Material Efficiency

The Can

- 1960

Material Efficiency

The Can

- 1960

- 1970

Material Efficiency

The Can

- 1960

- 1970

- 2024

Material Efficiency

The Can

- 1960
- 12 Oz
- Cylinder

- 1970
- 12 Oz
- Cylinder

- 2024
- 12 Oz
- Cylinder

Material Efficiency

The Can

- 1960
- 12 Oz
- Cylinder
- **80 Gm**

- 1970
- 12 Oz
- Cylinder

- 2024
- 12 Oz
- Cylinder

Material Efficiency

The Can

- 1960
- 12 Oz
- Cylinder
- **80 Gm**

- 1970
- 12 Oz
- Cylinder
- **60 Gm**

- 2024
- 12 Oz
- Cylinder

Material Efficiency

The Can

- 1960
- 12 Oz
- Cylinder
- **80 Gm**

- 1970
- 12 Oz
- Cylinder
- **60 Gm**

- 2024
- 12 Oz
- Cylinder
- **15 Gm**

Material Efficiency

The Can

- 1960
- 12 Oz
- Cylinder
- **80 Gm**

100%

- 1970
- 12 Oz
- Cylinder
- **60 Gm**

60 %

- 2024
- 12 Oz
- Cylinder
- **15 Gm**

20%

Material efficiency

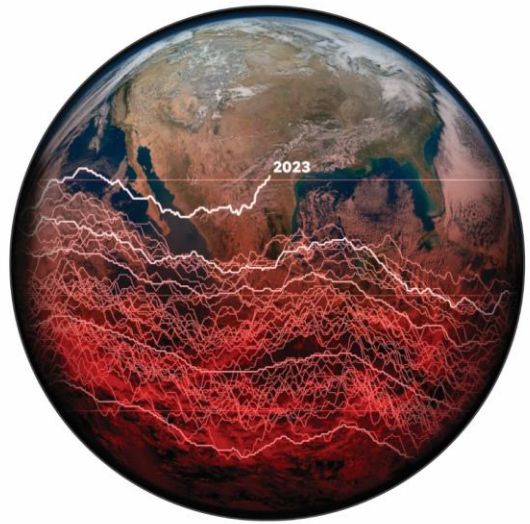
Drive

Finite Resources

Material efficiency

Drive

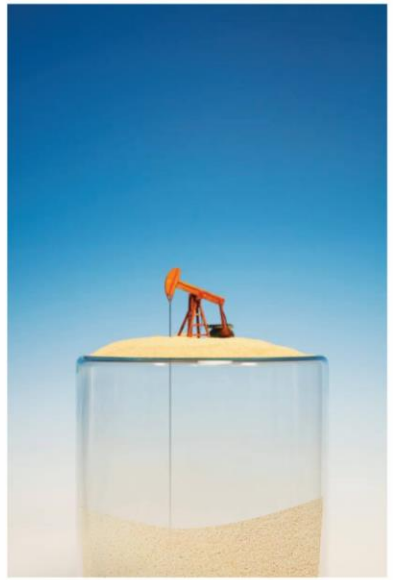
Finite Resources



Climate Change

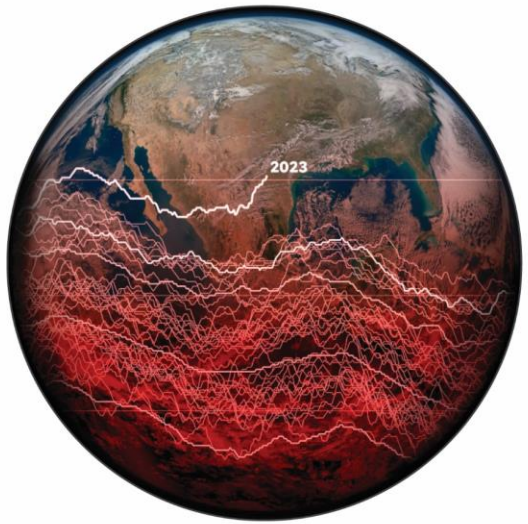
Material efficiency

Drive



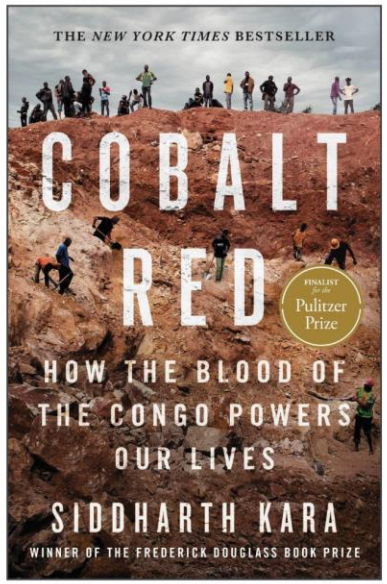
Finite Resources

https://www.gettyimages.nl/detail/foto/oil-pump-on-top-of-empty-glass-royalty-free-beeld/187138159?adppopup=true



Climate Change

https://us.macmillan.com/books/9781250284297/cobaltred



Human Rights

https://images.app.goo.gl/gRFhWNZJN8ZgNKYd8

Empirical Assessment of Glazing Serviceability Limit:
Exploring Occupant Acceptance.

Mentors:

Dr. Alessandra Luna Navarro

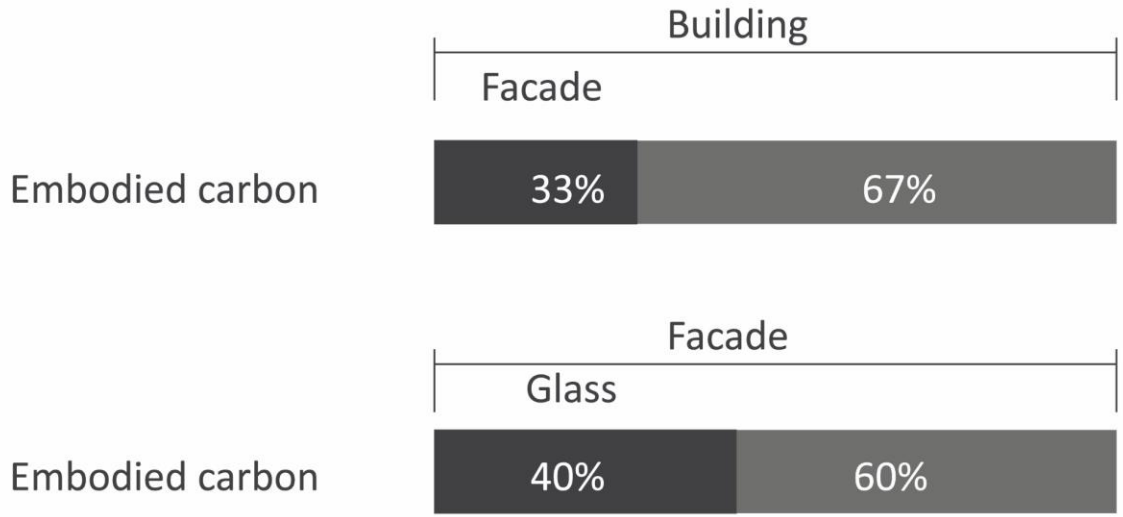
Prof. Dr. Mauro Overend

Advisor:

Pedro de la Barra Leugmayer

Background

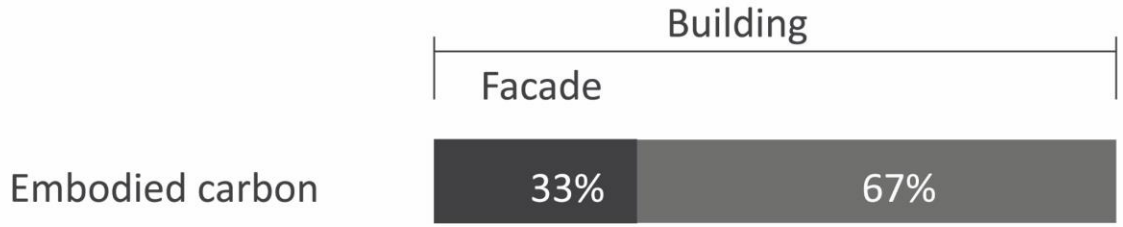
Embodied carbon

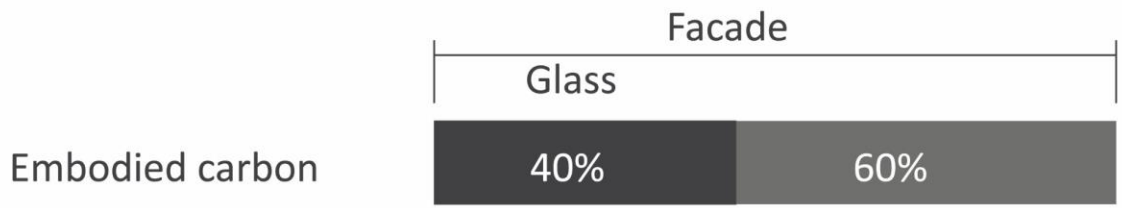


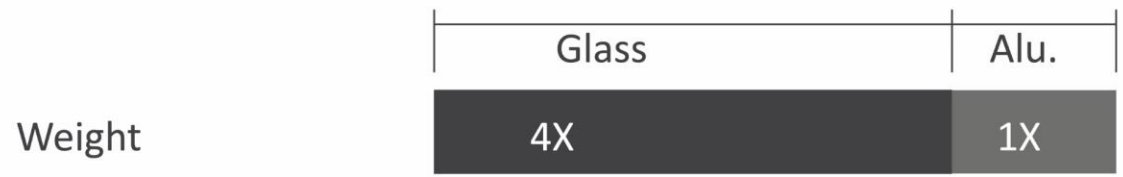
Glazing material contribution

Background

Embodied carbon





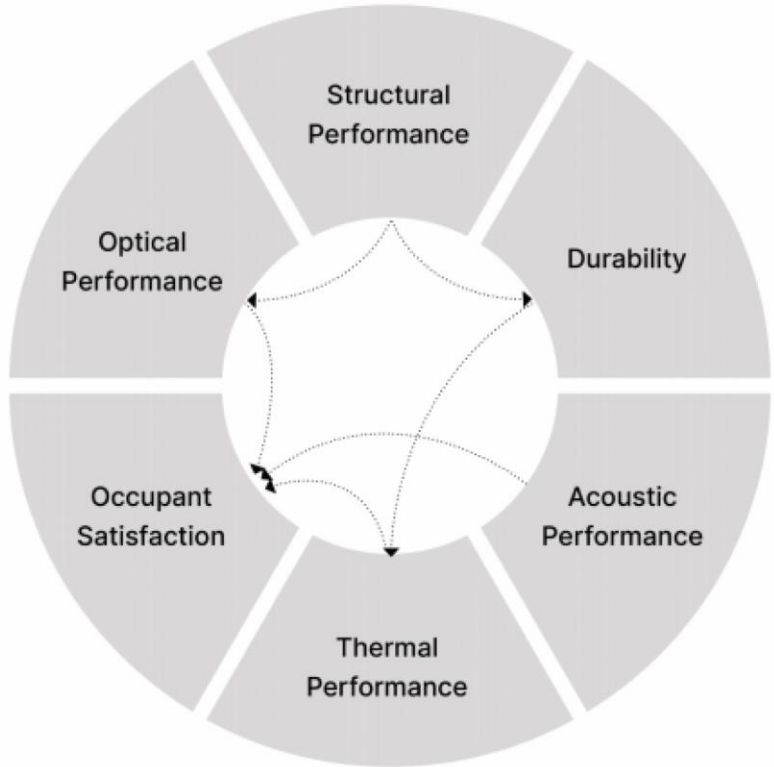


10-40 % by weight of the facade

230 billion Square meters of new building in the next four decade
Paris

Chapter

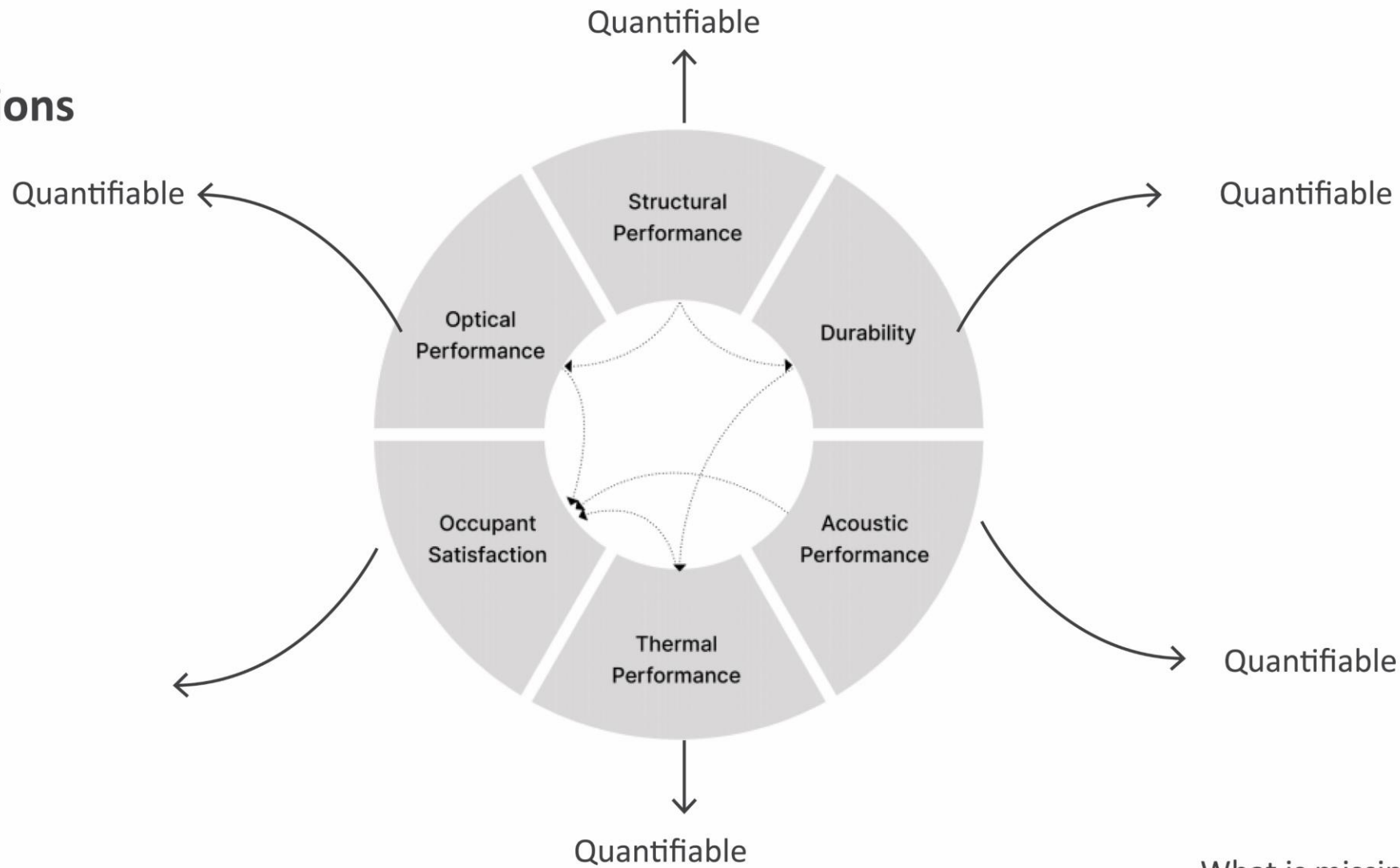
Functional considerations



(Sager Oke. ,2023)

