THE EFFECT OF BIOPHILIC GLARE CONTROL ON OCCUPANT PERCEPTION:

A laboratory experiment

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Advisory board: Kynthia Chamilothori

Company involved: VideowindoW

TU Delft

THE GREEN VILLAGE

INTRODUCTION

LITERATURE REVIEW

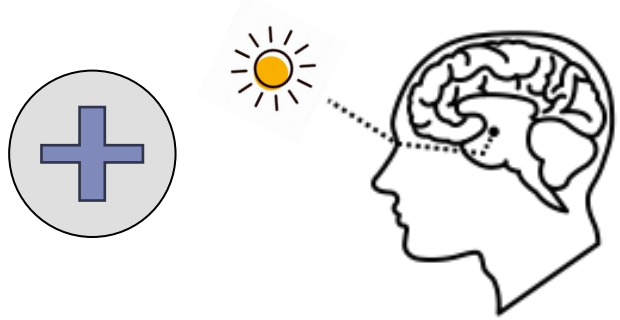
EXPERIMENTAL DESIGN

RESULTS & CONCLUSIONS

FAÇADE CELL

(Luna-Navarro A. et al., 2020)

DAYLIGHTING



Regulating sleep

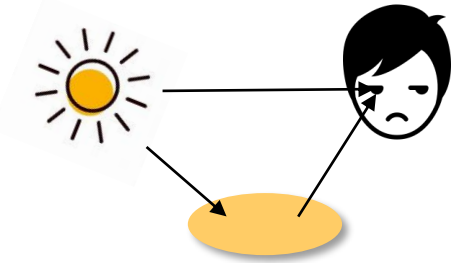
Productivity

Concentration

Alertness

Mood

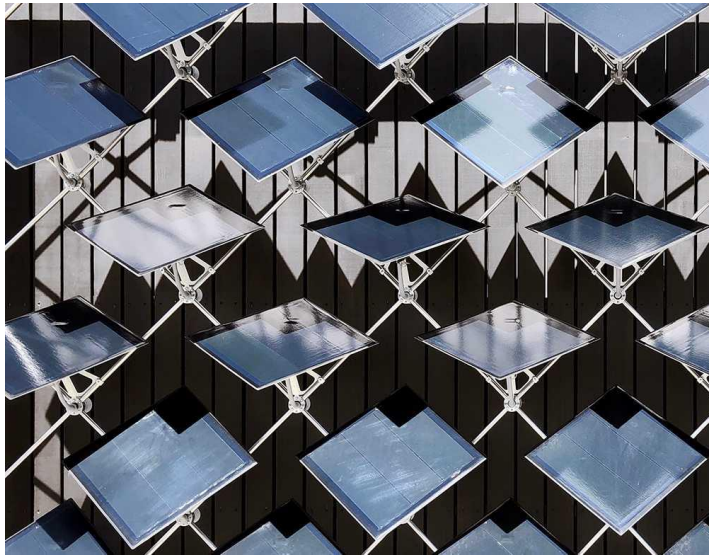
Thermal discomfort



Glare

SHADING SYSTEMS & CHALLENGES

FACADES AND OCCUPANT INTERACTION



Adaptive

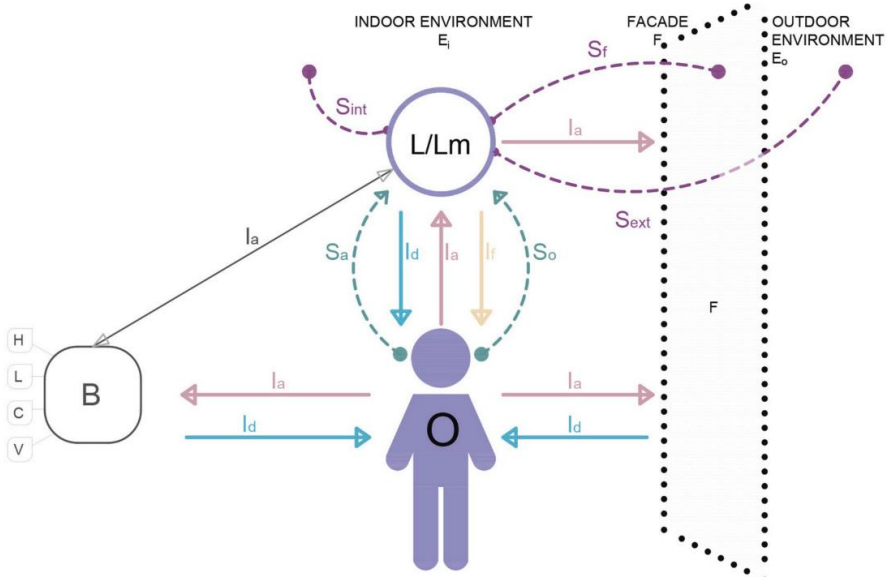
Smart

Kinetic

Responsive

Dynamic

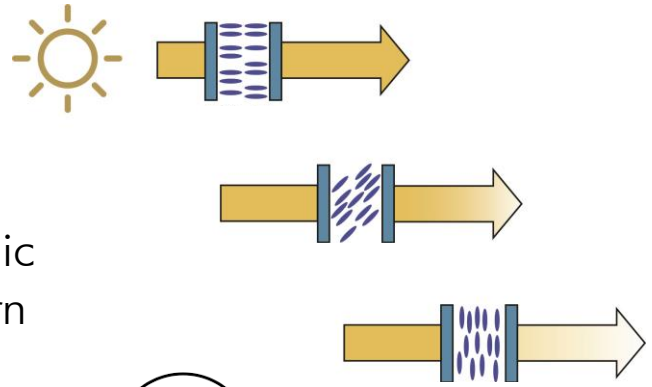
Intelligent



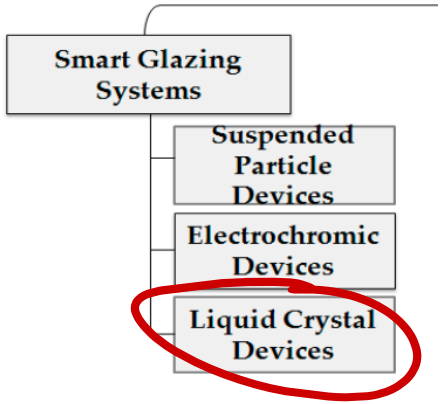
(Luna-Navarro A. et al., 2020)

VIDEOWINDOW

Biophilic pattern

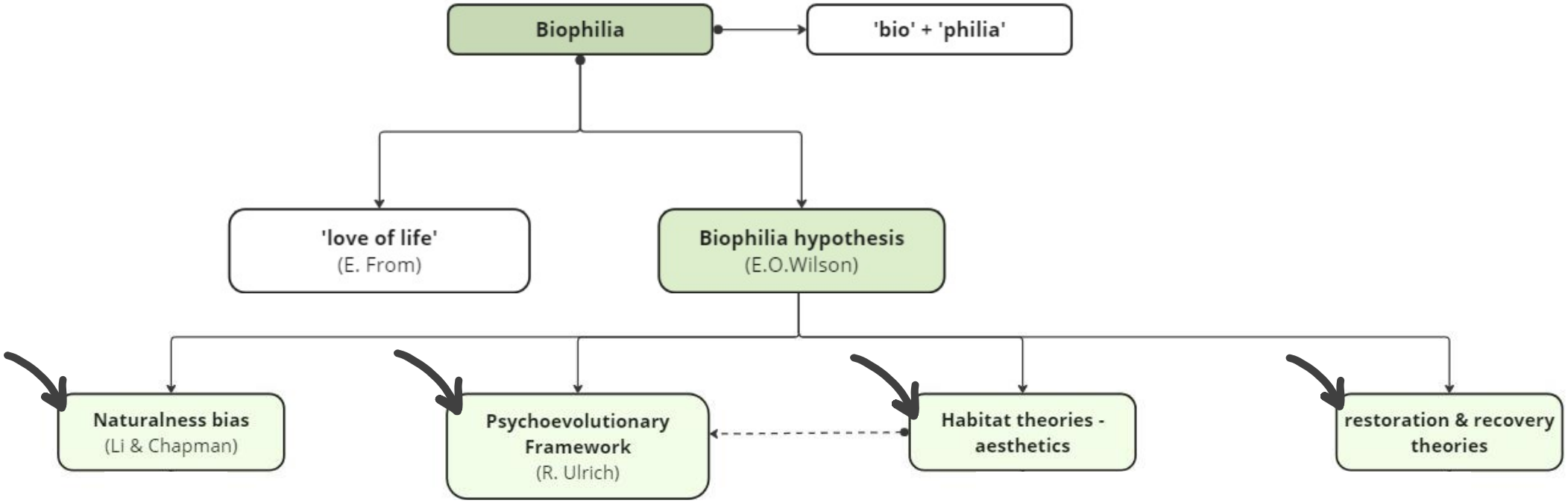


VideowindoW



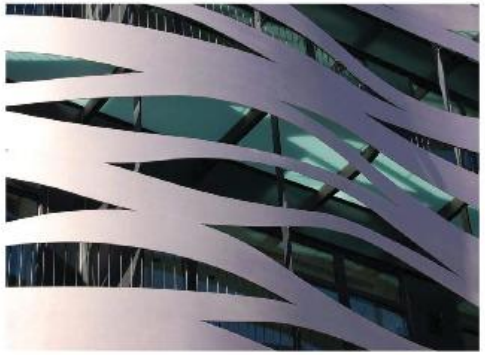
(Dakheel J. et al., 2017)

BIOPHILIA CONCEPT & RELATED THEORIES



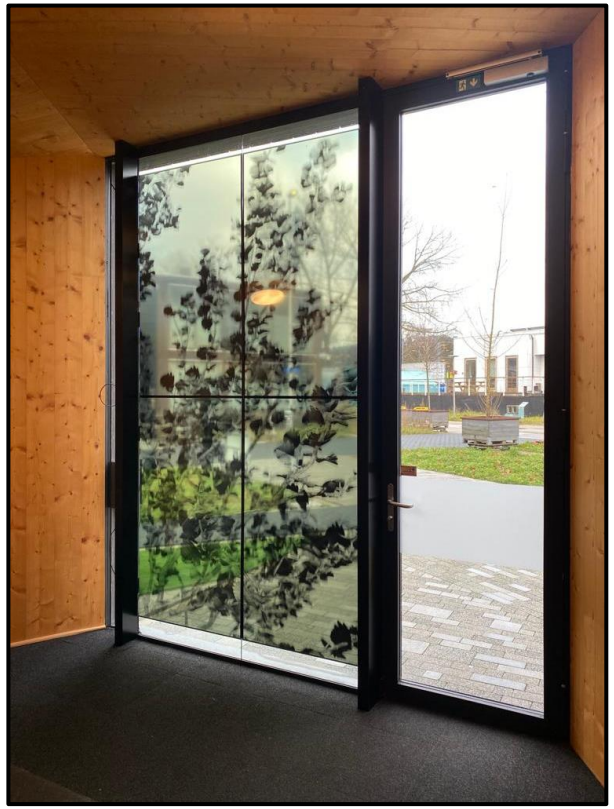
The innate tendency to like natural + urge for affiliation

BIOPHILIC DESIGN & BIOPHILIC EXPERIENCE

	Direct experience of nature	Indirect experience of nature	Experience of space & place
Building level	 Antoni Gaudi, La Sagrada Familia	 Santiago Calatrava, Oriente Station	 Frank Lloyd Wright, Falling water
Facade component	 Stefano Boeri, Bosco Verticale	 Toyo Yto, Suites Avenue	 Ned Kahn, Brisbane Airport

BIOPHILIC CHARACTERIZATION

Light penetration



Direct experience

Natural geometry - fractal

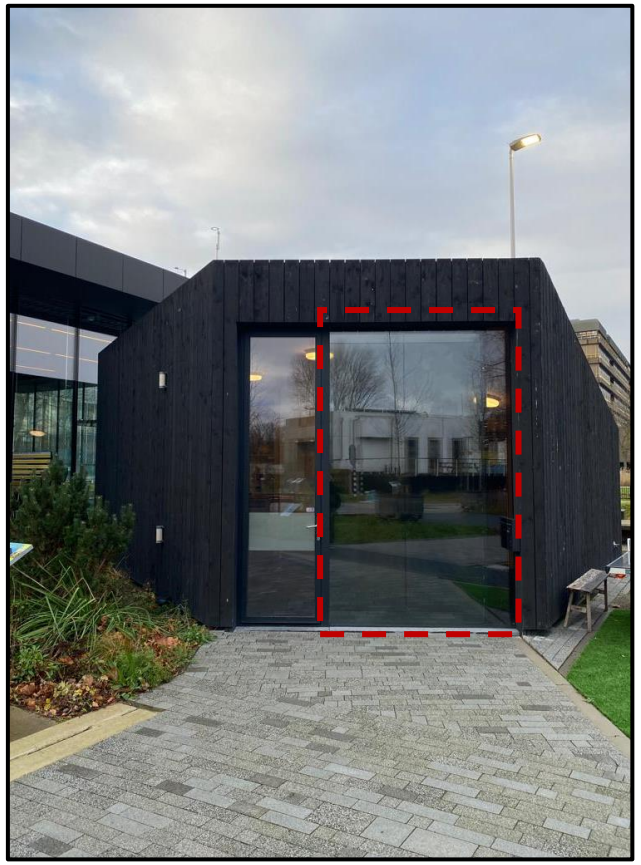
Indirect experience

Motion

Experience of space and place

LOCATION-GV

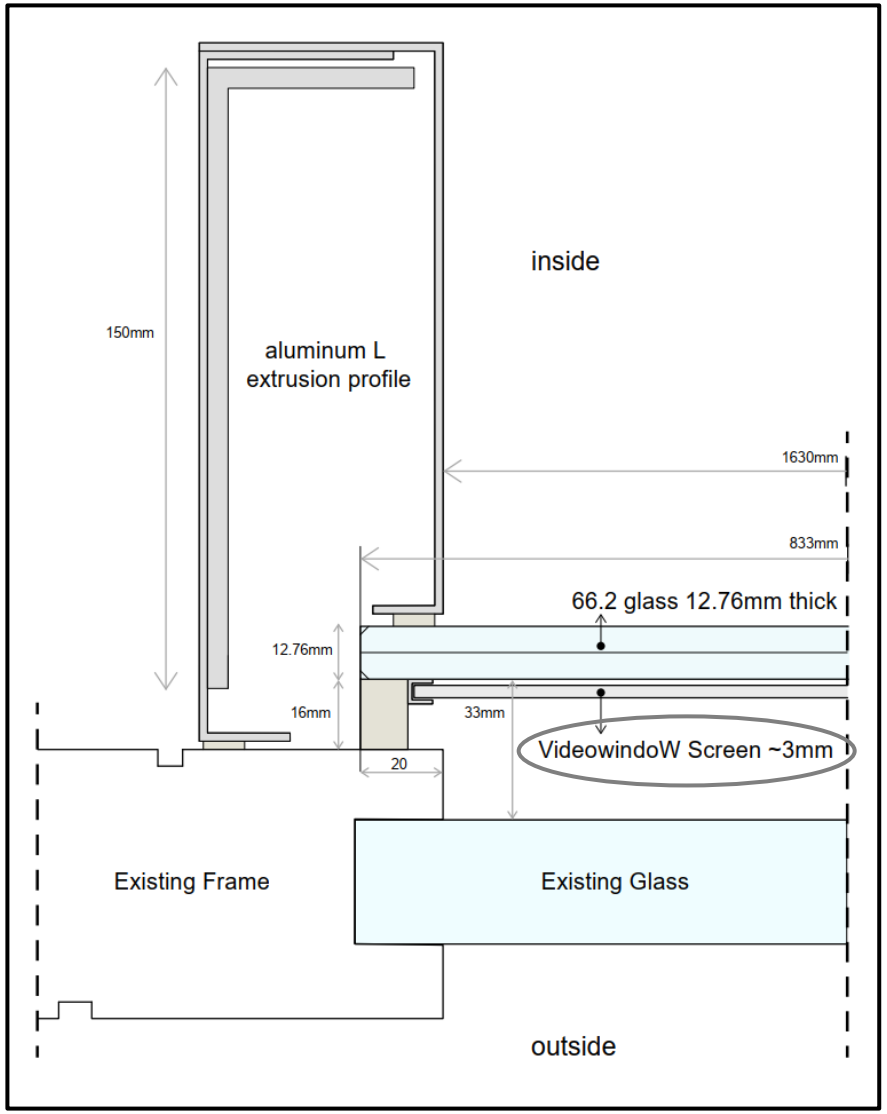
GV – Southeast orientation (google maps)



Dedicated part of the facade

View from the inside

BUILD-UP



Laminated 'safety' glass 66.2 (t = 12.76 mm)

- 2 glass plates of t = 6 mm &
- 2 transparent PVB films of t(total) = 0.76 mm in between

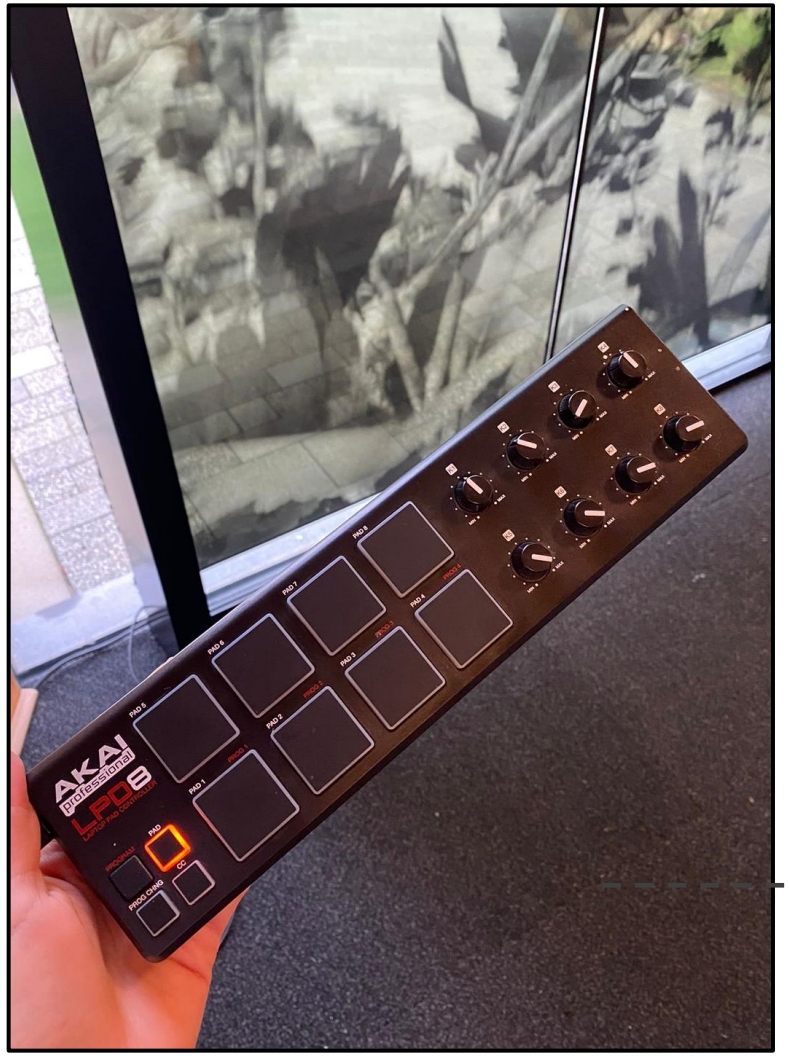
VideowindoW Screen (t=3mm)

- 4 screens 65'' Full HD modules – TFT modules
- Pixel size: 0.74 mm*0.74 mm
- Pixels: 1922*1083

Existing glass

Supporting components & controller

CONTROL



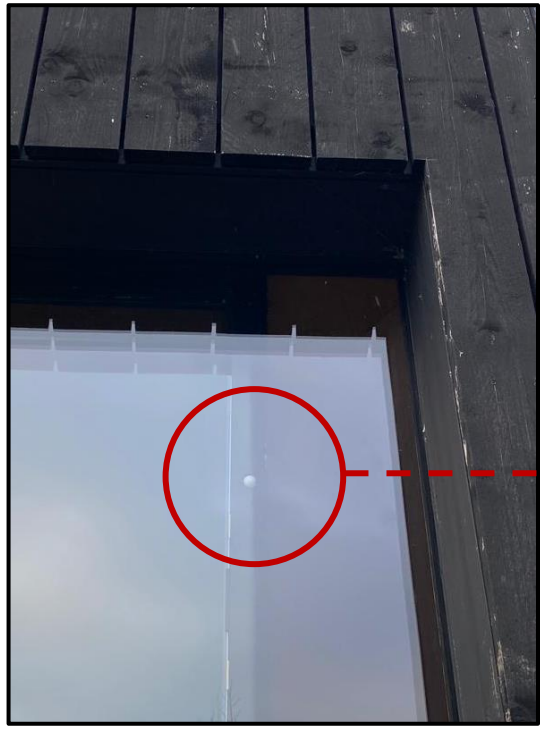
* dynamic{}	camera_offset	0.5
	camera_speed	1
	* camera_template	FrontCloseup
	camera_zoom	0.5
	growth_speed	1
	shadow_lightness	0.4
	wind_strength	0.5
graphics_quality		VeryHigh
tree_seed		139278
* tree_type		Oak

Adjustable parameters

- Content
- Size
- Growth speed
- Contrast
- Wind - motion
- Rotation

\+ Dimming effect

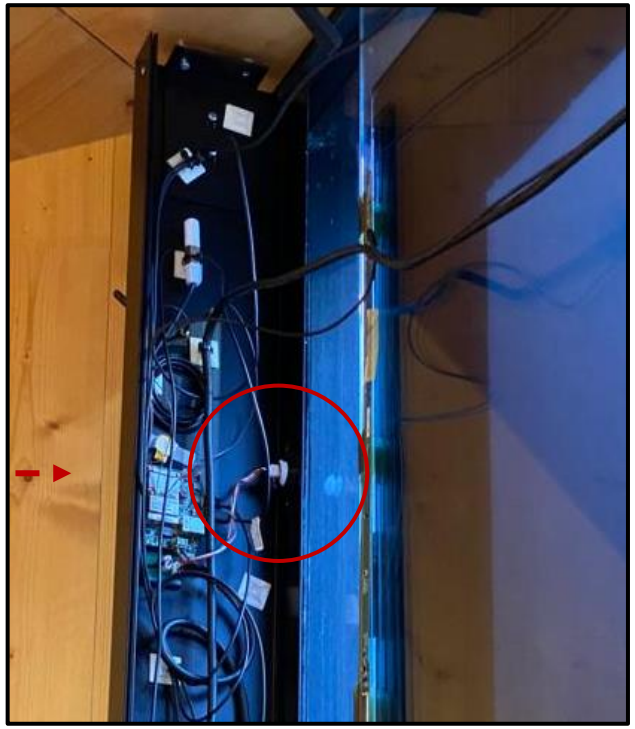
BIOPHILIC ACTUATION SYSTEM



Outdoor light sensor

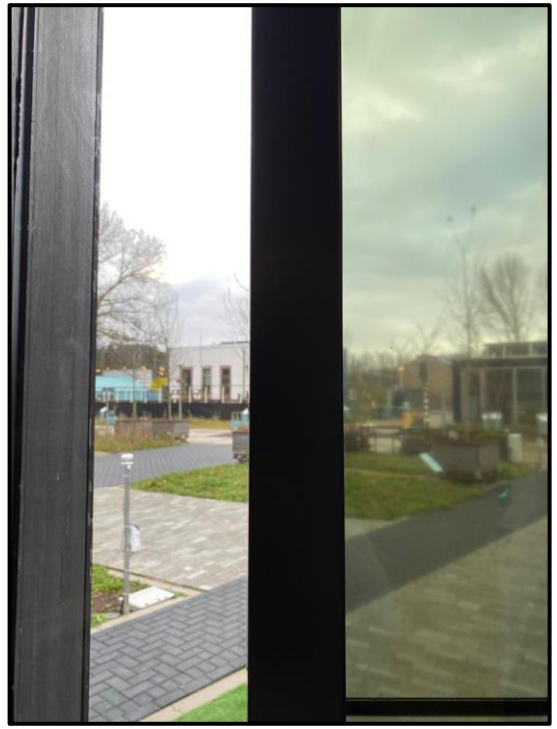
Collection of outdoor data in lux

(0-100.000 lux)



Supporting components

Pass the value to the system
&
Modify the content



Algorithm

Reach a desired level of light transmittance
&
generate of the video

Facade

Physical Representation of the pattern

PROBLEM STATEMENT 

A novel shading product that controls façade transparency has emerged, which can generate a variety of biophilic patterns and movements.

