

Low water consumption | Feasibility | Less environmental impact | Structural Integrity

Challenges – Design criteria

Water Consumption	Cost	Environmental Performance	Structural Stability	Maintenance
Low water consumption	Feasibility	Less environmental impact	Structural Integrity	Low maintenance

Challenges – Design criteria

- Choosing the living wall system with the least moisture exchange
  Using local material and local fabrication techniques.
  Using material with low environmental impact.
  Using as little as possible energy.
  Check the structural stability of the system
  Using lightweight but stiff units
  Ease of replacing damaged parts.
  The accessibility of the system.

- Choosing evergreen species that are drought tolerant with low watering demand.
  Choosing native evergreen species which is available in Damascus.
  Using plants with a low growth rate.
  Using plant that prevents insects.

- Using Substrate with a high water capacity.
  Low cost durable growing medium.
  Using material with low environmental impact.
  Light weight growing medium.
  sing artificial growing medium.

- Using recirculating irrigation system (Close loop Irrigation system)
  Retreating domestic greywater
  Using as little material as possible and benefits from the overlapping between the units. So that the container at the top irrigates the one underneath it.
  Using material with low environmental impact.
  Ease of replacing and repairing damaged parts.
  Using as little as possible energy.

How to achieve ?

Evaluate different LWS types

Evaluate different plant species

Compare the different growing mediums.

Choose local material as the primary fabrication material.

Looking into the potential of retreating domestic greywater

Design LWS which has self-standing overlapping between its units and using a close loop irrigation system

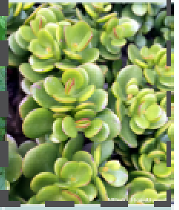
Check the structural performance of the system.

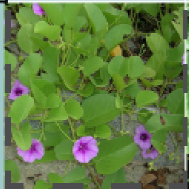
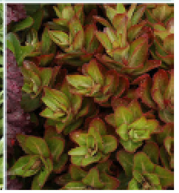
Compare the price with the design with the systems available in the market.

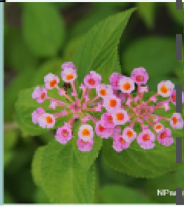
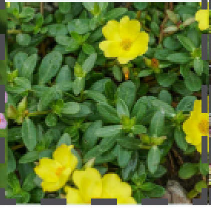
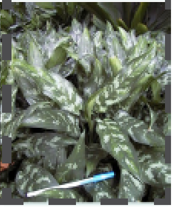
Evaluation of LWSs available in the market

Evaluation criteria		Explanation	Modulogreen	Flexipanel	Fytotextile	ANS	Vertiss plus	LivePanel	Greenwave	wall flore	weight	total weight
Feasibility	Cost per square meter	The price of the LWS system with growing medium	1	-1	-1	1	-1	0	1	0	25%	25%
	Amount of material used	The more materials the system uses the less feasible it is	1	0	-1	1	1	0	1	-1	10%	
	Ease of fabrication	Is the system easy to be fabricated in Damascus	1	-1	0	1	0	-1	1	-1	25%	
	Ease of installation	Does the system require special equipements	1	0	1	1	0	0	1	0	10%	
	Transportion cost	The bigger the system is the higher the transportaion cost	1	0	1	1	-1	-1	1	0	10%	
	Life expectancy	Life expectancy of the system as given by the manufacturer	1	-1	-1	1	0	1	1	-1	20%	
		score	**1**	**-0.45**	**-0.5**	**1**	**-0.25**	**-0.3**	**1**	**-0.55**	**100%**	
Water consumption	Irrigation system	Is the system active or passive	1	1	1	1	-1	1	-1	1	15%	35%
	Water consumption	the amount of water required to maintain the system in good condition	1	0	-1	1	0	-1	0	-1	50%	
	Risk of dehydration	the risk of dehydration	1	-1	0	1	1	-1	1	-1	10%	
	Hydroponic system	if the system uses Hydroponic system it is less Feasible	1	-1	1	1	1	-1	1	-1	25%	
		score	**1**	**-0.3**	**-0.1**	**1**	**0.2**	**0.7**	**0.2**	**-0.7**	**100%**	
Vegetation	Plants per unit	The amount of plants per units	1	0	1	1	0	-1	-1	1	20%	20%
	Plant selection	Does the system support wide range of species	1	0	-1	1	1	1	1	-1	40%	
	Growing medium	Is the growing medium artificial or organic	1	-1	-1	1	1	-1	1	-1	40%	
		score	**1**	**-0.4**	**-0.6**	**1**	**0.8**	**-0.2**	**0.6**	**-0.6**	**100%**	
Maintenance	Maintenaning growing medium	The easy of keeping the growing medium in a good condition without the need of detaching the whole unit	1	-1	1	1	1	0	1	-1	25%	20%
	Ease of replacing plants	The ease of replacing the dead plants without affecting other plants	1	-1	-1	1	0	0	1	-1	25%	
	Ease of replacing damaged parts	Accessibility to all the system parts in case of damage	1	0	-1	0	1	1	1	-1	25%	
	plant maintenance	if the system supports a wide range of species, low maintenance plants can be utilised	1	0	-1	1	1	1	1	1	25%	
		score	**1**	**-0.5**	**-0.5**	**0.75**	**0.75**	**0.5**	**1**	**-0.5**	**100%**	
		1= fulfills the criteria, 0= neutral, -1 = does not fulfill the criteria **total score**	**1**	**-0.39**	**-0.38**	**0.95**	**0.317**	**0.28**	**0.76**	**-0.6**		100%

Evaluation of Plant species

criteria	Asparagus setaceus	Alternanthera ficoidea	Mentha piperita	Crassula ovata
common name	asparagus fern	Joseph's coat	Peppermint	jade plant
Maintenance	Moderate	Moderate	Moderate	low
growth rate	normal	normal	relatively fast	normal
frost tolerant	-3	0	-15	0
evergreen	yes	yes	yes	yes
drought tolerant	sensitive	sensitive	sensitive	yes
height	0.3-3m	0.1m	0.3-0.6 m	0.5-1.2 m
expansion	0.6-2m	0.2m	0.4-0.8 m	0.3-1 m
leaf area index	3.5	4.5	3	4.5
light intensity	semi shade	bright light	Full Sun, semi shade	Semi-Shade, Full Sun
Plant Growth Form	Shrub	Shrub	Shrub	Shrub
Life span	perennials	perennials	Perennial	Perennial
native environment	Mediterranean Subtropical	tropical	Mediterranean	Tropical, Sub-Tropical
Water Preference	Moderate	Moderate	high	Little
photo				

criteria	Ipomoea pes-caprae	Hedera helix	Chlorophytum comosum	sedum
common name	goat's foot	English ivy	spider plant	oblongleaf stonecrop
Maintenance	low	Moderate	low	low
growth rate	Fast	Fast	normal	low
frost tolerant	0	-10	0	0
evergreen	yes	yes	yes	yes
drought tolerant	yes	yes	yes	yes
height	0.1-0.2 m	max 2 m	0.3 - 0.6	0.5-1.2 m
expansion	5-30 m	max 2 m	0.3 - 0.6	0.4-0.8 m
leaf area index	4.5	5 - 3	3.5	4.5
light intensity	Full Sun	Semi-Shade, Full Sun,shade	Semi-Shade	Full Sun
Plant Growth Form	Shrub	Shrub, climber	Herbaceous	Shrub
Life span	Perennial	Perennial	Perennial	Perennial
native environment	Tropical, Sub-Tropical	Mediterranean	Sub-Tropical	Mediterranean Subtropical
Water Preference	little	Moderate	Little	Little
photo				

criteria	Lantana camara L	Portulaca oleracea	Ophiopogon jaburan	Aglaonema
common name	lantana	purslane	White Lilyturf	Chinese evergreen
Maintenance	low	low	low	low
growth rate	normal	low	normal	normal
frost tolerant	0	0	0	0
evergreen	yes	yes	yes	yes
drought tolerant	yes	yes	yes	yes
height	max 1.2 m	0.05- 0.15 m	0.1-0.5 m	max 1 m
expansion	0.3 - 0.6	0.2-0.5	0.1-0.5 m	0.3-1 m
leaf area index	-	-	3.5	3.5
light intensity	Semi-Shade, Full Sun	Full Sun	Semi-Shade, Full Sun,shade	semi-shade, shade
Plant Growth Form	Shrub	Shrub,creeper	Herbaceous	Herbaceous
Life span	Perennial	annual	Perennial	Perennial
native environment	Tropical	Mediterranean	Mediterranean Subtropical	Tropical
Water Preference	little	little	low	Moderate
photo				

Presents the plant species that are suitable for the context of Damascus

- Mentha piperita Prevents beetles, caterpillars, shield insects and whiteflies
- Hedra Helix has a high leave index. However, it requires more water than other species. Therefore, it will be botted in the bottom part of the living wall system where the moisture is maximum.
- The rest have low growing rate, drought tolerant, suitable of Full Sun, semi shade with little to low water consumption.

Advantages and disadvantages of different growing medium

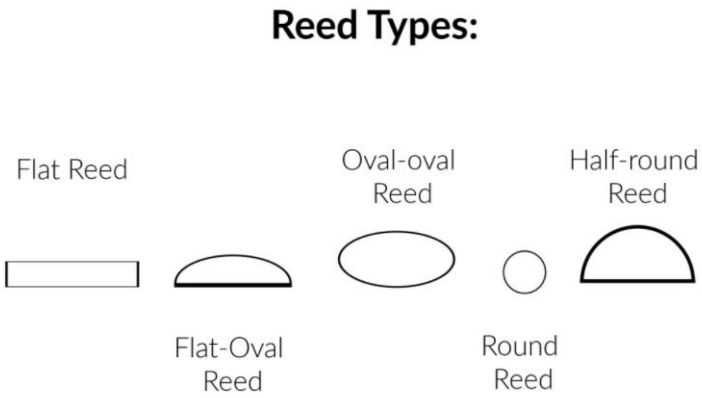
Substrate	pro's	con's
Expanded clay pebble	high pore space which means fewer blockage	Low water holding capacity
	Good air holding capacity which keep root zone oxygenated	Fairly costly
	Fairly renewable and environment-friendly	Can cause problem with pumps
	Easy to plant and harvest	Relatively heavy
Coco coir	Sustainable as you can reuse it	Hard to find
	High water holding capacity	Problems from salt
	It doesn't cost much	
	Light weight and compact	
plastic-based growing media	roots embed deeply into the medium and the plants and medium become one	Expensive, not re-usable
		Need to have a top layer that stays 100% dry, or it promotes algae growth
Oasis Cubes	Inexpensive	Not sustainable and Not organic
	No pre-soaking	Useful for germination only, not as a full growing medium
Rockwool	Great water retention	It's Not Environmentally Friendly
	Easy to dispose of	
Growstones	Lightweight	Hard to clean
	High water, air capacity	Not reuse able
	Sustainable	
Gravel	Easy to clean	Heavy
	Very inexpensive	Low water holding capacity
	Drains well	






Growstones is lightweight and can hold up to 30% of it is volume water.
It is made o recycled glass and it is going to be mixed with peat which is fossil organic matter

Materialization - Giant Reed

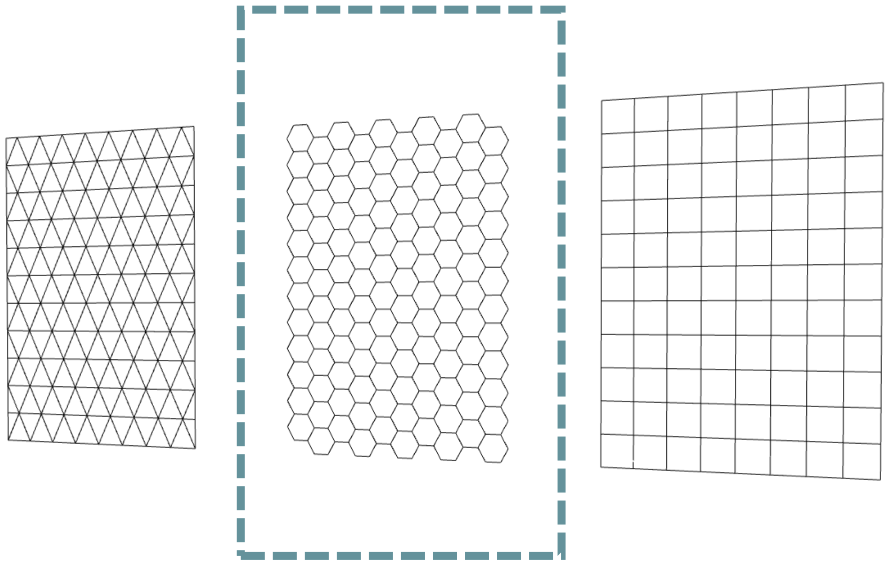


Mechanical properties	Density [g/cm3]	Tensile strength [MPa]	Young's modulus [GPa]	Elongation at break [%]
Giant reed fibre	1.168	248	9.4	3.24

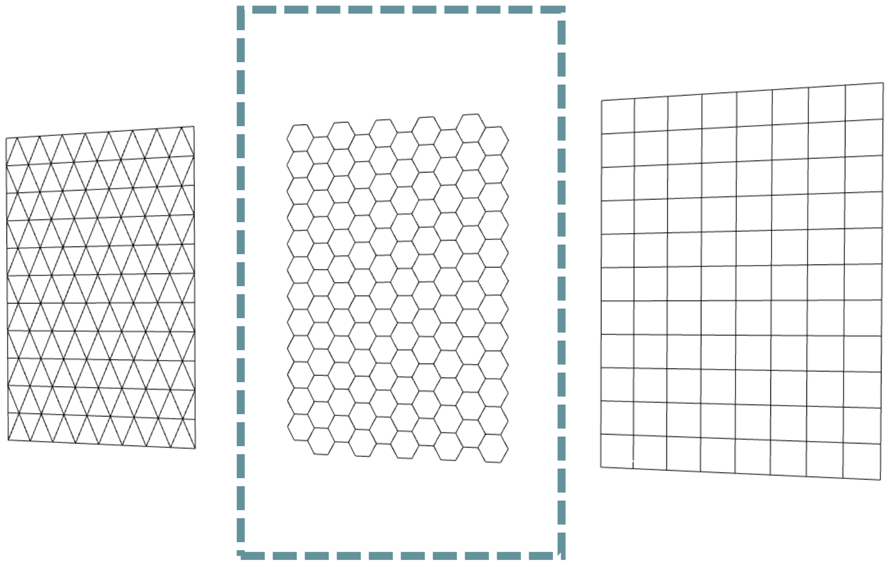
(textiLeindie, n.d.)