Background

Functional considerations

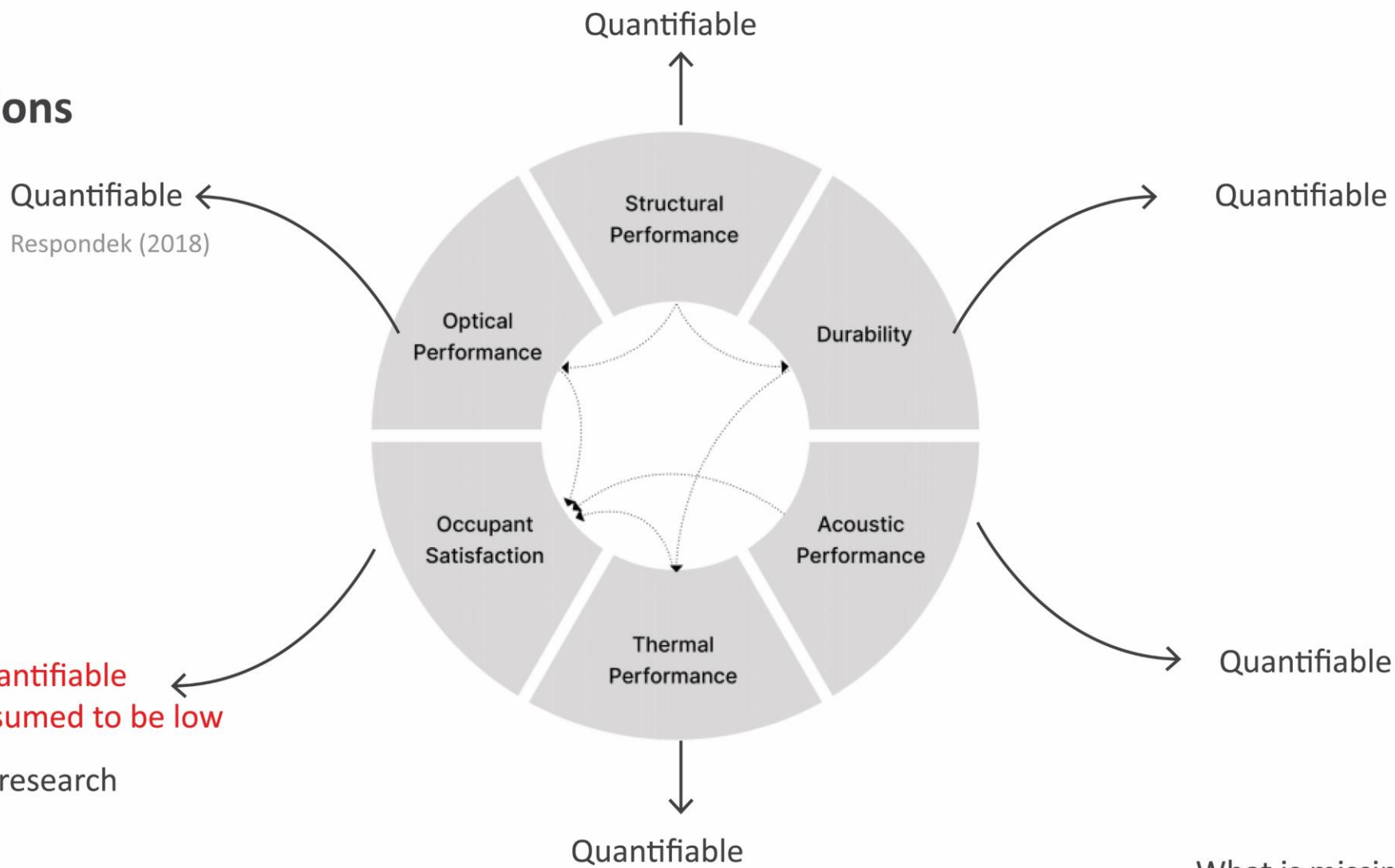


What is missing

Background

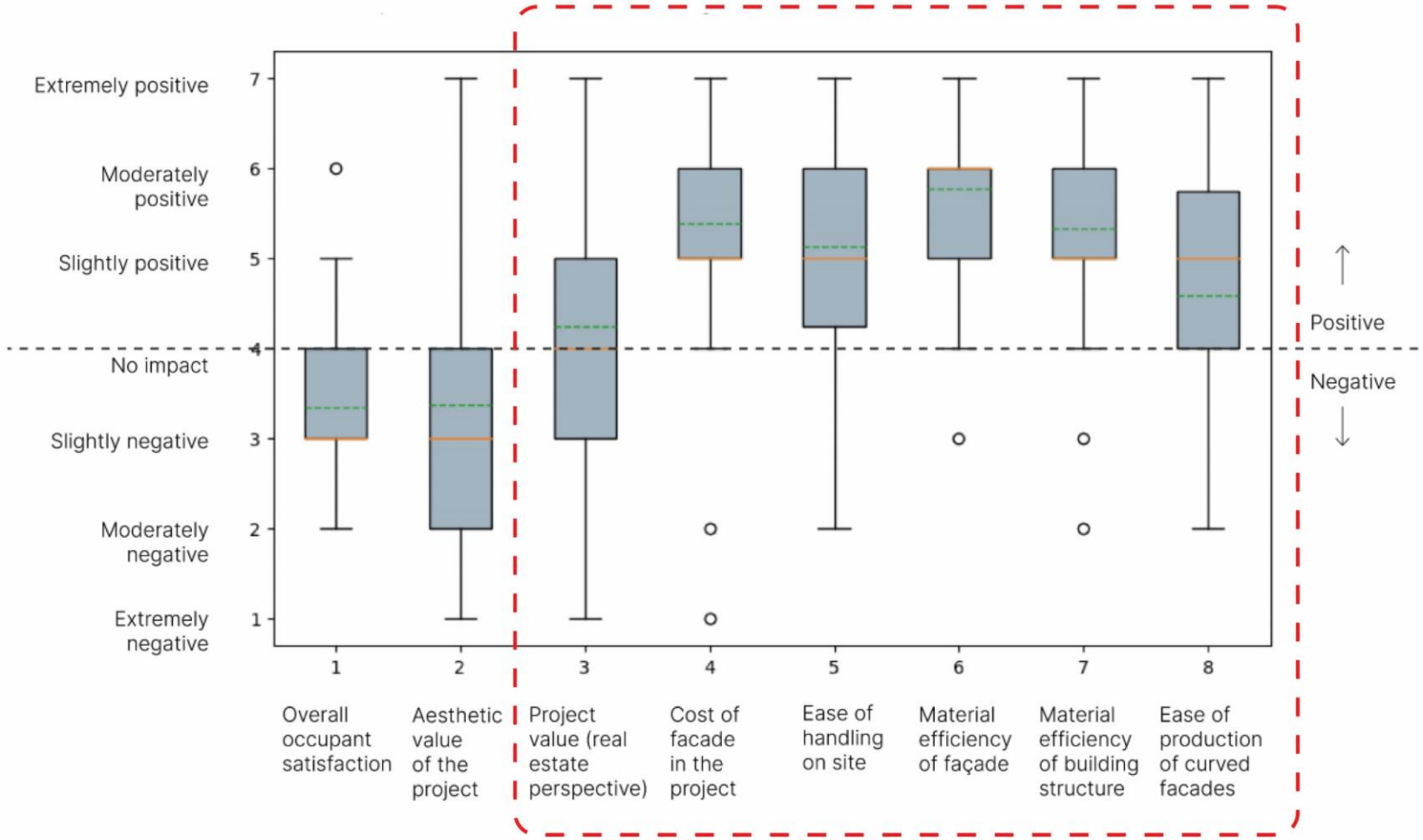
Functional considerations

Datsiou and Overend (2016) and Quaglini et al. (2020).



Background

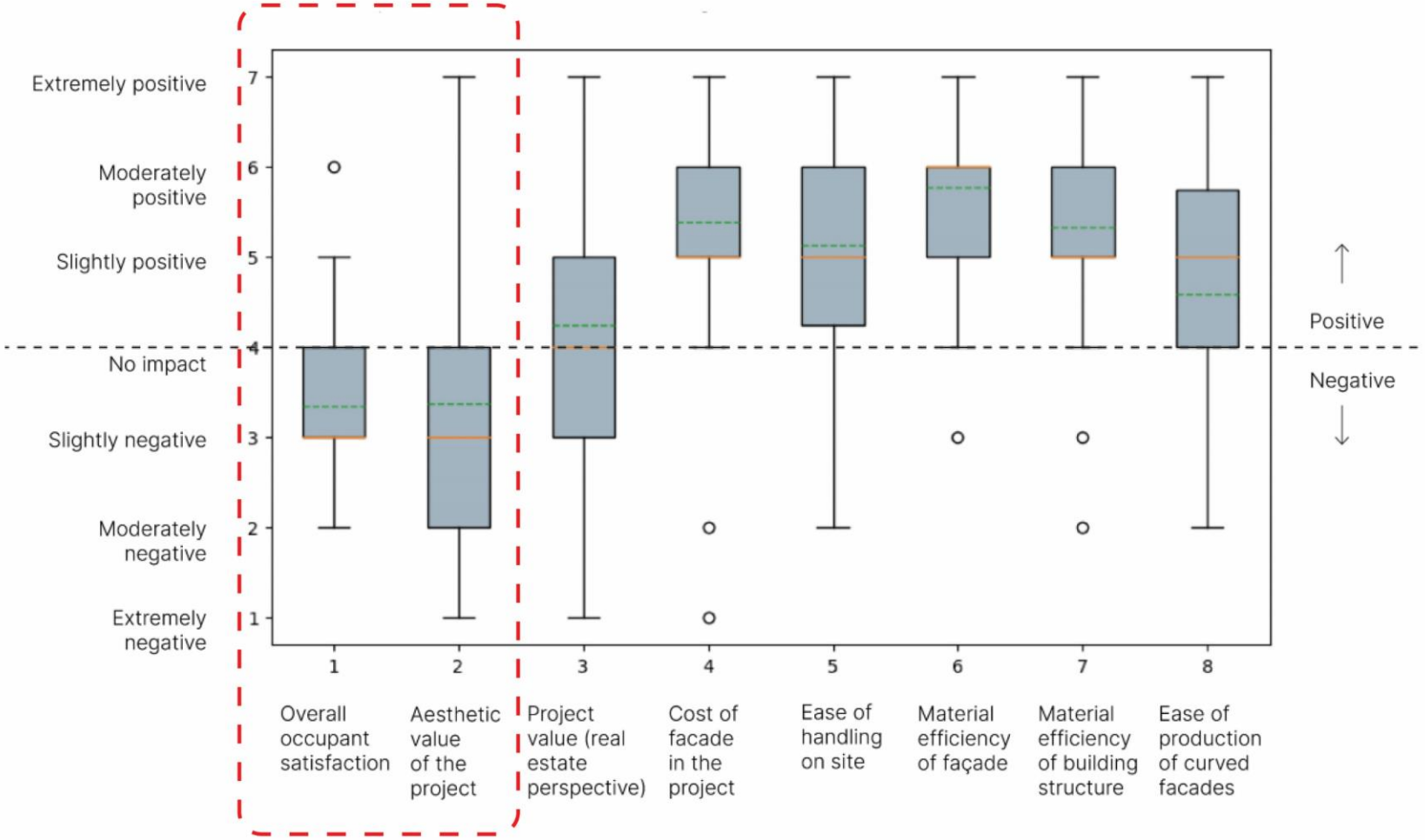
Industry survey



Survey was conducted to check impact of thin glass
(Sager oke, 2023)

Background

Industry survey

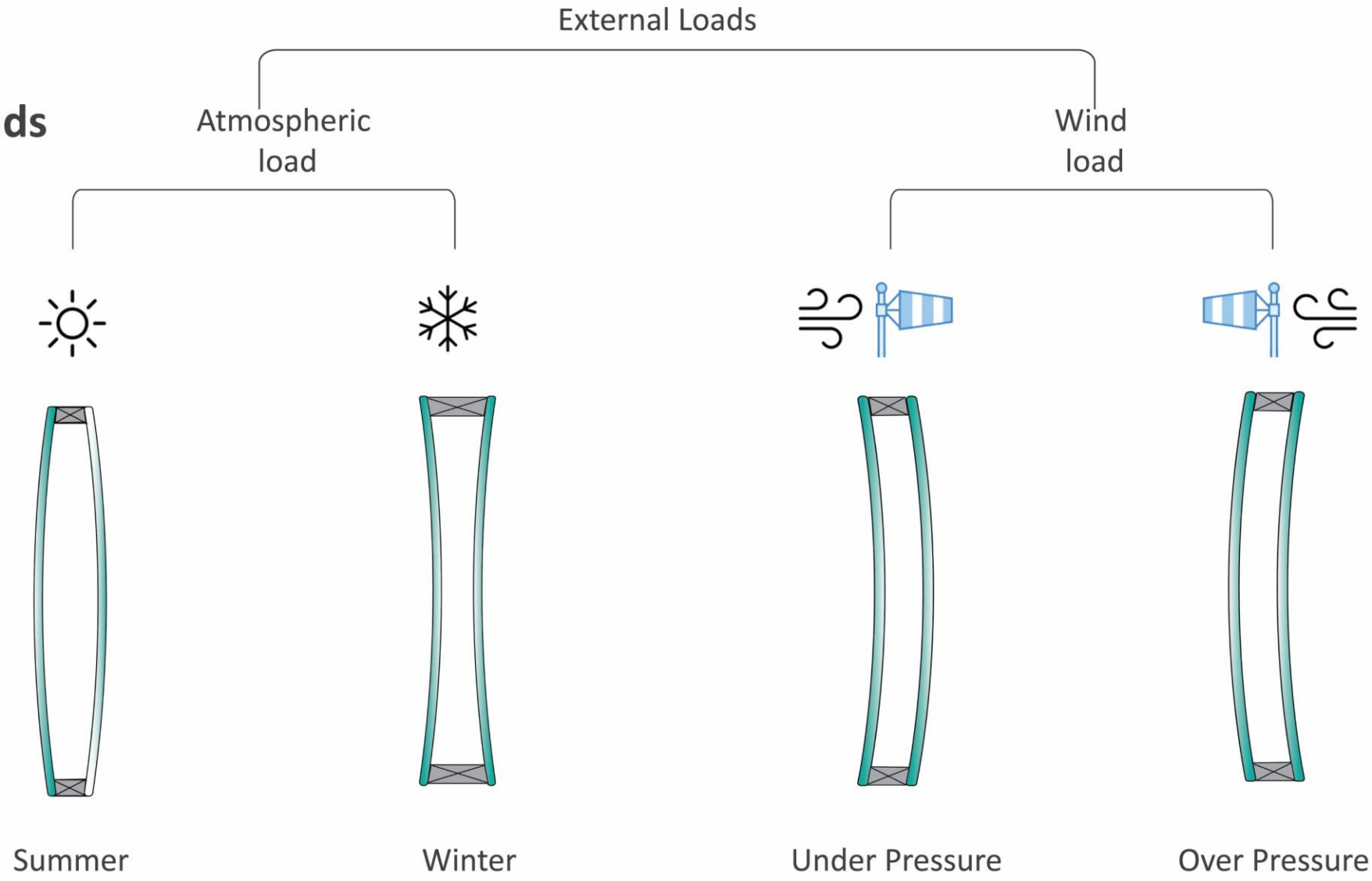


(Sager oke, 2023)

Background

External Loads

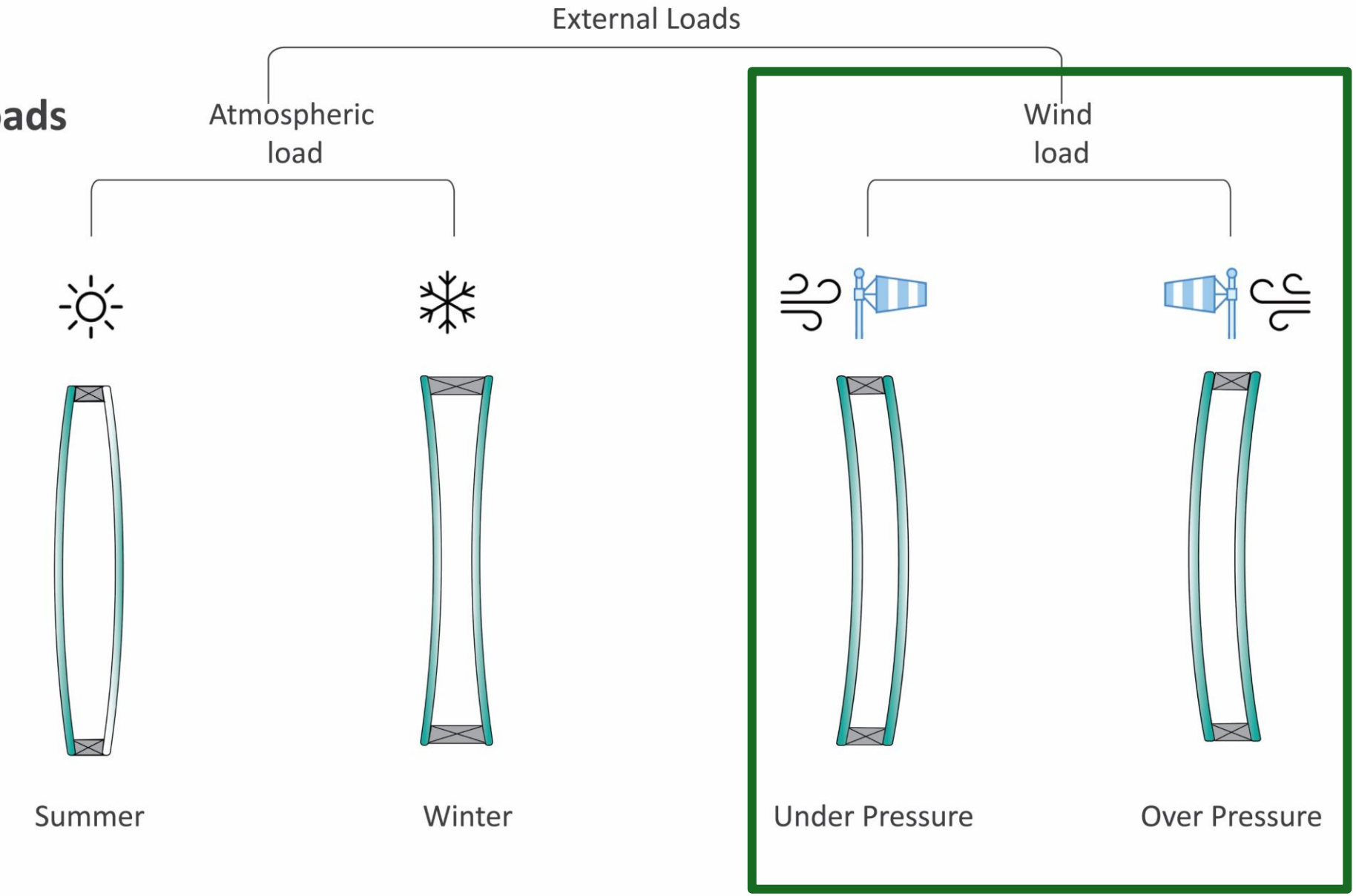
Why the Concern?



Background

External Loads

Why the Concern?



Background

Limit states

ULS

Ultimate Limit State

Resistance of load with out material **failure**

Background

Limit states

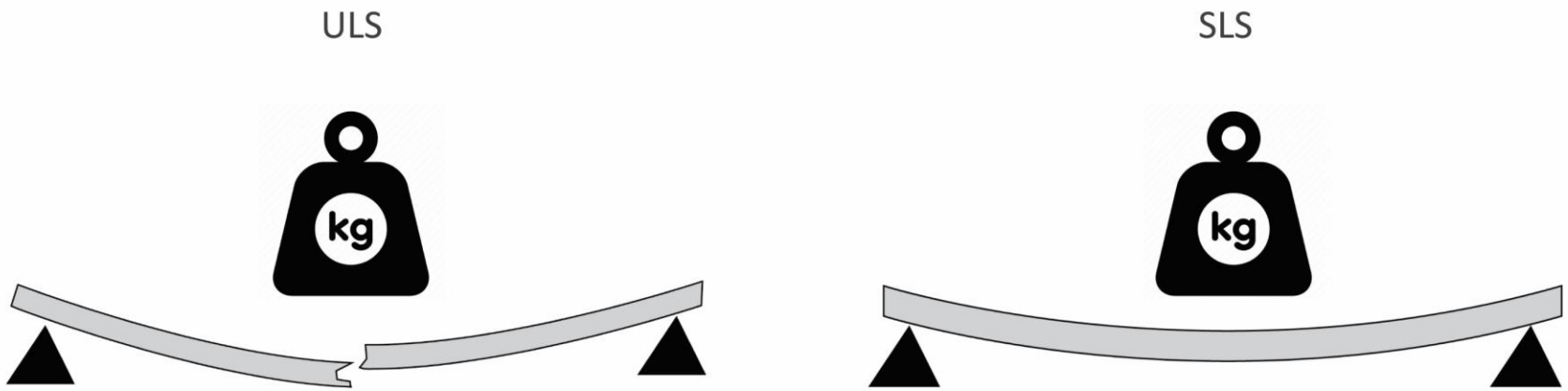
Ultimate Limit State

Resistance of load with out material **failure**

Serviceability Limit State

A condition at which a component is **fit for use**

"Functional"



Background

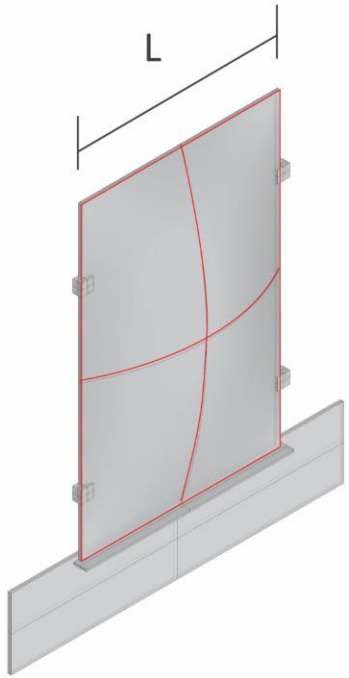
Limit states

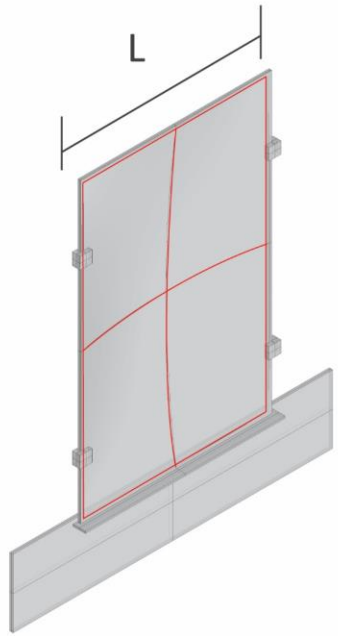
Serviceability Limit State

A condition at which
a component is **fit for use**

"Functional"

Servicability limit of Insulated Glass Unit





L/50

(FprCEN/TS 19100-2)

Framework

Hypothesis

Problem statement

Minimum possible thickness of glass is not often governed by strength or manufacturing limits but rather by the deflection(**serviceability limit**)

Despite this **importance** the **occupants satisfaction** to glazing deflection remains **unexplored** leading to a **conservative design**.