However, the impact of this technology on discomfort glare, outside view perception, and visual satisfaction, remains uncertain.

Controlling this technology properly might have a positive impact on occupants' well-being.

RESEARCH QUESTION

Does integrating biophilic patterns on building facades influence occupants' perception compared to non-natural patterns or clear conditions?

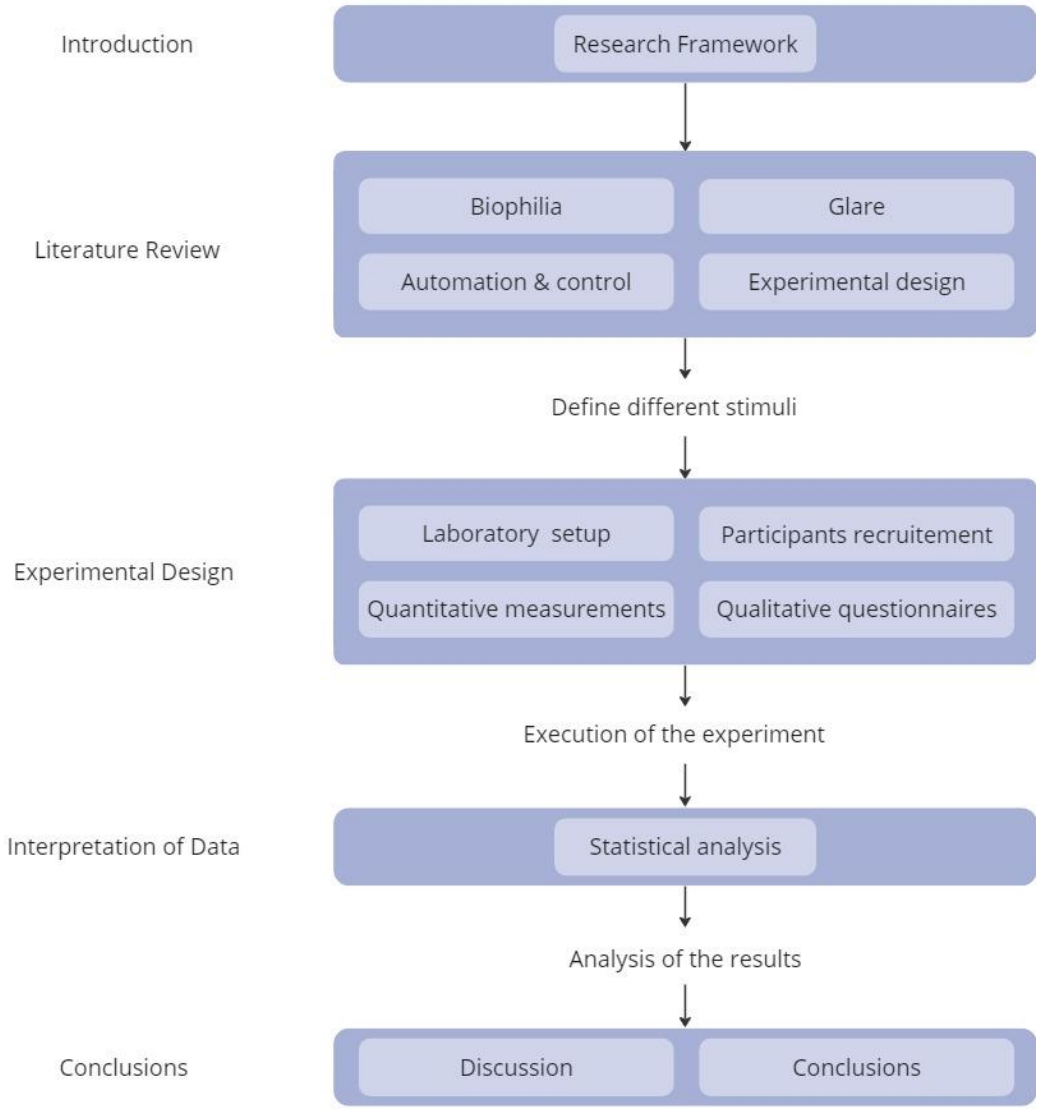
Background questions

- What is the evidence of the impact of biophilic design and patterns on occupants?
- What are the factors that affect discomfort glare?
- What are the challenges of automation systems according to occupant perception?

Sub-questions

- Does the pattern affect occupants' glare sensation?
- Does the pattern affect visual comfort and daylight satisfaction?
- Does the pattern affect satisfaction with the outdoor view?
- Does the pattern itself affect visual satisfaction in terms of aesthetics?
- Which pattern is most preferred by occupants based on their overall satisfaction and perceived connection with nature?

APPROACH & METHODOLOGY



Theoretical part

Practical part

Interpretation of data – Results

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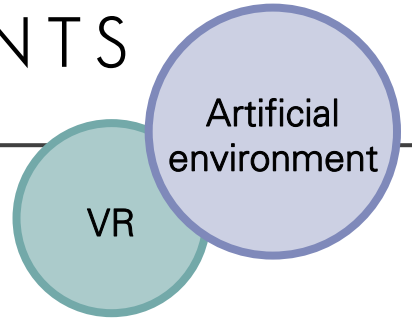
EVIDENCE ON BIOPHILIC DESIGN ON OCCUPANTS

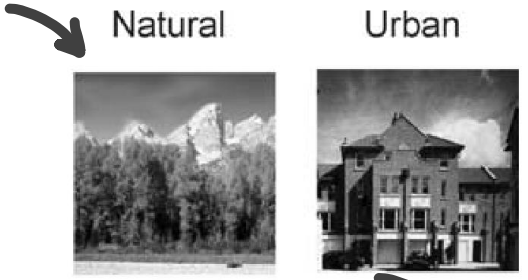


Natural Source (light)

Natural Content (image - view)

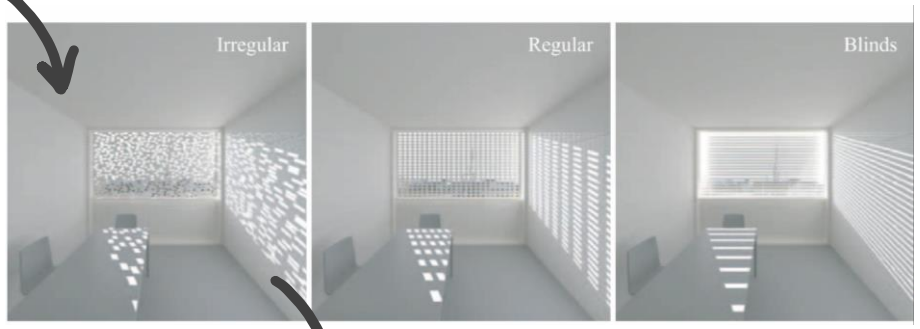
Natural Patterns (projected-rendered)

Natural Pattern (VR facade)

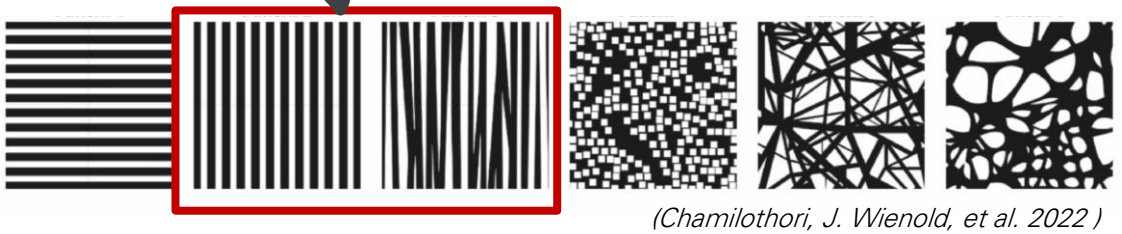


(Tuaycharoen et al. 2005)

(Abboushi et al. 2019)



(Chamilothori, Chinazzo, et al. 2019)



(Chamilothori, J. Wienold, et al. 2022)

EVIDENCE ON BIOPHILIC DESIGN ON OCCUPANTS

Real environment

Natural Content (window view)

(Tuaycharoen et al. 2007)

Natural Pattern (window)

No significant differences in visual comfort, visual interest, view satisfaction

Obstruction?

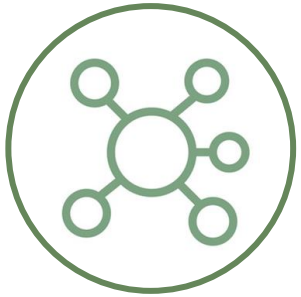
(Abboushi, Elzeyadi, Wymelenberg, et al. 2021)

GLARE FACTORS

Lighting

- Luminance of the glare source
- Adaptation level (vertical and background illuminance)
- Contrast effect
- Saturation effect
- Size of the glare source as seen by the observer
- Position of the glare source as seen by the observer

Context



- View direction and position
- Attractiveness of the view outside
- Room temperature
- Time of the day
- Season
- Task difficulty
- Glare rating scales and experimental design

Observer

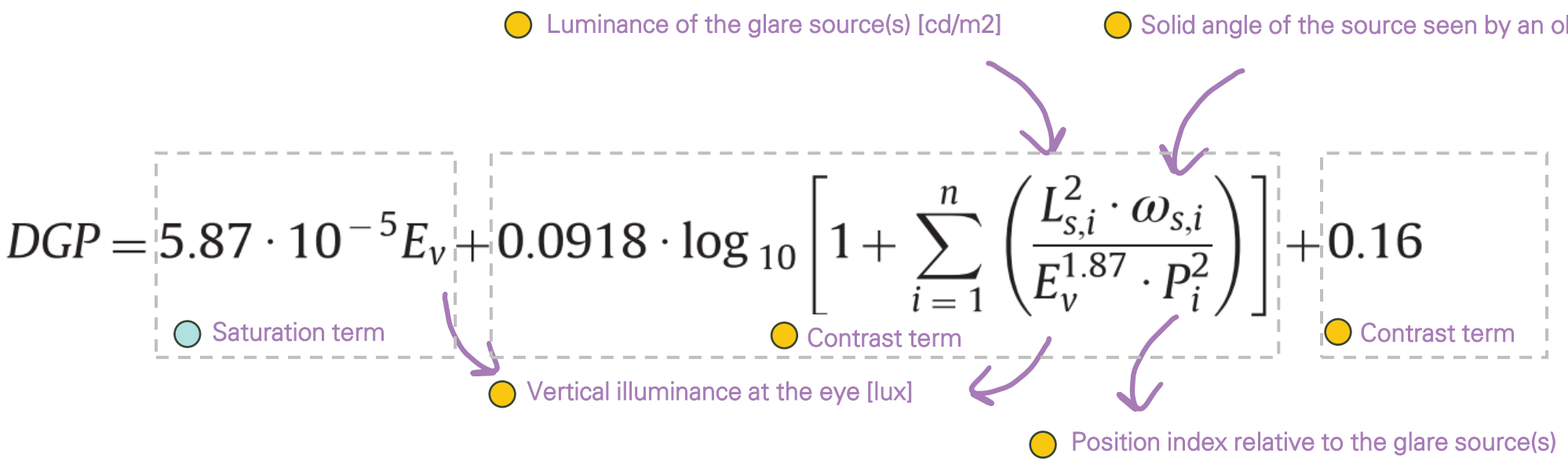
- Gender
- Age
- Culture
- Optical correction
- Contrast sensitivity
- Emotional state
- Caffeine ingestion
- Fatigue

Influence factor scale

Almost certain | More likely | Somewhat likely | inconclusive | Almost certainly null

(Clotilde p. et al., 2018)

DAYLIGHT GLARE PROBABILITY(DGP)



0.45 < DGP < 0.80 : intolerable
0.40 < DGP < 0.45 : uncomfortable
0.35 < DGP < 0.40 : noticeable
0.20 < DGP < 0.35 : imperceptible

max
min

Influence factor scale

Almost certain More likely

EVIDENCE ON FAÇADE AUTOMATION & CONTROL

Pros

- Energy efficiency
- Keep good IEQ
- Feedback systems

?

Cons

- Lack of understanding of user individual requirements on daylight, view
- Lack of understanding of the impact of control strategies on users
- Can be considered disruptive

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AIM & METHODOLOGY

Aim

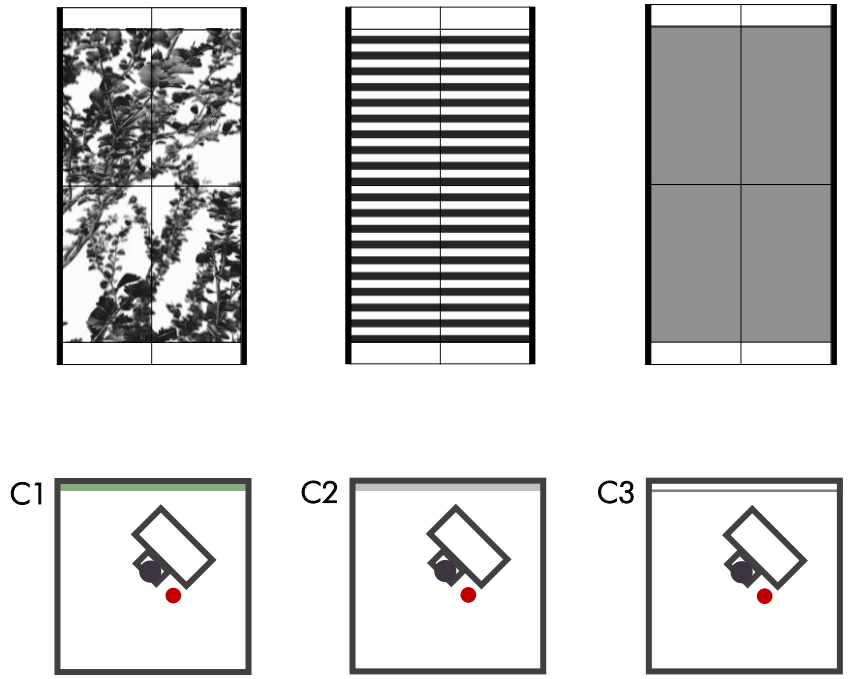
Compare the effect of (static) biophilic patterns on building façade with non-natural patterns and homogeneous-clear conditions on occupant perception.

Methodology

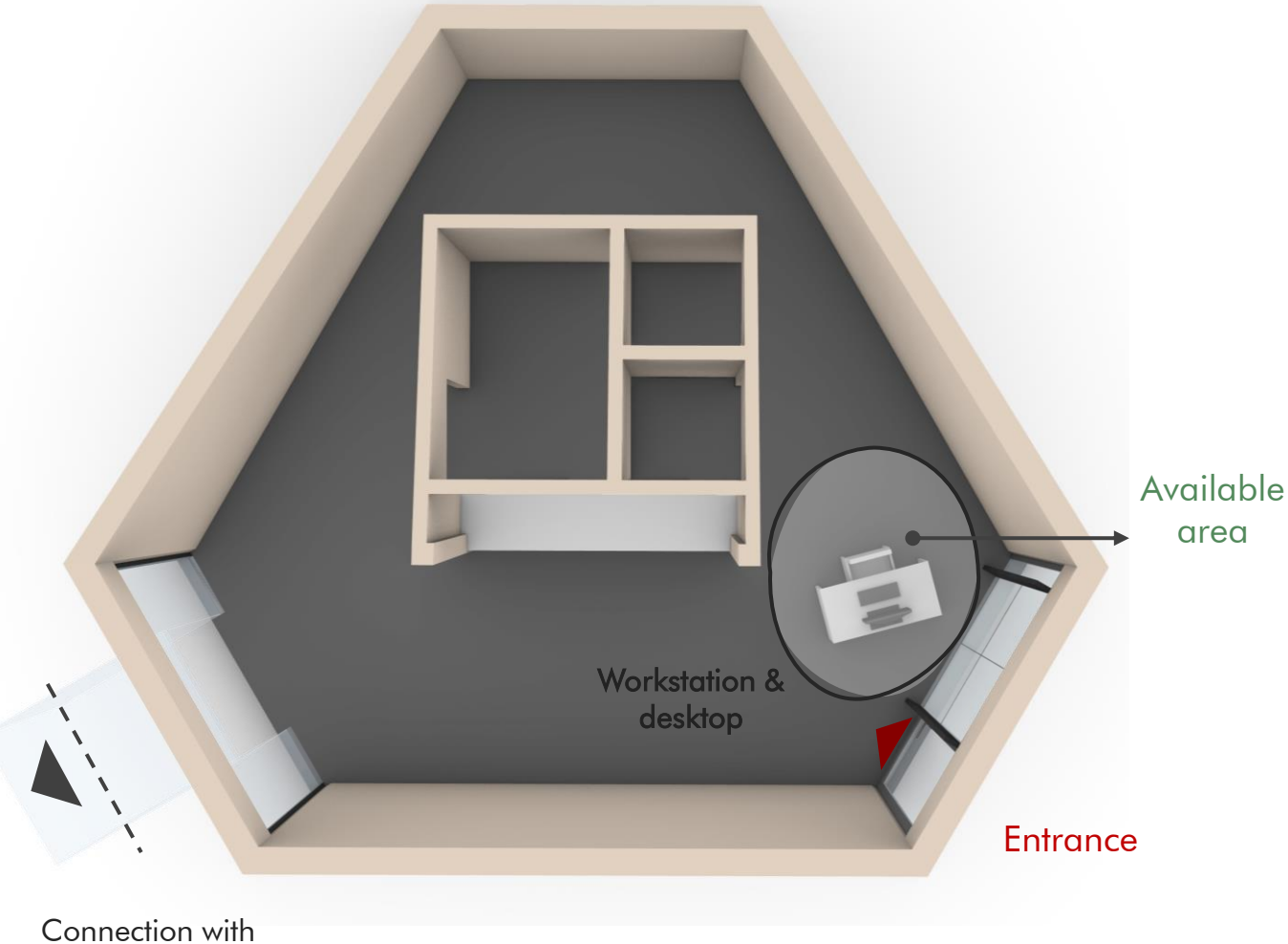
Collect:

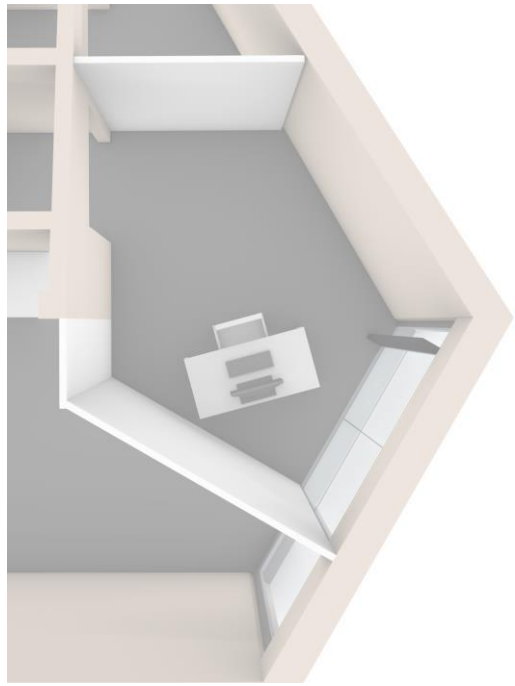
- Quantitative data: environmental measurements through equipment
- Qualitative data: user perception through questionnaires