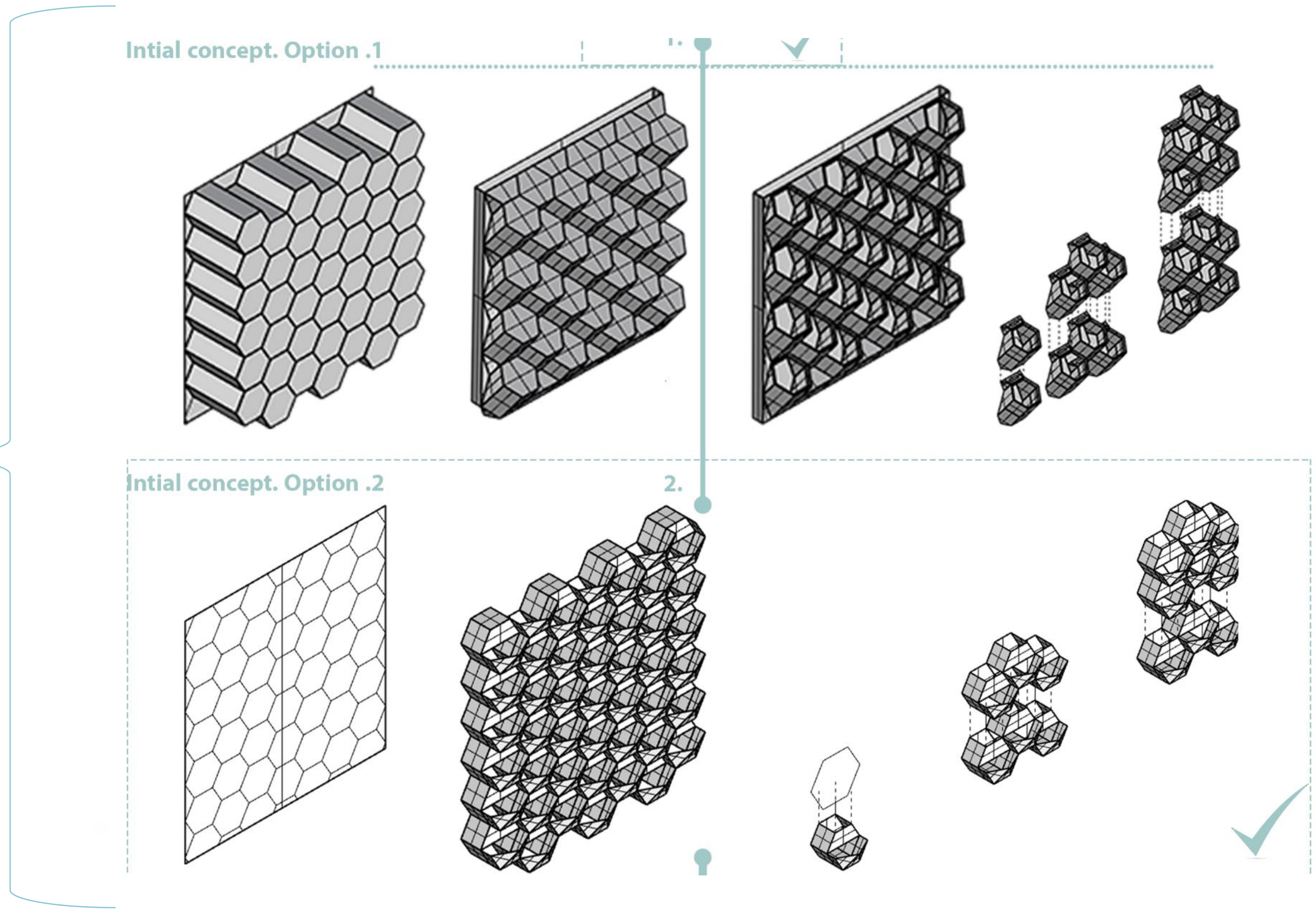
(Barreca et al., 2019)

First step: Initail design concept

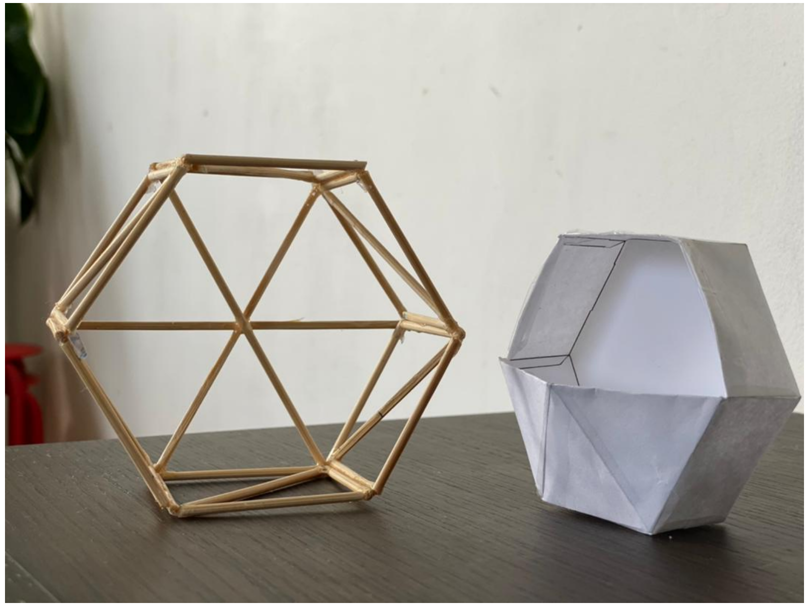


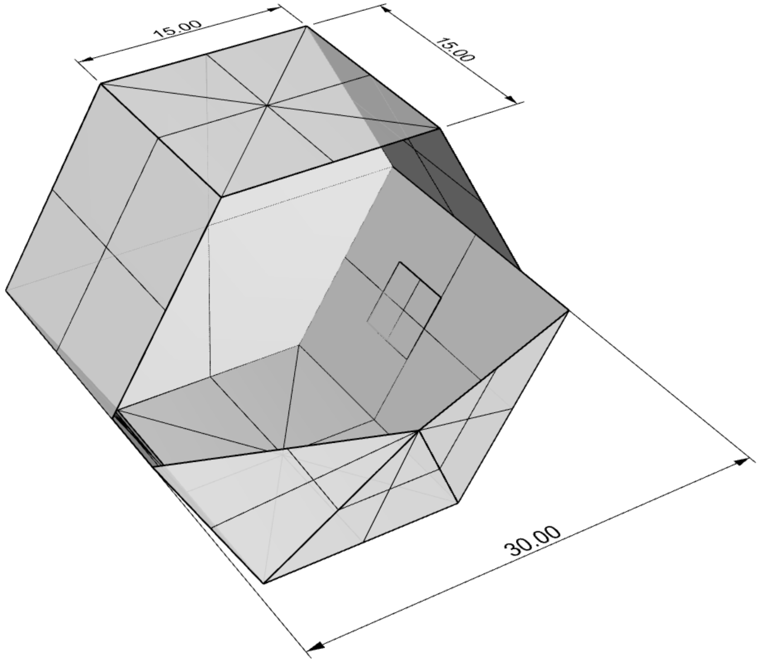
First step: Initail design concept

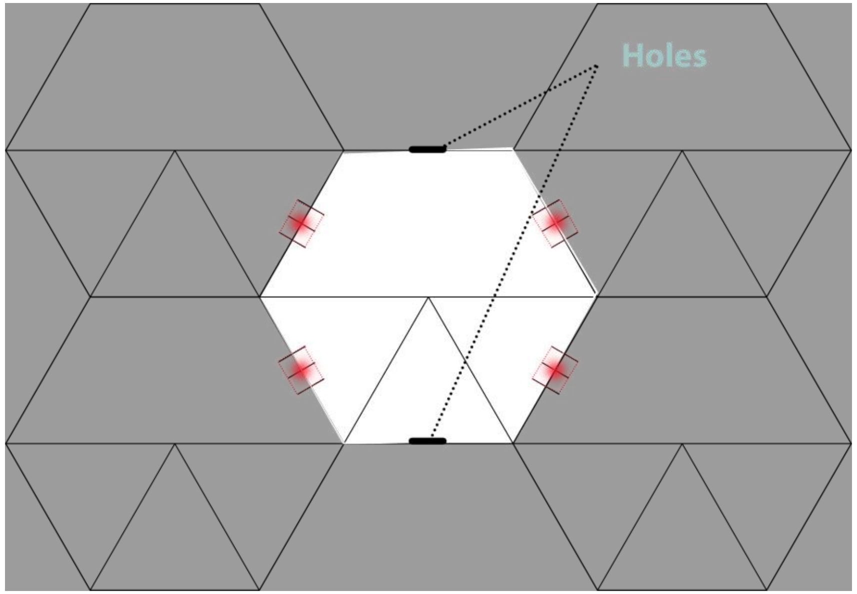




First step: Initial design concept







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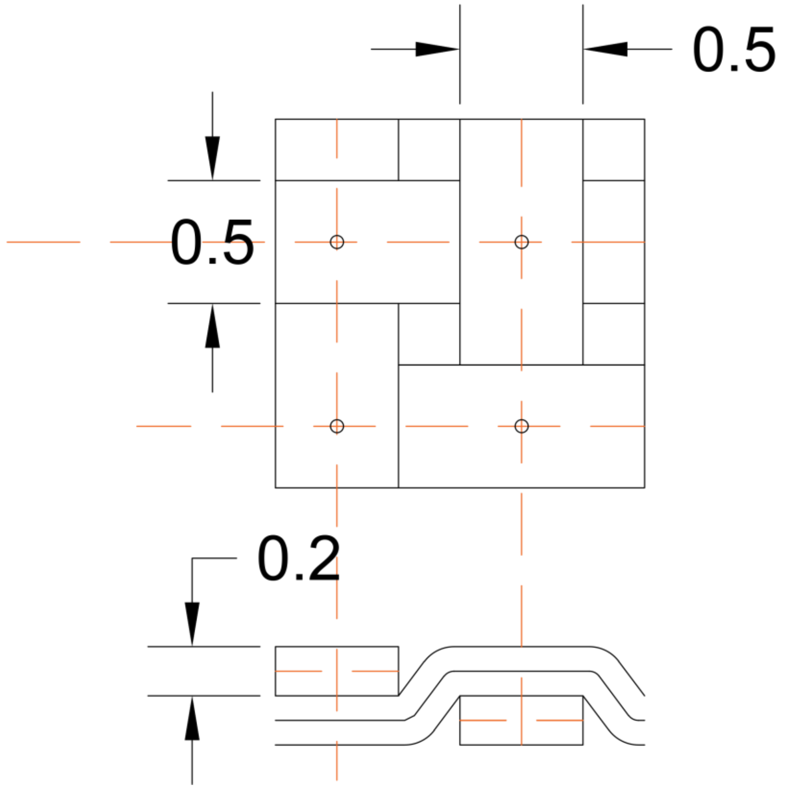