Hypothesis

The research hypothesizes that **addressing** the gap in data related to **assessing human perception and acceptance** to glazing deflection will provide insights into **material Saving in glazings**.

Framework

Research Question

To What extent can we **relax the serviceability limit** on Insulated glass units with out being **detrimental** to the **performance of the facade**?

What is the **Serviceability limit** in practice

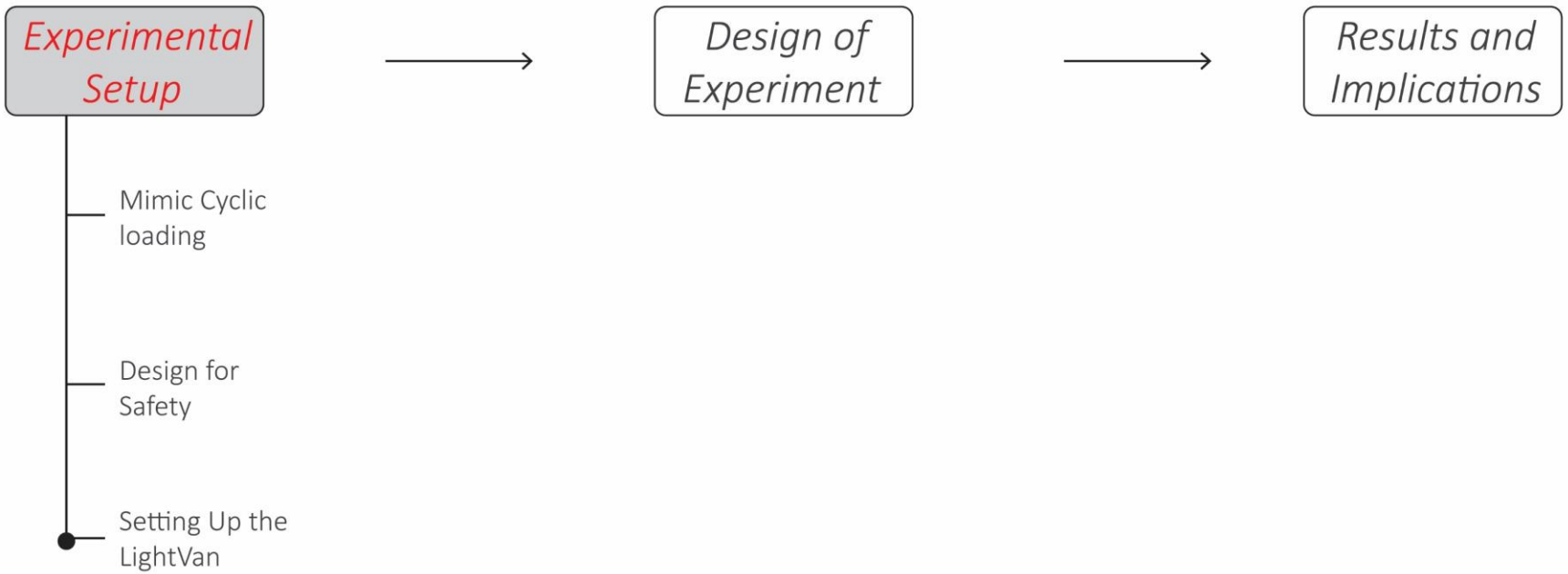
What are the **factors** affecting **occupants perception** and **acceptance** of IGU deflection?

What is the threshold of acceptance to IGU deflection?

What are the **implications** of reducing thickness on the **embodied carbon of glazings** and the **design practice**?

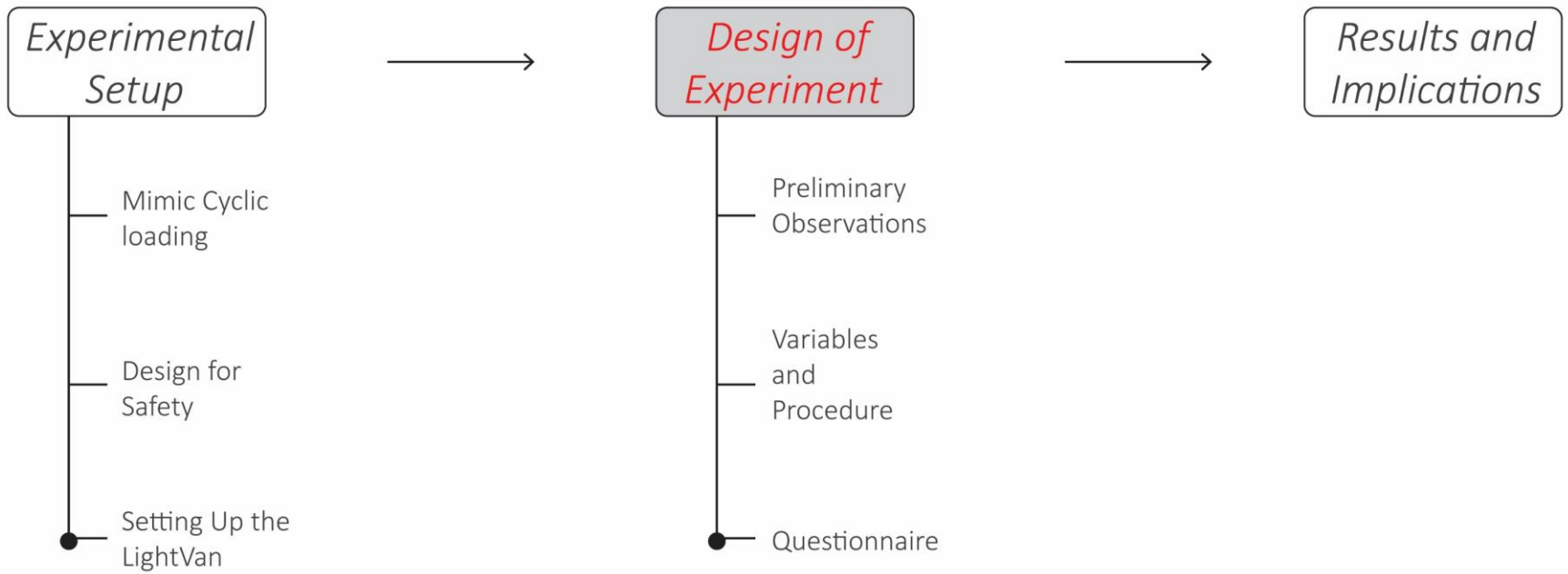
Correlating CGD with Perception and Acceptance

Overview



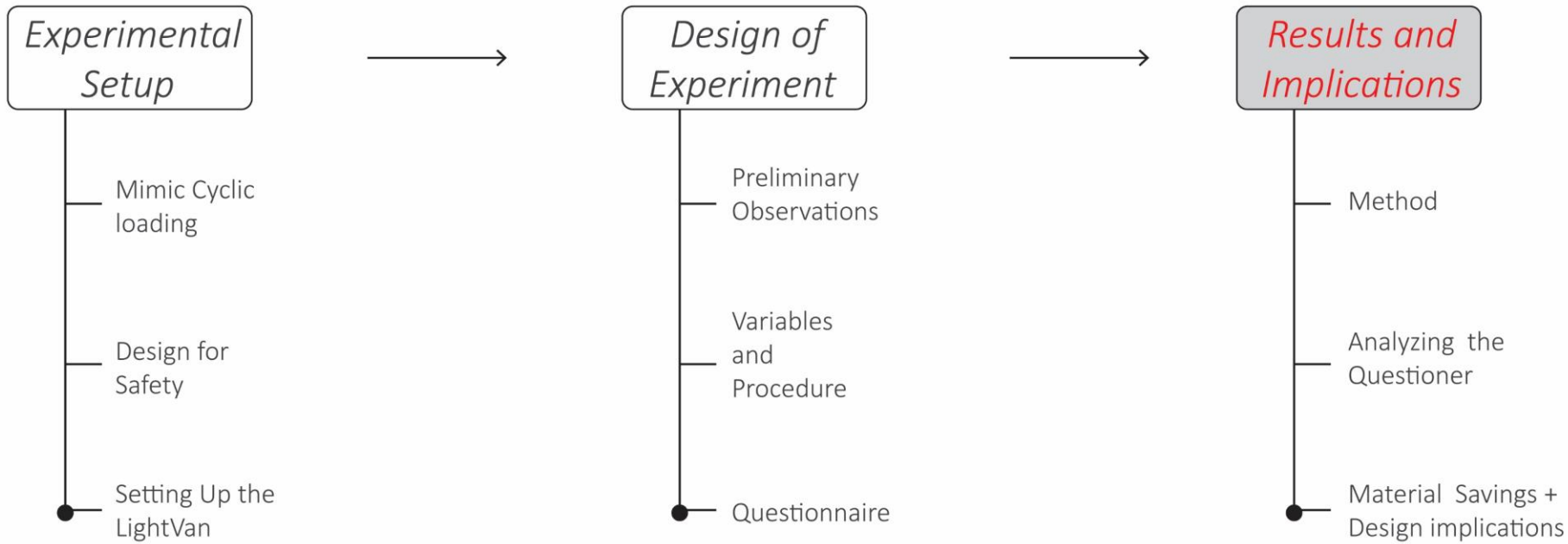
Correlating CGD with Perception and Acceptance