Through an experiment at the Nonohouse building at the Green Village



ROOM LAYOUT – PARTITIONS



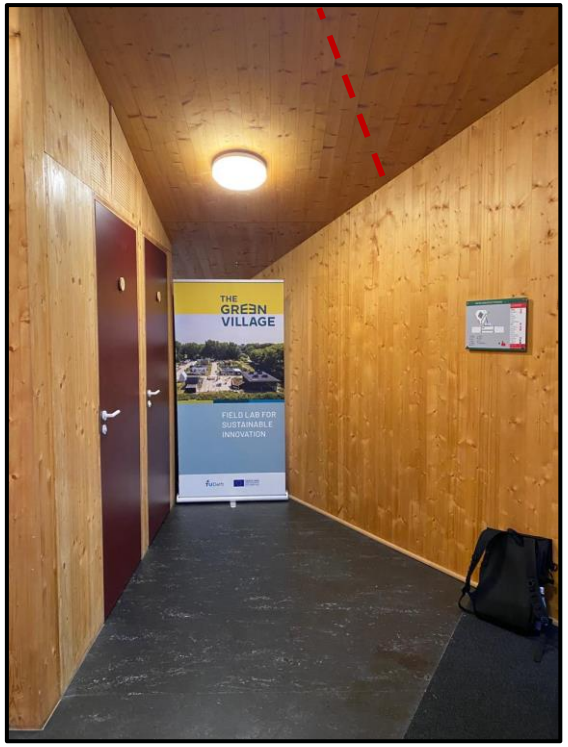


C1

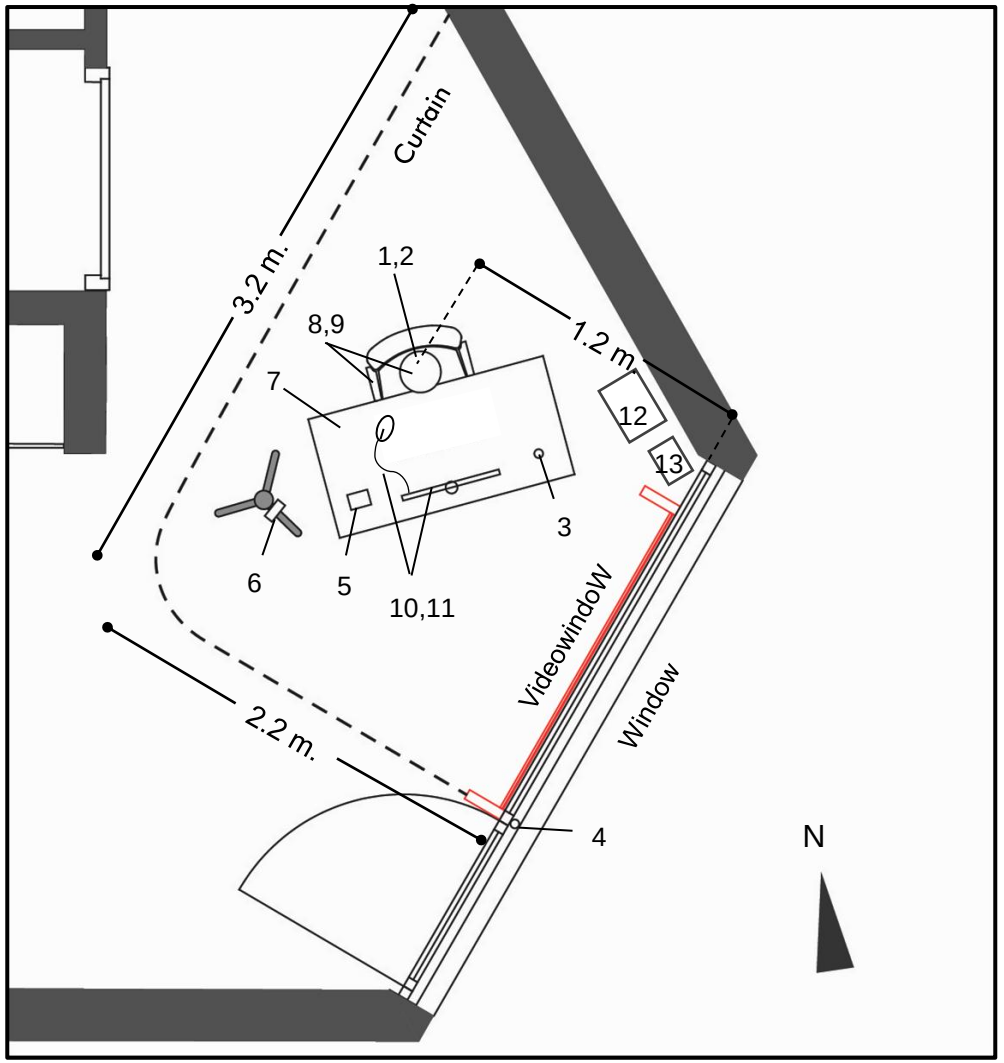
Option selected under communication with the Green Village

C2

ARTIFICIAL LIGHTING & CURTAIN DESIGN



EQUIPMENT AND SET-UP



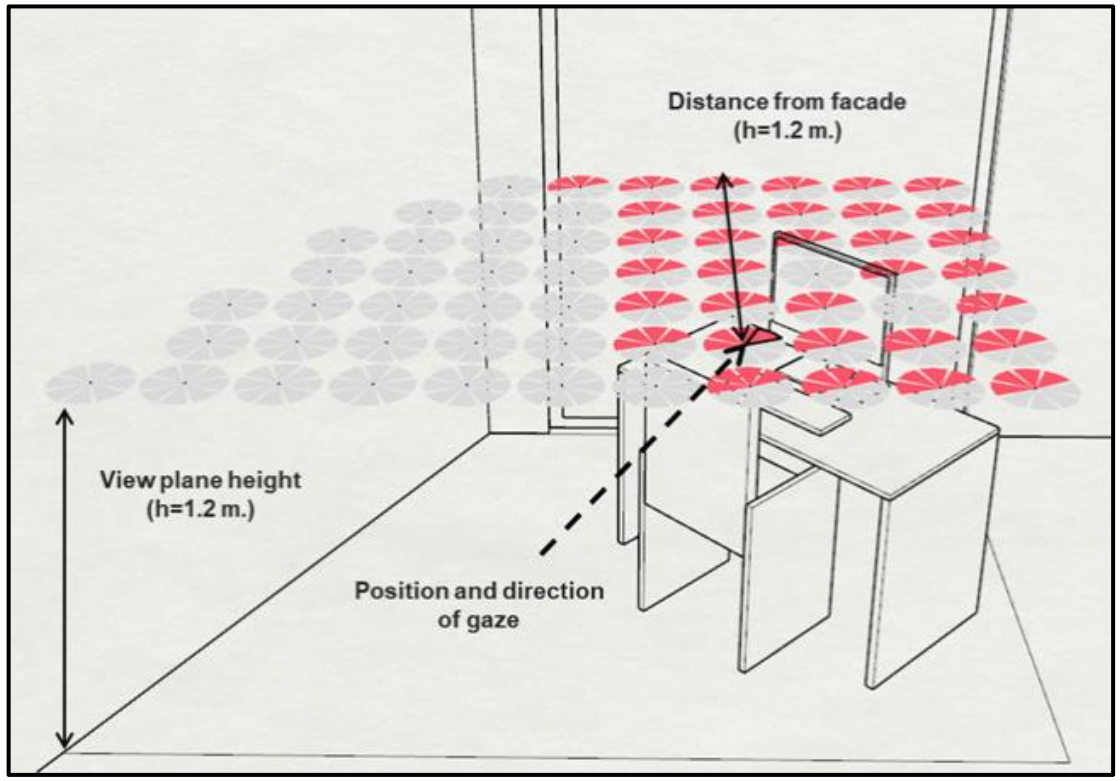
Equipment legend:

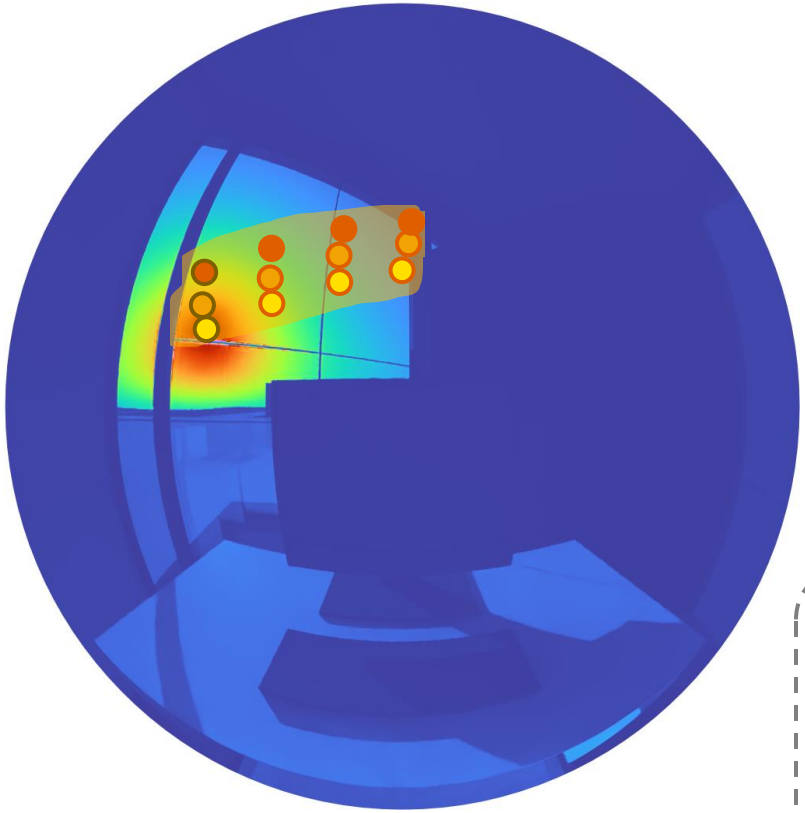
1. Canon EOS 70D camera
2. Konica Minolta illuminance meter
3. Li-cor illuminance meter
4. Li-cor illuminance meter
5. Hobo
6. Hobo
7. Workstation
8. Desk chair
9. Subject's head
10. Mouse
11. Monitor
12. Laptop connected to monitor
13. Alpha-log

EQUIPMENT AND SET-UP

1. Canon EOS 70D camera
2. Konica Minolta illuminance meter
3. Li-cor illuminance meter
4. Li-cor illuminance meter
5. Hobo
6. Hobo
7. Workstation – desk

TEST SESSION UNDER DIRECT SUN





March 1

March 15

March 31

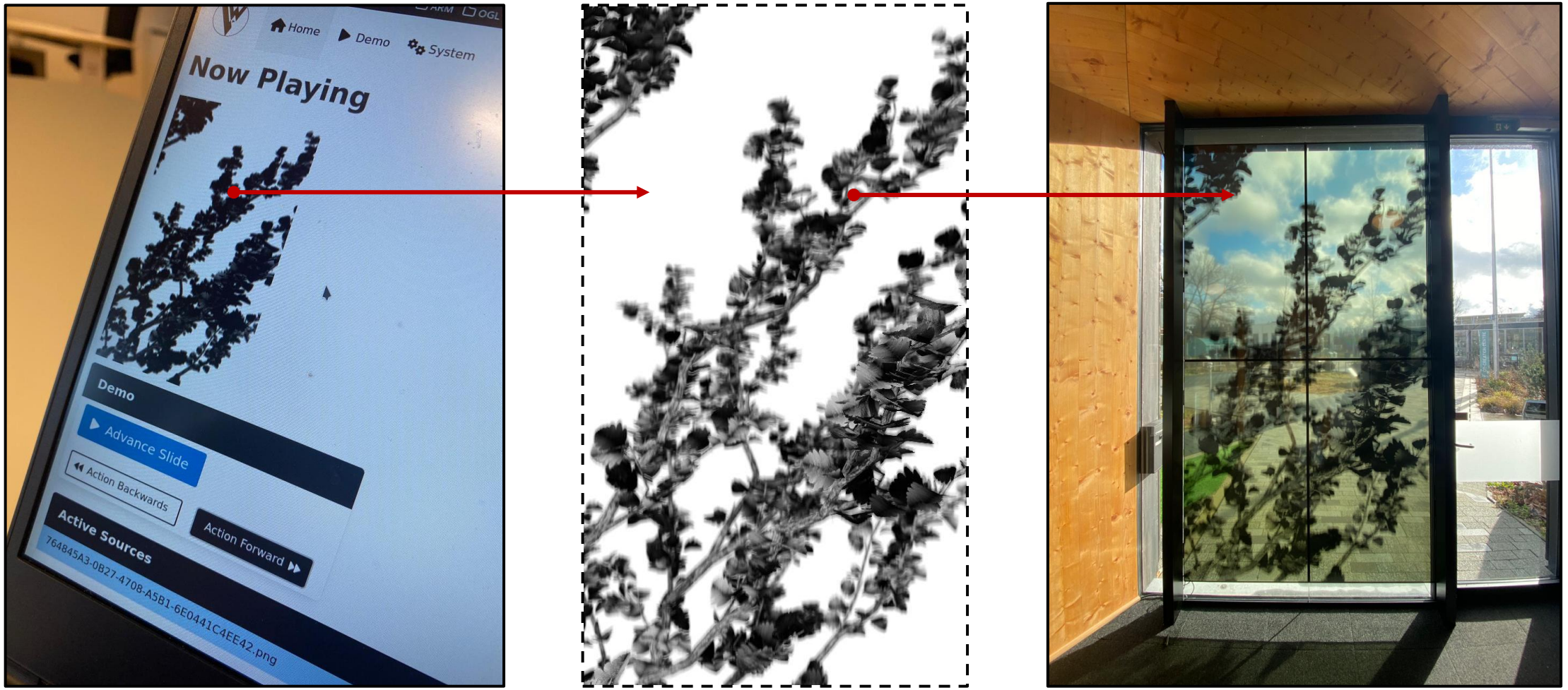
Sun position at 9:00, 10:00, 11:00, 12:00

Test sessions:

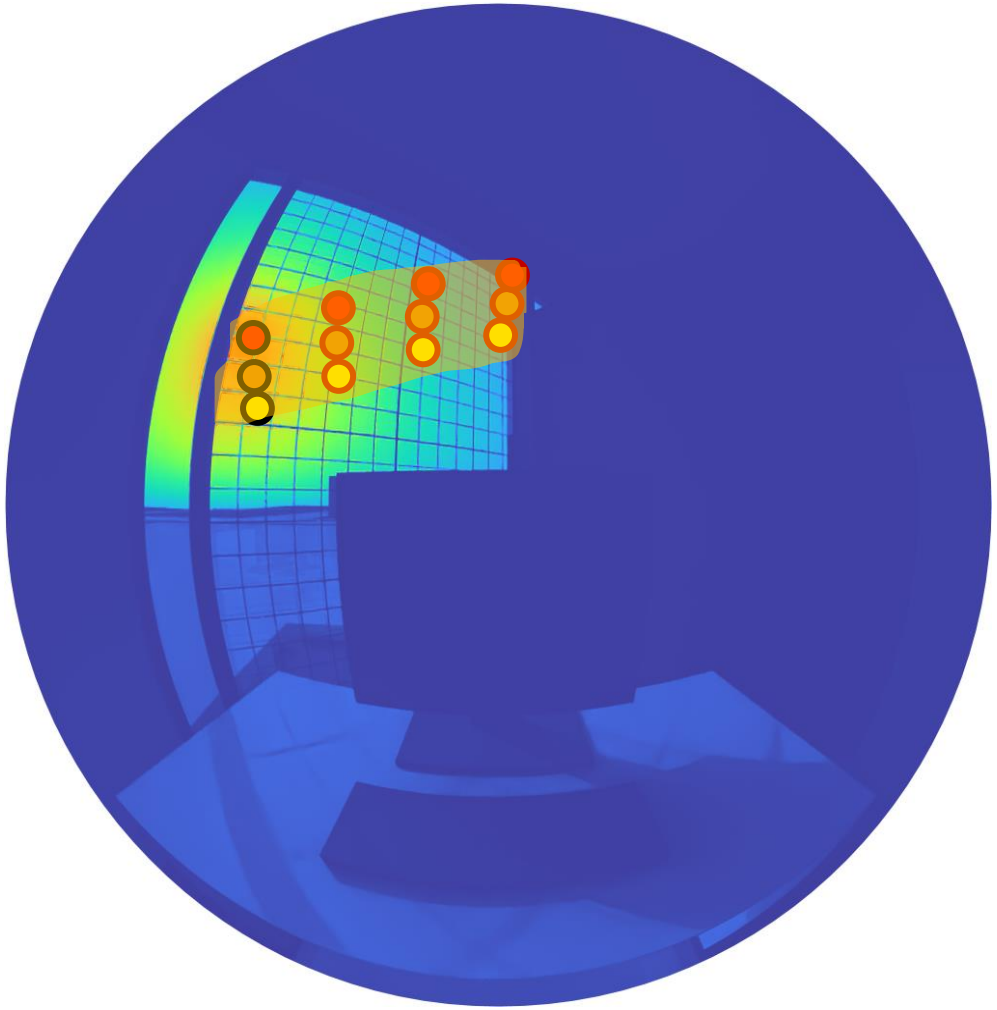
(A) 9:00 - 10:30

(B) 10:30 - 12:00

STATIC BIOPHILIC PATTERN



SUN POSITION IN THE FAÇADE GRID TOOL

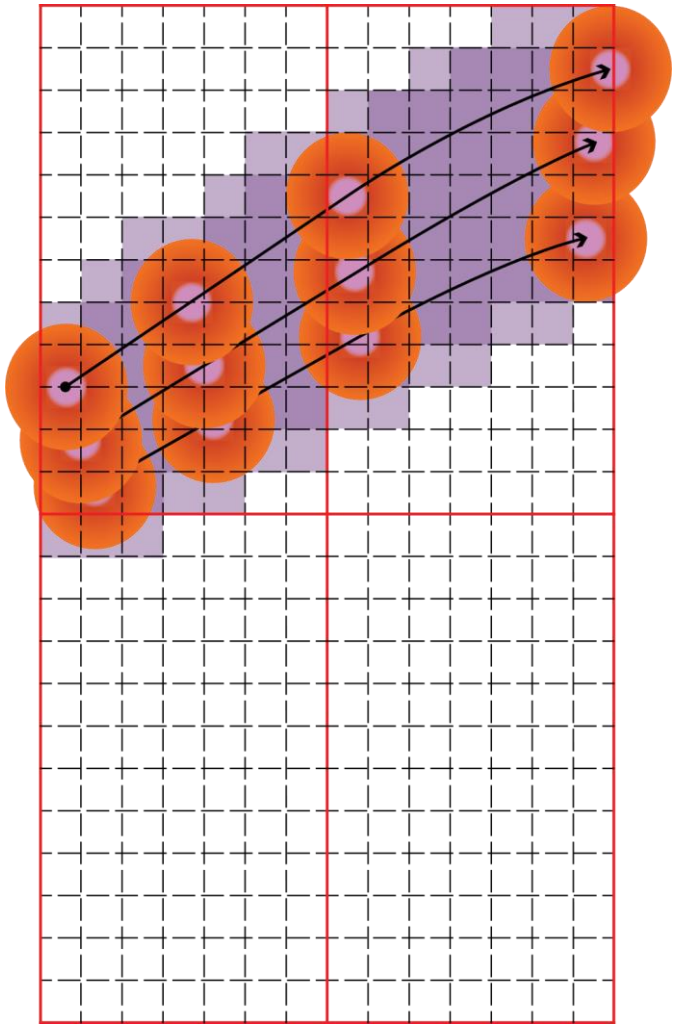


March 1

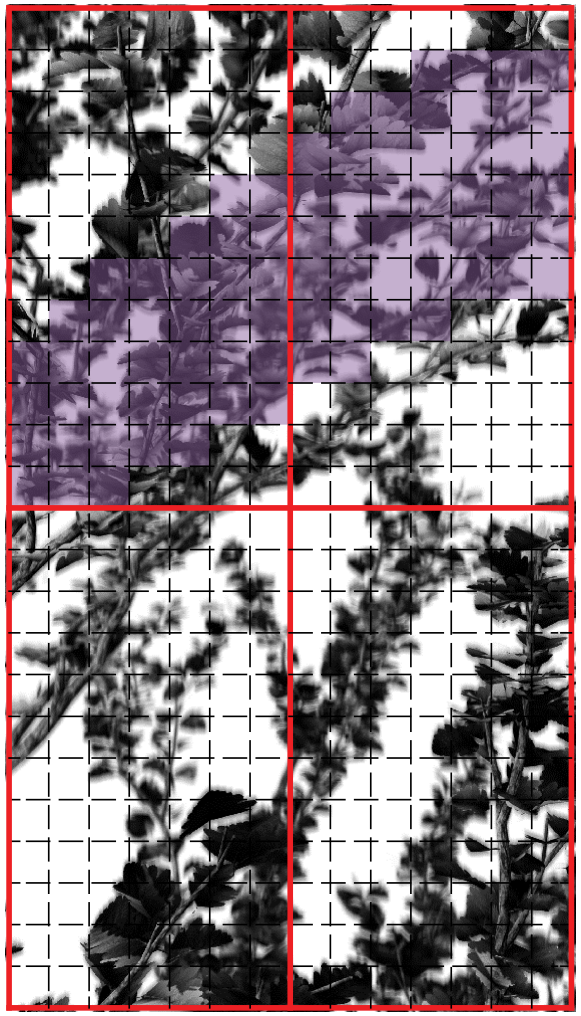
March 15

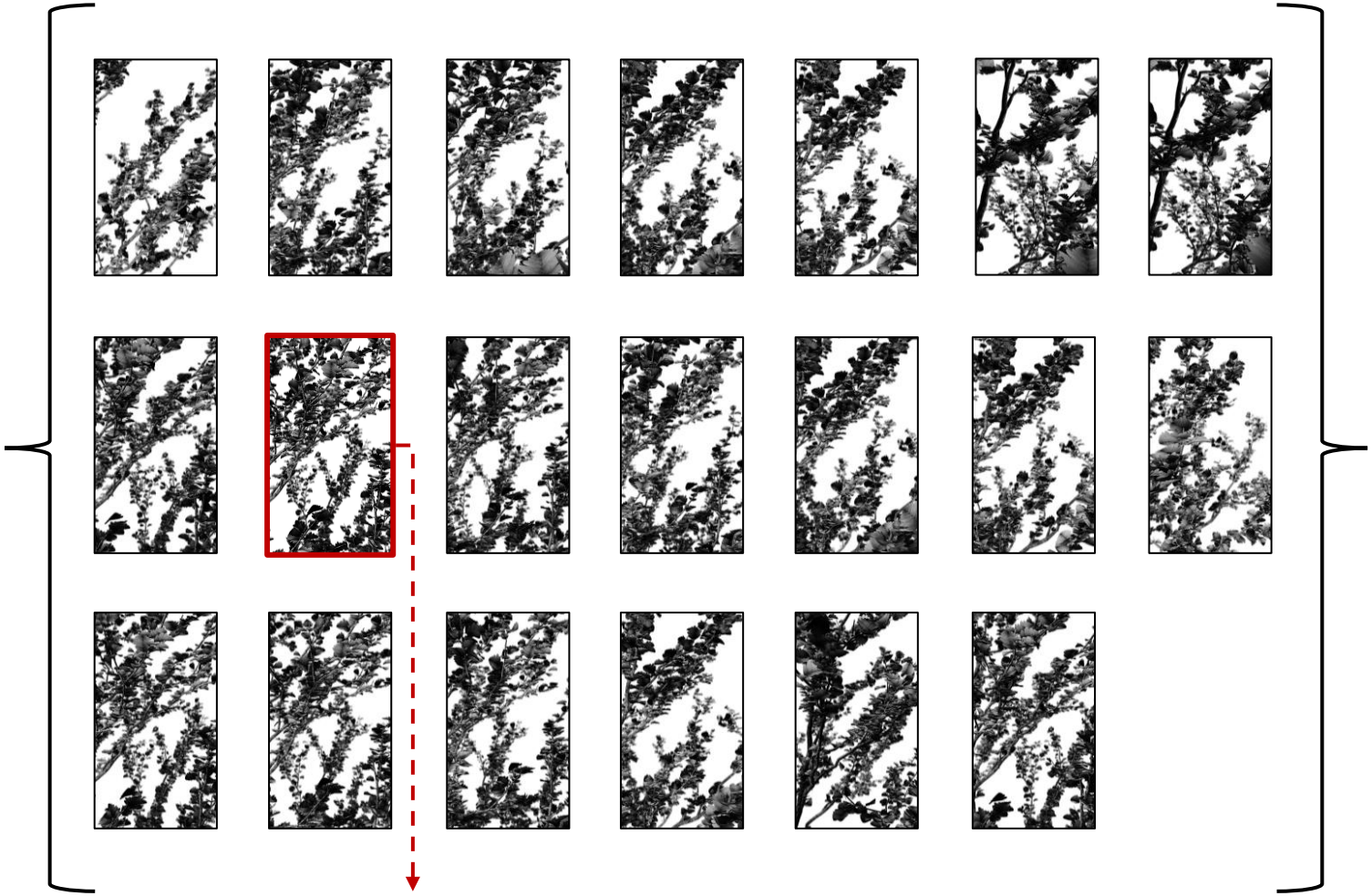
March 31

Position of the sun in the deconstructed fisheye facade grid



BIOPHILIC PATTERN SELECTION





20 variations checked in the grid

Better branch placement – proportion - uniformity

OPTIONS FOR NON-BIOPHILIC PATTERN?