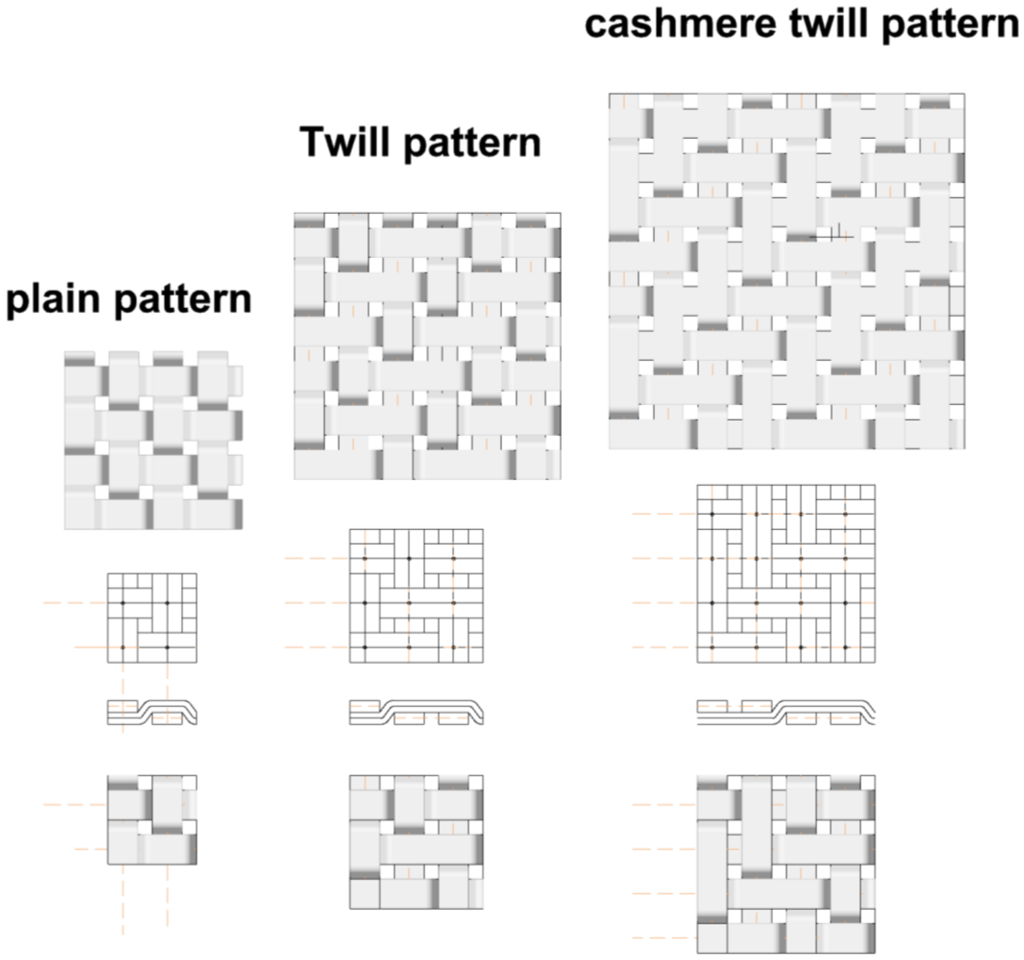

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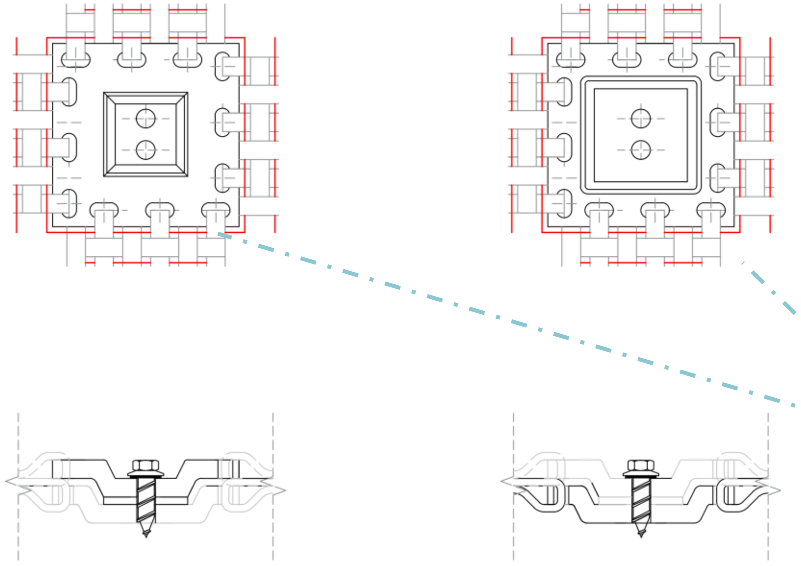
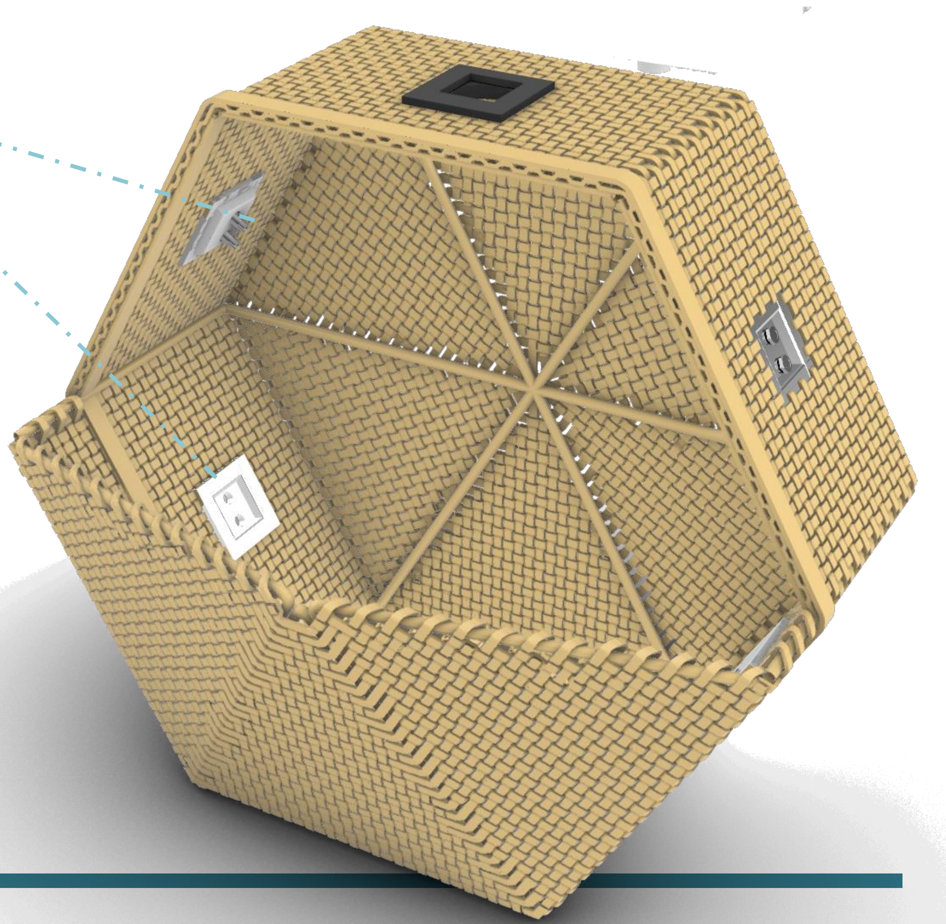
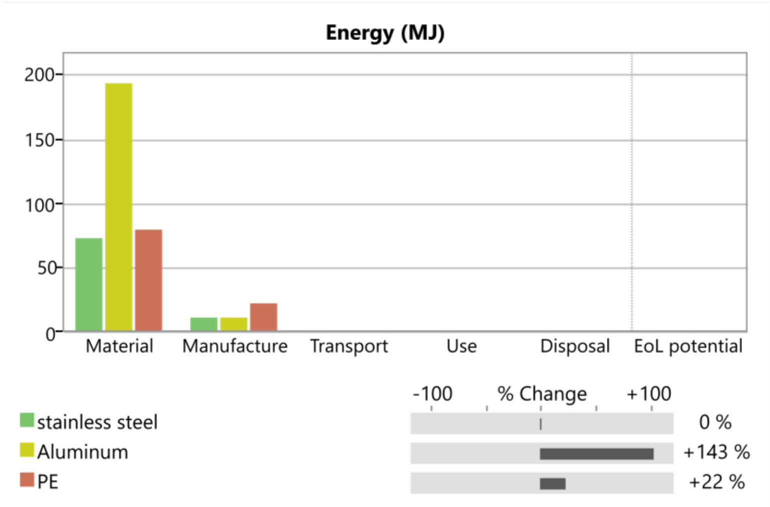
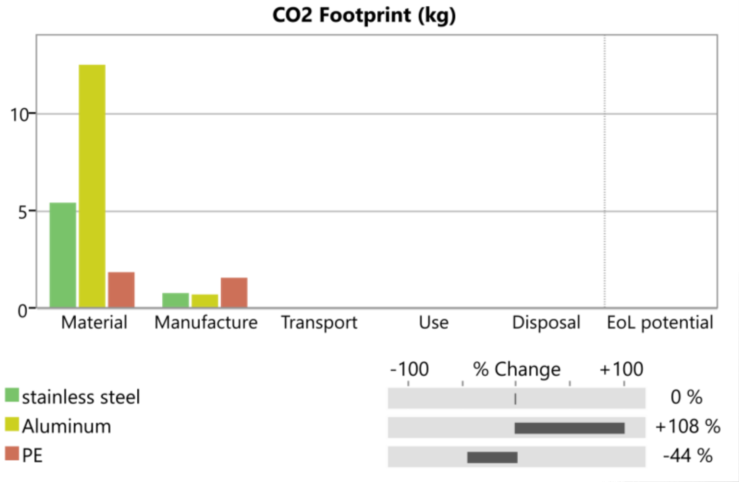


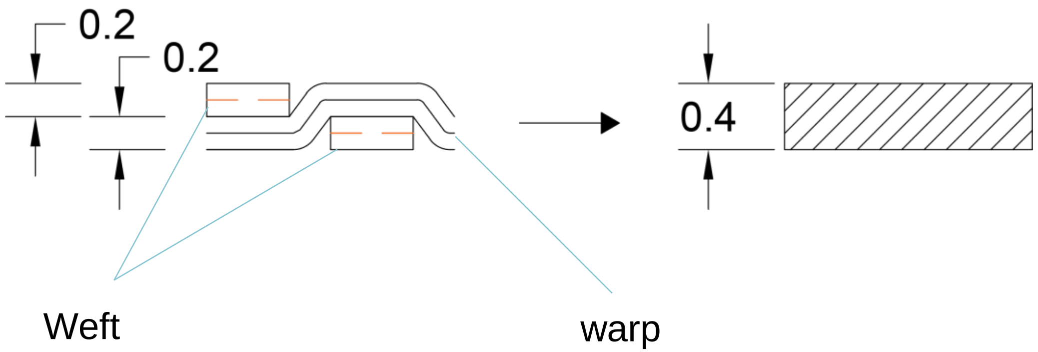






Second step: check the structural performance

1.Find equivalent cross section



$$p = p_1$$

where $p_1 = \frac{m_a}{h}$ => $p_1 = 1.03\ g/cm^3 = 1030\ Kg/m^3$

m_a : the mass per unit rea = 0.41 g/cm^2

h : the overall thickness of the woven cross section (4mm)

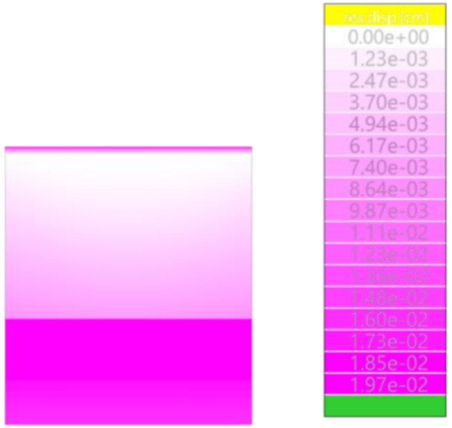
Load due to Self-weight of the basket without substrate = 0.906 * 9.81 = 8.88 N ≈ 9 N

Load due to the saturant Self-weight of the Growstone = 1.644* 9.81 = 16,12 N ≈ 16 N

The saturant weight of the saturant basket with the substrate is 2550 g

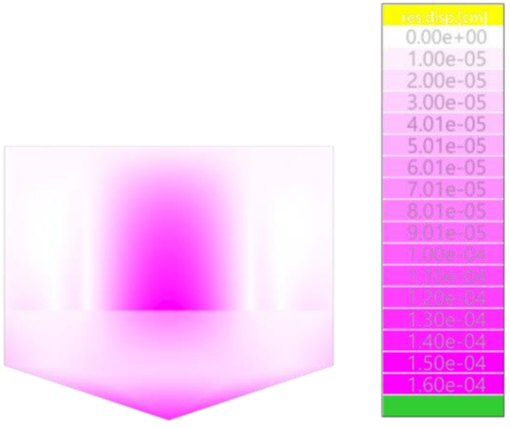
Second step: check the structural performance- maximum deformation

Karamba structural analysis



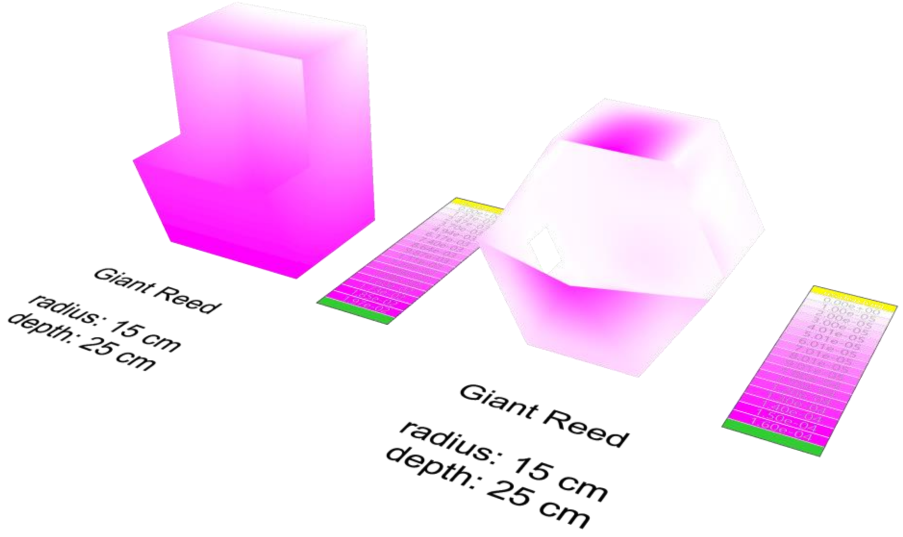
Giant Reed

radius: 15 cm
depth: 25 cm



Giant Reed

radius: 15 cm
depth: 25 cm

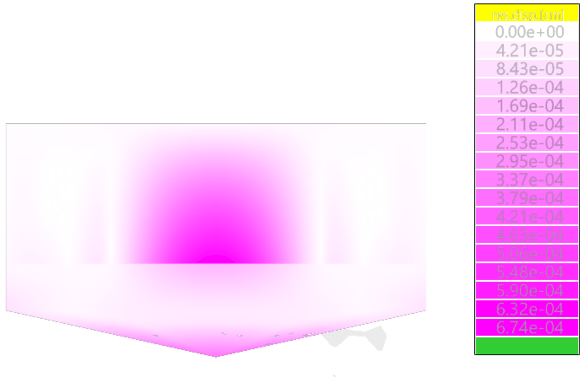


Maximum deformation is

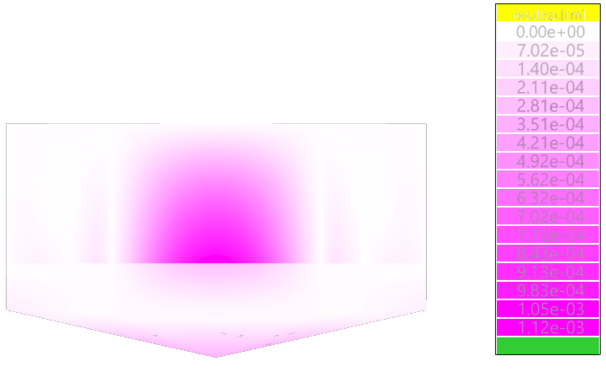
Hexagonal basket with 30cm diameter = 1.55*10-4 cm