Overview



Correlating CGD with Perception and Acceptance

Overview



Experimental Setup

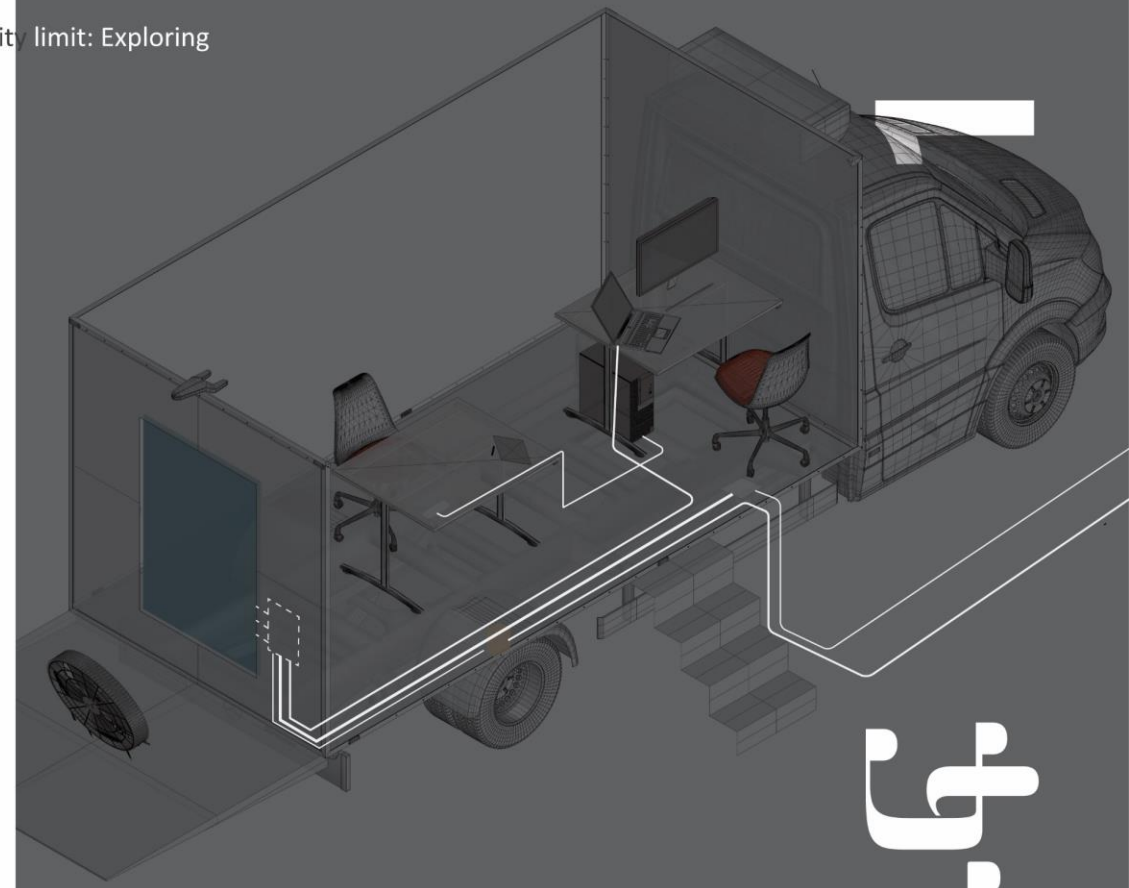
↓

Design of Experiment

↓

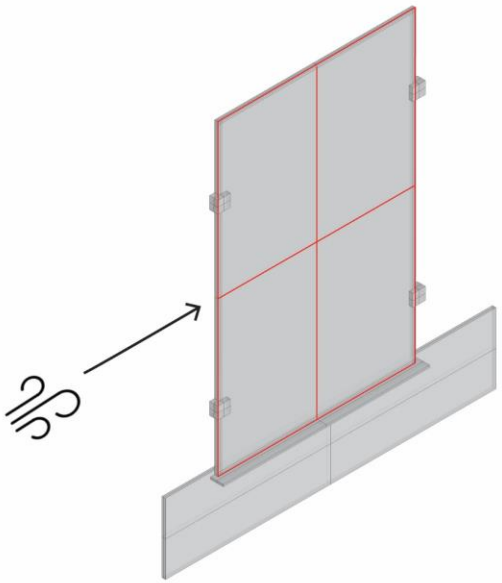
Results and Implications

- *Mimic Cyclic loading*
- *Safety of experiment*



Experimental set up

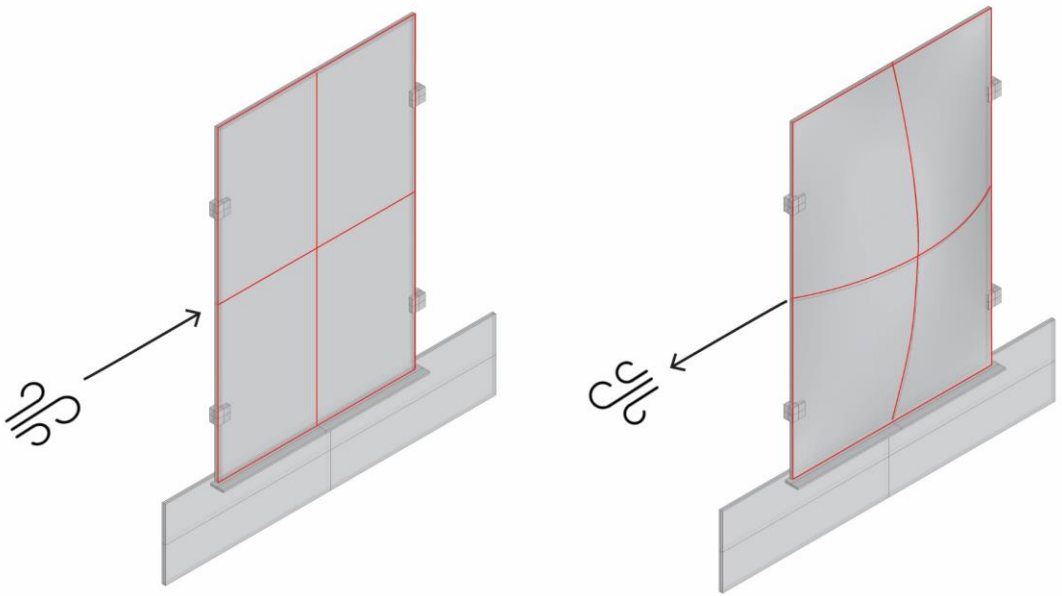
Method



Inflate

Experimental set up

Method

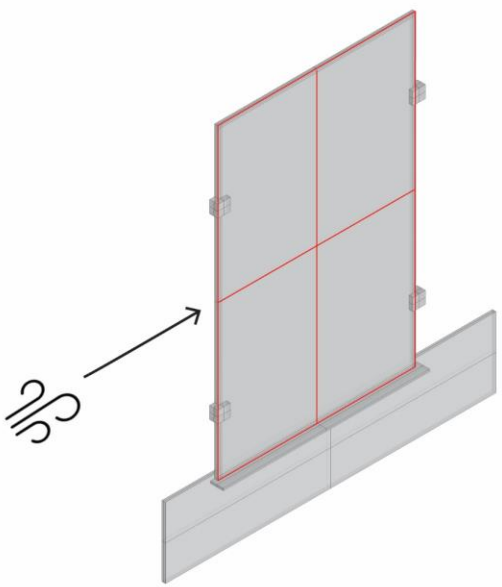


Inflate

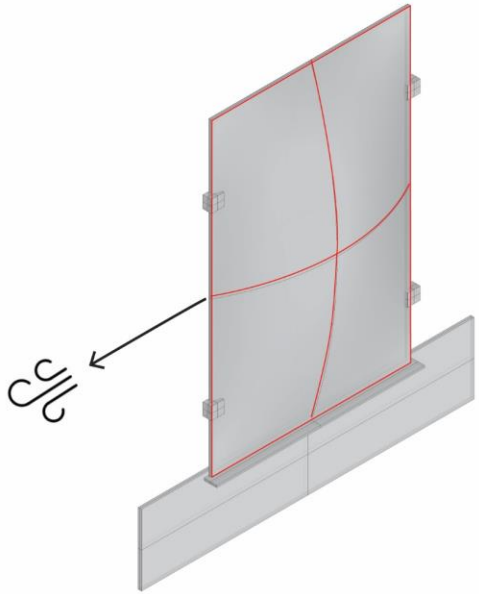
Deflate

Experimental set up

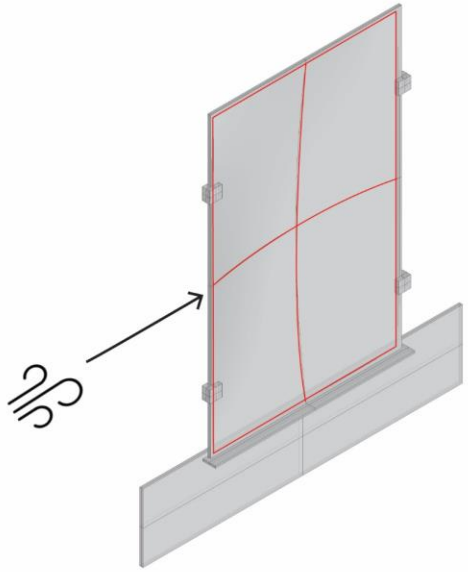
Method



Inflate



Deflate



Inflate

Components

Pneumatic

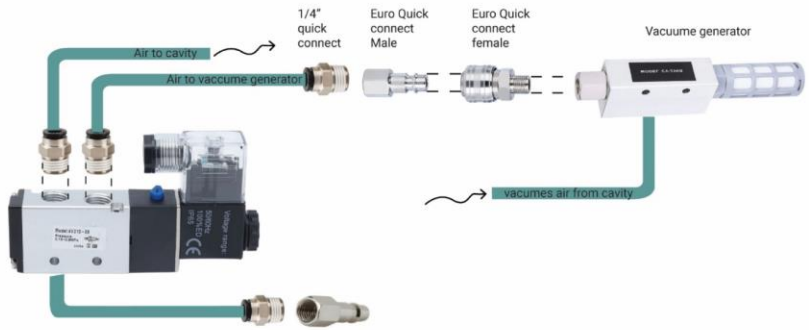
Electronic

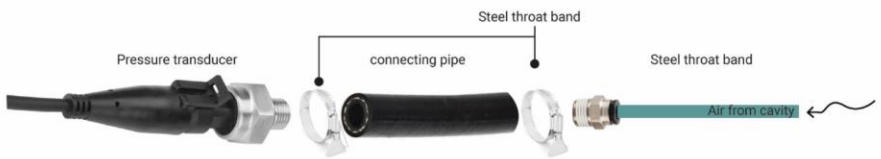
Control Algorithm

Experimental set up

Pneumatic Components

- Air Pump
- Vacuum Generator
- Solenoid
- Ball Valve
- Connectors
- Tubing



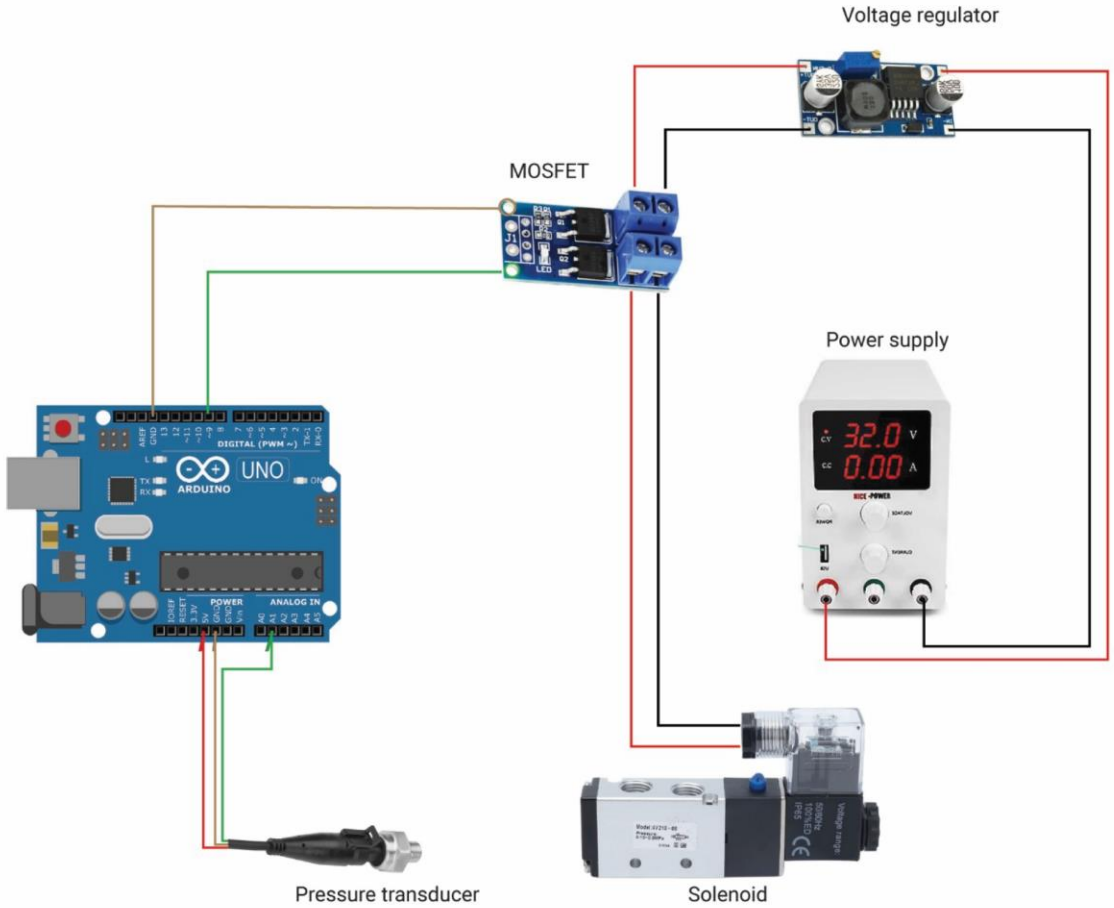


Experimental Setup → *Mimic Cyclic loading* → *Design for Safety* → *Setting Up the LightVan* → *Design of Experiment* → *Results and Implications*

Experimental set up

Electronic Component

- Micro controller
- Pressure transducer
- MOSFET
- Voltage regulator



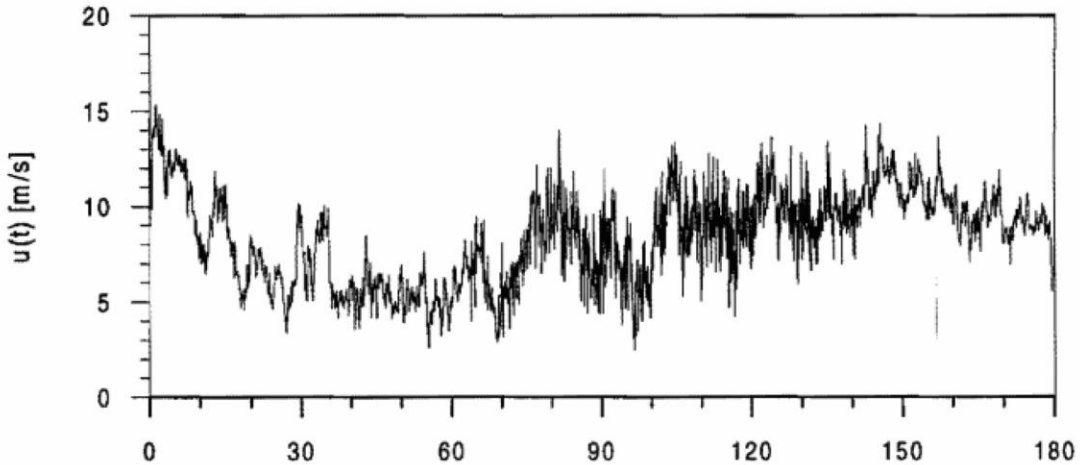
Experimental set up

Control Algorithm

- **Wind load behaviour**

  -Cyclic

  -Rises in pressure and flactuates between a certain threshold



Experimental set up

Control Algorithm

- **Wind load behaviour**

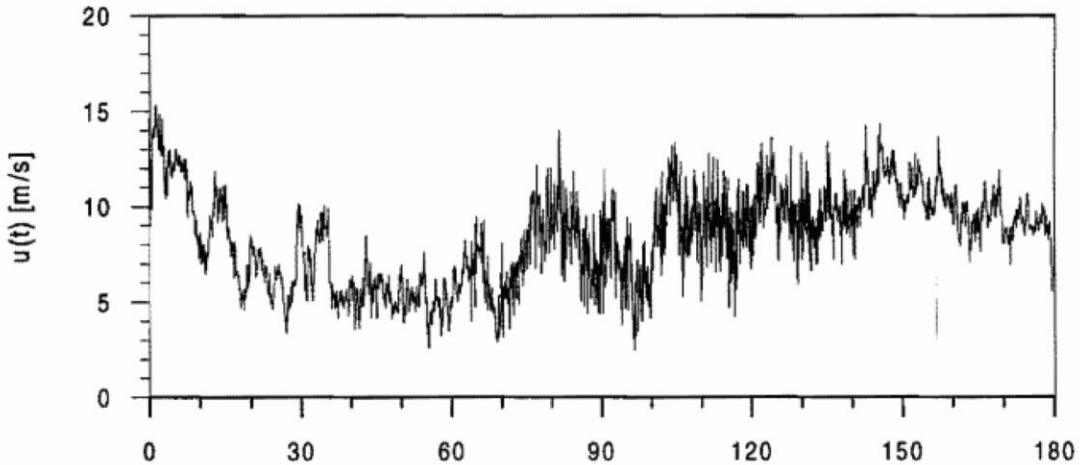
  -Cyclic

  -Rises in pressure and flactuates between a certain threshold

- **Function**

  -Read pressure

  -Send signal to pump
  -Continuously read pressure
  -Switch solenoid to vacuum
  -Repeate the cycle



Experimental set up

Control Algorithm

- **Wind load behaviour**

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  -Rises in pressure and flactuates between a certain threshold

- **Function**

  -Read pressure

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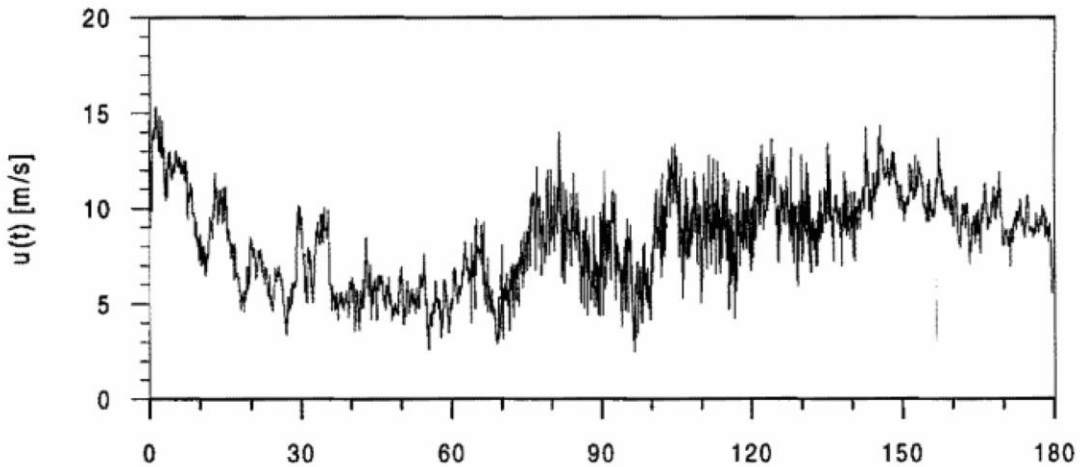
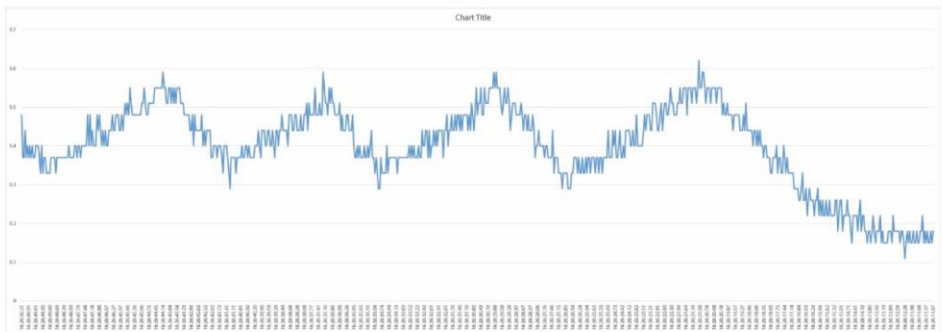
  -Repeate the cycle

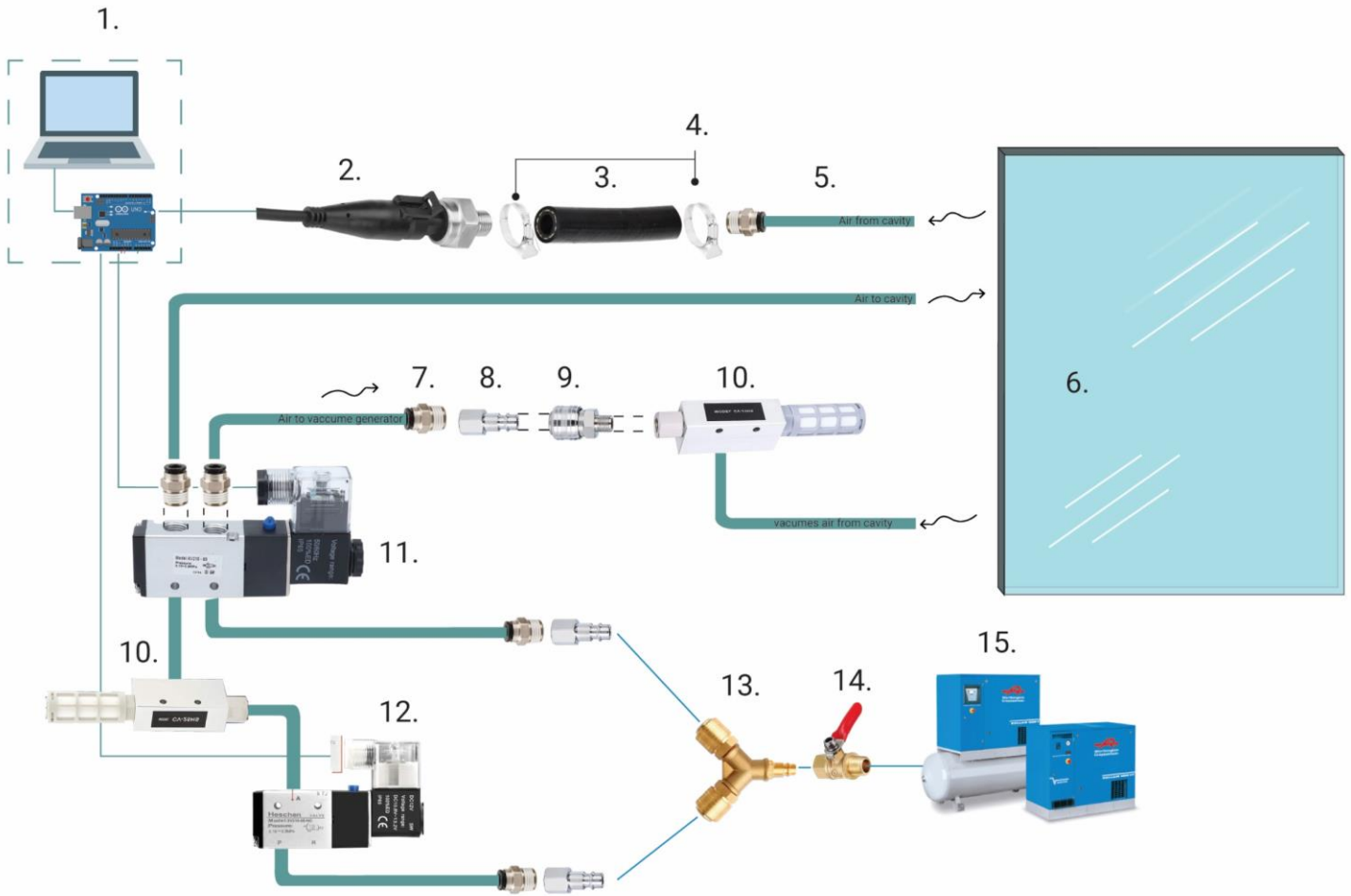




Experimental Setup → Mimic Cyclic loading → Design for Safety → Setting Up the LightVan → Design of Experiment → Results and Implications

Experimental set up

Cyclic loading



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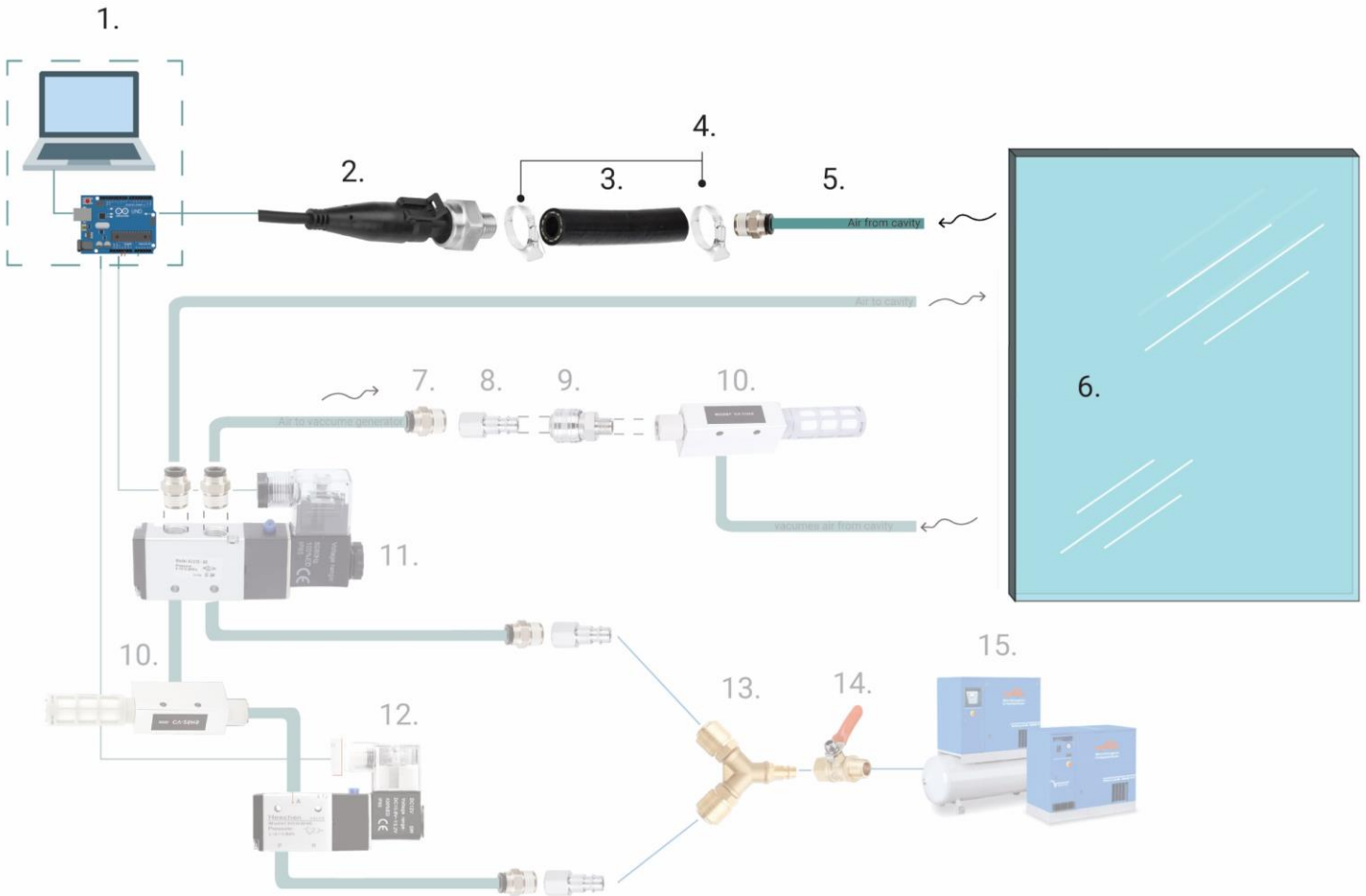
Experimental set up