Clear condition

Horizontal Stripes

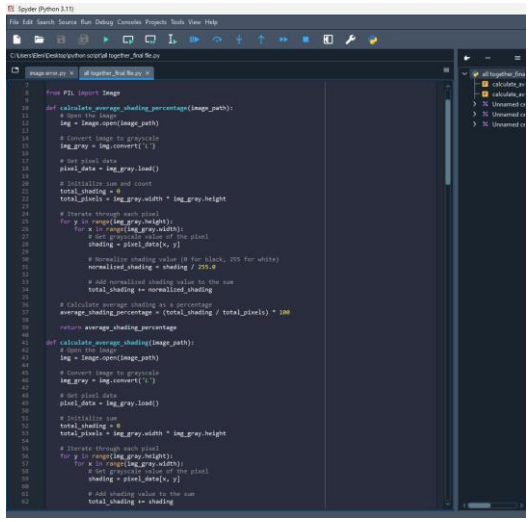
- Avoid biophilic design characteristics
- Familiarity with conventional shading systems

Homogeneous / No-pattern

- Include a no-pattern case of shading
- Avoid biases and create a comparable case

(Abboushi, Elzeyadi, Wymelenberg, et al. 2021)

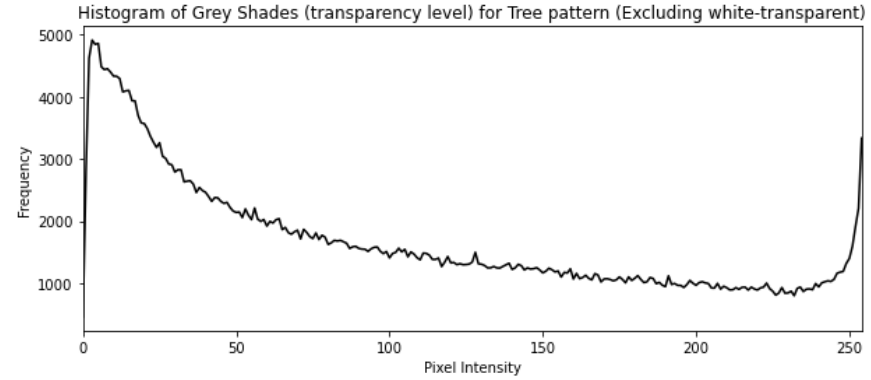
CREATION OF COMPARABLE STIMULI

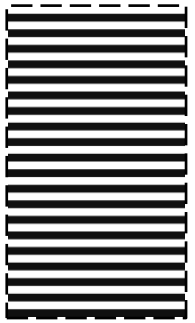


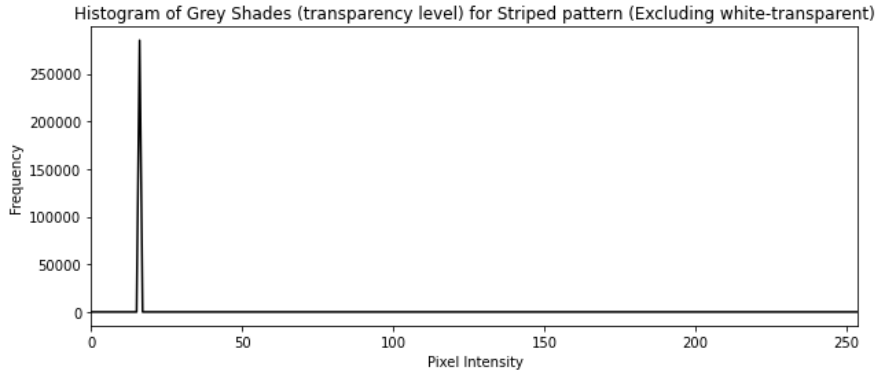
Use of python script to calculate the average ‘transparency’ = ‘shading’ = 53%

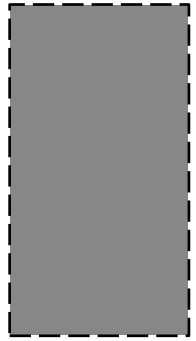
(considering 100% = total white)

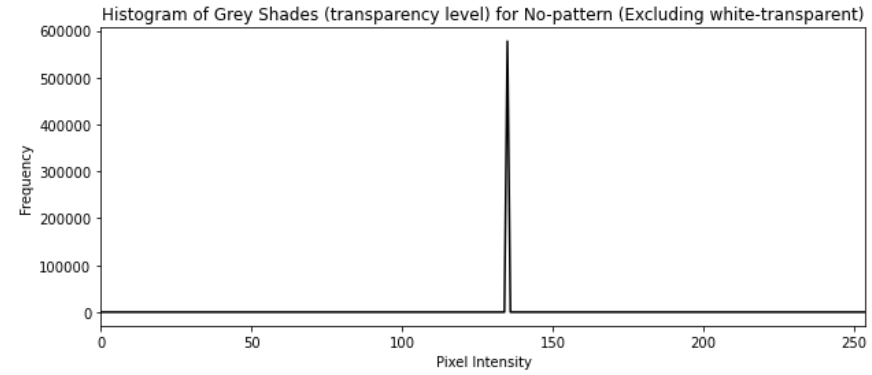
To create the striped pattern & the no-pattern with the same average ‘shading’