Rectangular basket with same capacity = 2.22*10-2 cm

Second step: check the structural performance- maximum deformation

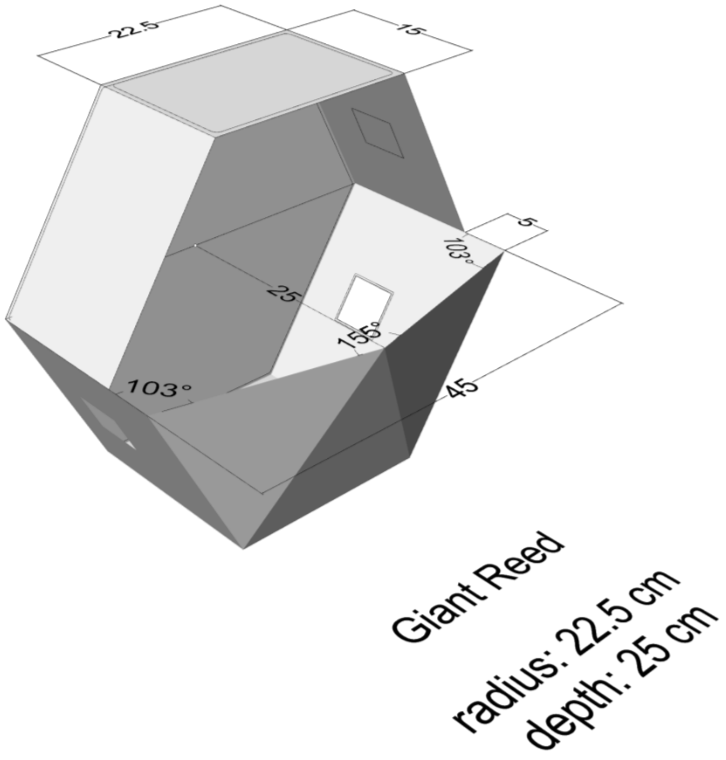


polypropylene
Price: 1.35 USD/Kg
thickness: 0.4 cm



Giant Reed

radius: 22.5 cm
depth: 25 cm

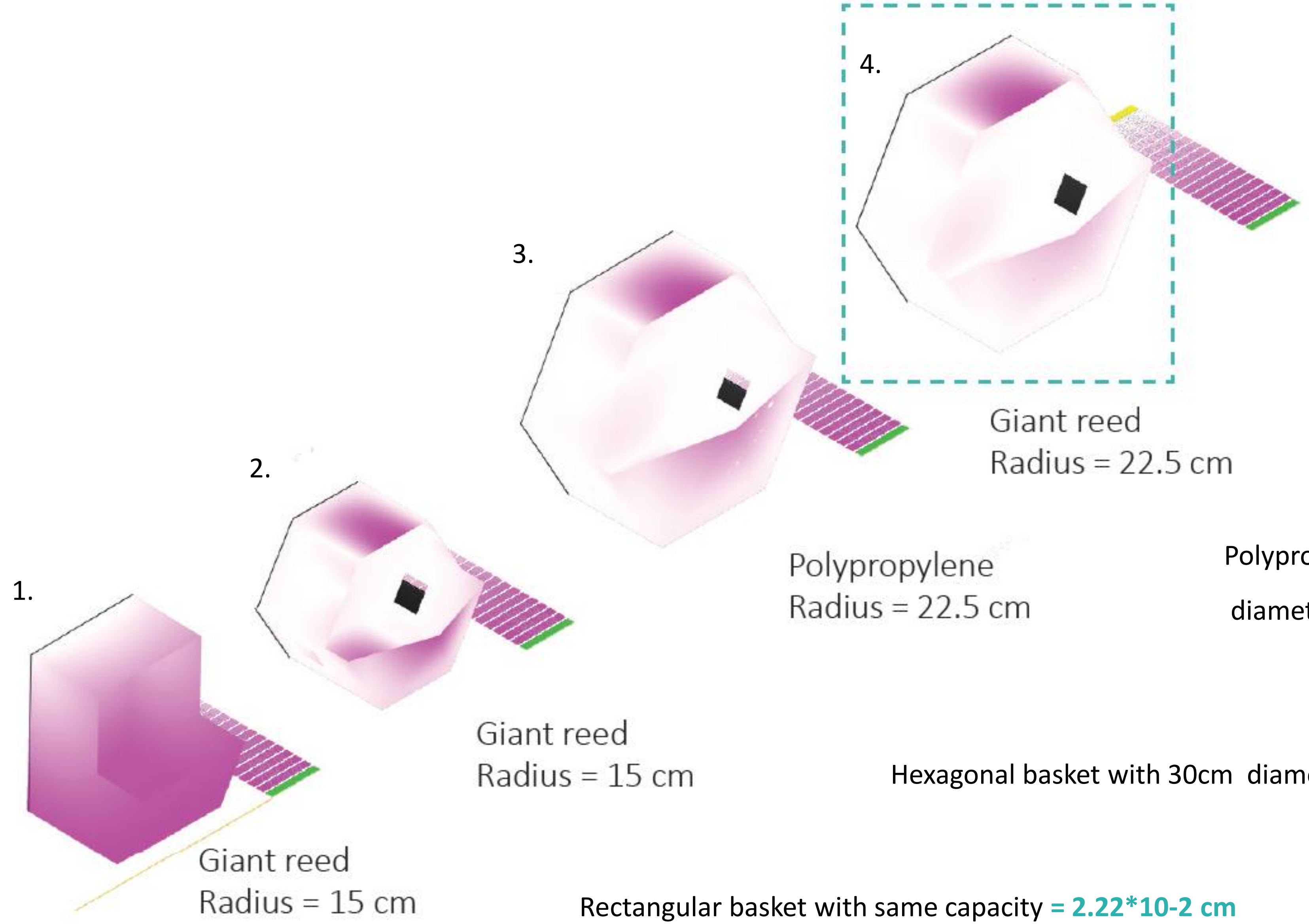


Maximum deformation is

Giant reed hexagonal basket with 45cm diameter = 1.12 *10-3 cm

Polypropylene reed hexagonal basket with 45cm diameter = 2.22*10-2 cm

Second step: check the structural performance- maximum deformation



Giant reed hexagonal basket with 45cm diameter = **1.12 *10-3 cm**

Polypropylene reed hexagonal basket with 45cm diameter **= 2.22*10-2 cm**

Hexagonal basket with 30cm diameter = **1.55*10-4 cm**

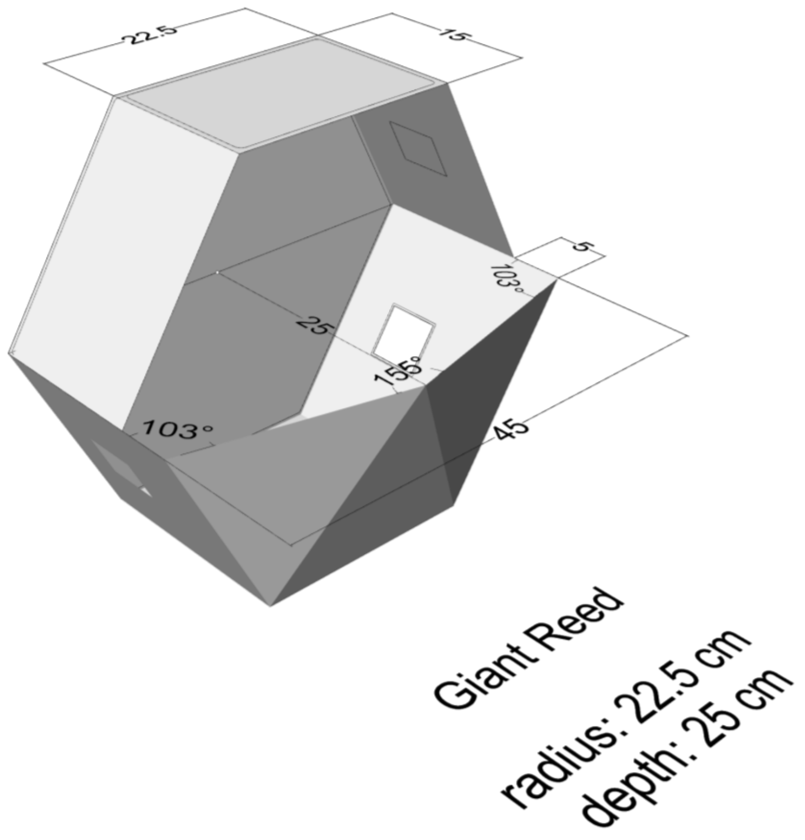
Rectangular basket with same capacity **= 2.22*10-2 cm**

Second step: check the structural performance – weight of the system per square meter

Weight per square meter is approximately **20 Kg/m2**, which is equal to **0.196 kn/m2**

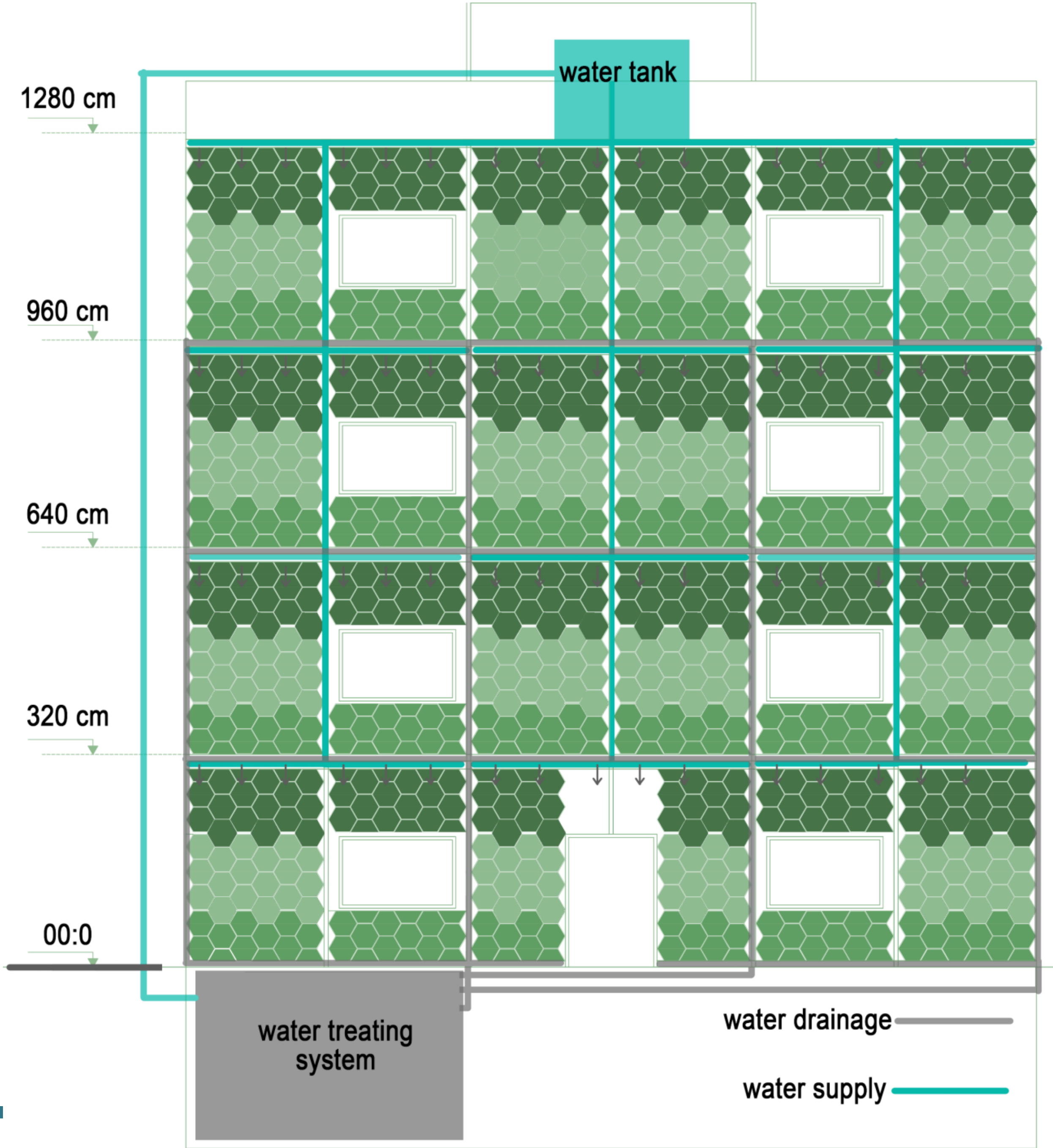
The residential buildings in Damascus are designed and constructed to hold **1700 kg/m2= 16.66 Kn/m2** with a 1.5 safety factor for the dead load.

in reality, the structure can hold up **to 24.99 Kn/m2.**



Third step: Irrigation system

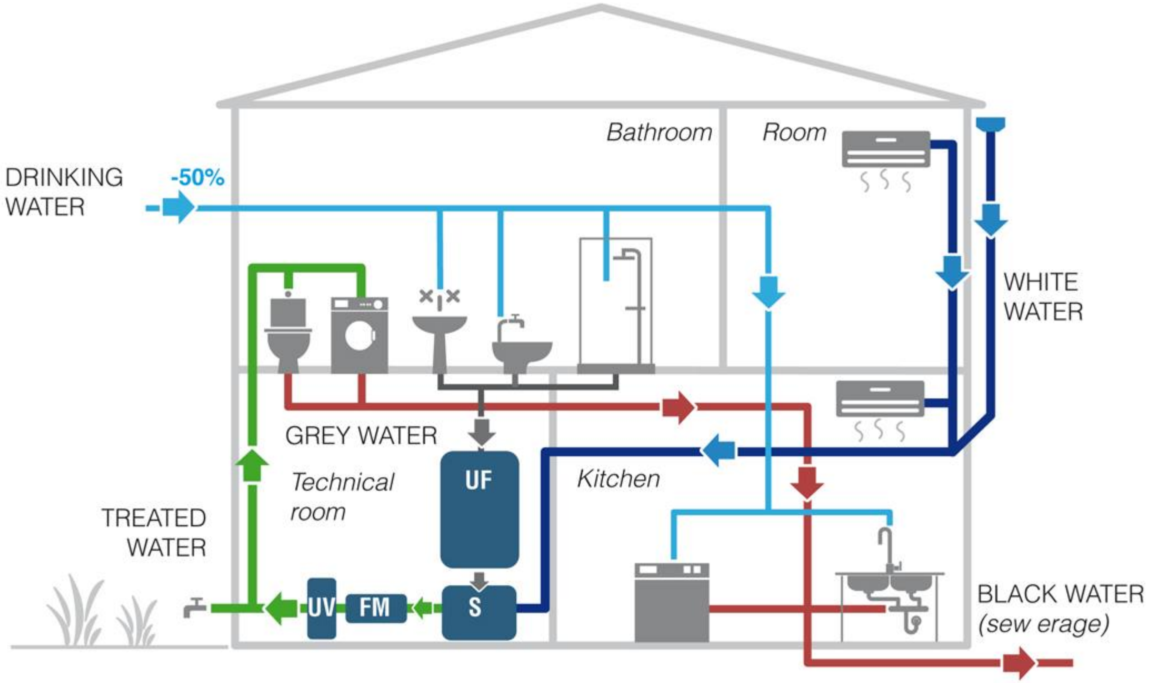
This system mainly consists of a water tank to store water at the top of the building, a timer, Irrigation tubes, a drainage channel at the lowest module to collect excess water, and a pump to return the water to the tank.



Third step: Irrigation system

On an average, a family with four members consumes **50 L/day per person**, from which **15 L/day per person is greywater.**
⇒ each family produces **60 L of greywater per day**. That is enough to irrigate **28 square meters of LWS**.

Water treating system costs on **average 2000$** which considered to be relatively high.
However, this will be paid back from the money saved from the water bill over time.