Cyclic loading



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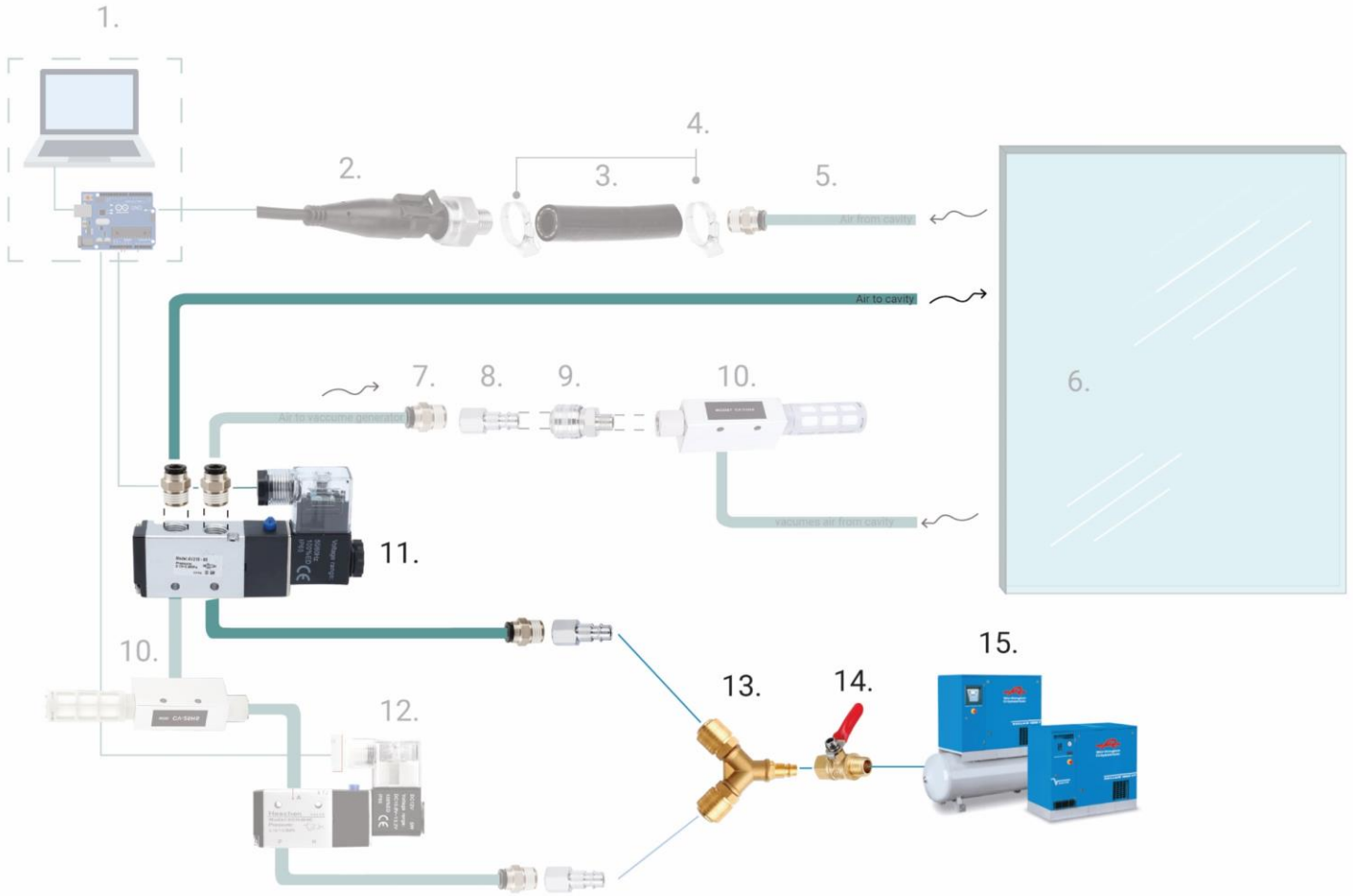
Experimental set up

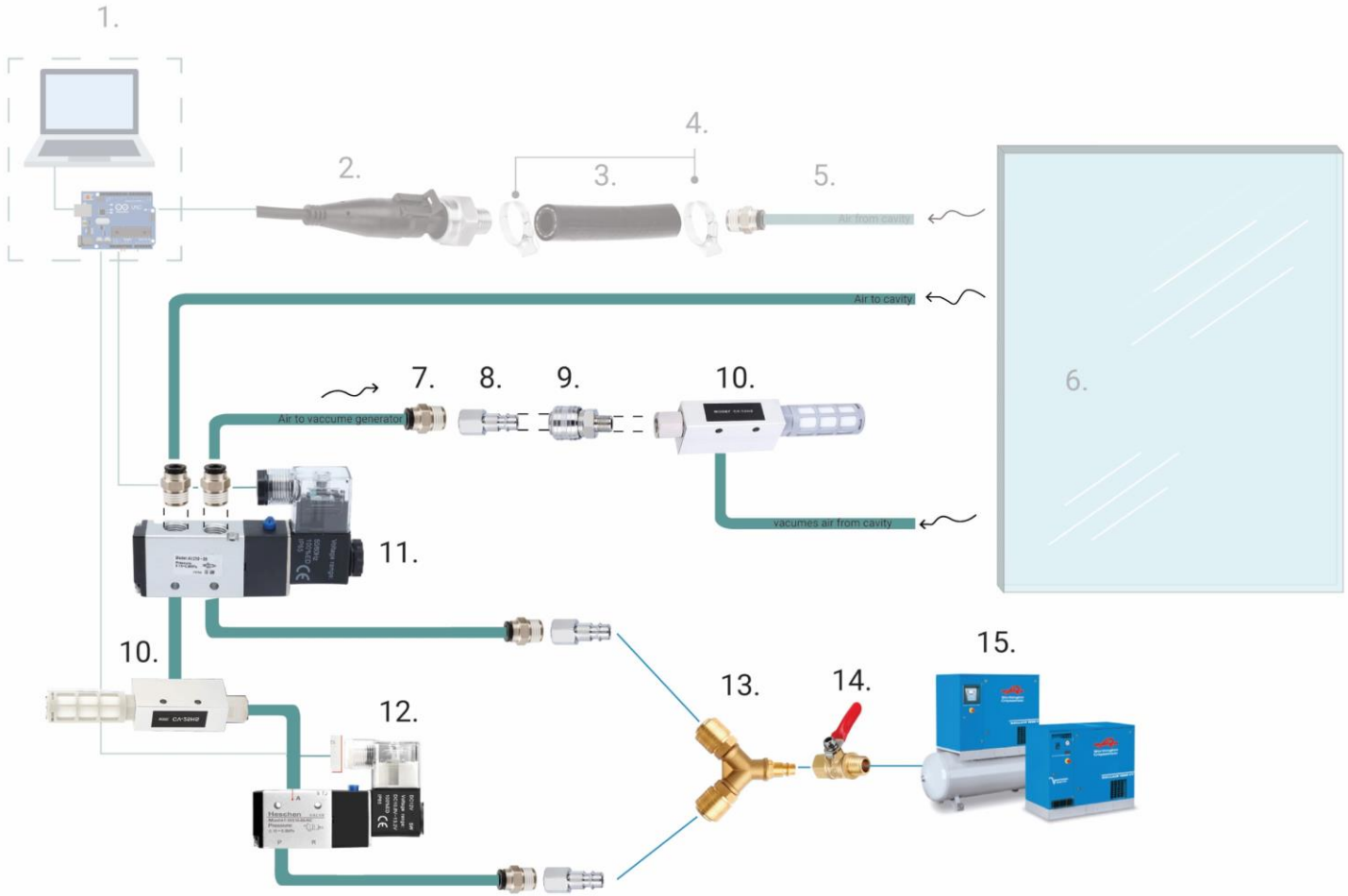
Cyclic loading



Experimental Setup → Mimic Cyclic loading → Design for Safety → Setting Up the LightVan → Design of Experiment → Results and Implications

Experimental set up

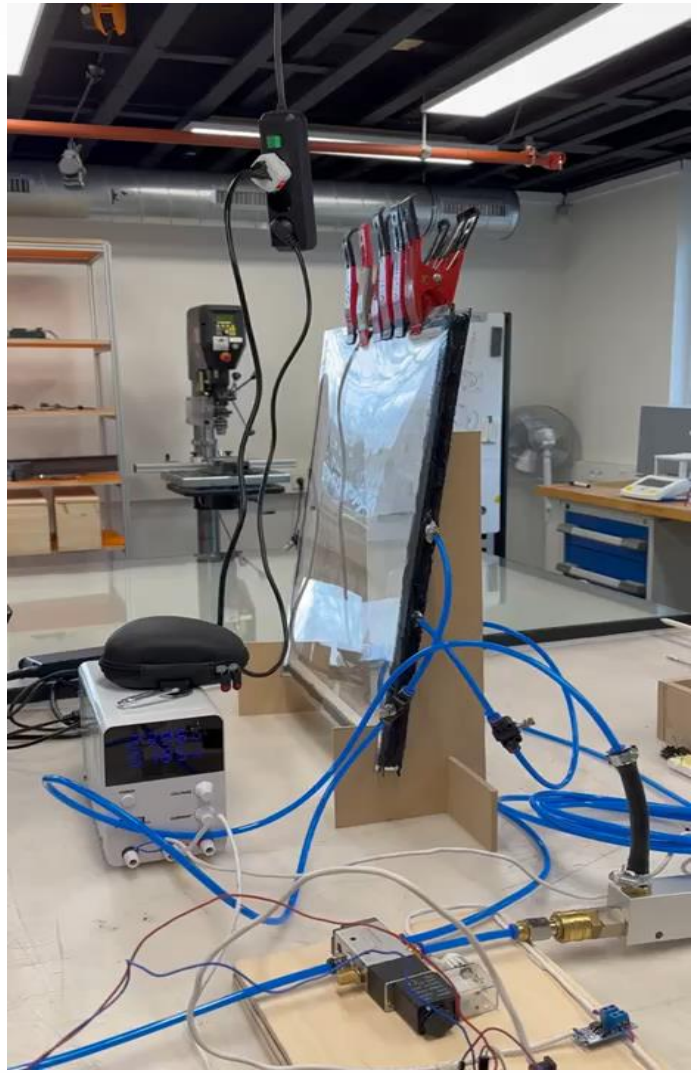
Cyclic loading



Experimental Setup → *Mimic Cyclic loading* → *Design for Safety* → *Setting Up the LightVan* → *Design of Experiment* → *Results and Implications*

Experimental set up

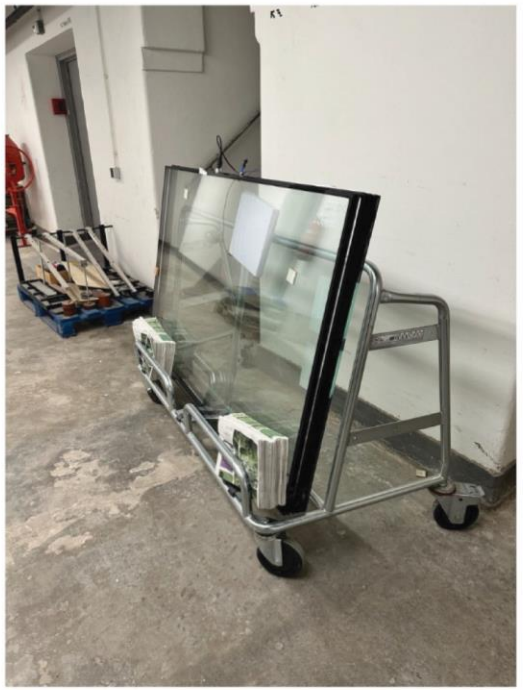
Cyclic loading



Experimental set up

Glass Specimen

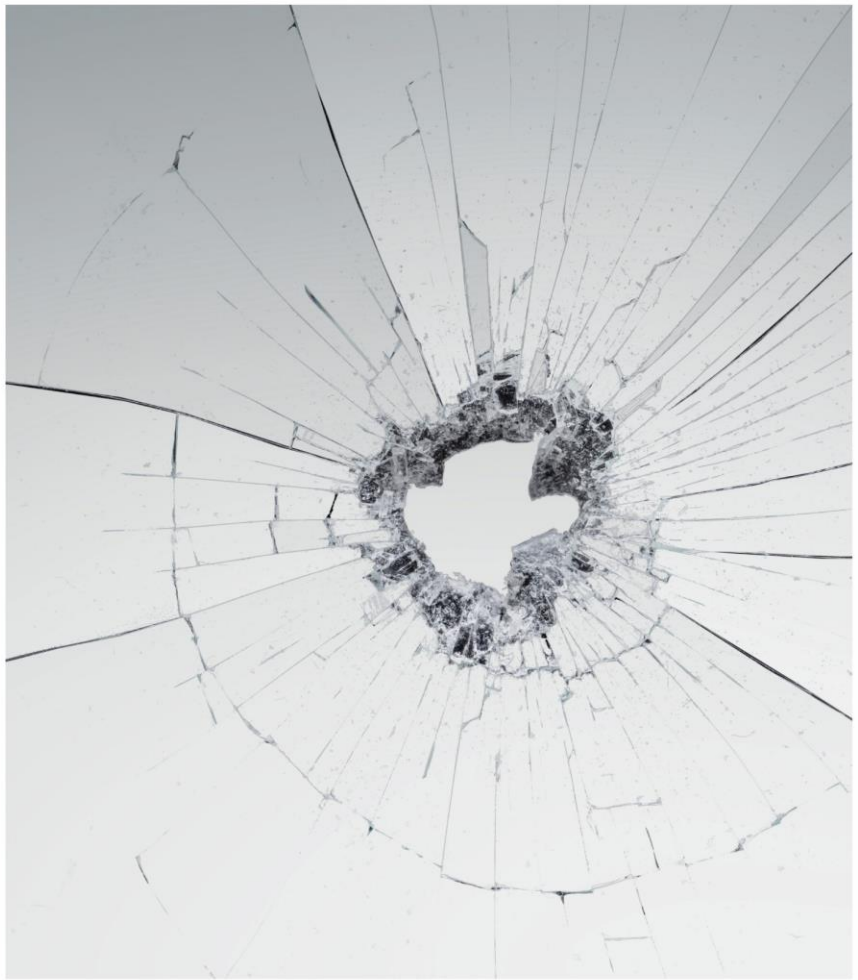
- 3 DGU
- 3 TGU
- 1- Annealed
- 2- Tempered



Experimental set up

Design for Safety

- Safety fim
- Break Test
- ASTM Blast arena test



Experimental set up

Safety Film

- Safety fim
- Break Test
- ASTM Blast arena test

Experimental set up

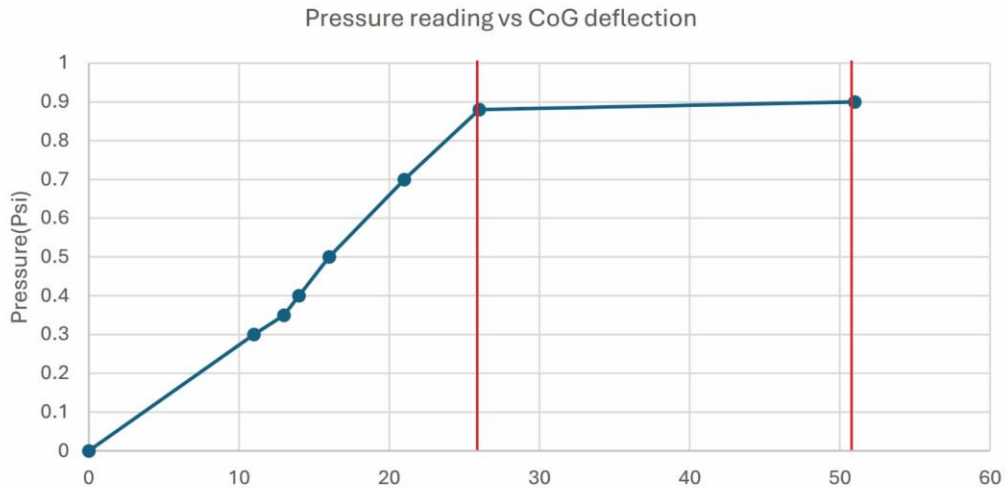
Break Test

- Performance of Safety film
- Break Point(Pressure)
- Center of Glass Deflection

Experimental set up

Results

- Pressure-6000 Pa
- CGD- 26 mm
- The Safety film retains the glass



Steps	Pressure in Psi	Pressure in Pascal	Deflection in mm
1	0.3	2068.4	11 mm
2	0.35	2413	13 mm
3	0.4	2757.9	14 mm
4	0.5	3447.4	16 mm
5	0.7	4826.33	21 mm
6	0.88	6067	26 mm
	0.9	6205.3	51 mm