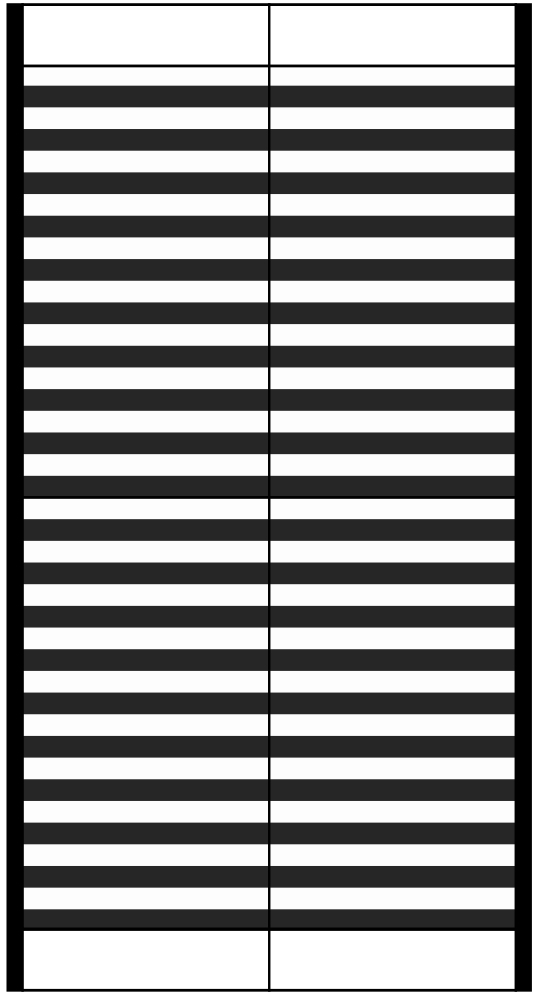




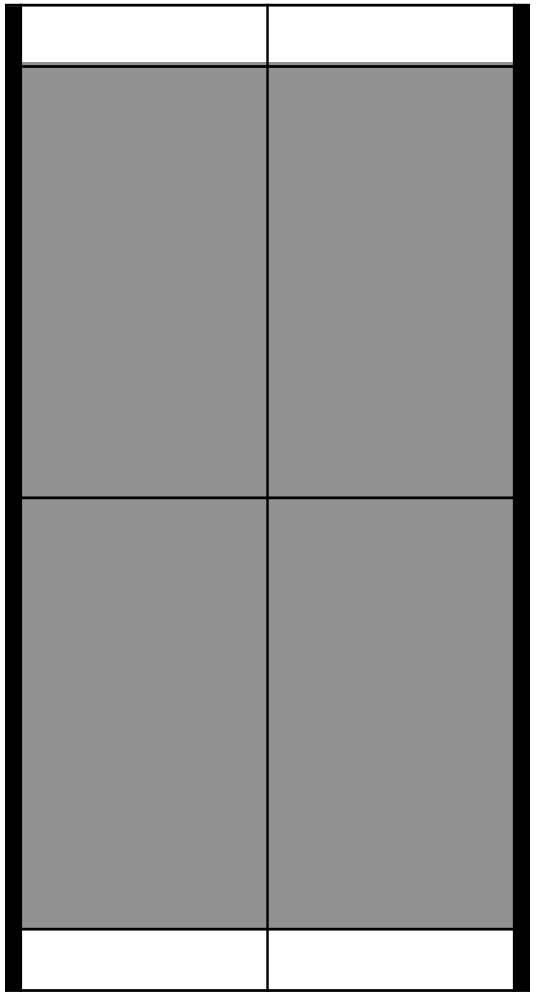


3 SELECTED STIMULI

A. Tree pattern



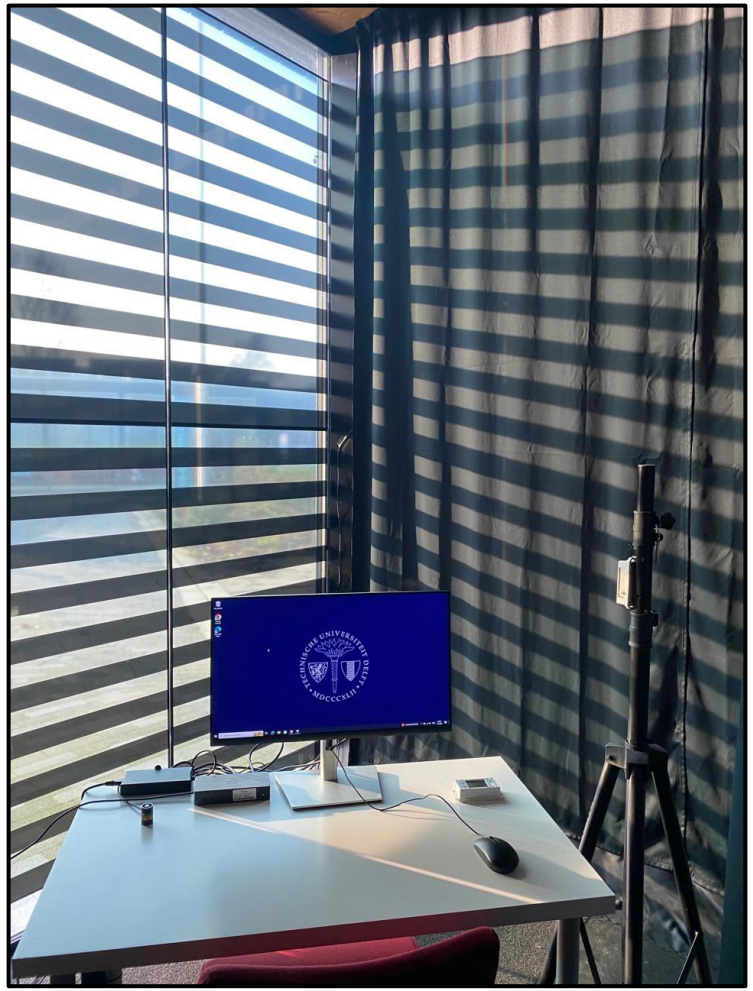
B. Stripes



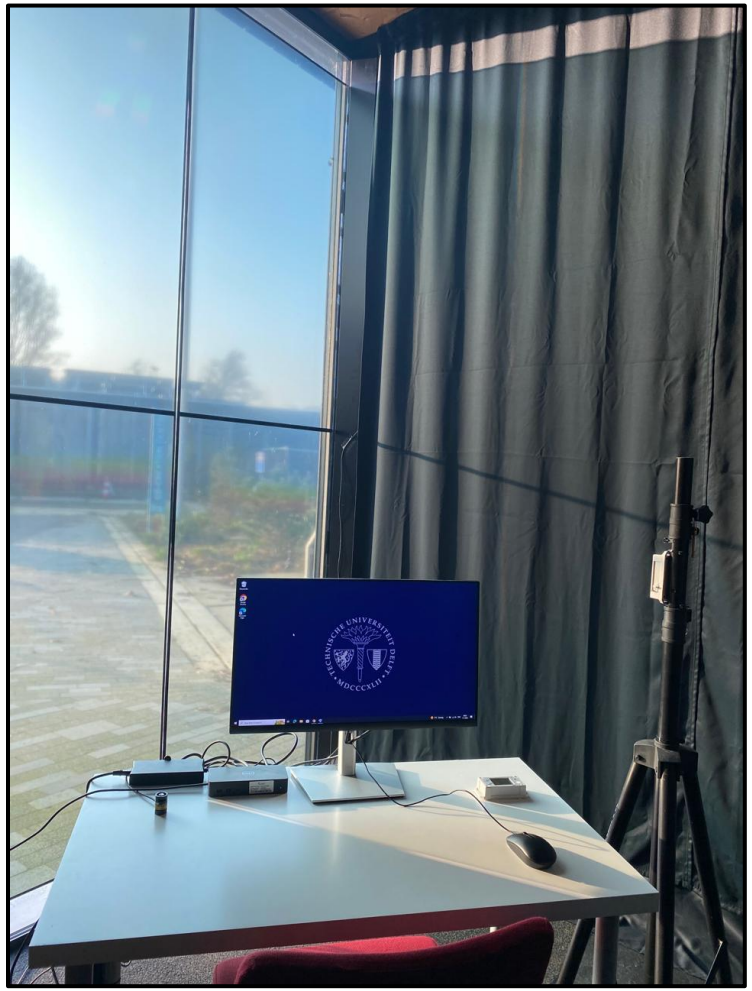
C. No pattern

3 SELECTED STIMULI

A. Tree pattern

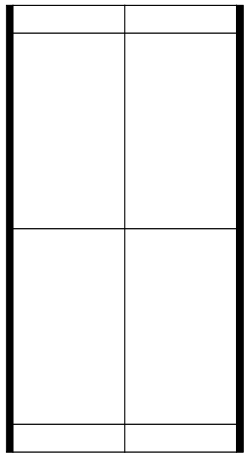


B. Stripes



C. No pattern

EXPERIMENTAL PROCEDURE



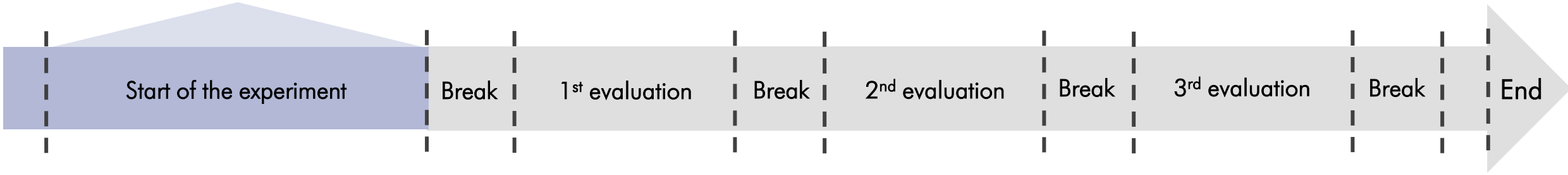
Clear state

Explanation

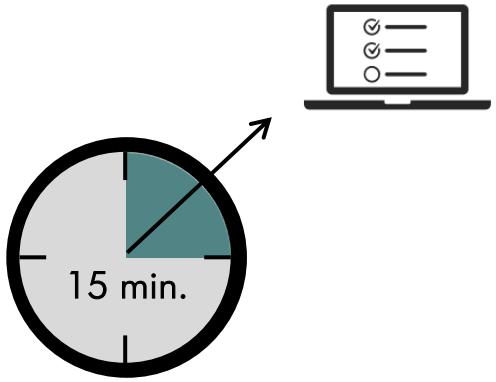
Consent form

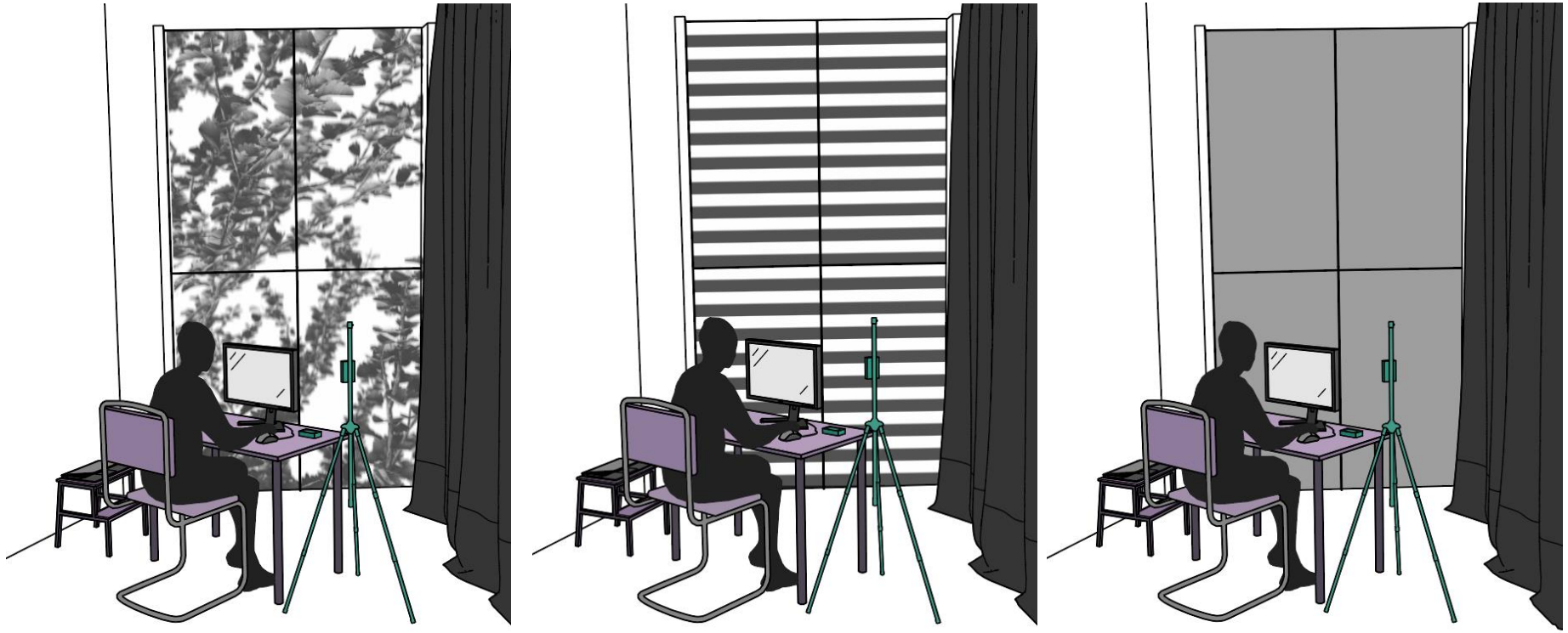
Participant enters

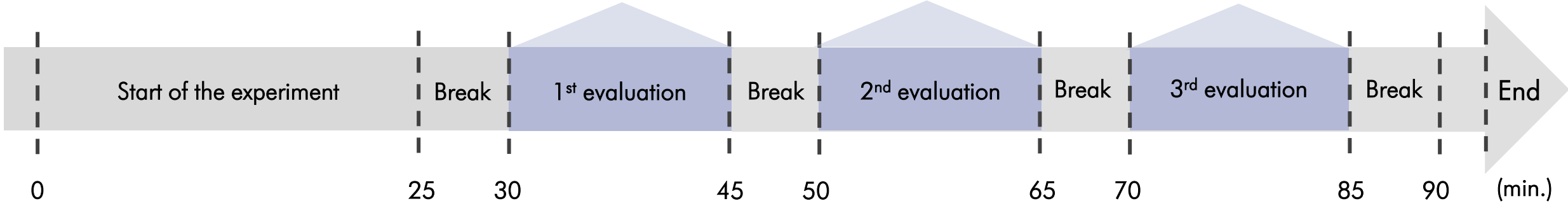
Q-demographics



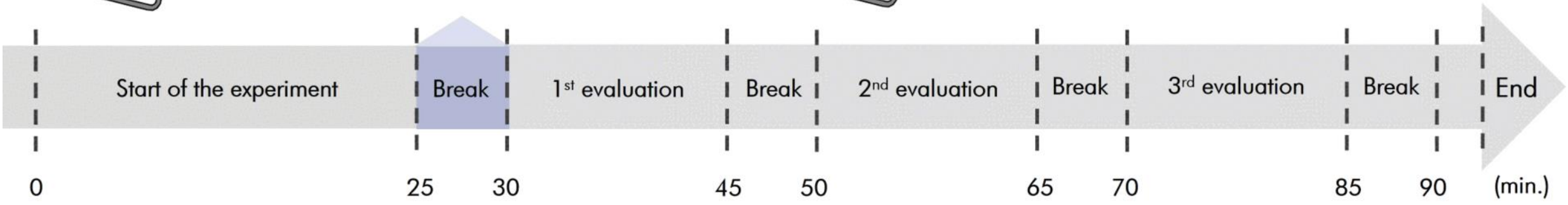
EXPERIMENTAL PROCEDURE



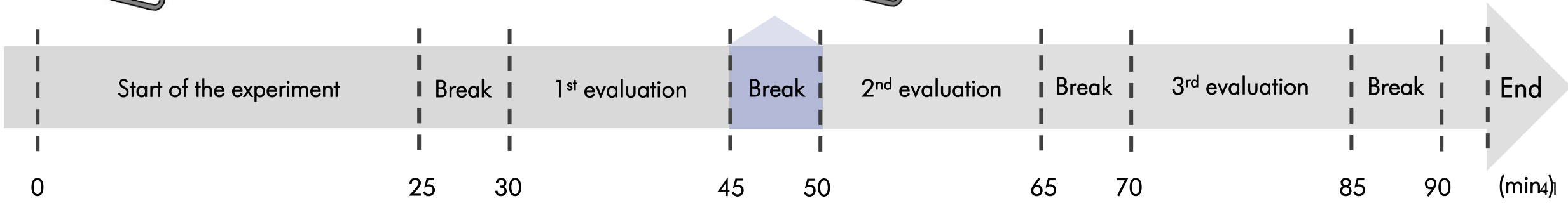




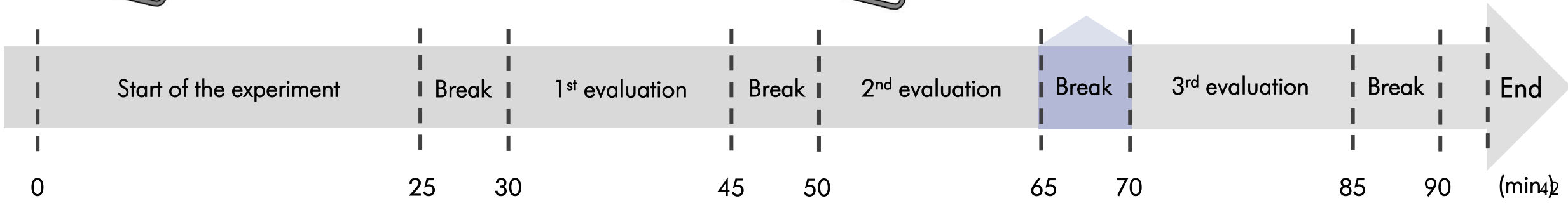
EXPERIMENTAL PROCEDURE



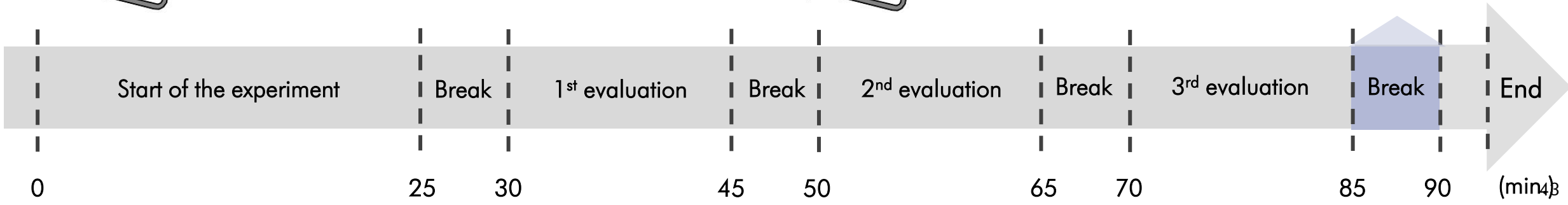
EXPERIMENTAL PROCEDURE



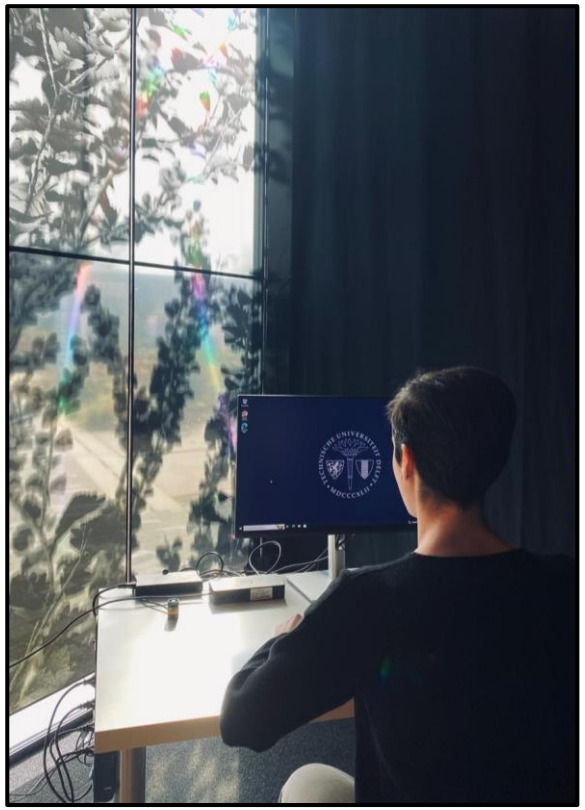
EXPERIMENTAL PROCEDURE

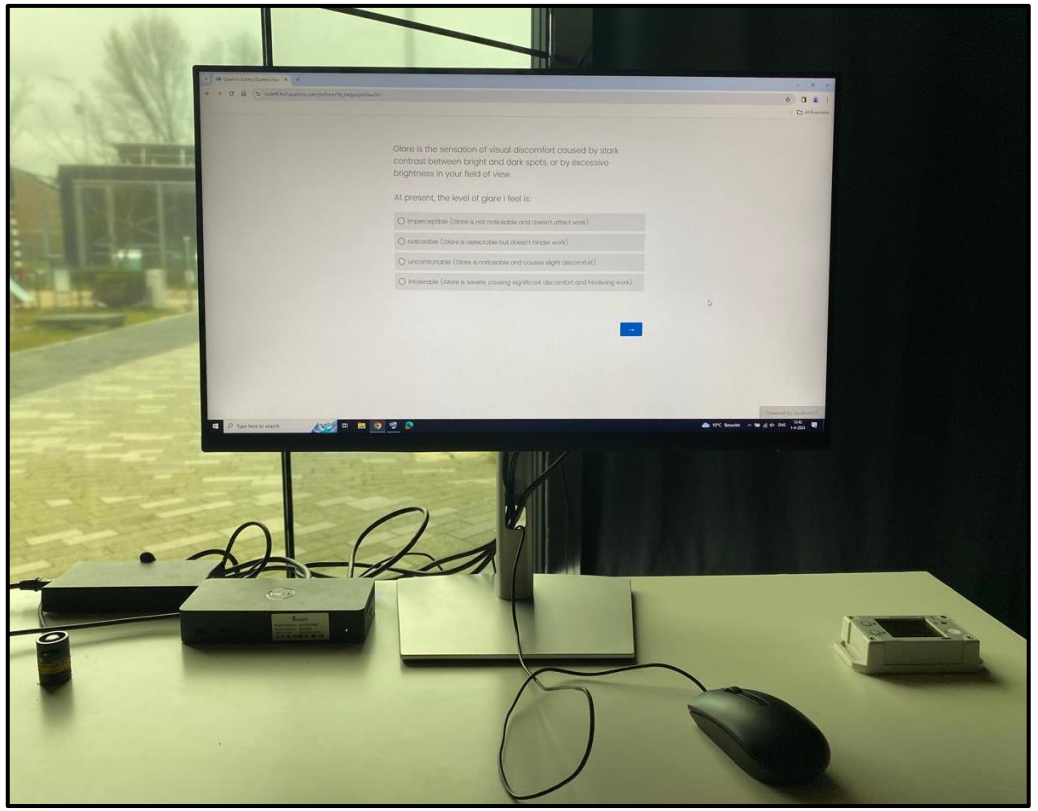


EXPERIMENTAL PROCEDURE

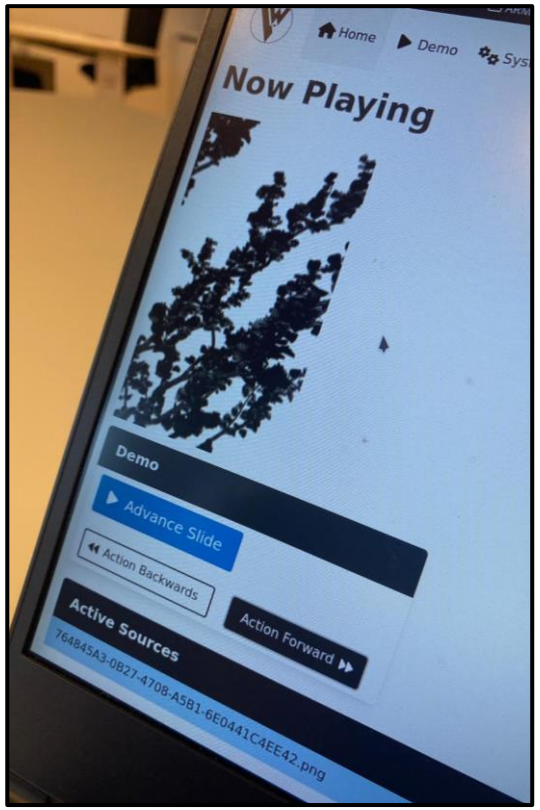


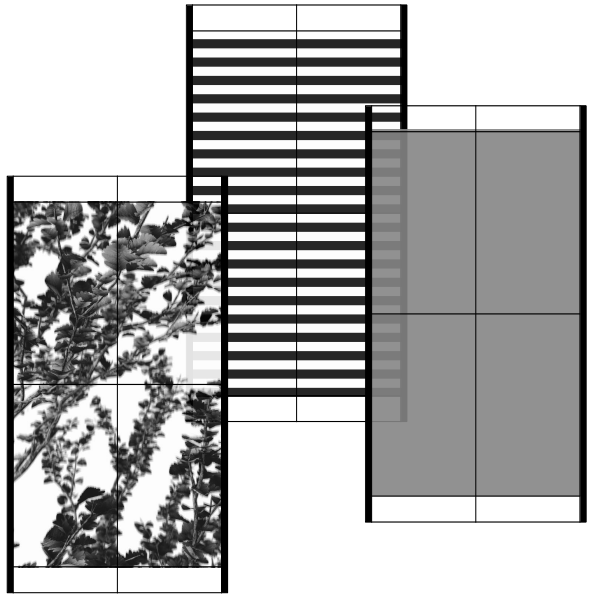
PARTICIPANT TASKS





EXPERIMENTER TASKS





QUESTIONNAIRE

Variables	Questions	Scale
(Q1) Glare perception	*'At present, the level of glare I feel is: '*	4-point scale (imperceptible, noticeable, uncomfortable, intolerable)
(Q2) Daylight satisfaction	*'I am satisfied with the amount of daylight entering the room.'*	5-point Likert scale (strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree)
(Q3) Color of daylight satisfaction	*'I am satisfied with the color of daylight through the window.'*	
(Q4) Visual comfort	*'I find the visual environment of the office comfortable for working.'*	
(Q5) Satisfaction with the view out	*'I am satisfied with the view through the window.'*	
(Q6) Acceptance of obstruction of view	*'I don't find the pattern/dimming effect on the glazing to be an obstruction to the outdoor view.'*	
(Q7) Pattern aesthetics	*'I like the pattern/dimming effect on the glazing in terms of aesthetics.'*	
(Q8) Sunlight pattern aesthetics	*'I find the sunlight patterns created by the pattern/dimming on the glazing to be visually interesting.'*	
(Q9) Room temperature feeling	*'How do you feel in the room at the moment?'*	7-point ASHRAE thermal sensation scale
(Q10) Psychological and emotional state	*'Which of the following describes best your psychological or emotional state when exposed to the current scenario?*	Sense of calm and relaxation, reduction of stress, mental fatigue recovery, improved productivity, fascination, other

+

Intro:
- Demographics
- Vision characteristics
- Present state
- Experience of space

Closure:
- Favorite pattern
- Connection with nature
- Comments

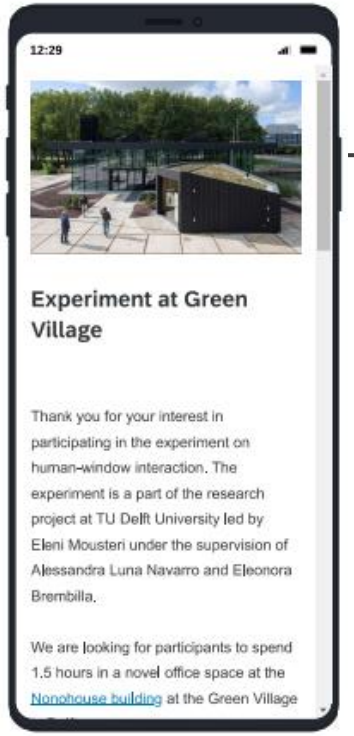
44 PARTICIPANTS

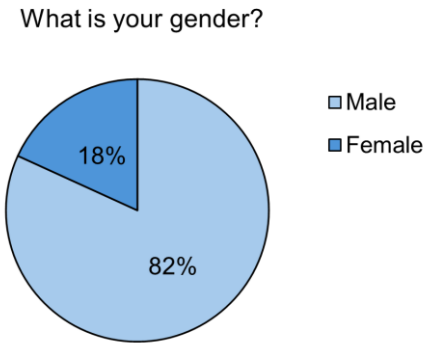
General characteristics

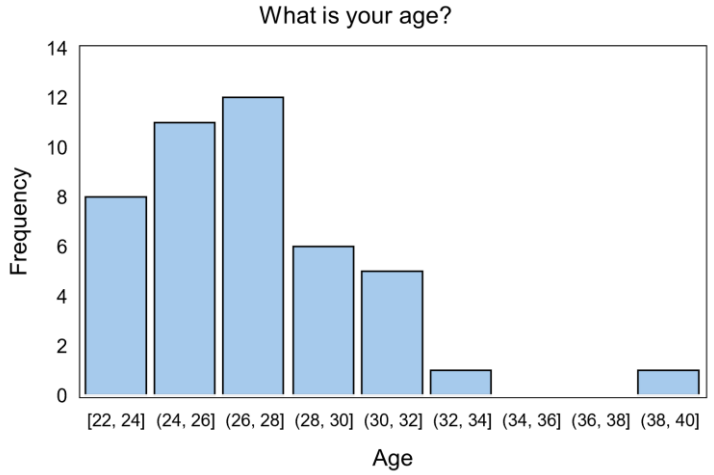
- 36 males, 8 females
- Age range: 22-39 y.o.
- Wide range of cultural background

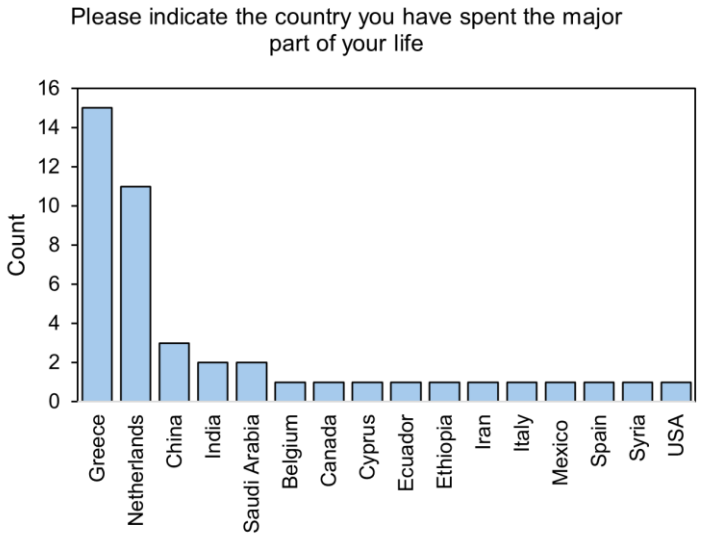
Vision characteristics

- Optical correction: glasses (n=16), contact lenses (n=5), none (n=23)
- Contrast sensitivity: yes (n=13), unsure (n=11), no (n=20)
- Color blindness: none



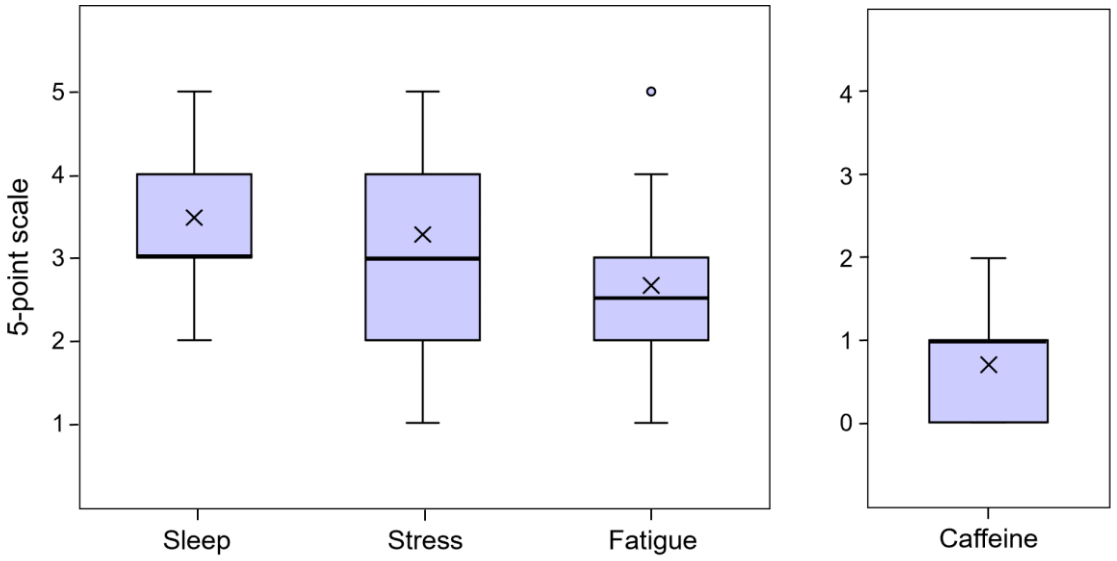




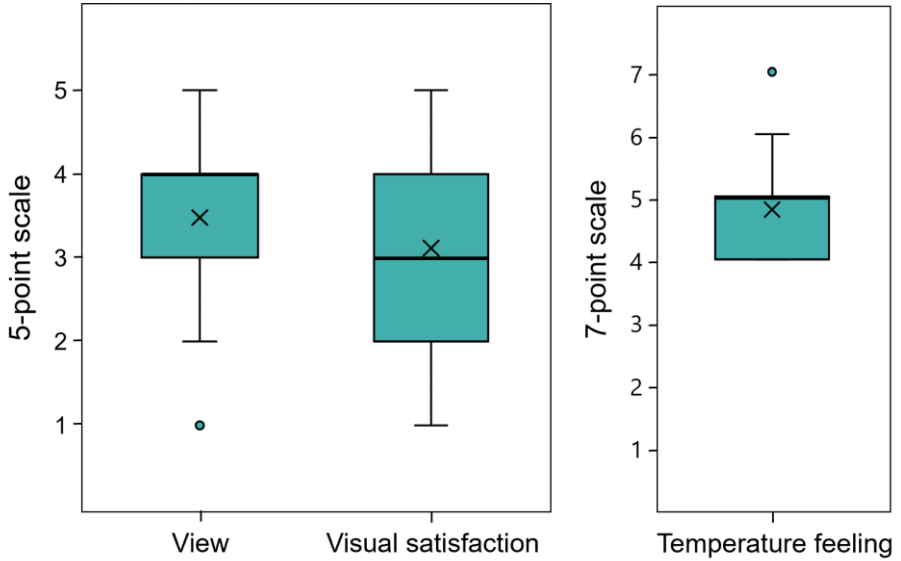


44 PARTICIPANTS

Present state



Experience of space

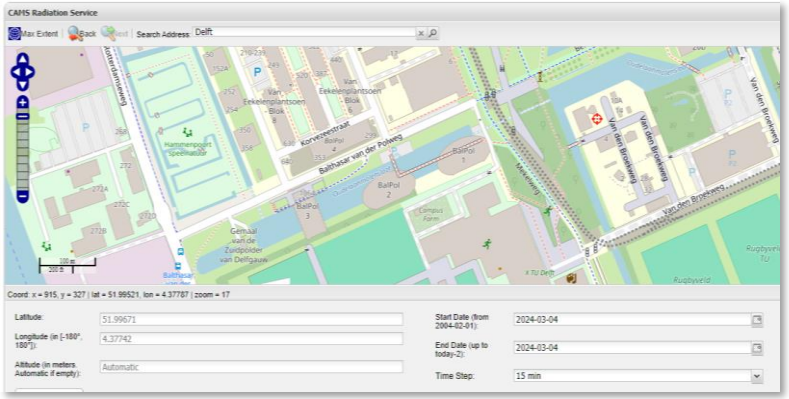



INTRODUCTION
LITERATURE REVIEW
EXPERIMENTAL DESIGN
RESULTS & CONCLUSIONS

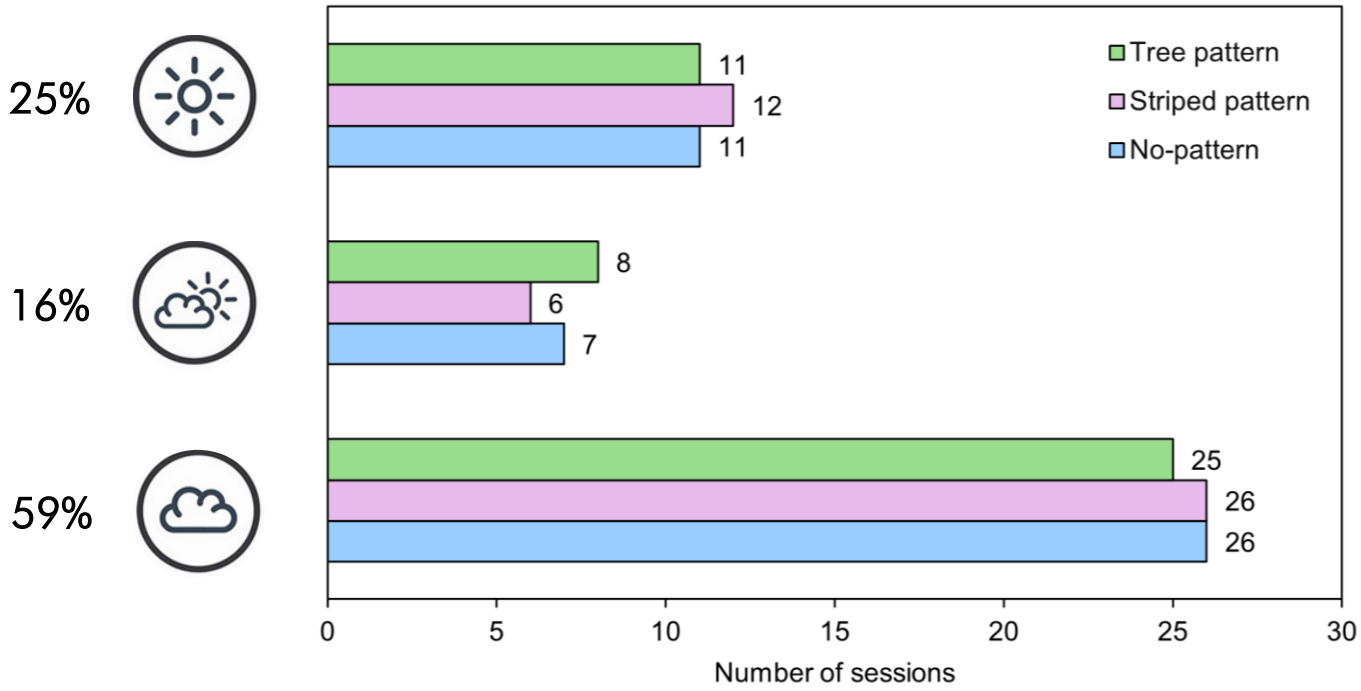
SKY CONDITION CLASSIFICATION

Ratio for classification:
sky ratio = horizontal diffuse irradiance / horizontal global irradiance = DHI / GHI