Grey water Treatment system

Living Wall system maintenance consideration

Before installation

1. The plant species are chosen to be suitable for the climatic condition and have low maintenance and growth rate.
2. The system is designed to replace any damaged parts without the need to remove the whole system.
3. Improving the durability of the woven reed basket by following these steps:

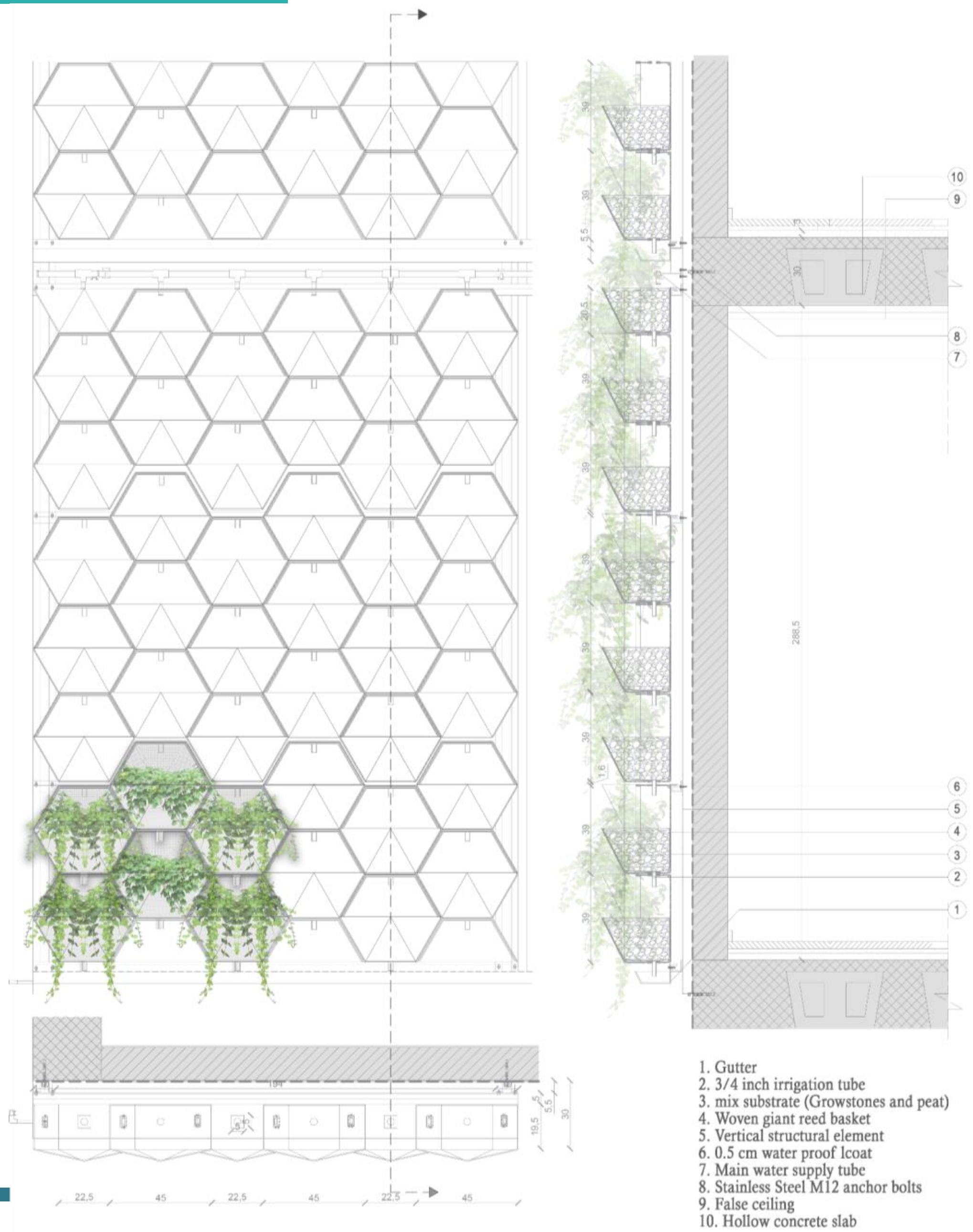
- Treating the reed fibers before weaving against potential insects using a mixture of boric acid minerals.
- Sealing the woven basket with a polyurethane finishing product. That adds extra protection against moisture and dirt.
- Adding a plastic layer at the bottom of each basket to ensure that water will not accumulate.
- Placing burlap bag inside the basket before adding the substrate mixture.

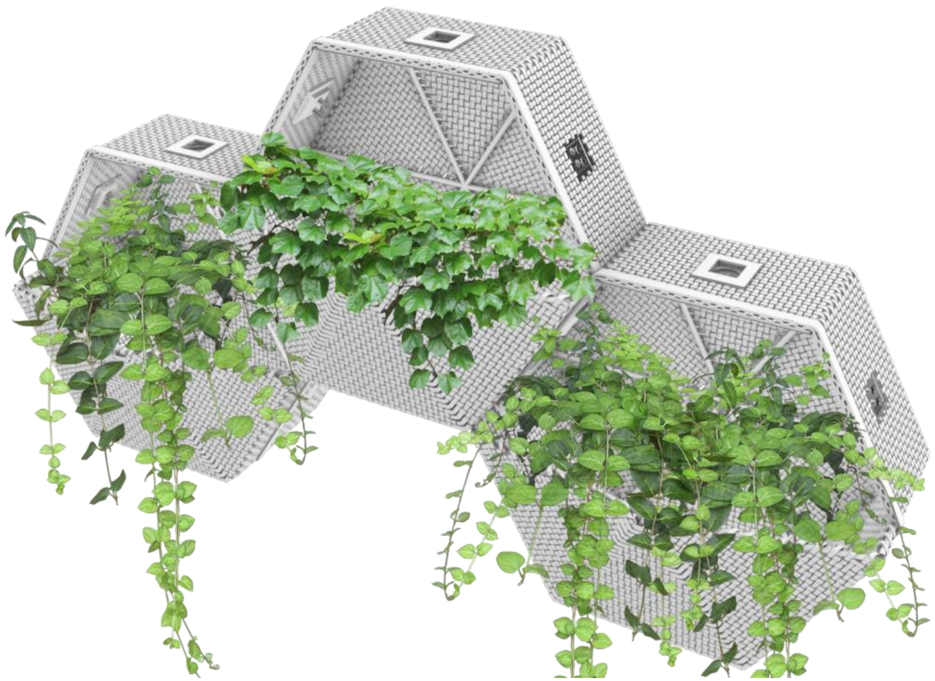
After installation

1. Check that there is no water collection buildup as a result of clogged drainage.
2. Check the plants for diseases, damaged leaf or any dead foliage
3. Check the system for any damaged parts.

Final Design

Mosaic
Living Wall System





Final Design

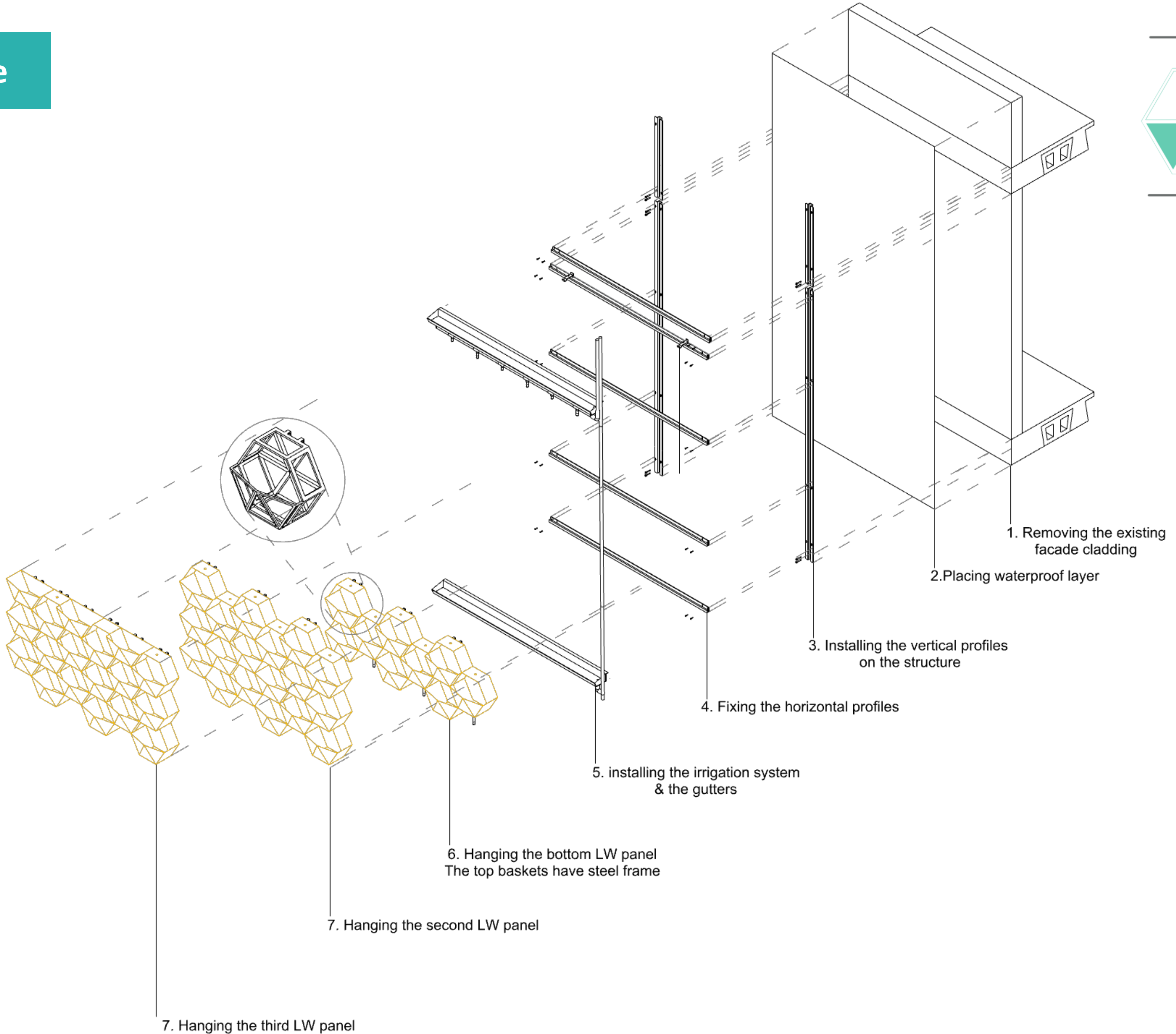
Mosaic

Living Wall System

- The average price of the potting containers is between 116 to 139 euros per square meter, while the price of woven baskets is 65 euros per square meter.
- When comparing the material used regularly in LWS with Mosaic living wall system, It can be clearly seen that the environmental is less.
- The saturant weight of Mosaic is 20 kg per square meter which is also less than other LWSs .