Experimental set up

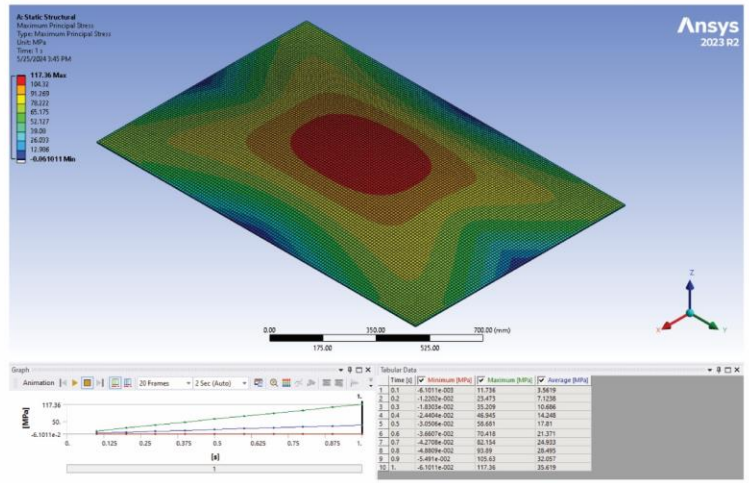
Results

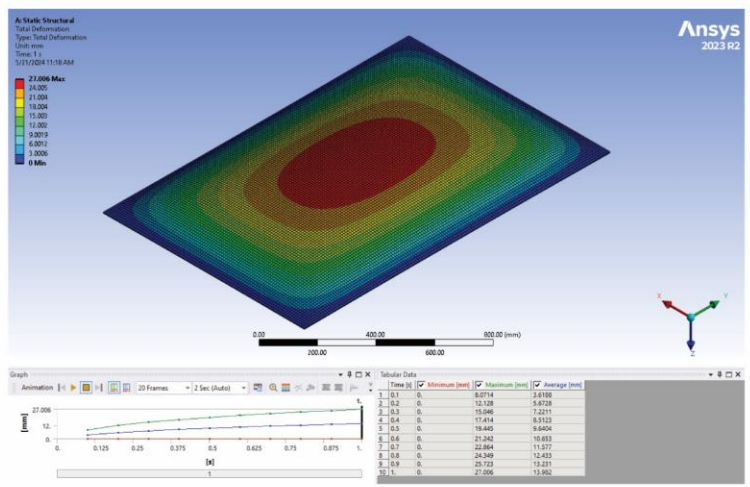
- Pressure-6000 Pa
- CGD- 26 mm
- The Safety film retains the glass

Experimental set up

Validation using FEA

- Compare measured Value
- Select a working pressure
- Center of Glass deflection



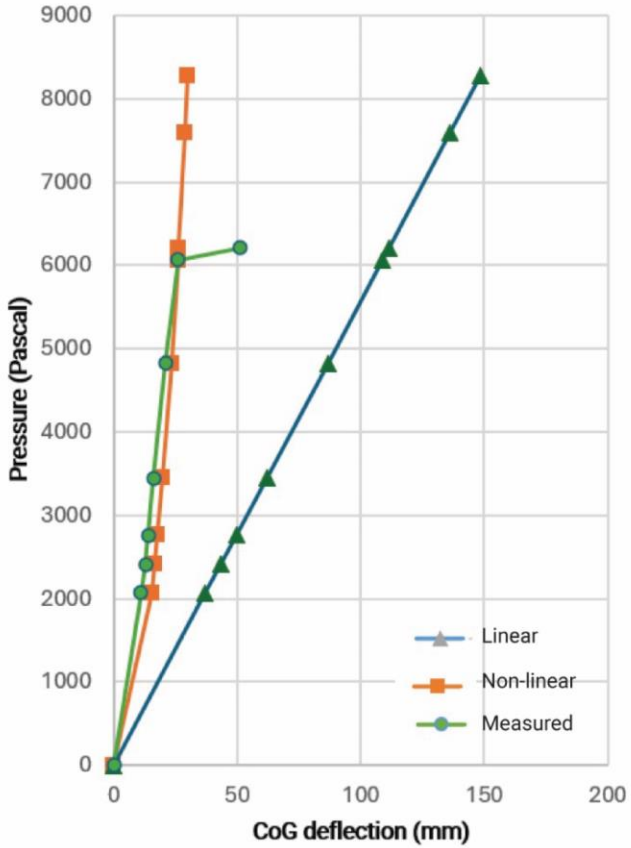


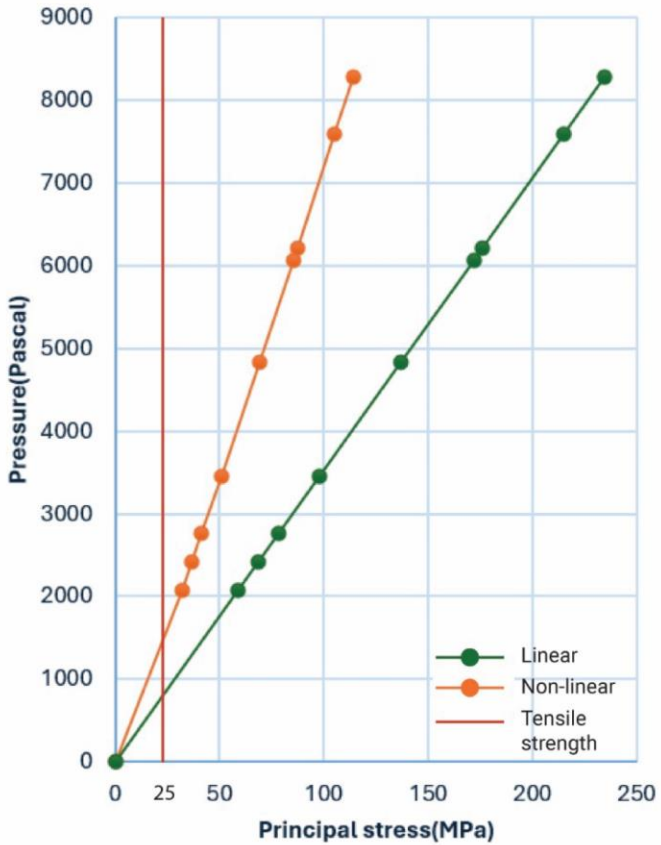
Experimental Setup → *Mimic Cyclic loading* → *Design for Safety* → *Setting Up the LightVan* → *Design of Experiment* → *Results and Implications*

Experimental setup

Validation using FEA

- Nonlinear analysis closely predict CGD
- But overestimates maximum principal stress





Experimental Setup → Mimic Cyclic loading → Design for Safety → Setting Up the LightVan → Design of Experiment → Results and Implications

Experimental setup

The LightVan

- Frame assembly
- The small office

Experimental setup

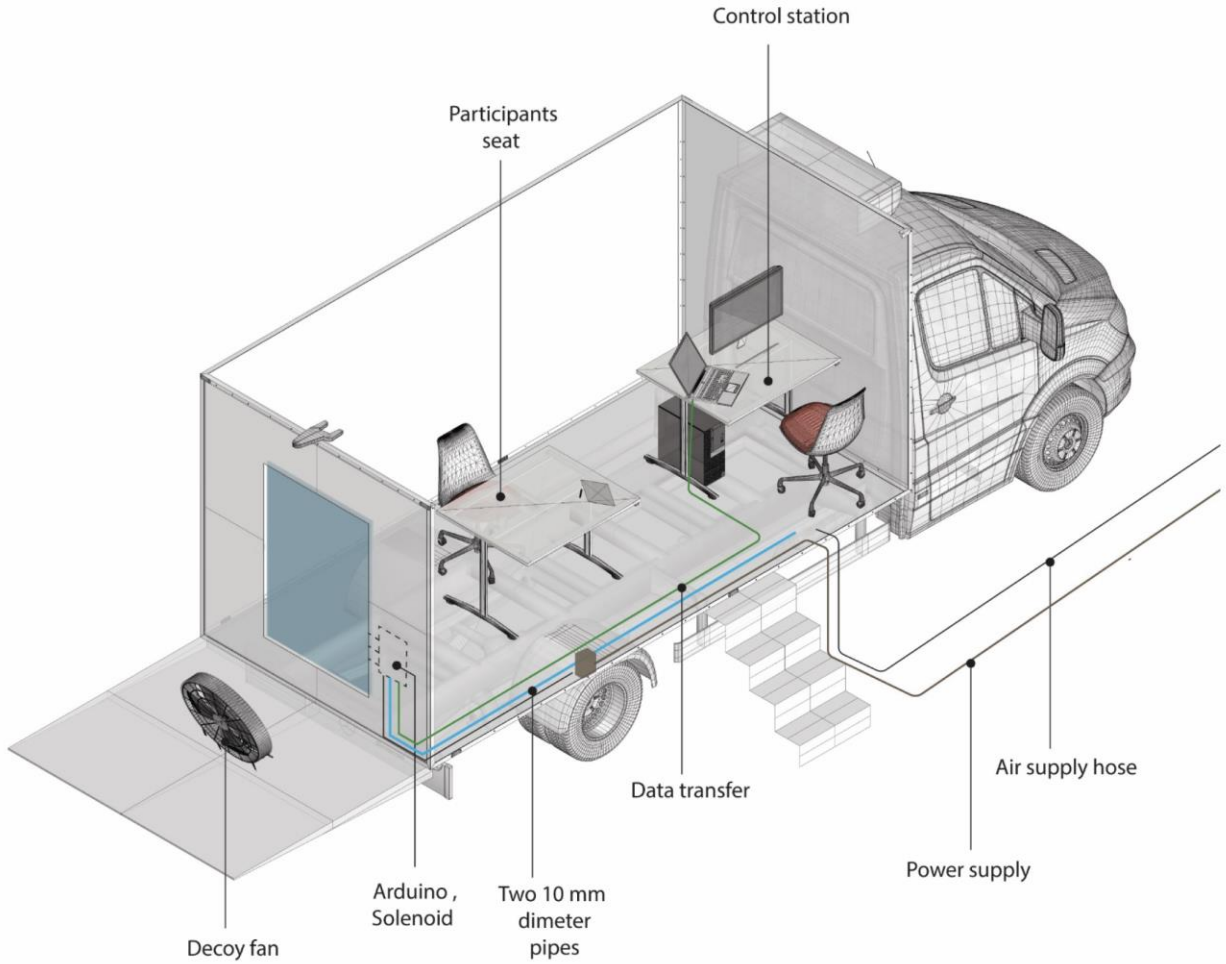
The LightVan

- Frame assembly
- Wiring and Scaling up prototype

Experimental setup

The LightVan

- Zones
- Decoy Fan
- Connectivity
  - -Data cable
  - -Power supply
  - -Air supply



Experimental setup

The LightVan

Experimental Setup

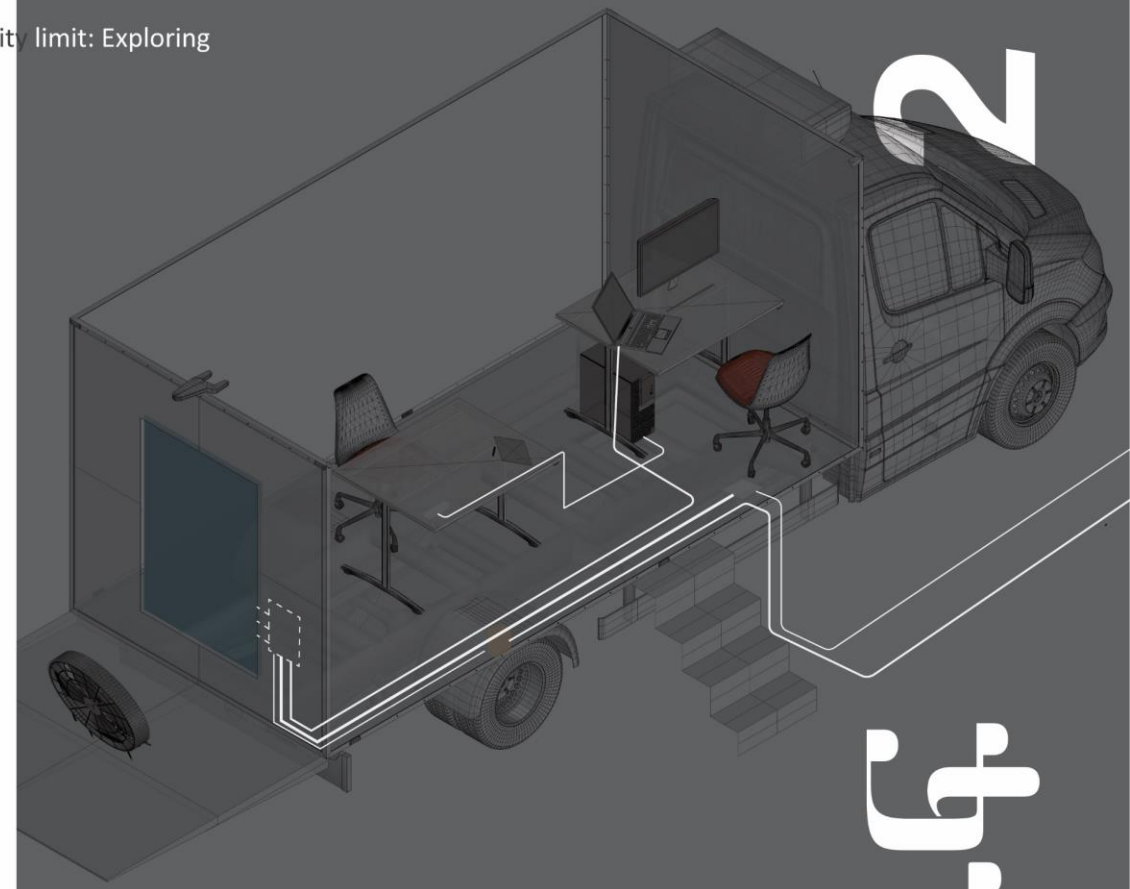
↓

Design of Experiment

↓

Results and Implications

- *Documenting occupant's perception and acceptance*
- *Questionnaire*
- *Facial recognition*



***Aim**:*

Design and test an experimental setup to capture occupant's response to deflection and deformation

Design of Experiment

Preliminary Observation

- What is percieved
- What is the right question to ask

Night time

Day time

Design of Experiment

Observations

- Perceptions

  -Glass movement
  -Change in reflection
  -Distortion of the view outside
  -Distraction when engage in an activity
  - Safety

Night time

Day time

Experimental Setup → Design of Experiment → *Preliminary Observations* → *Variables and Procedure* → *Questionnaire* → Results and Implications

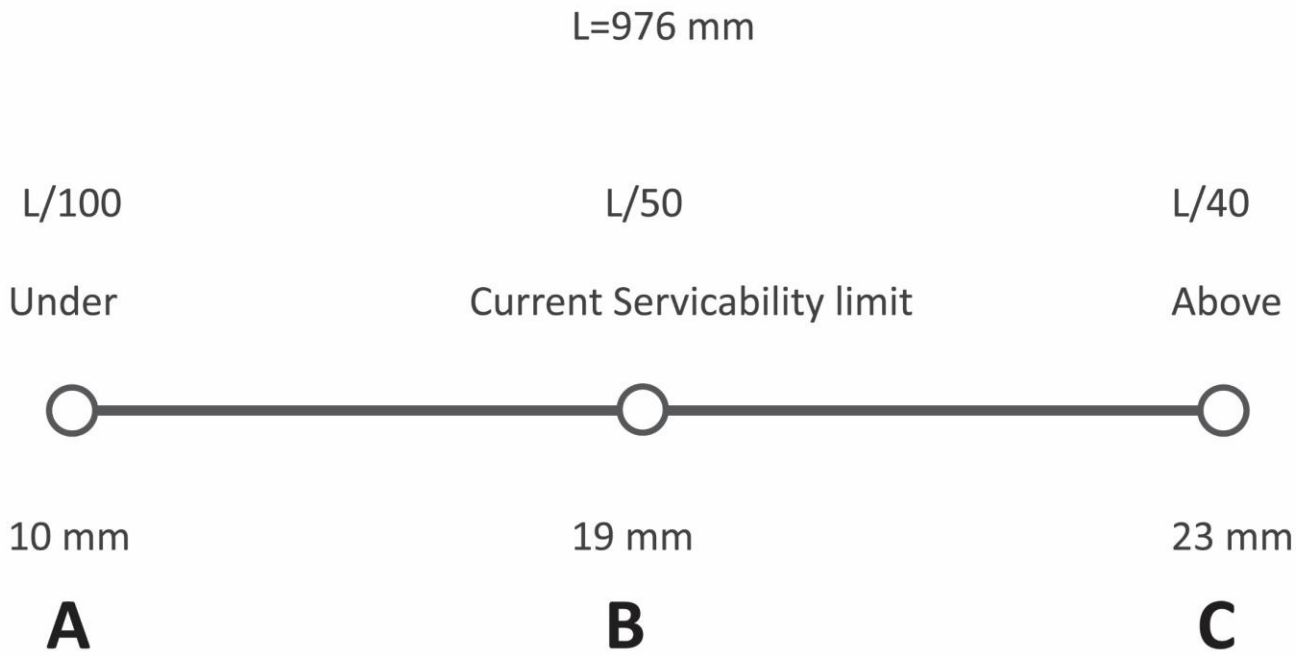
Design of Experiment

Variables

Independent	Dependent	Confounding
Center of Glass Deflection	Perception and acceptance of movement, Change in reflection and view distortion	Acoustical cues
Knowledge of glass	Perception of safety.	Lighting condition
	Perceived annoyance and disturbance	weather
		IEQ
		view
		Prior knowledge
		Age