Classification of sky condition:
- Clear: sky ratio < 0.3
- Partly cloudy: 0.3 < sky ratio < 0.8
- Overcast: sky ratio > 0.8



(CAMS Radiation Service)

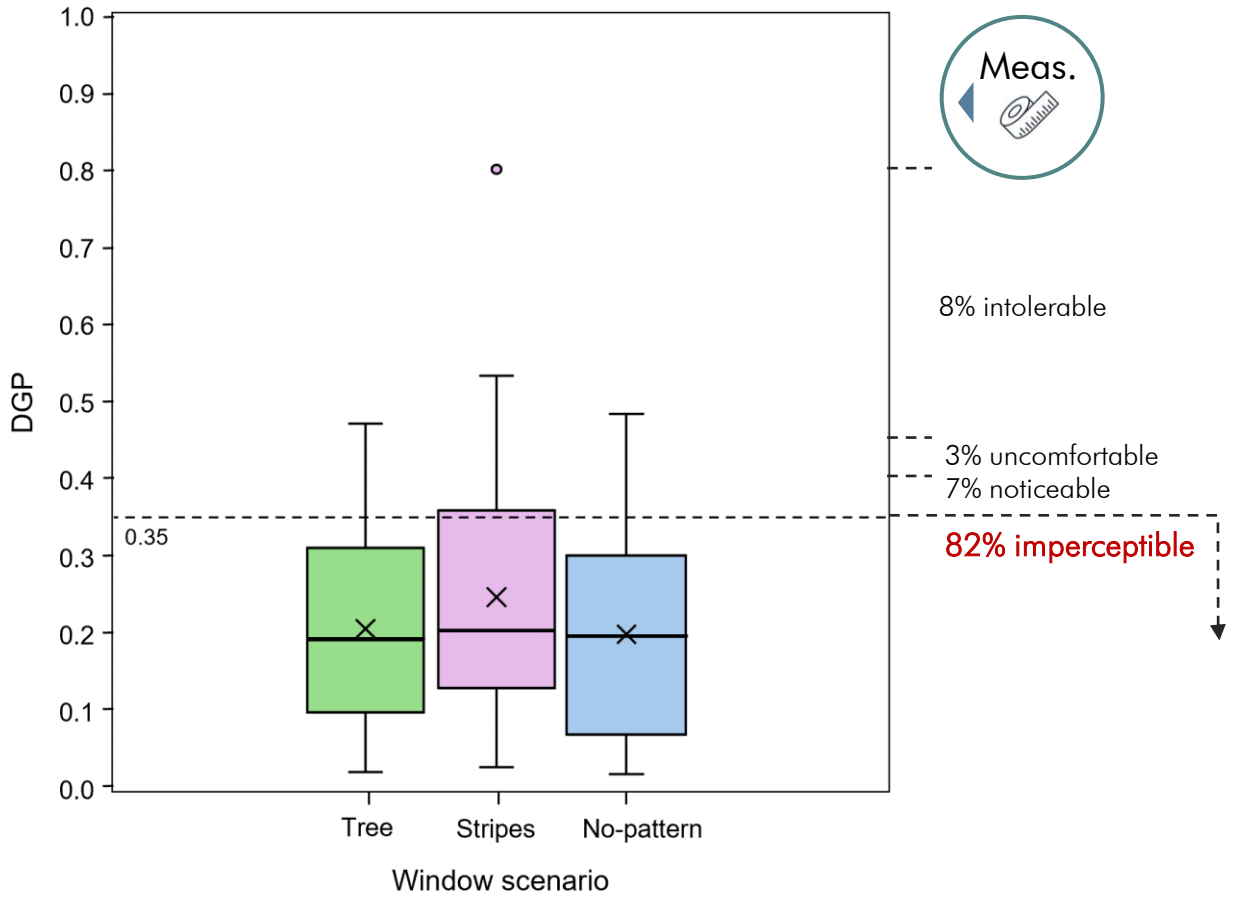


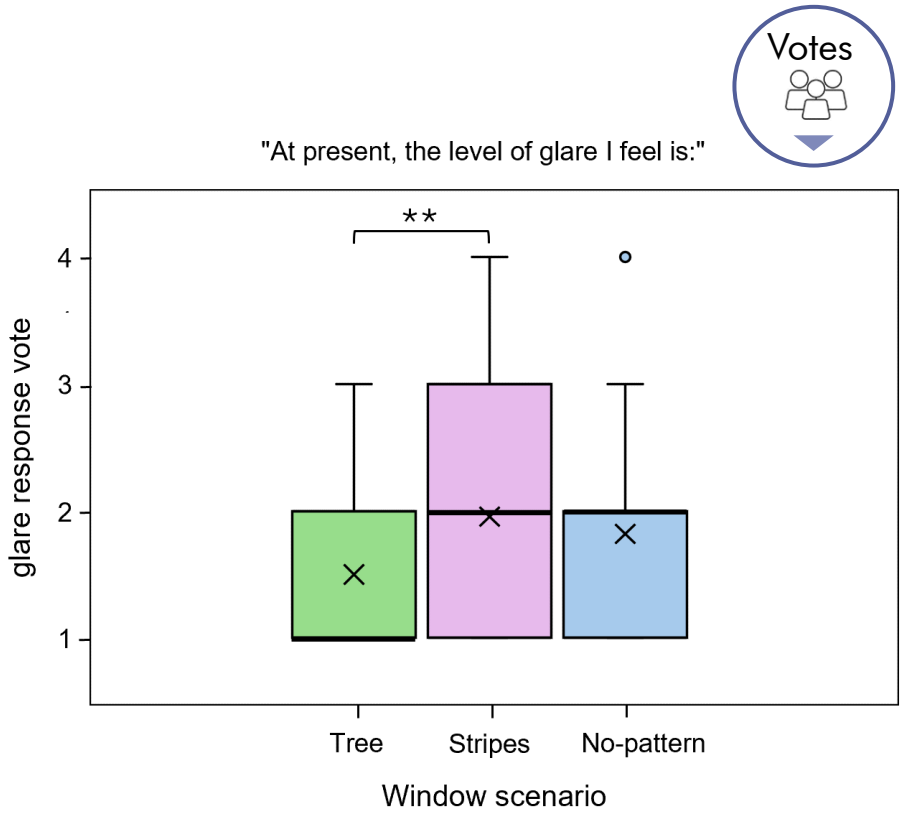
DGP & GLARE PERCEPTION

- Linear Mixed Models Analysis (significant results)

Variable	Window scenario	DGP	Window scenario* DGP
Glare perception	p = .002	p = .011	p = .686

Pairwise comparisons	Window scenario
Tree vs Stripes	p = .003**
Tree vs No-pattern	p = .061
Stripes vs No-pattern	p = .637





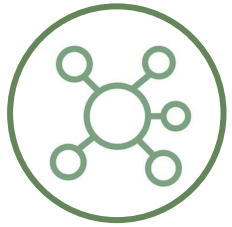
Significance
p<.05*
p<.01**
p<.001***

4=intolerable
3=uncomfortable
2=noticeable
1=imperceptible

POTENTIAL GLARE FACTORS

Lighting

Context



Observer

- Regression analysis

DGP

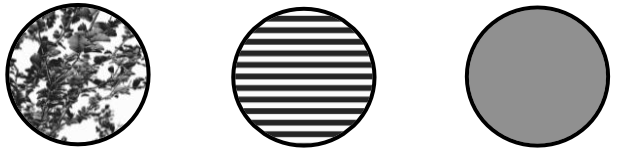
Temperature feeling
View satisfaction

Gender
Age
Culture
Optical correction
Contrast sensitivity
Color blindness

Sleep quality
Stress level
Fatigue level
Caffeine intake

- Significant results

DGP (positive association)

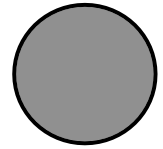


.026* .014* .029*

DGP ↑ Glare perception ↑

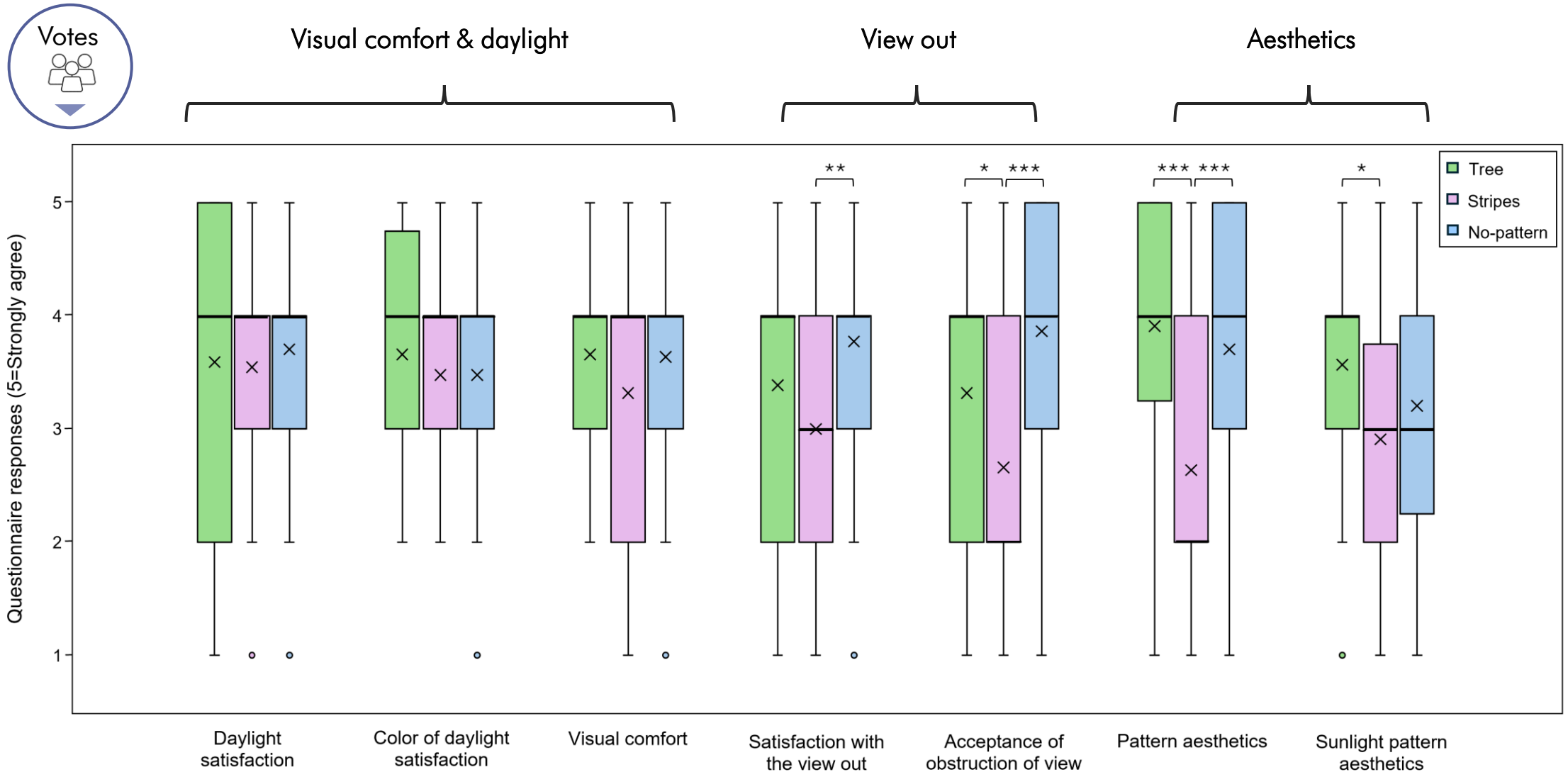
Stress ↓ Glare perception ↑

Stress level (negative association)



.010*

RESPONSES FROM QUESTIONNAIRES

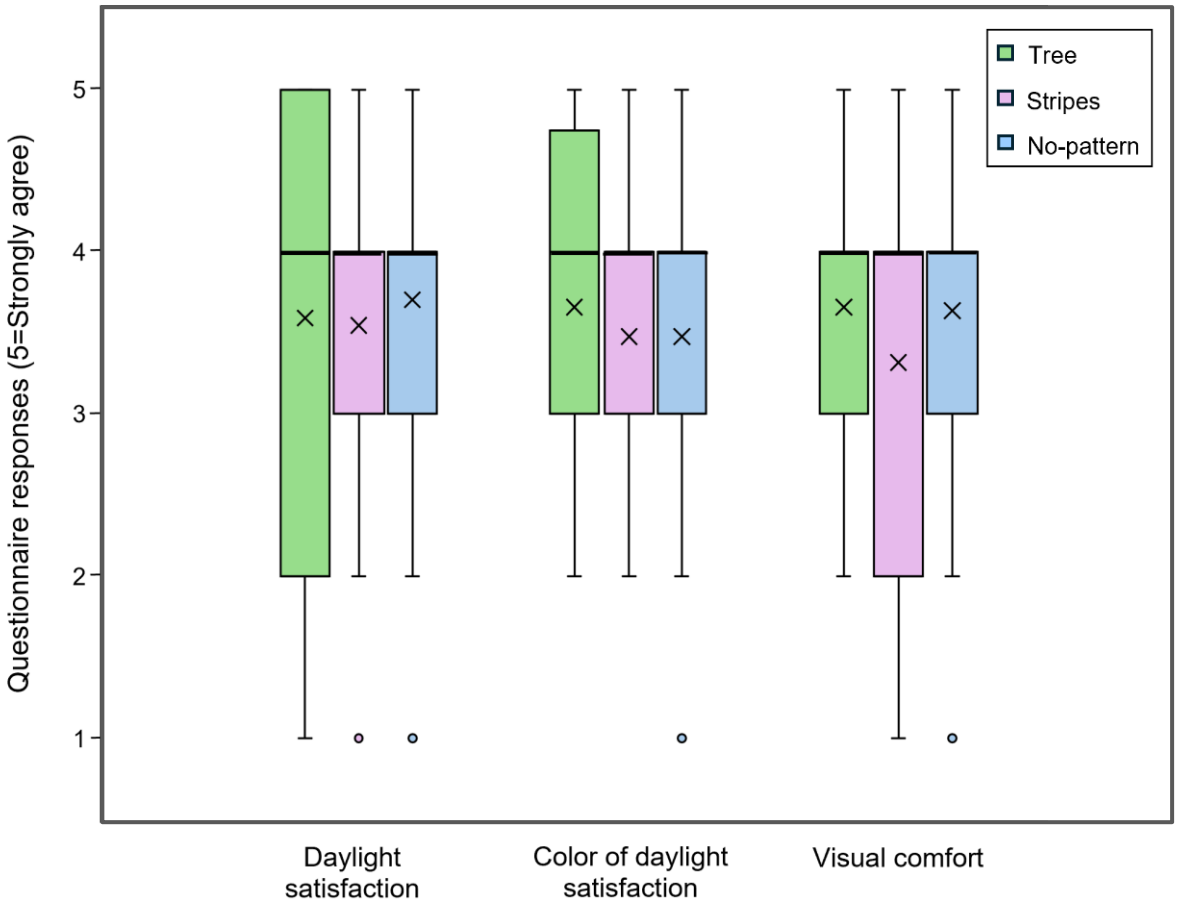


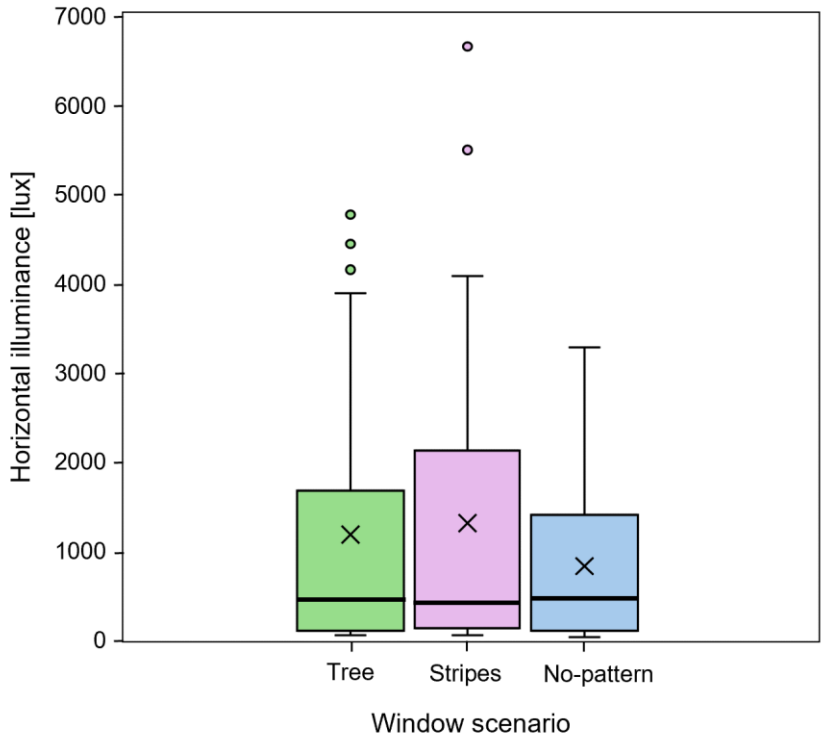
DAYLIGHT AND VISUAL COMFORT

Votes

- Linear Mixed Models Analysis (no significant results)

Variable	Window scenario	Horizontal illuminance (Eh)	Window scenario* Horizontal illuminance (Eh)
Daylight satisfaction	p = .387	p = .737	p = .320
Color of daylight satisfaction	p = .756	p = .672	p = .683
Visual comfort	p = .592	p = .260	p = .561





Meas.