Assembly Sequence

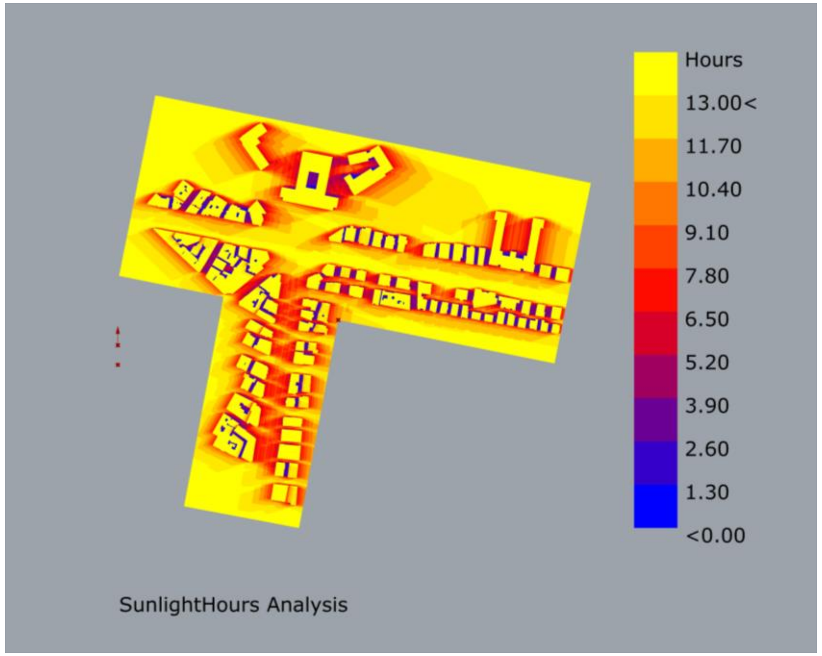
Mosaic
Living Wall System

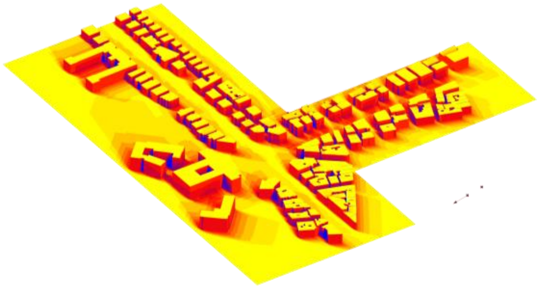


Evaluation

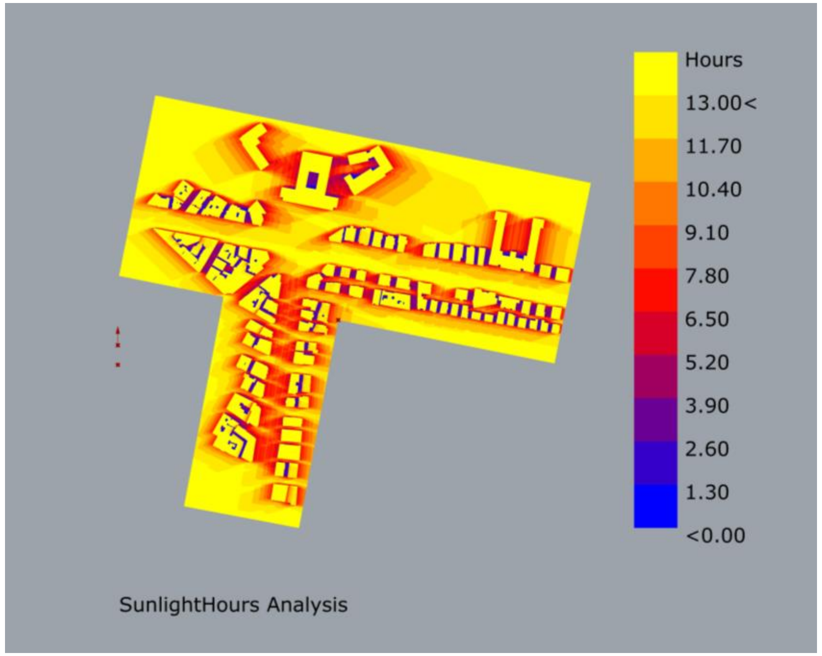
Phase 3

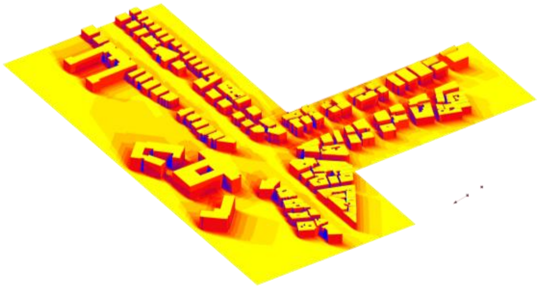
Evaluation of the urban canyon

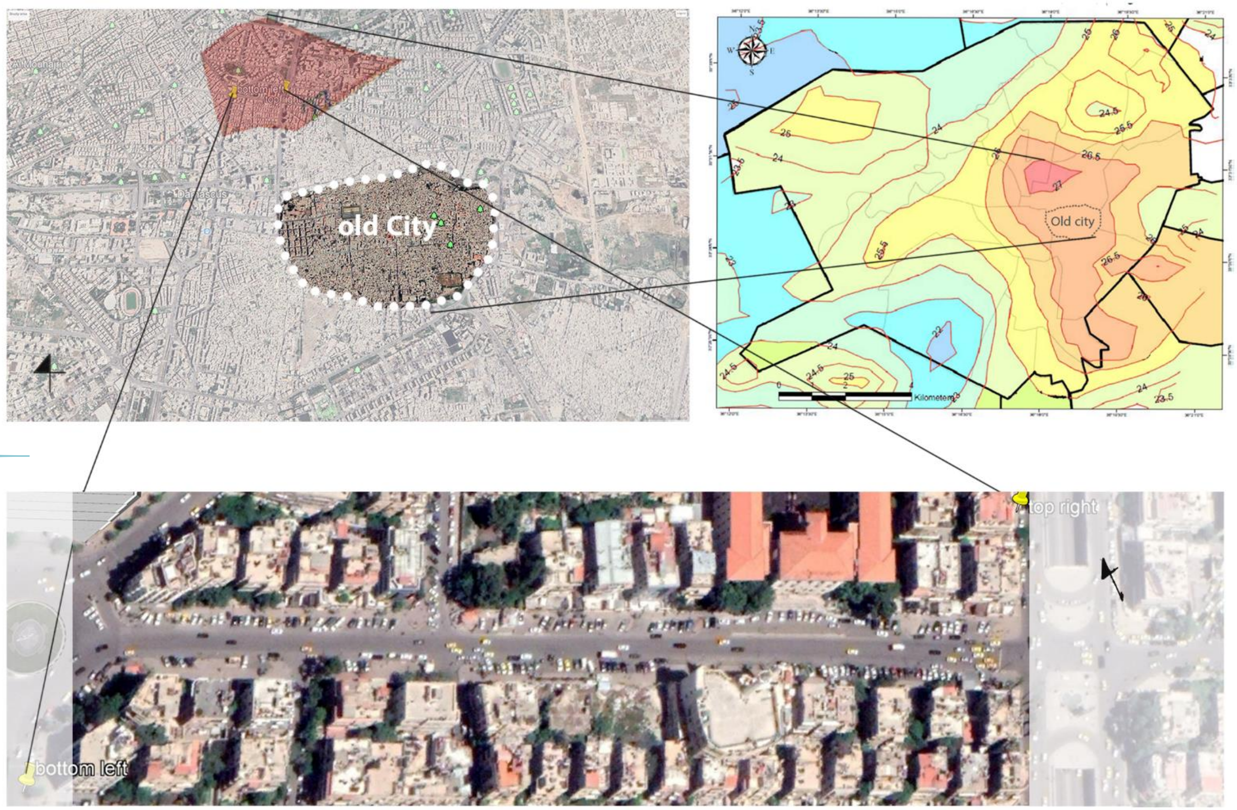




Evaluation of the urban canyon

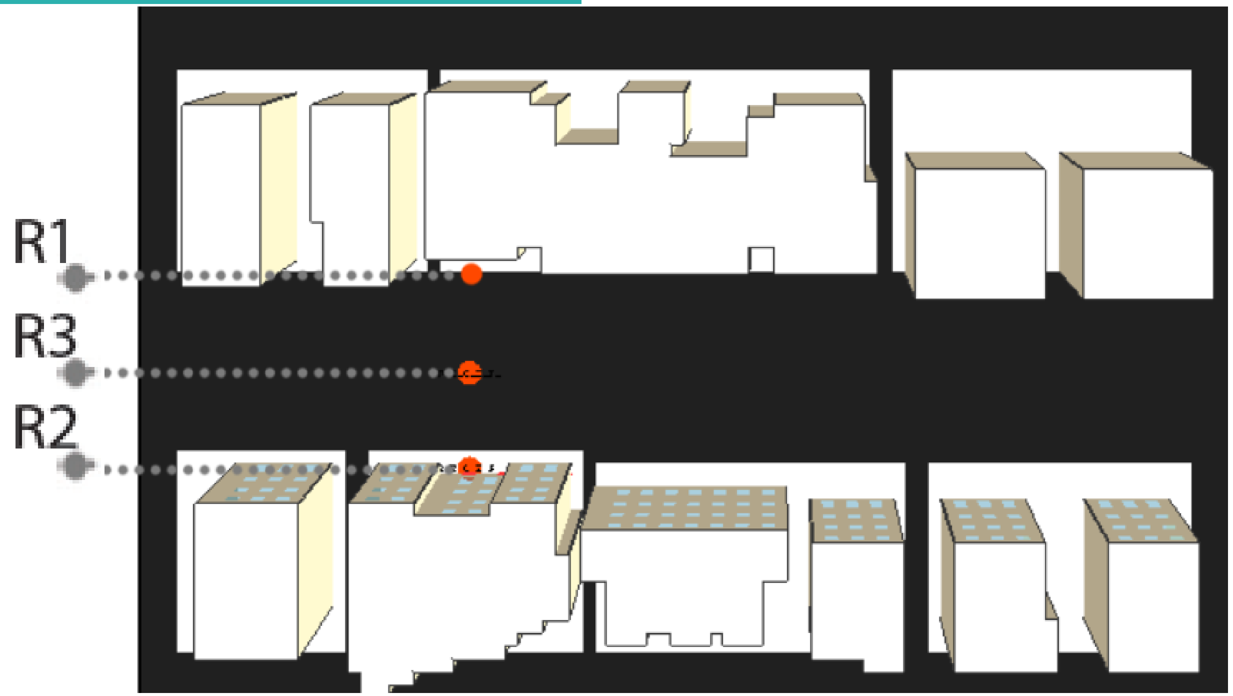


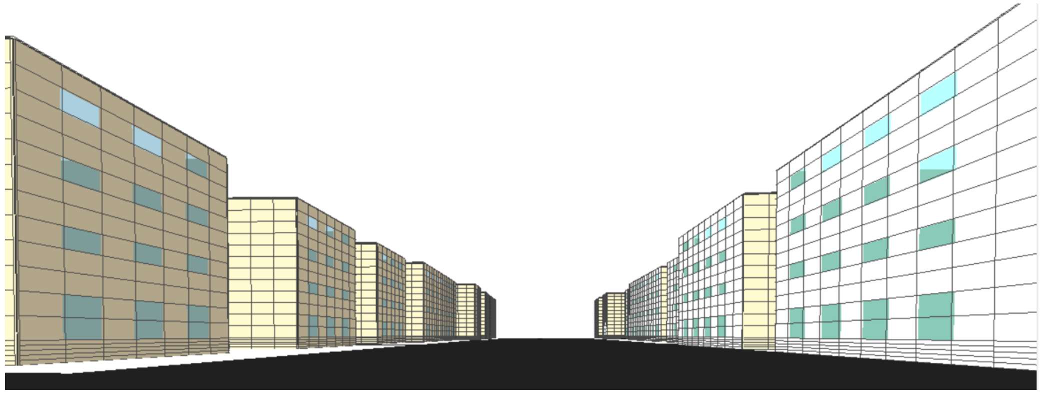




	Orientation	urban canyon width	Urban canyon height	Buildings	Aspect ratio H/W
Baghdad Ave	E-W with 10 degree in a clockwise direction from the north line	30m	13m	Detached	0.43

Evaluation Simulation setup





Boundary conditions	Input
Simulation duration	24h
Starting time	7:00am- 23/06/2018
End time	6:59am- 24/06/2018
Wind speed	1m/s
Wind direction	192 degree with the north direction (south-southwest)
Forcing	Simple forcing
Max. temperature	34 degree
Min . Temperature	20 degree
Simulation period	Typical summer day

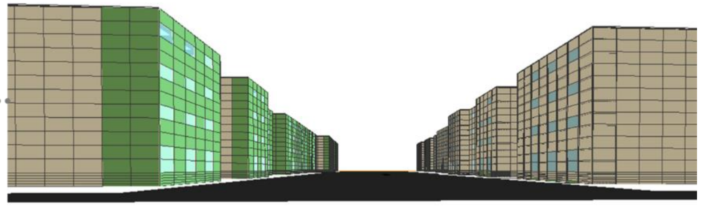
Characteristic of the road, pavement,wall and roof for the studied area

Surface	Exterior wall	Roof	Road	Pavemnet
Material	Limestone	concrete	asphalt	grey concrete
Albedo	0.45	0.3	0.2	0.5
Emissivity	0.93	0.9	0.9	0.9
Absorption	0.7	0.7	0.8	0.6
Density (Kg/m^3)	2711	2400	2322	2400
Specific heat J (Kg/k)	800	879	900	879
Thermal conductivity (w/mk)	1.26	0.8	0.75	0.8

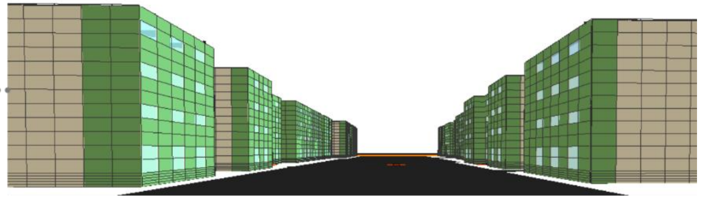
Evaluation scenarios

simulate potential air temperature (T), wind speed (W speed), mean radiant temperature (T mrt), and relative humidity (Q.rel) for four different scenarios
and then compare them with the base case.

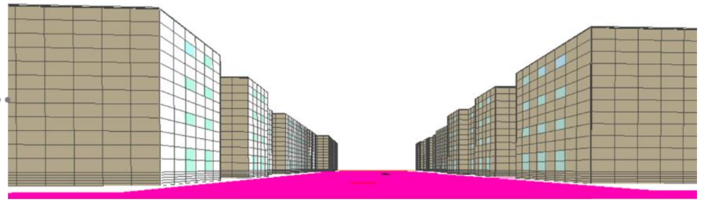
Scenario .1
With LWS on south facade
the green coverage
percentage is 45%



Scenario .2
With LWS on south and
north facades
the green coverage
percentage is 90%

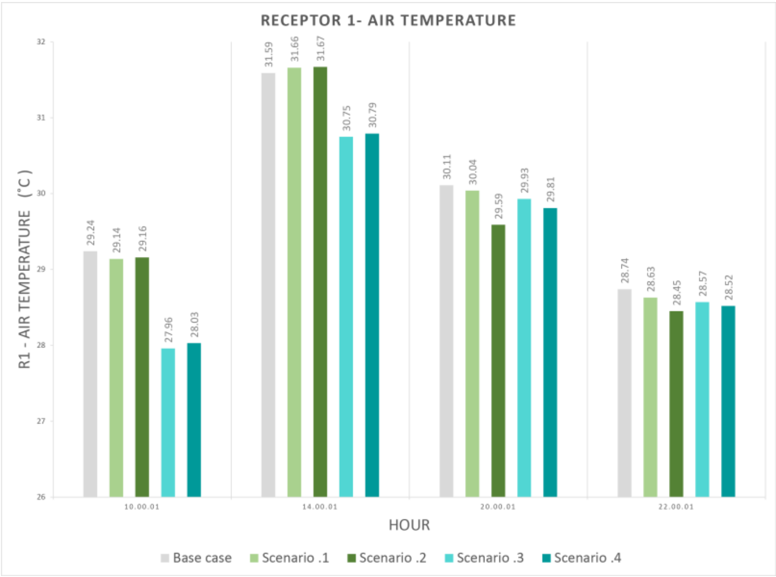


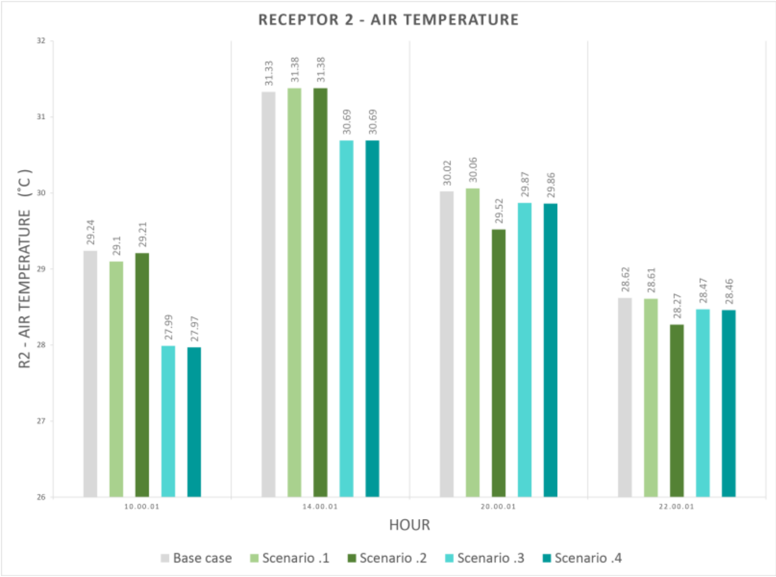
Scenario .3
High albedo material for
the pavements and roads

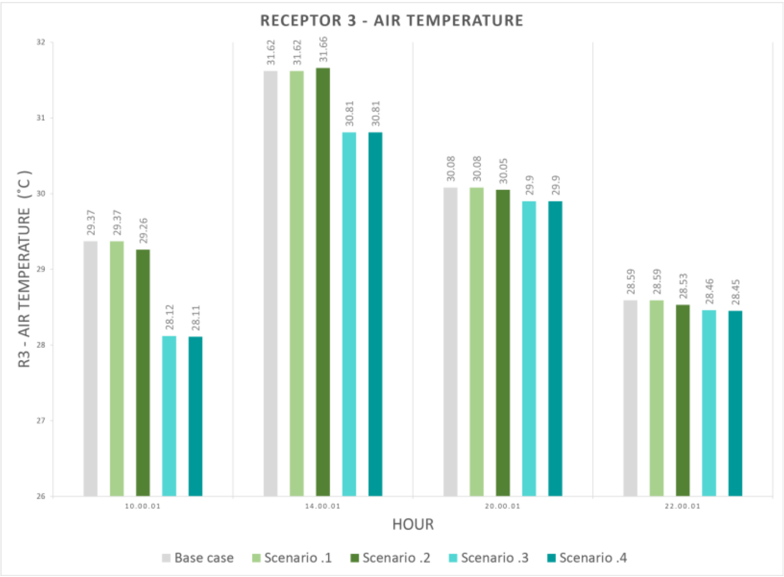


Scenario .4
combined scenario of LWS
and HAM for roads and
pavements

Results and discussion- Potential Air Temperature (T - °C)







Potential Air Temperature for the base case and four different scenarios at R1,R2 and R3

- it has been found that during the daytime, a significant reduction in the potential air temperature is recorded with the use of High albedo materials for the road and pavements in scenarios 3 and 4 (1.24 - 1.27 °C respectively compared to the base case).
- Whereas the use of LWS in scenarios 1 and 2 causes a slight increase in the air temperature at R1, R2.

While during the night, all the scenarios have a cooling impact. Scenario 2 has the highest cooling effect because of evapotranspiration (between 0.29 - 0.5°C at R1 & between 0.35 - 0.5°C at R2).