Design of Experiment

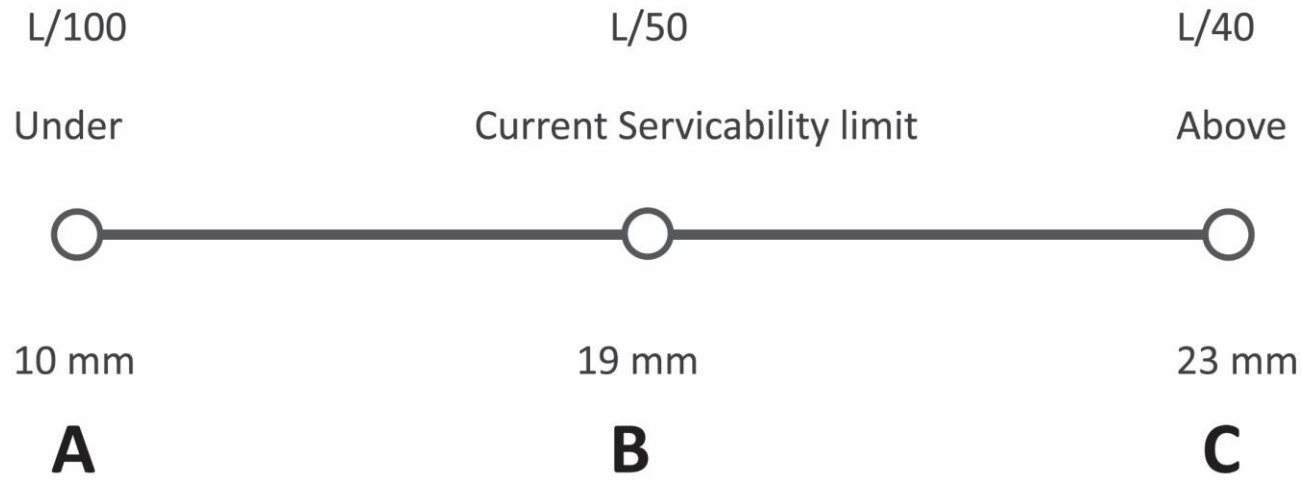
Variables



Design of Experiment

Variables

L=976 mm

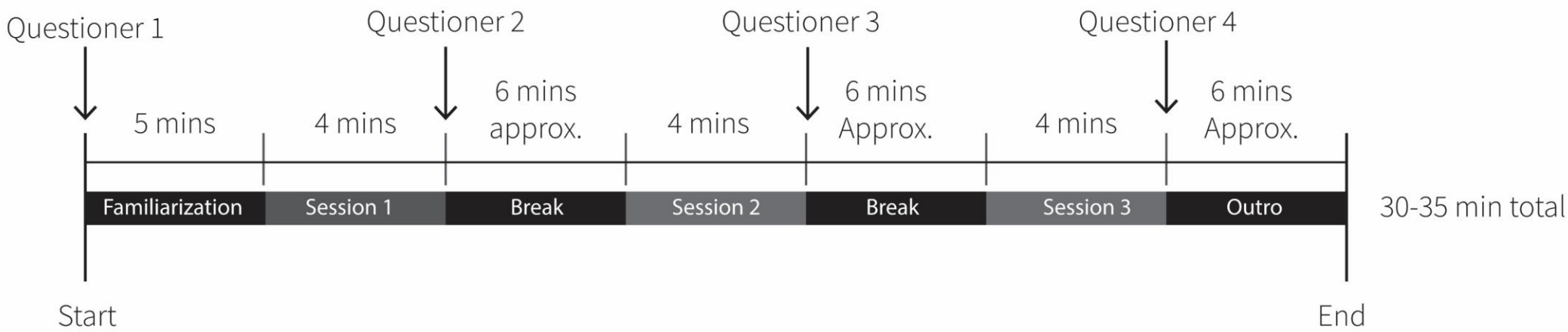


Randomized

1	2	3	4	5	6
ABC	ACB	BAC	BCA	CAB	CBA

Design of Experiment

Procedures



Design of Experiment

Procedures

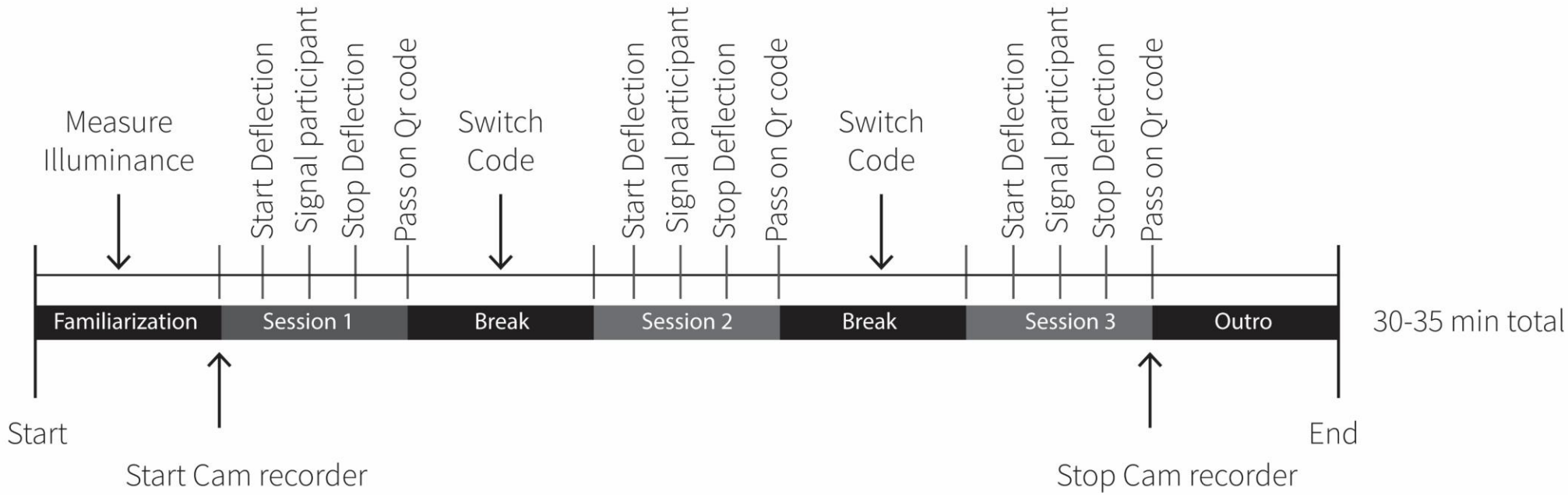
Fill in questionnaire

Observe

Perform Task

Design of Experiment

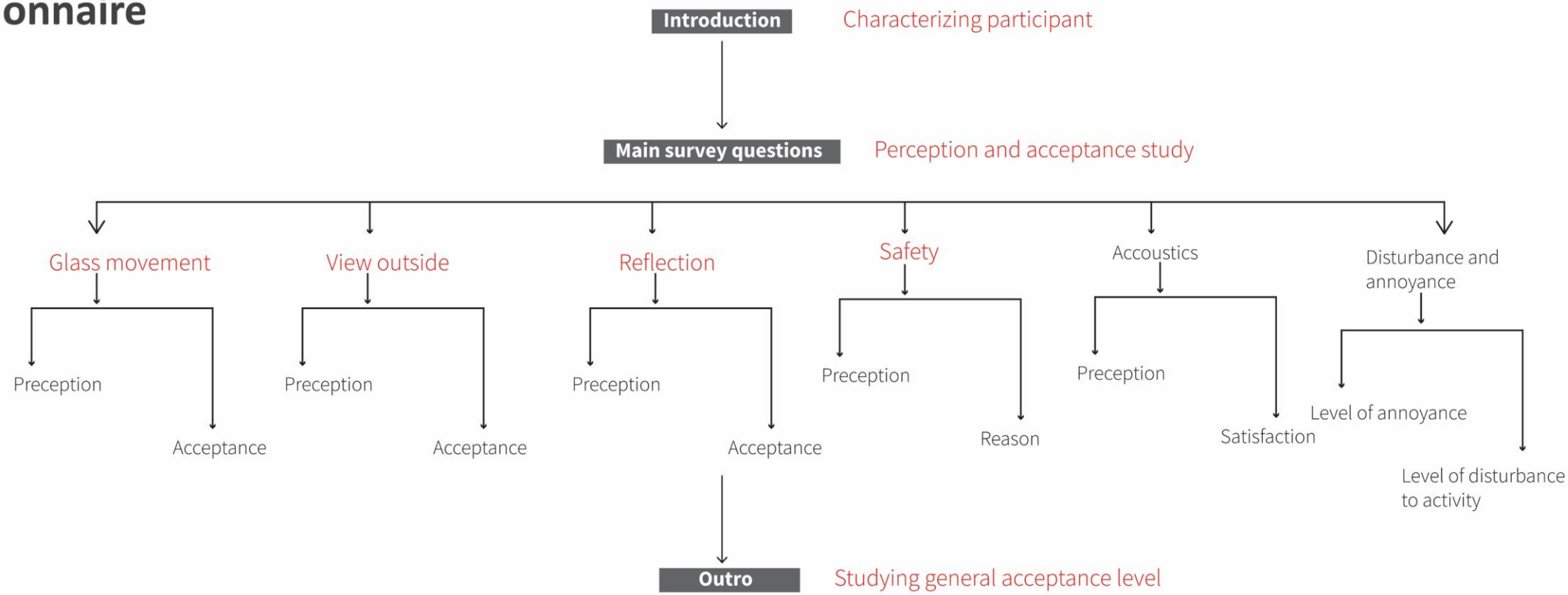
Procedures



Experimental Setup → Design of Experiment → *Preliminary Observations* → *Variables and Procedure* → *Questionnaire* → Results and Implications

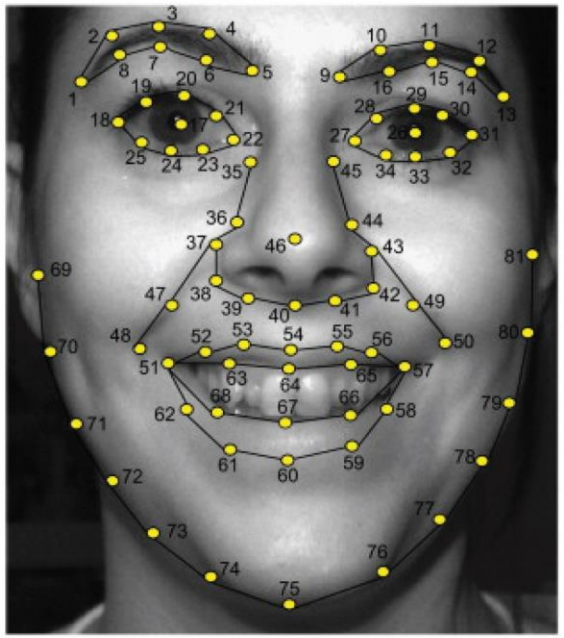
Design of Experiment

Questionnaire



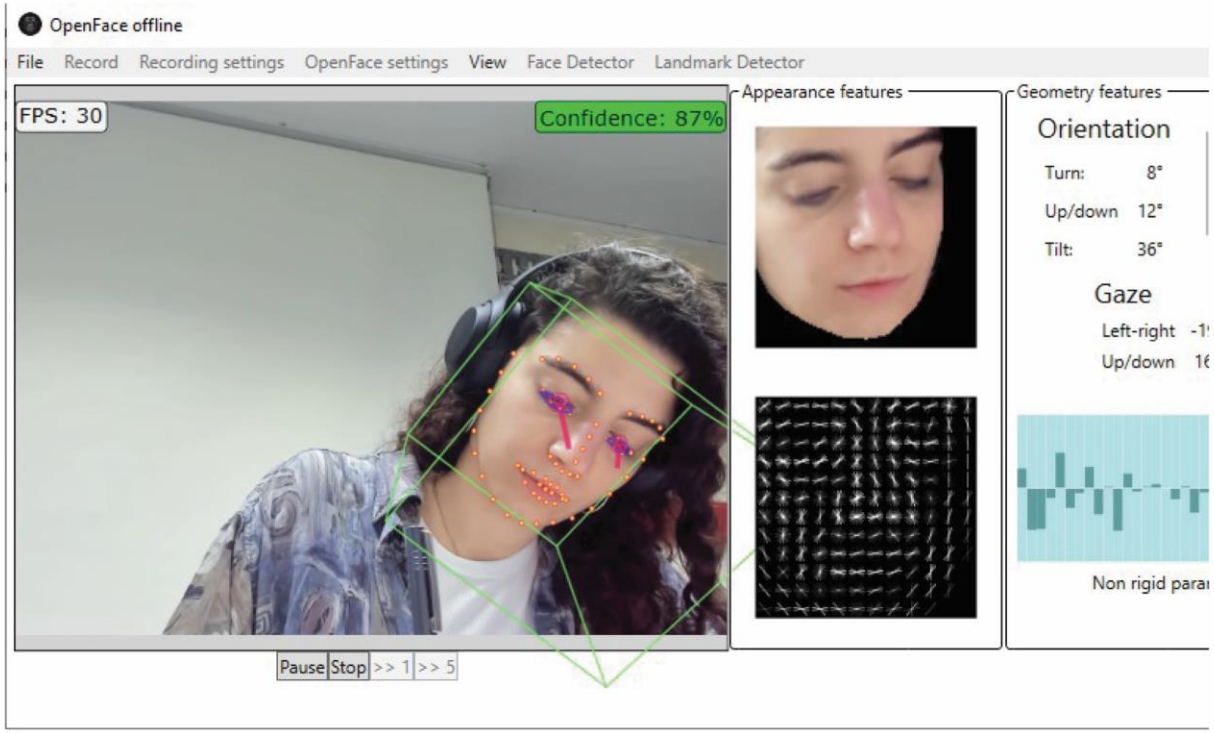
Design of Experiment

Facial expression



Design of Experiment

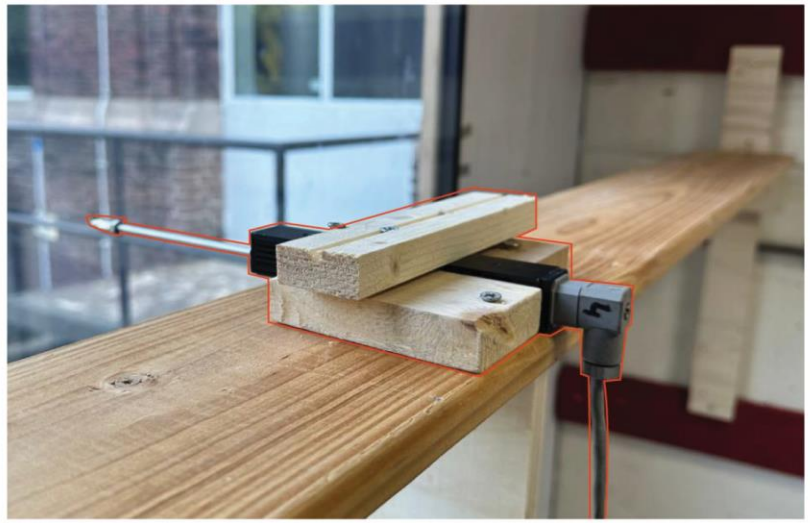
Facial expression



Experimental Setup → Design of Experiment → *Preliminary Observations* → *Variables and Procedure* → *Questionnaire* → Results and Implications

Design of Experiment

Calibrating Deflection



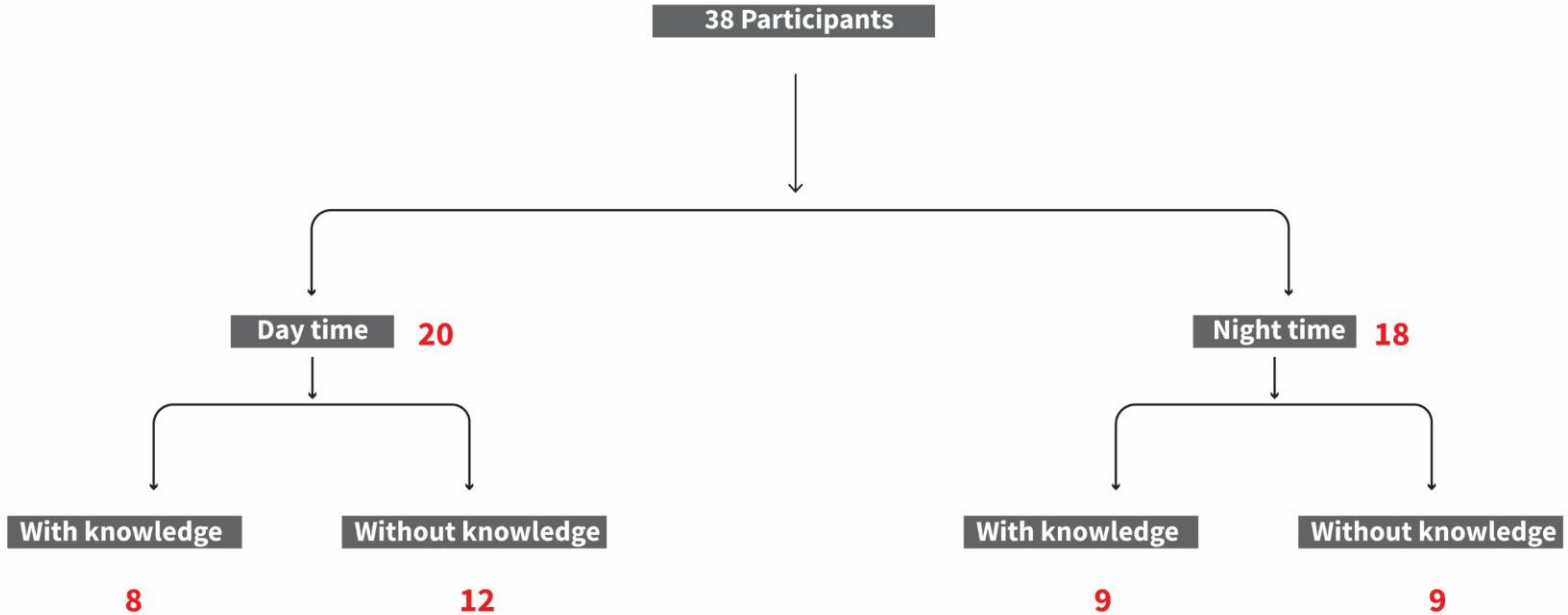
Linear Variable Differential Transformer (LVDT)

Positioning

Experimental Setup → Design of Experiment → *Preliminary Observations* → *Variables and Procedure* → *Questionnaire* → Results and Implications