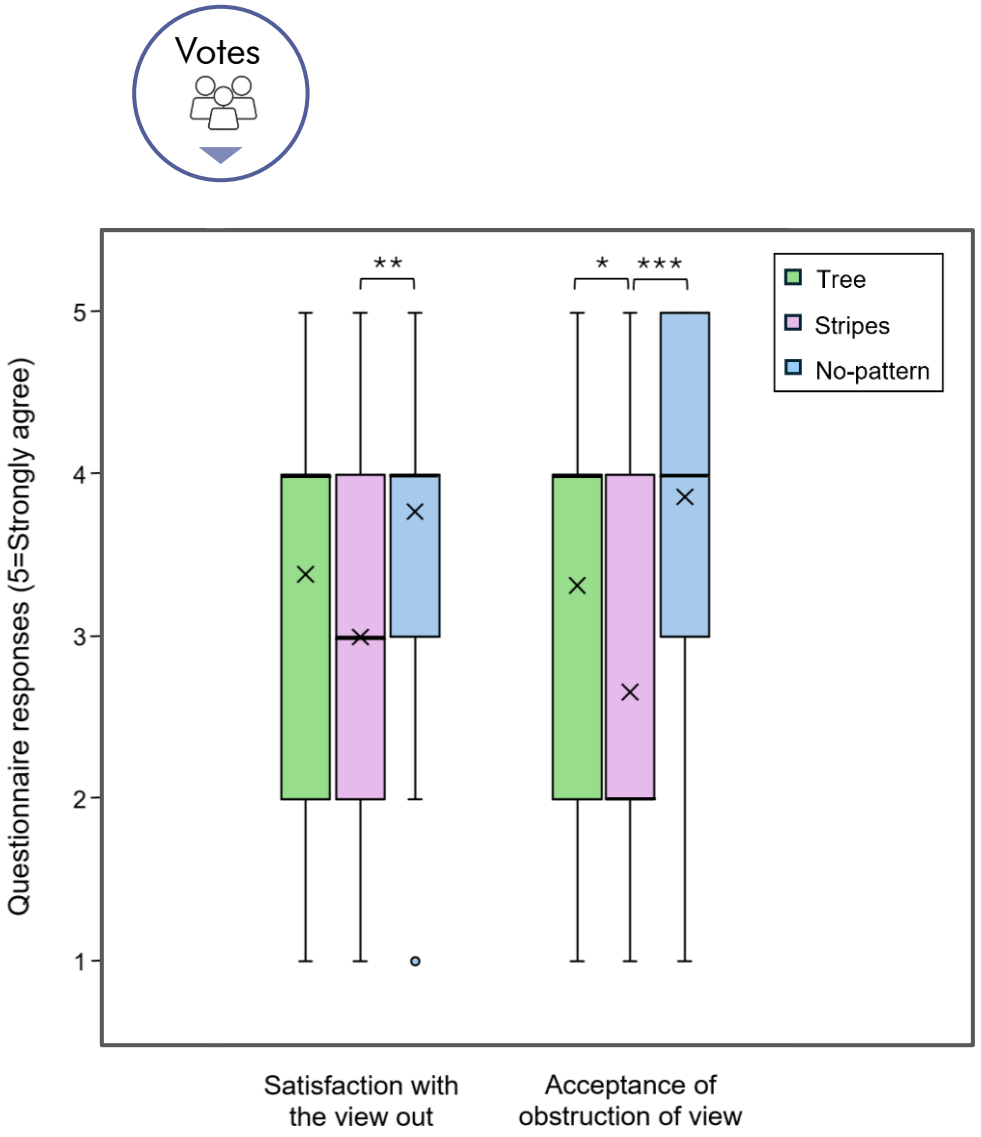
Significance

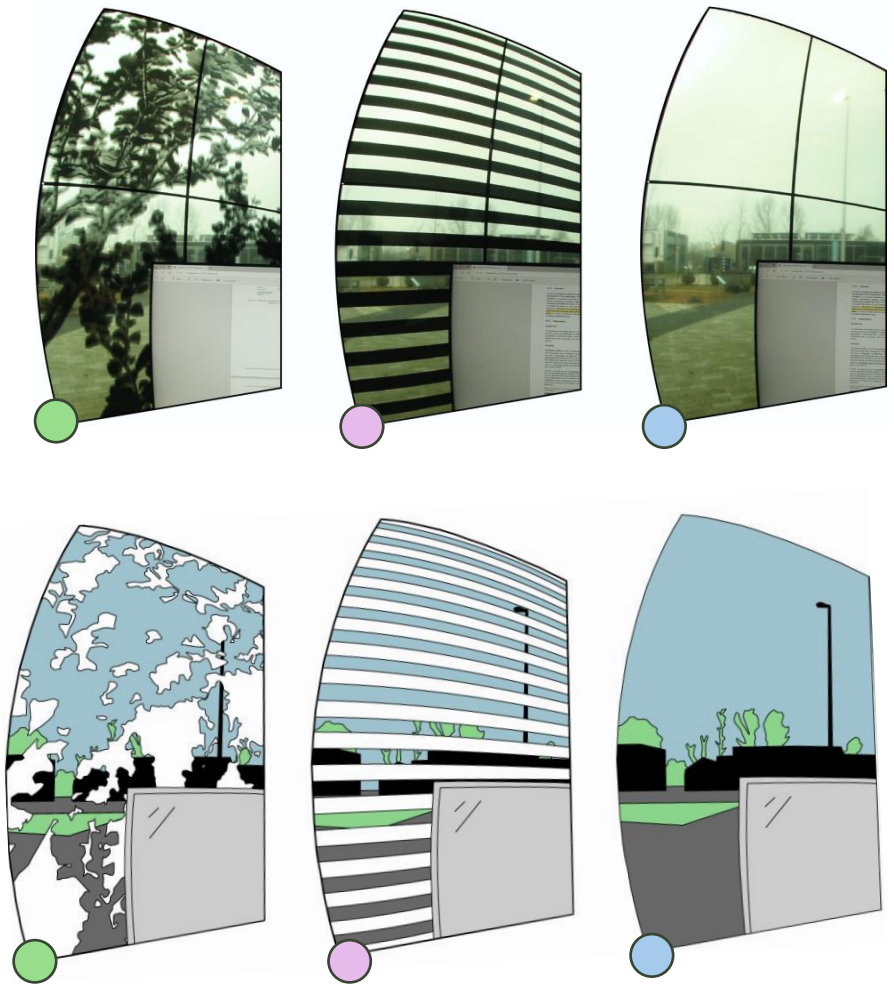
p<.05*

p<.01**

p<.001***

VIEW SATISFACTION & OBSTRUCTION



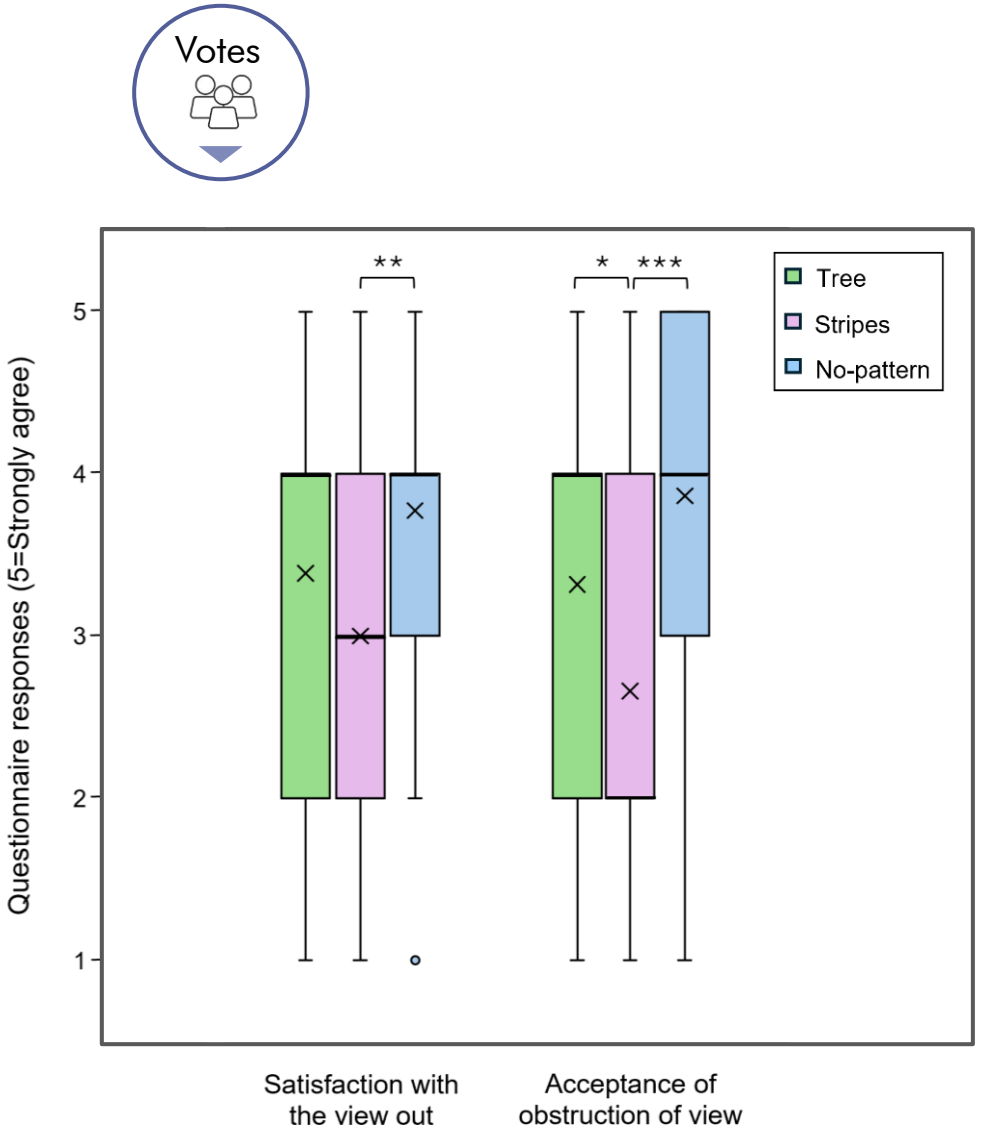


View out

Obstruction

(=colorful areas)

VIEW SATISFACTION & OBSTRUCTION



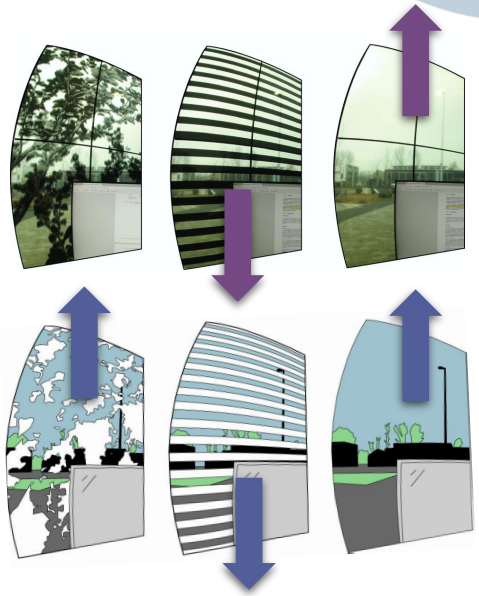
- Linear Mixed Models Analysis (significant results)

Variable	Window scenario
Satisfaction with the view out	p = .002
Acceptance of obstruction of view	p < .001

Significance
p<.05*
p<.01**
p<.001***

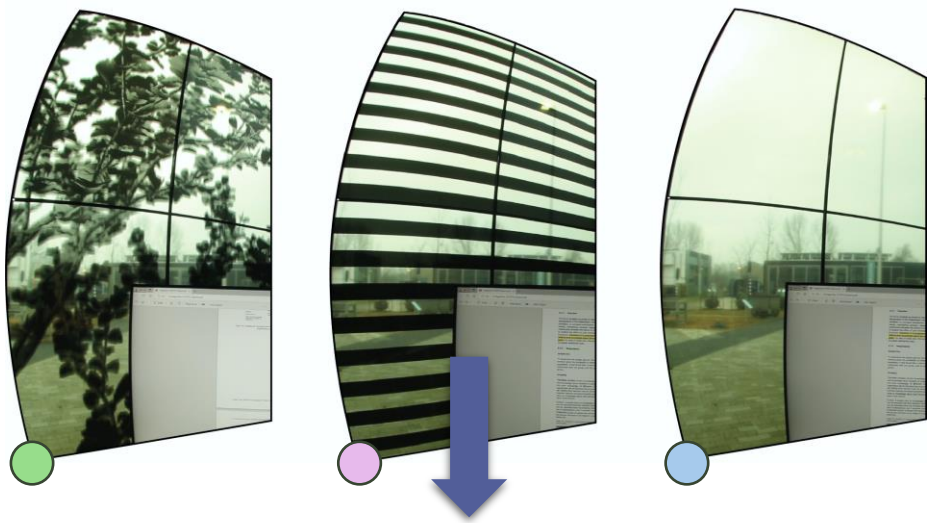
Pairwise comparisons	View satisfaction
Tree vs Stripes	p = .198
Tree vs No-pattern	p = .198
Stripes vs No-pattern	**p = .001 *** **

Pairwise comparisons	Acceptance of obstruction
Tree vs Stripes	**p = .034 ***
Tree vs No-pattern	p = .105
Stripes vs No-pattern	**p <0.001 *** **



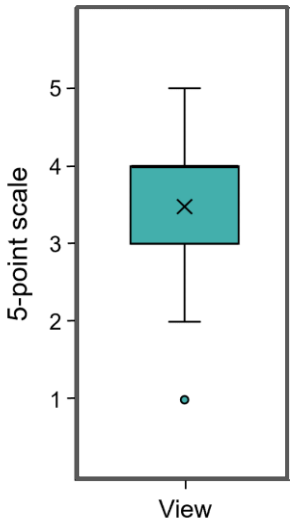
VIEW RATES UNDER CLEAR & PATTERN SCENARIOS

View out



Pattern scenarios

Clear view



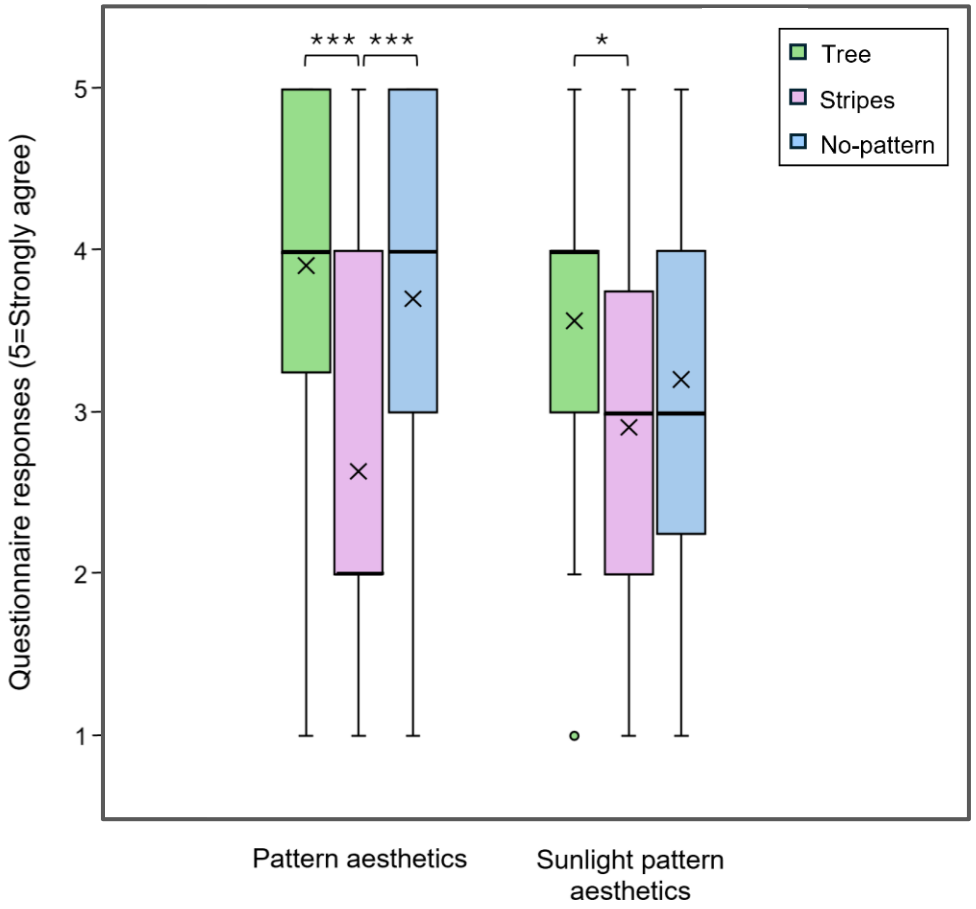
- Paired-sample t-tests

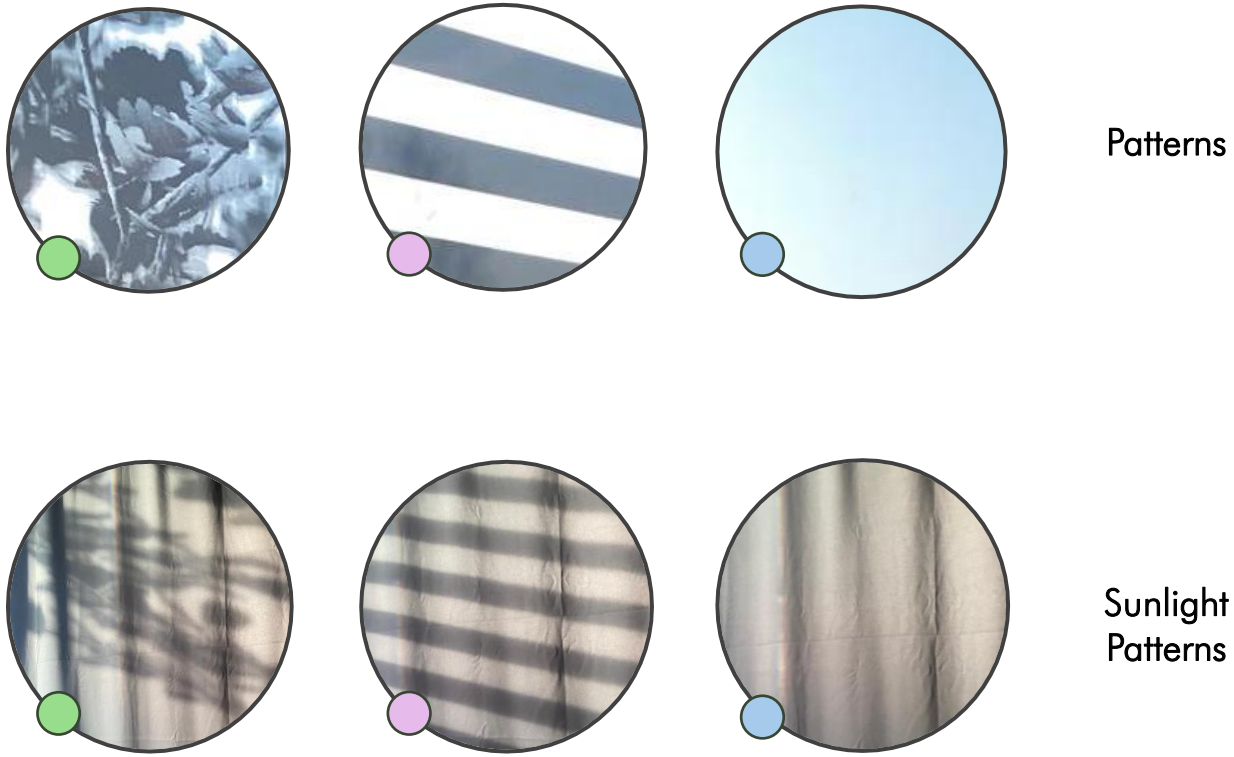
Condition	Mean satisfaction
Clear view	3.48
Tree pattern	3.39
Striped pattern	3.00
No-pattern	3.77

Comparison	p values
Clear view vs. Tree	0.585
Clear view vs. Stripes	**0.031***
Clear view vs. No-pattern	0.102

PATTERN & SUNLIGHT PATTERN AESTHETICS

Votes

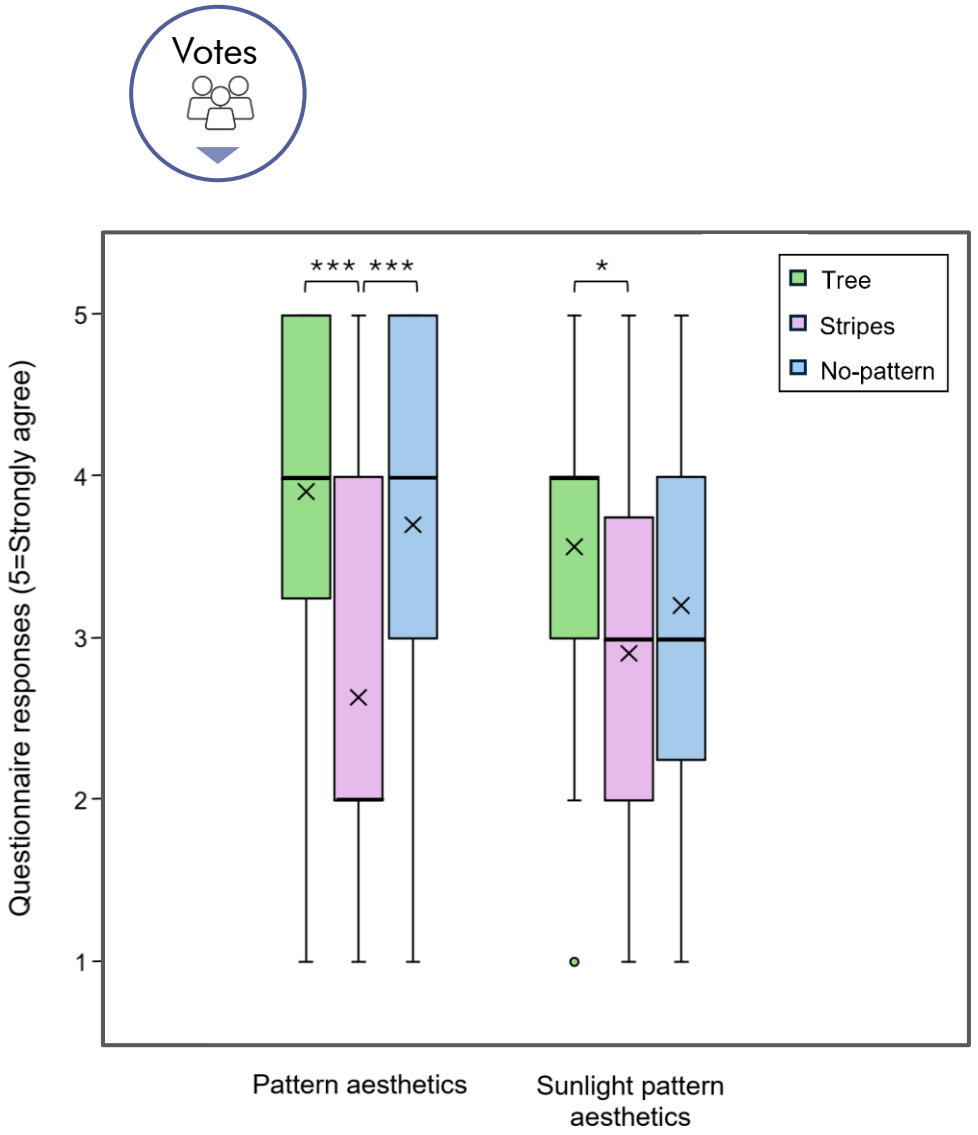




Patterns

Sunlight Patterns

PATTERN & SUNLIGHT PATTERN AESTHETICS



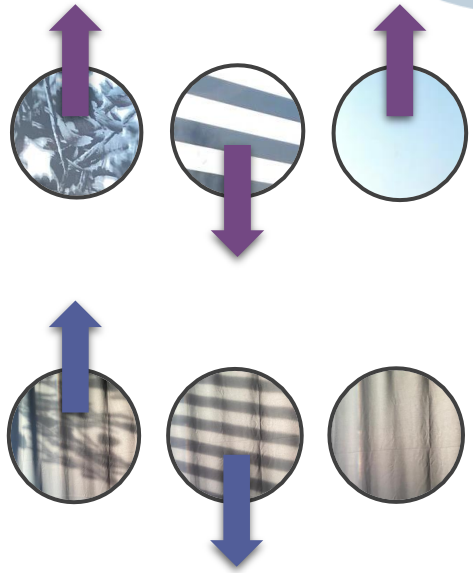
- Linear Mixed Models Analysis (significant results)