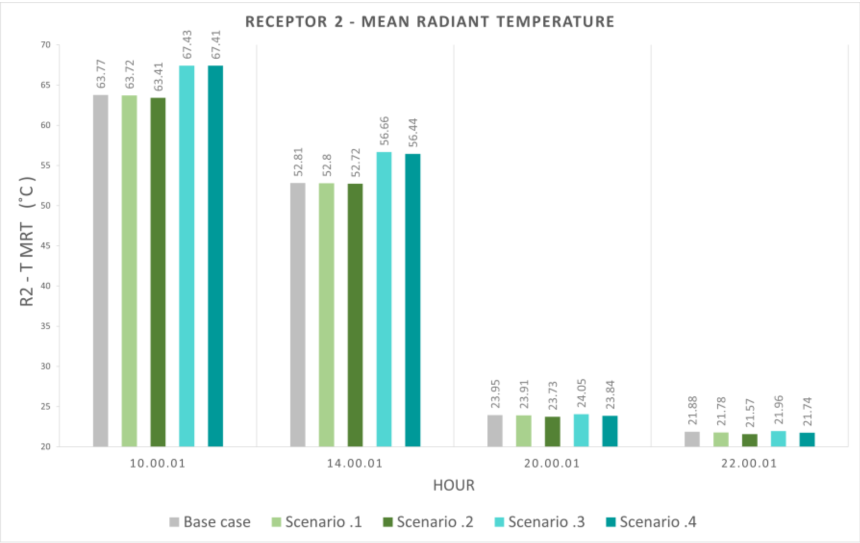
Results and discussion- Potential Air Temperature (T - °C)

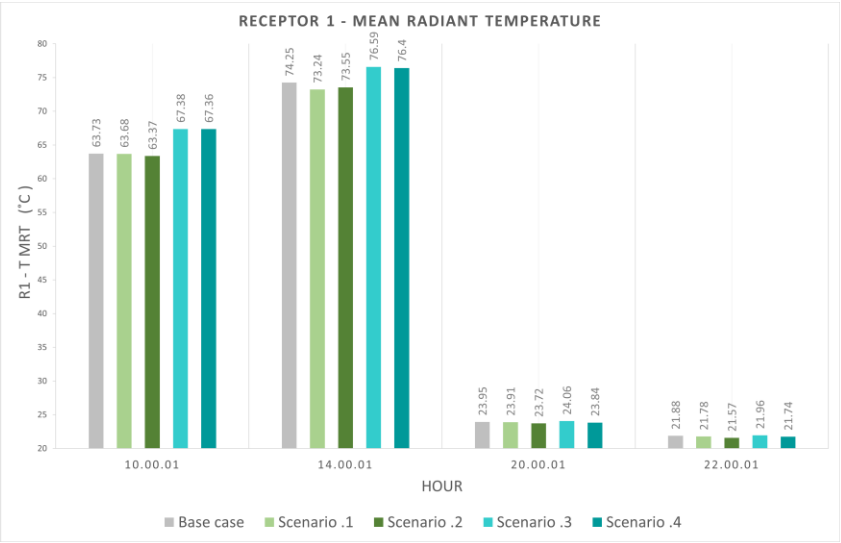
Nighttime is a crucial period for air conditioning in the residential areas in Damascus. According to a study on the effect of urban greening and night cooling on energy consumption in Cairo, it has been found that in an east-west oriented urban canyon, reducing air temperature **by 0.1°**C reduces the cooling energy consumption by 0.5%. This is equal to 0.68 kWh daily and **81 kWh** during the summer period for each building.

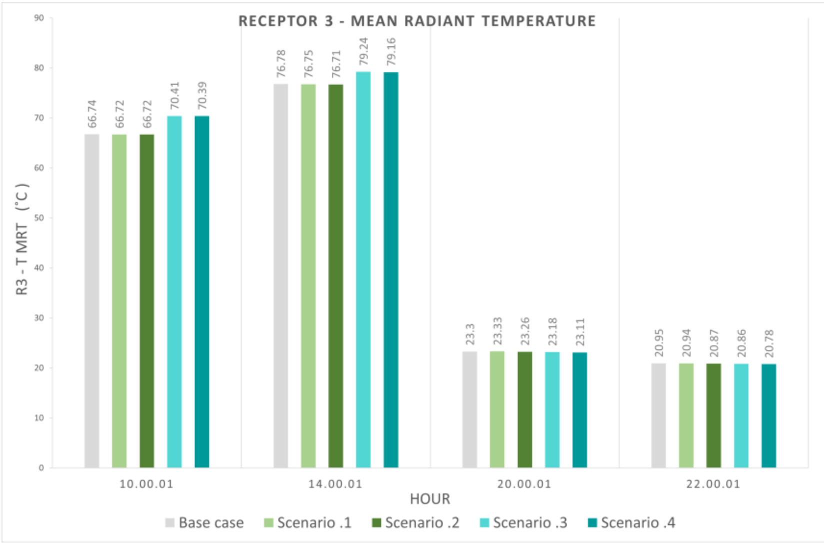
When comparing these results with the result for Damascus, especially that both have approximately the same climatic and urban characteristics, It can be found that a reduction of 0.3°C to 0.5°C could help reduce cooling energy consumption by 1.5% to 2.5%. This is equal to 122.4 to 204 kWh and 95$ to 150$ yearly.

This saving is significant when calculating it for the whole urban canyon, in addition to that the LWS'S thermal insulation and shading effect.

Results and discussion- Mean radiant temperature (Tmrt - °C)







Mean radiant temperature for the base case and four different scenarios at R1,R2 and R3

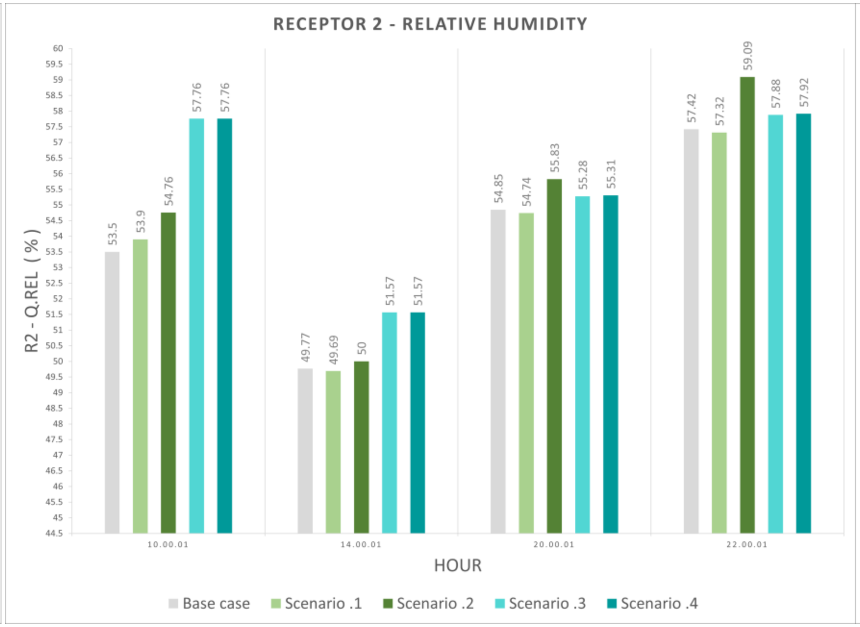
Results and discussion- Mean radiant temperature (Tmrt - °C)

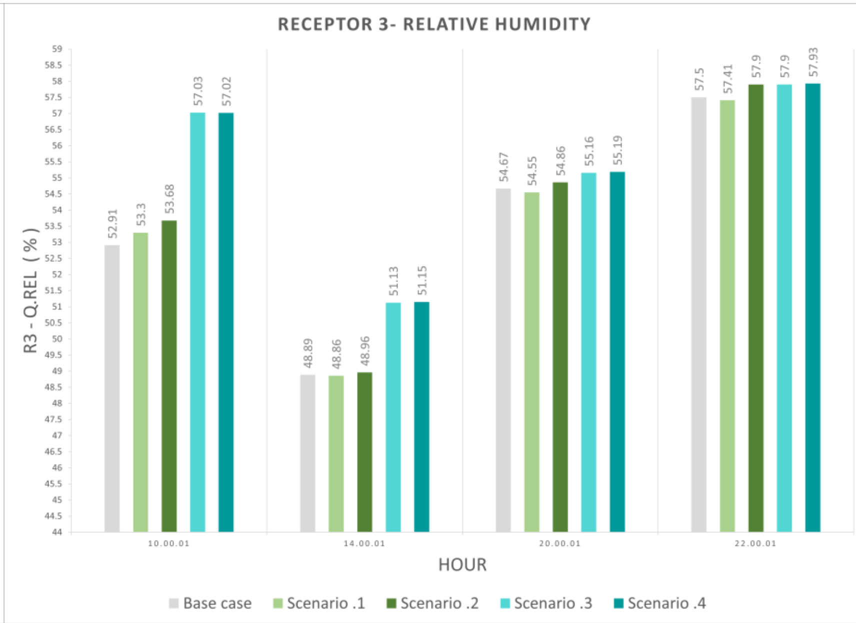
Mean radiant temperature for the base case and four different scenarios at R1,R2 and R3

Tmrt has a substantial impact on the PET index. Thus, it has a strong influence on the occupant's thermal comfort. The evaluation results show that the use of LWS help in reducing Tmrt at R1 and R2 during the daytime. This is the period where people spend their time outdoor.

The highest reduction is achieved using LWS on both façades in scenario 2 (0.7 °C). However, LWS has a negligible impact on Tmrt at R3. Conversely, the use of high reflectance materials for the pavement and road as in scenarios 3 and 4 increases the mean radiant temperature, leading to the increase in the reflected radiation and consequently increases the risk of reducing the outdoor thermal comfort at the street level.

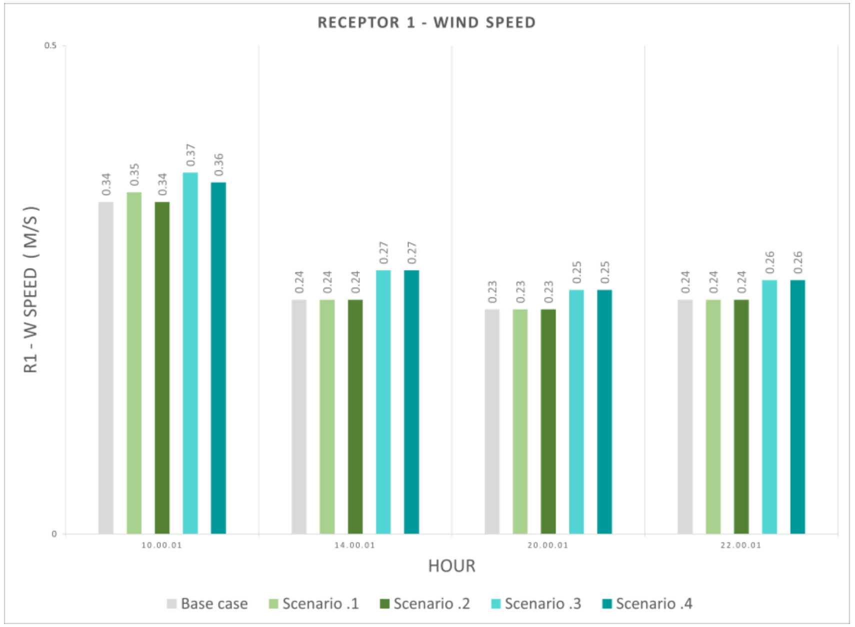
Results and discussion- Relative humidity (%)

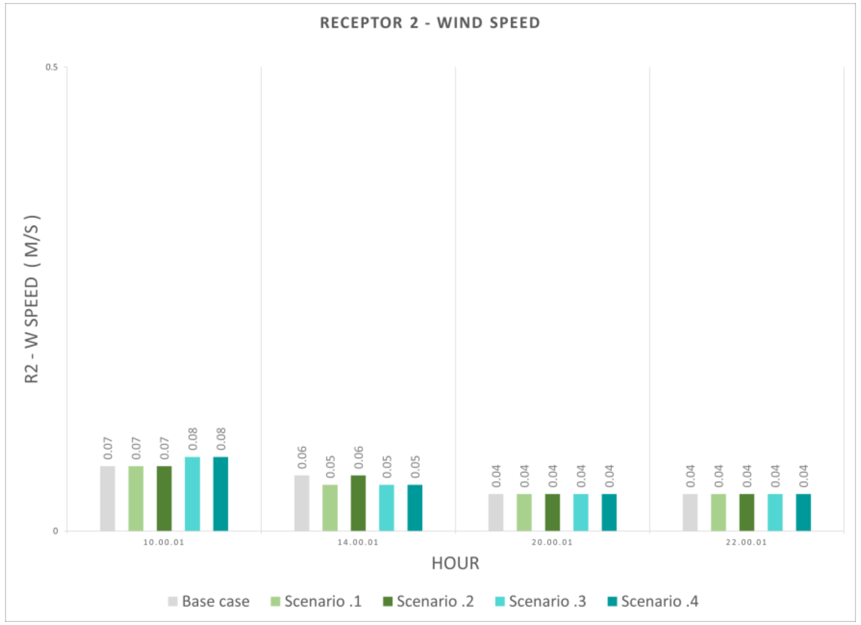


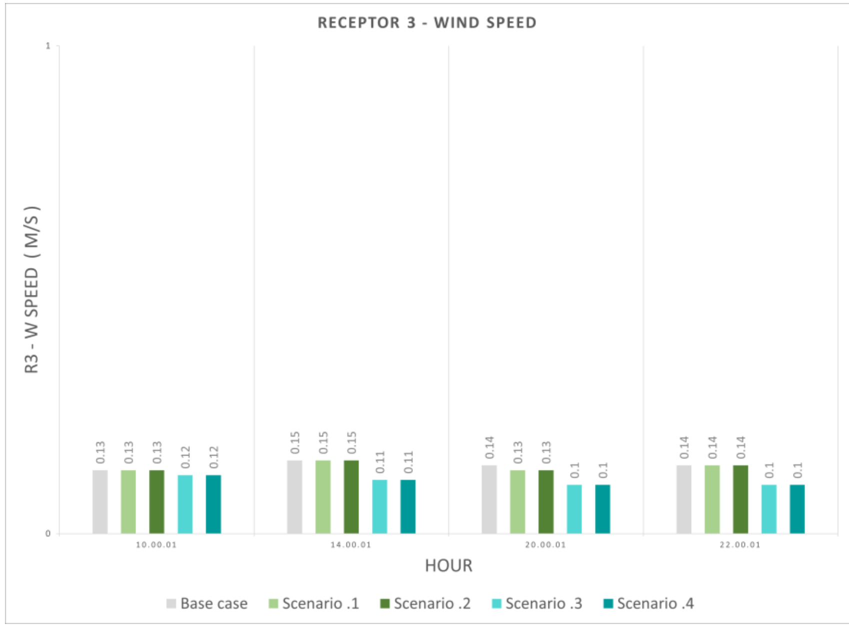


Relative humidity for the base case and four different scenarios at R1,R2 and R3

Results and discussion- Wind speed (W speed – m/s)