Variable	Window scenario
Satisfaction with the view out	p < .001
Acceptance of obstruction of view	p = .016

Significance
p<.05*
p<.01**
p<.001***

Pairwise comparisons	Pattern aesthetics
Tree vs Stripes	**p < .001 *** **
Tree vs No-pattern	p = 1.000
Stripes vs No-pattern	**p < .001 *** **

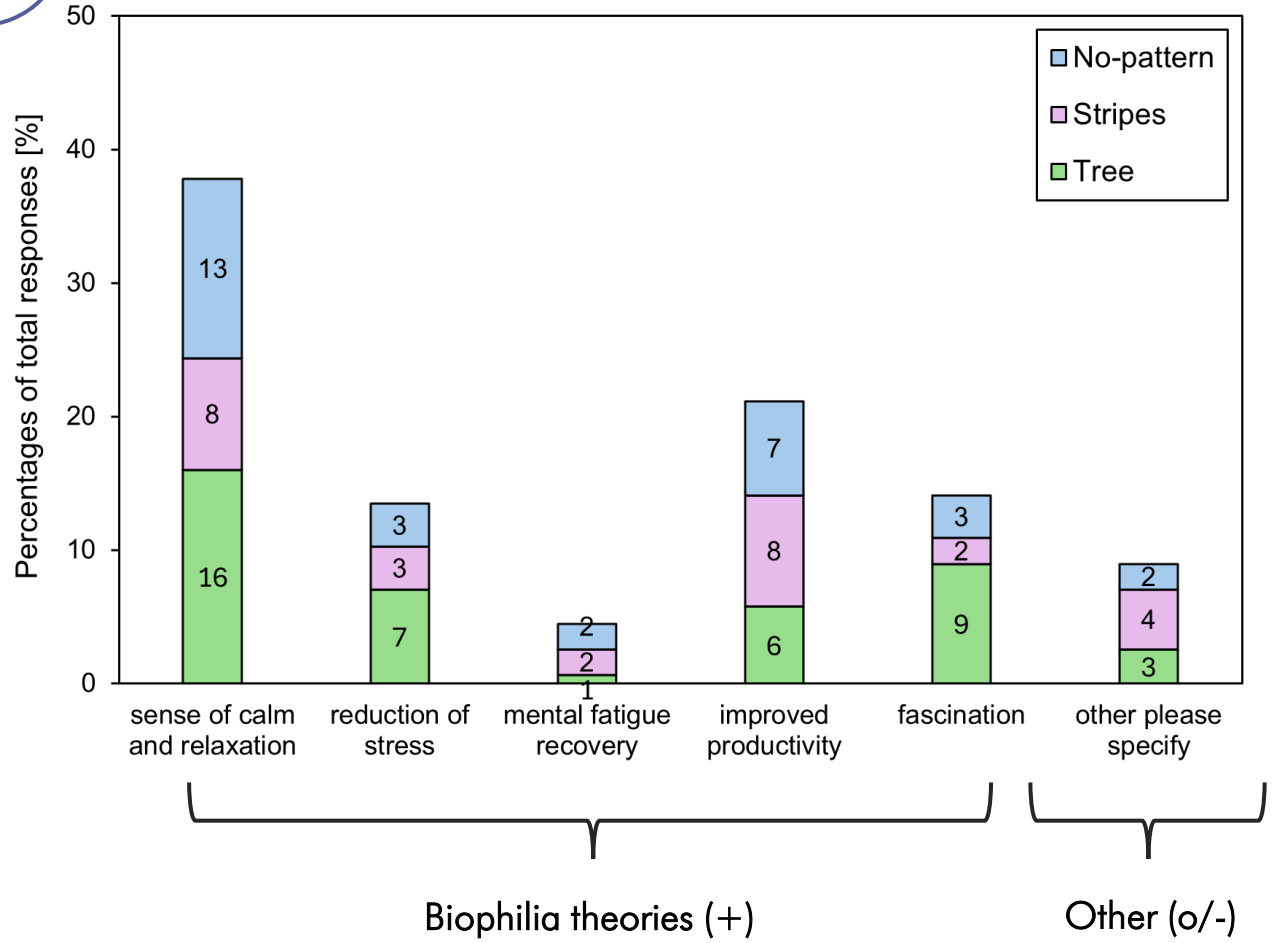
Pairwise comparisons	Sunlight pattern aesthetics
Tree vs Stripes	**p = .013 ***
Tree vs No-pattern	p = .329
Stripes vs No-pattern	p = .578



PSYCHOLOGICAL & EMOTIONAL STATE

Votes

Please select all that apply: Which of the following describe your psychological or emotional state when exposed to the current scenario?



Biophilia theories

39 votes

23 votes

28 votes

Other (o/-)

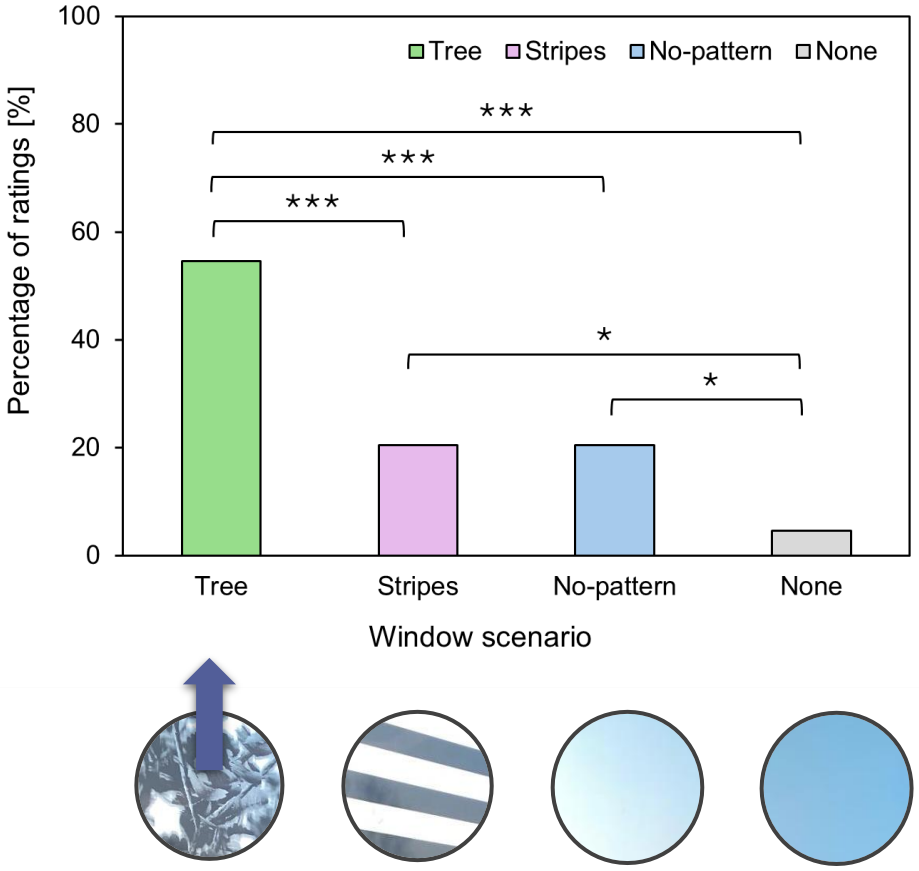
'Distraction'
'Discomfort'
'Normal'

'Prison-like environment'
'Sleepiness'
'Fatigue-discomfort'
'Normal'

'Visual discomfort'
'Normal'

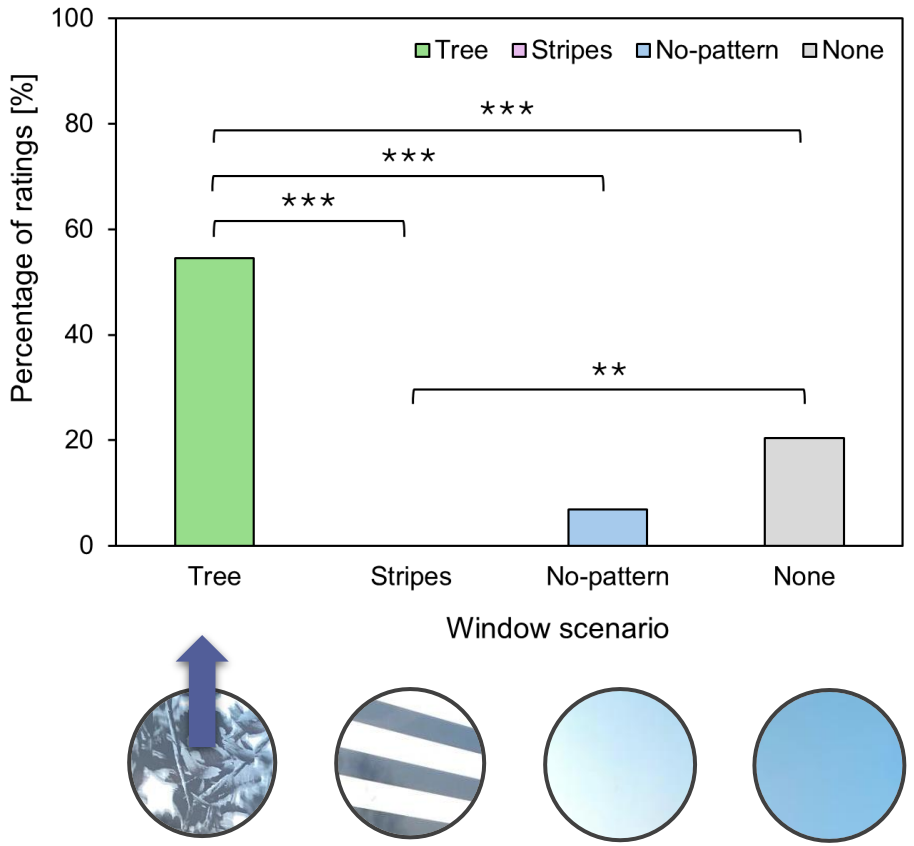
PATTERN PREFERENCE & NATURAL CONNECTION

Among the patterns you have experienced on the glazing, which one is your favorite?



Votes

Which of the different scenarios made you feel a connection with nature?



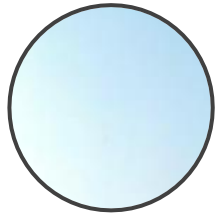
Significance

p<.05*

p<.01**

p<.001***

COMMENTS

			
+	*'Irregular and organic features that enable natural connection'* *'Natural variation of light and shadows'* *'Natural - aesthetic – attractive'* *'Calm, relaxing, cozy atmosphere* *'Spacious feeling, mimicking the outdoor space'*	*'Practical appeal, minimize distractions'* *'Sense of order, better concentration and focus'* *'Familiarity with conventional window blinds'*	*'More sunlight in the room'* *'Inviting and comfortable space'* *'Unobstructed view outside'*
−	*'Resolution and blurry effects'* *'Distraction for office activity'*	*'Uninviting space and coldness'* *'Too geometric and artificial'* *'Uncomfortable and obstructive'*	*'More glare situations'* *'Light intensity'*

CONCLUSIONS

Main question

Does integrating biophilic patterns on building facades influence occupants' perception compared to non-natural patterns or clear conditions?

✓
- Glare perception
- Satisfaction with the view out ⟷
- Acceptance of obstruction of view ≠
- Pattern aesthetics
- Sunlight pattern aesthetics ⟷

✗ ≈
- Visual comfort ⟷
- Daylight satisfaction

✓ ≈
- Preference ⟷
- Association with nature

LIMITATIONS & FURTHER RESEARCH

Laboratory setting

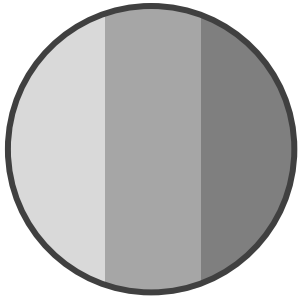
Lack of glare conditions

Short-term exposure

Pattern selection

+

Physiological response



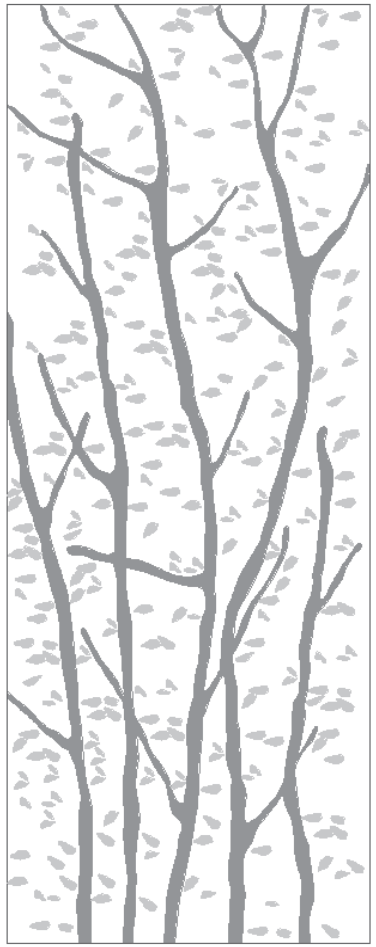
Transparency thresholds for glare

Acceptance of automated practice

PATTERN DESIGN

Denser patterns for glare protection

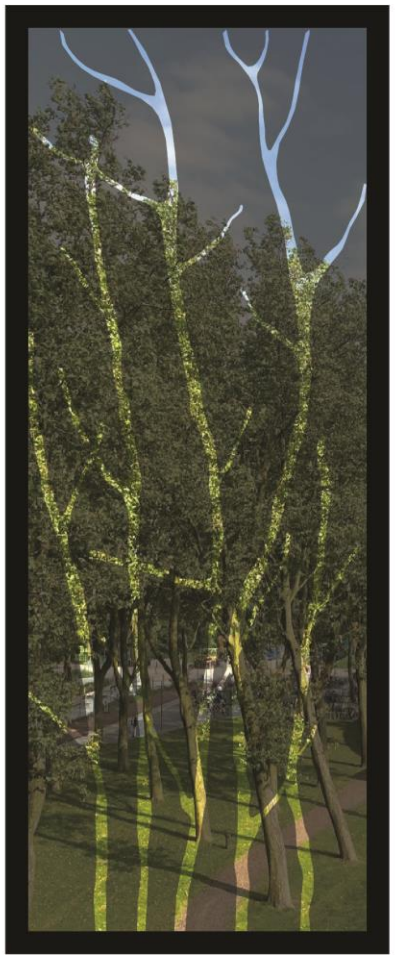
Patterns with inverted transparency for more access to the view outside



Distinctive patterns for minimum glare maintaining the biophilic characteristics

PATTERN DESIGN & POTENTIAL ON VIEW

Cover an unwanted view

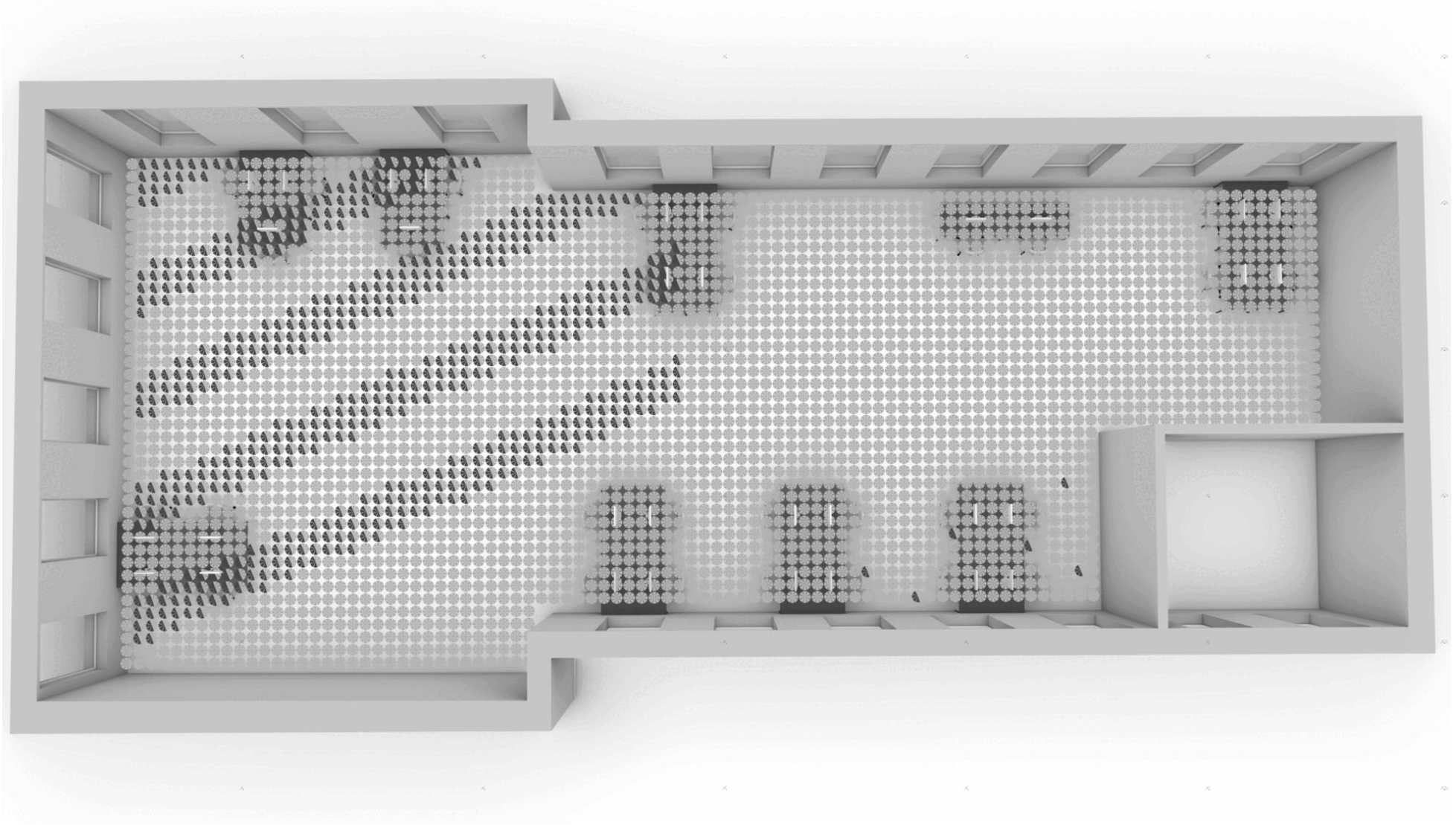


Maintain a natural view

Add biophilic value

APPLICATION & CHALLENGES

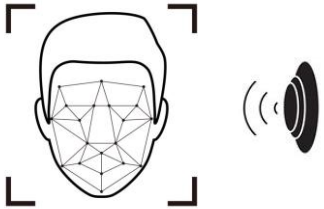
APPLICATION & CHALLENGES



BRIDGING AUTOMATION & PERSONAL CONTROL

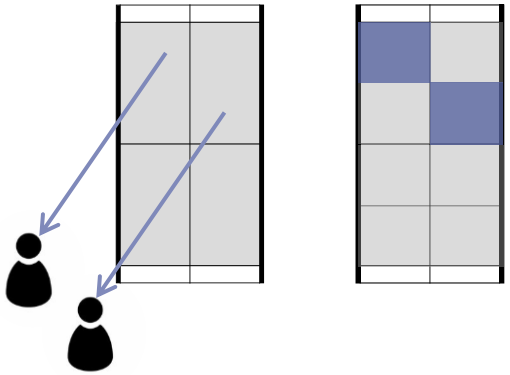
- Automated system

Point cloud system



Occupancy detector

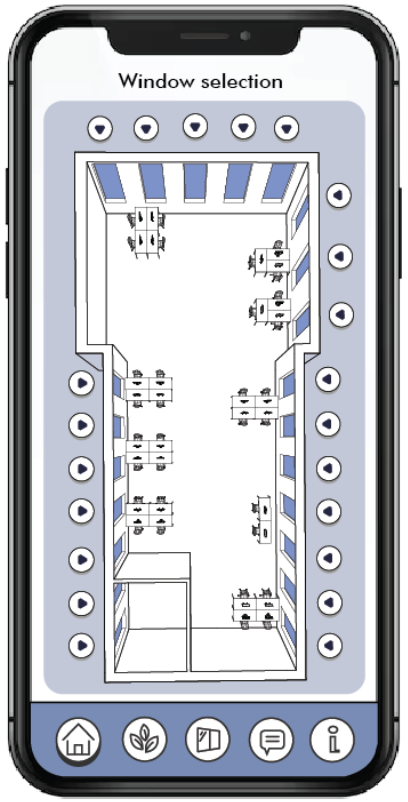
Photosensors for lighting data

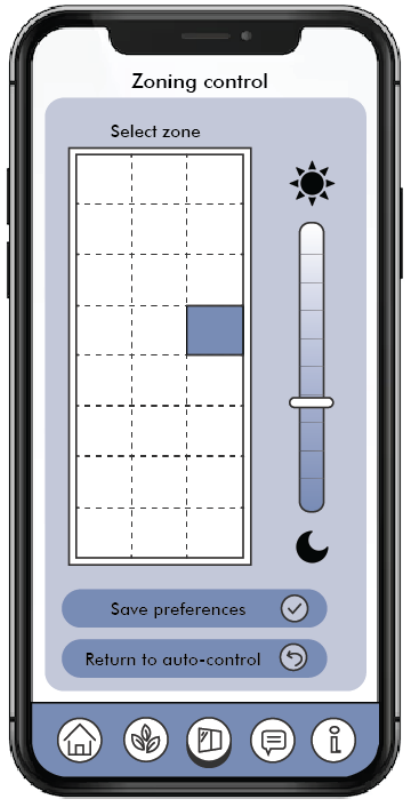


Sun ray tracing

Zonal control for independent adjustments in the problematic areas

- User-friendly interface for personal control





THANK YOU!