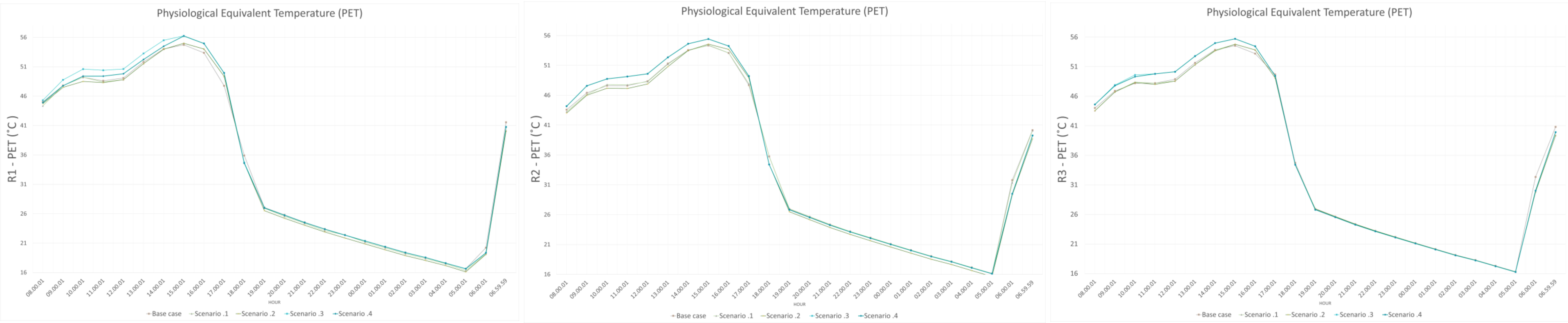






Wind speed for the base case and four different scenarios at R1,R2 and R3

Results and discussion- physiological equivalent temperature (PET - °C)



PET for the base case and four different scenarios at R1,R2 and R3

Results and discussion- physiological equivalent temperature (PET - °C)

Considering the average PET during the Day, scenario 2 is the most effective. However, the impact is limited to the microclimate around the vegetation and reduces with the distance from the wall. Moreover, this cooling impact is not enough to achieve outdoor thermal comfort levels. Especially that the sun is the main source of heat, and there is a limited shading effect in the canyon.

Conclusion

“How to design a ***Living Wall System*** *that can be integrated into the built environment Of* ***Damascus*** *and how efficient is the proposed design as an* ***Urban Heat Island mitigation strategy****? “*

Conclusion

*"How to design a **Living Wall System** that can be integrated into the built environment Of **Damascus** and how efficient is the proposed design as an **Urban Heat Island mitigation strategy**? "*

- Select drought-tolerant plants, suitable for Full Sun, semi-shade with little water consumption and low growth rate.
- Feasible artificial substrate with low weight and high water capacity. This can be achieved by mixing Growstones with peat.
- Using local material and fabrication technics. Giant reed is a good material for LWS
- Use self-standing hexagonal units. Because they are stable and have minimum deflection. Moreover, LWSs with hexagonal units are flexible, can adapt to different façade typologies, and have minimum deflection when creating them from woven reed fibers.
- Use a recirculating irrigation system and greywater treatment system to achieve low water consumption while ensuring the LWS is in good condition
- Maintain the LWS to check if anything is broken or damaged to increase the life expectancy of the LWS and benefit the most from it.

Conclusion

*“How to design a **Living Wall System** that can be integrated into the built environment Of **Damascus** and how efficient is the proposed design as an **Urban Heat Island mitigation strategy**? “*

- The higher the green coverage percentage, the more elevated the cooling impact of the LWS regardless the orientation of it.

- With 90% green coverage, a maximum reduction of 0.5°C in T is achieved at night. This reduction could help reducing cooling energy consumption by 1,5 % to 2,5 % for each building = 122.4 to 204 kWh = 95$ to 150$ yearly. This saving is significant when calculating for the whole urban canyon.

- 90% green coverage caused a maximum reduction of 0.7°C in T mrt during the day. This helps to improve outdoor thermal comfort during the daytime, which is the period people spend their time outdoors.

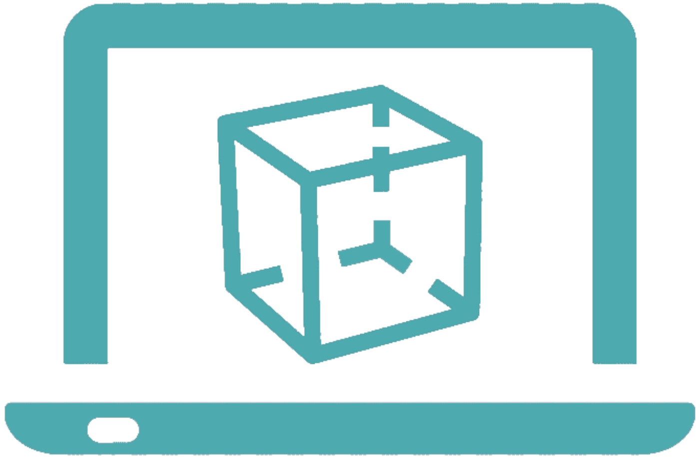
- 90% green coverage increases q rel by 1.67% compared to the base case, and the higher the relative humidity, the less the UHI is.

- 90% LWS helps in reducing PET values (between 0.3 -0.5°C compared to the base case) and improves outdoor thermal comfort.

- However, the cooling effect is limited to the air layer around the LWS and reduces with the increase in distance from the wall, and it has no impact on the local climate in the middle of the shallow urban canyon.

- 90% green coverage means 1500 m^2 of LWS, 2982 L of water each irrigating time, around 24000$ for greywater treatment systems, in addition to the cost of the LWS. When comparing these values with the cooling impact achieved, it can be concluded that LWS is not a feasible strategy to be applied in Urban canyons with the same characteristics as the studied. Therefore, it is wise to implement other strategies next to LWS for future work, such as green roofs and urban trees, which provide more shading. Then investigate the efficiency of these strategies. It is also essential to look into the energy performance of the buildings by taking into account the shading and insulation effect of LWS.

Limitation

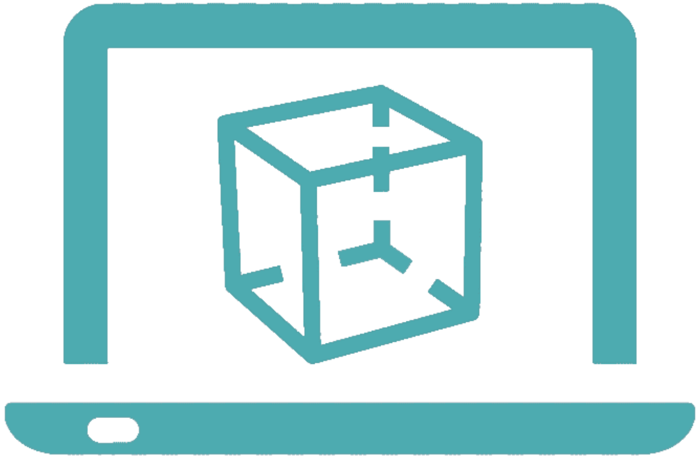


Simulation

The impact of LWS on indoor climate and energy consumption

Experimental testing

Further Research



Simulation different
urban canyon with other
mitigation strategy

Investigate the impact of LWS
on indoor climate and energy
consumption

Experimental testing
testing for giant reed
specimens from Damascus is
also needed.

Thank you

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Challenges – Design criteria

Low water consumption

Choosing the living wall system with the least moisture exchange with the surrounding environment.

Choosing evergreen species that are drought tolerant with low watering demand.

Using Substrate with high water capacity.

Using recirculating irrigation system (Close loop Irrigation system)
Retreating domestic grey water

Feasibility

Using local material and local fabrication techniques

Choosing native evergreen species which is available on Damascus market.

Low cost durable growing medium.

Using as little material as possible and taking an advantage of the overlapping between the units so that the container at the top irrigates the one underneath it.

Less environmental impact

Using material with low environmental impact.

Using as little as possible energy.

Structural Integrity

Check the structural stability of the system.
Using lightweight but stiff units.

x

Light weight growing medium.

X

Low maintenance

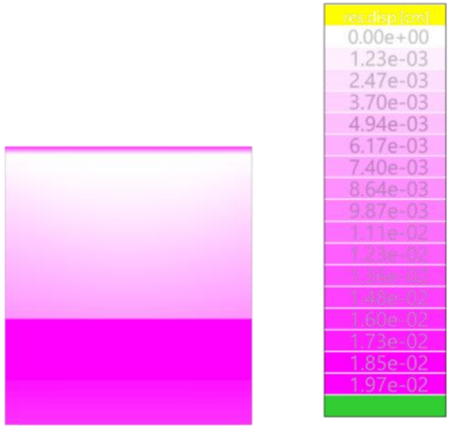
Ease of replacing damaged parts.
The accessibility of the system.

Using plants with a low growth rate.
Using plant that prevents insects.

Using artificial growing medium.

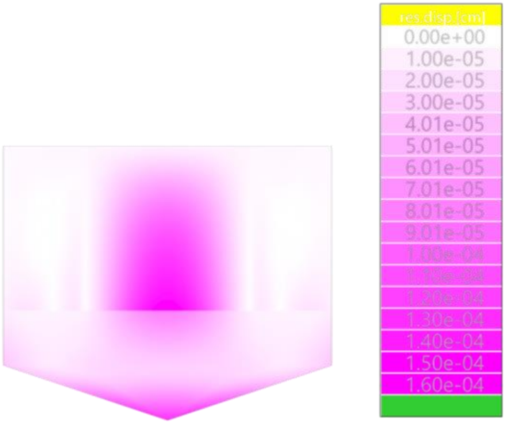
Ease of replacing and repairing damage parts.

Second step: check the structural performance



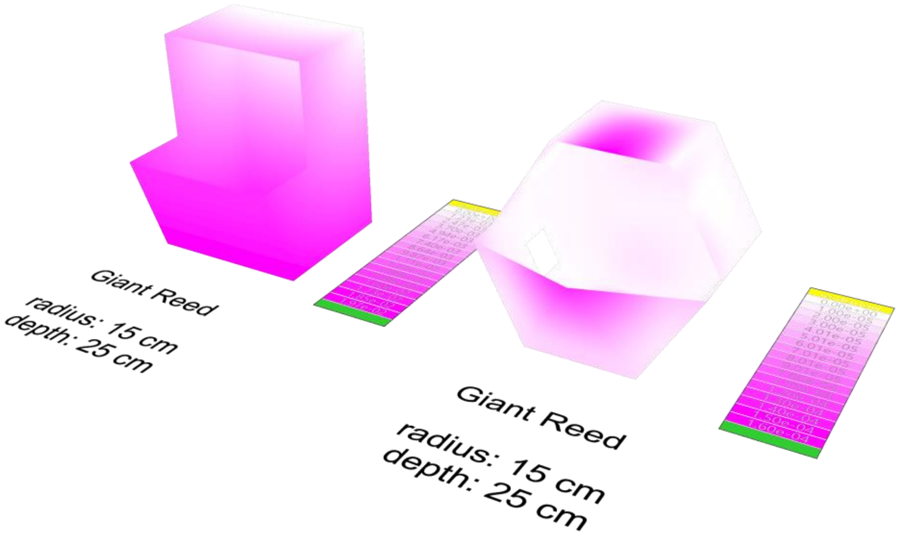
Giant Reed

radius: 15 cm
depth: 25 cm



Giant Reed

radius: 15 cm
depth: 25 cm

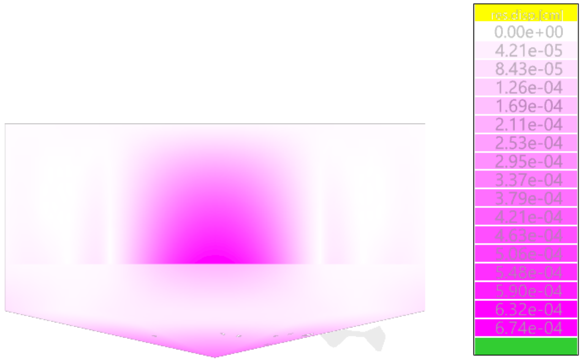


Maximum deformation is

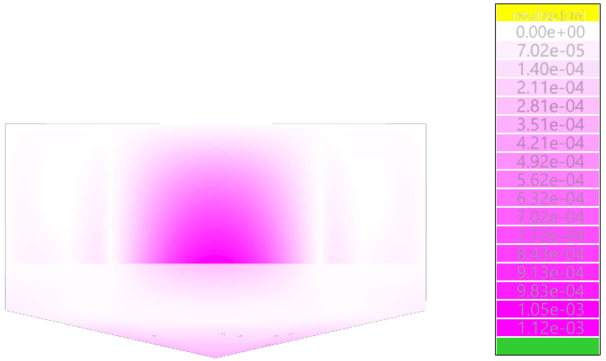
Hexagonal basket with 30cm diameter = 1.55*10-4 cm

Rectangular basket with same capacity = 2.22*10-2 cm

Second step: check the structural performance

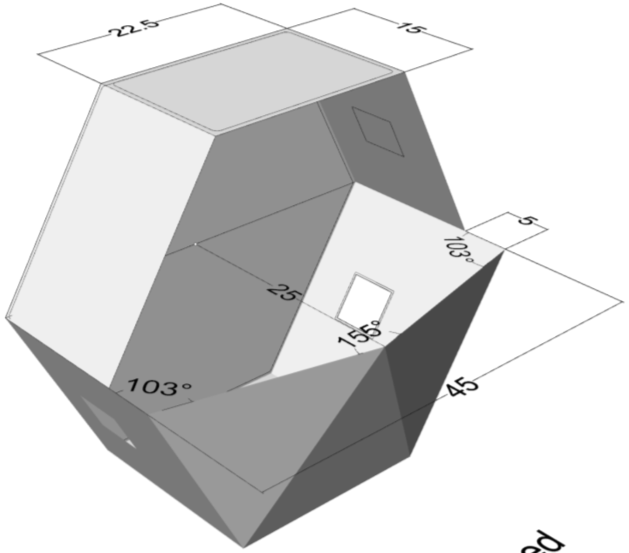


polypropylene
Price: 1.35 USD/Kg
thickness: 0.4 cm



Giant Reed

radius: 22.5 cm
depth: 25 cm



Giant Reed
radius: 22.5 cm
depth: 25 cm

Maximum deformation is

Giant reed hexagonal basket with 45cm diameter = 1.12 *10-3 cm

Polypropylene reed hexagonal basket with 45cm diameter = 2.22*10-2 cm

The sixth step: Final design