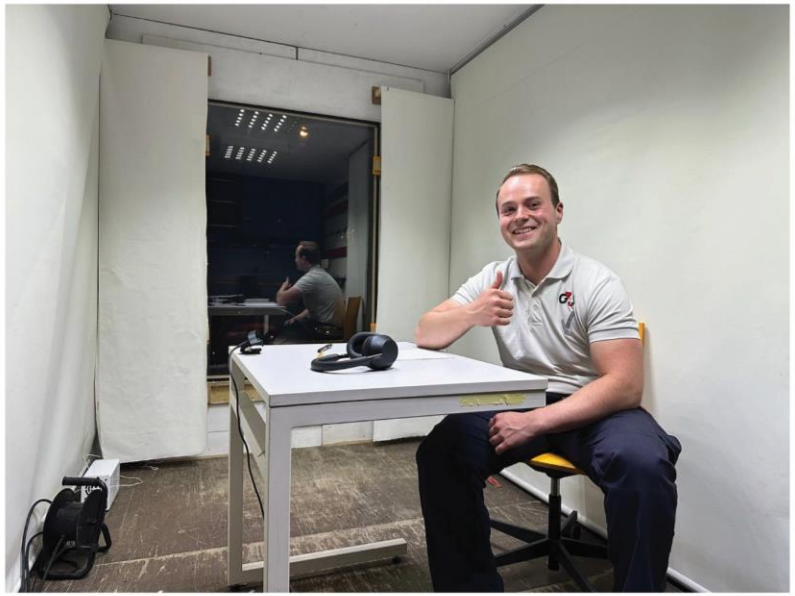
Design of Experiment

Participants



Design of Experiment

Participants



Experimental Setup

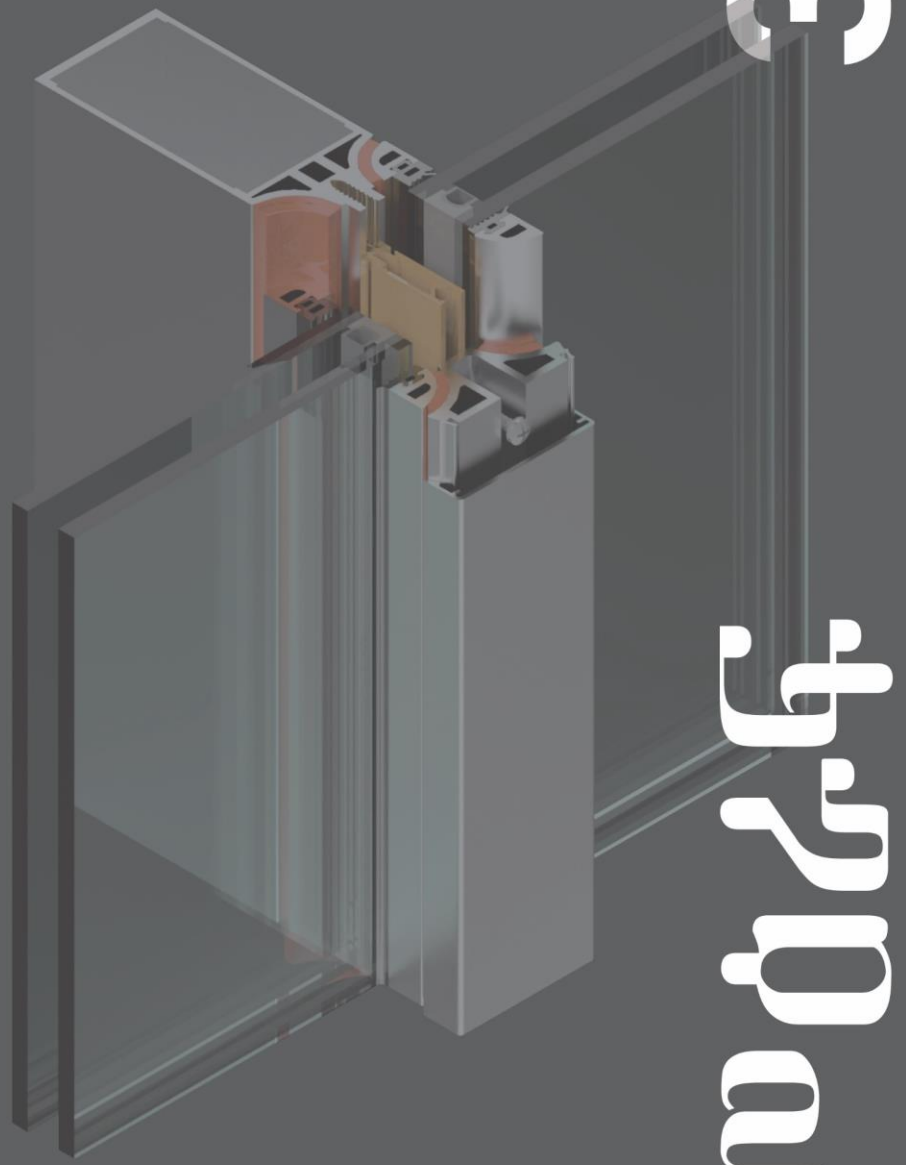
↓

Design of Experiment

↓

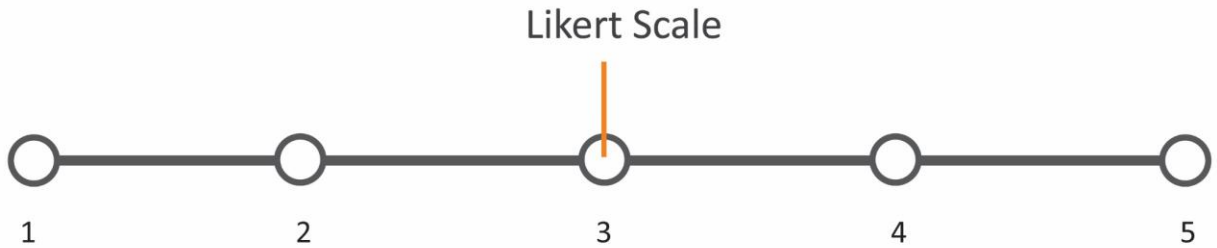
Results and Implications

- *Analyzings result*
  - *-Questionnaire*
  - *-Action units*
- *Material reduction*
- *Embodied carbon*
- *Design implication*



Results and Implications

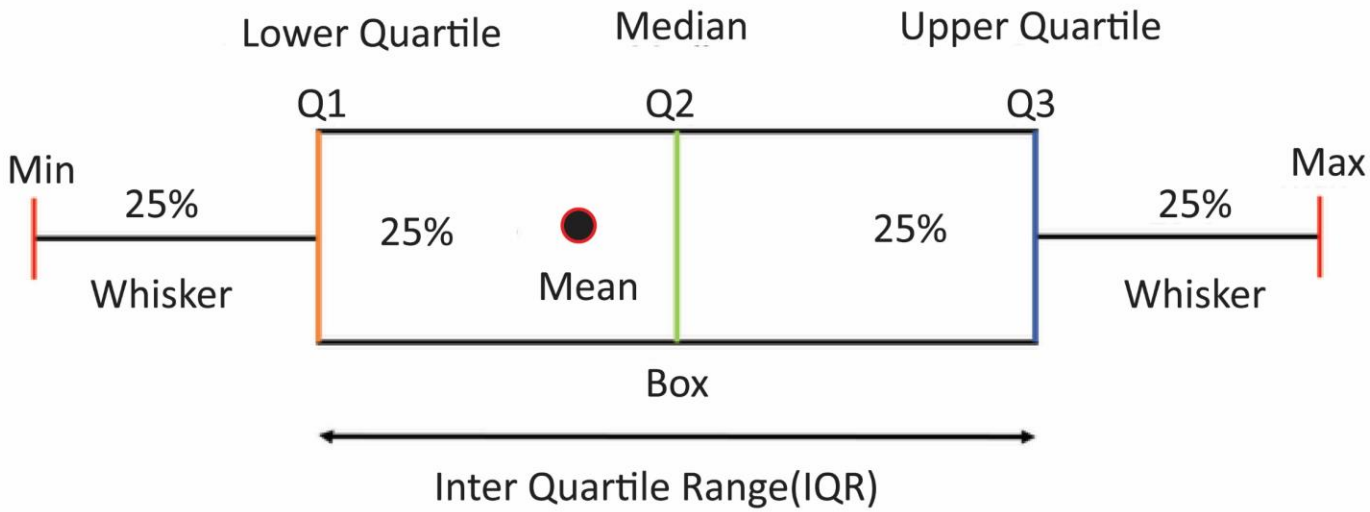
Likert scale



Level of Acceptance	Unacceptable	⟷	Totally Acceptable
Level of Perception	imperceivable	⟷	perceivable
Level of Agreement	Totally Disagree	⟷	Totally agree

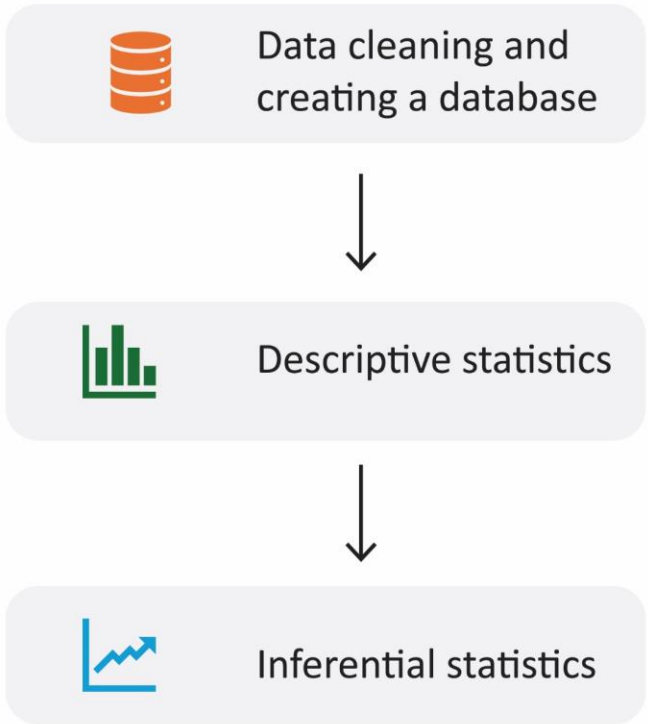
Results and Implications

Box plot



Results and Implications

Data processing



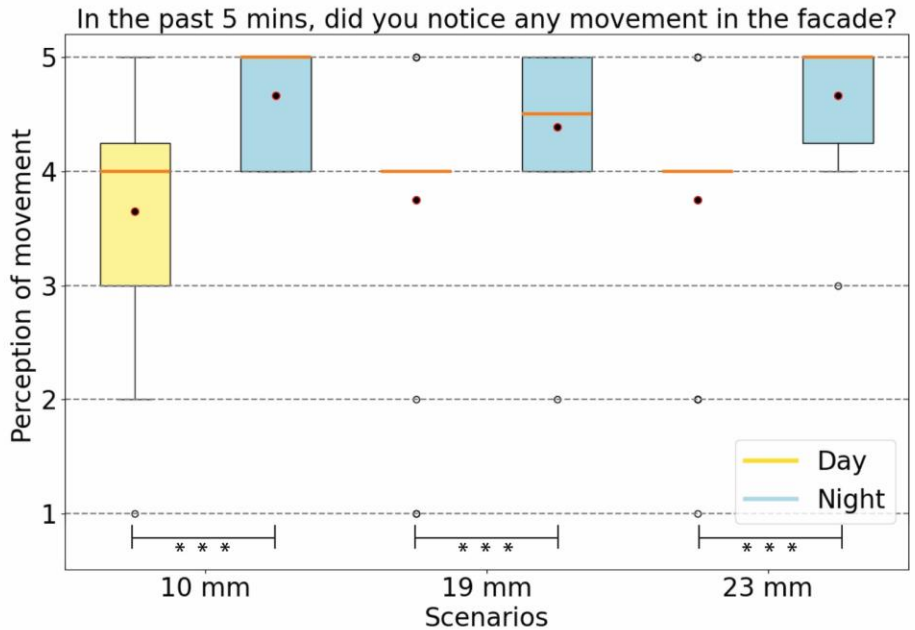
Results and Implications

Perception and Acceptance of Movement

Strongly agree

Neutral

Strongly disagree

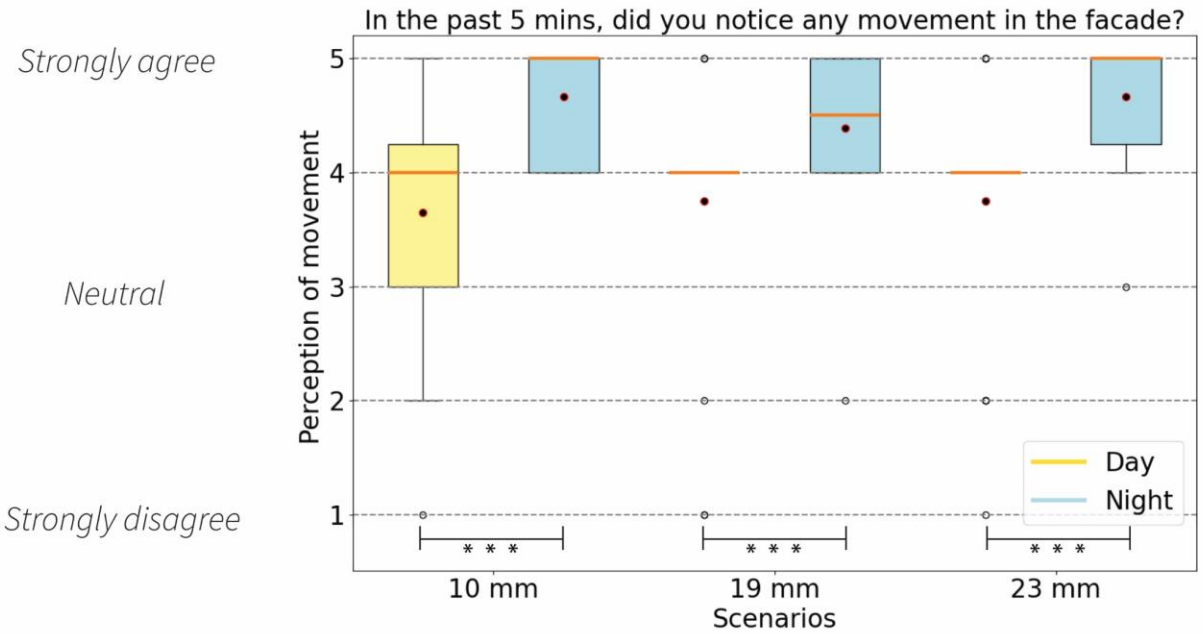


Strongly disagree: no I did not notice anymovement in the facade → *Strongly agree: Absolutly, there was a signigicant movement in the facade*

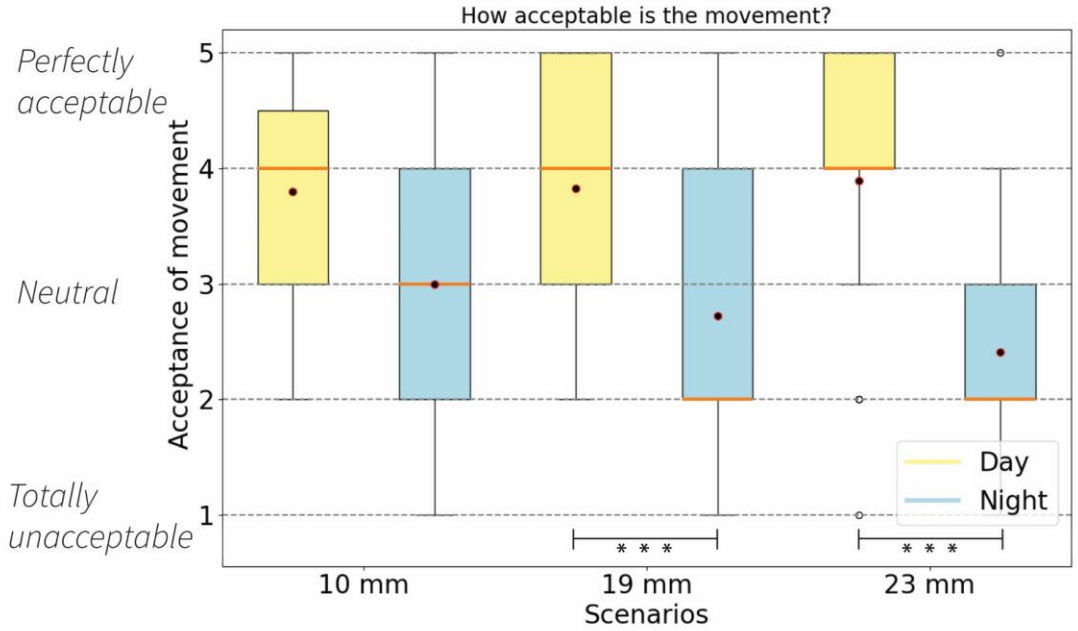
Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Perception and Acceptance of Movement



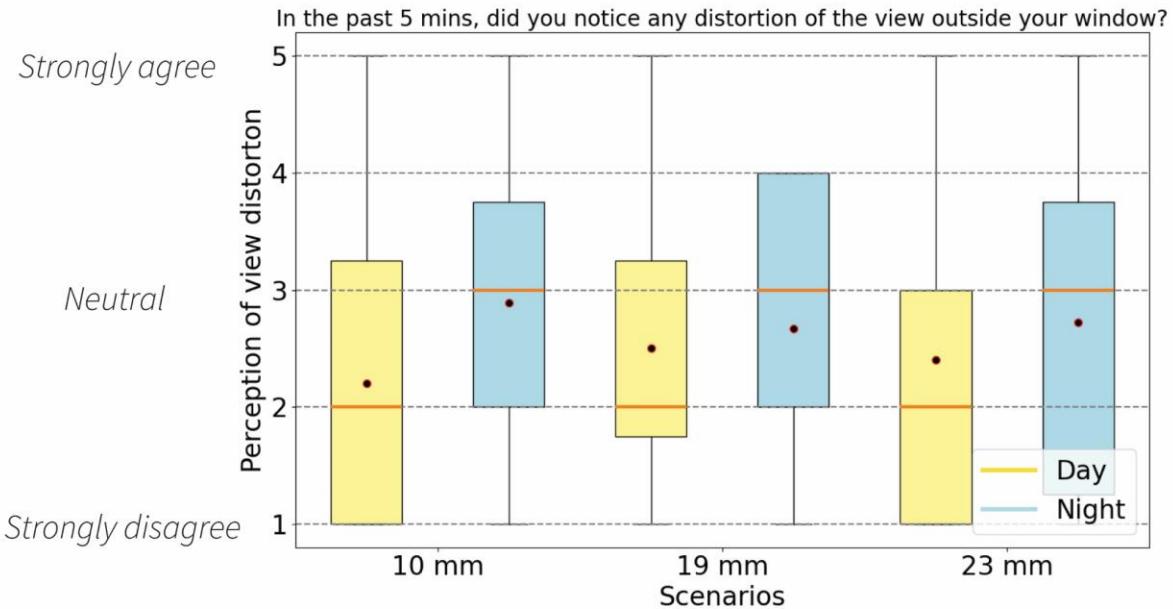
Strongly disagree: no I did not notice anymovement in the facade → *Strongly agree: Absolutly, there was a signigicant movement in the facade*



Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Perception and Acceptance of View distortion

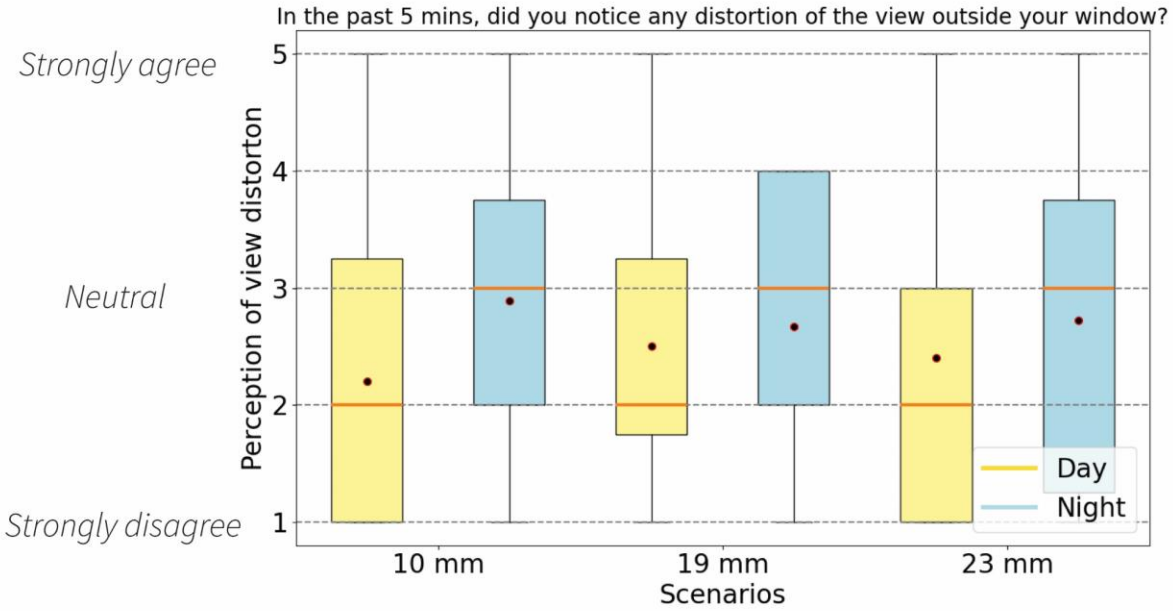


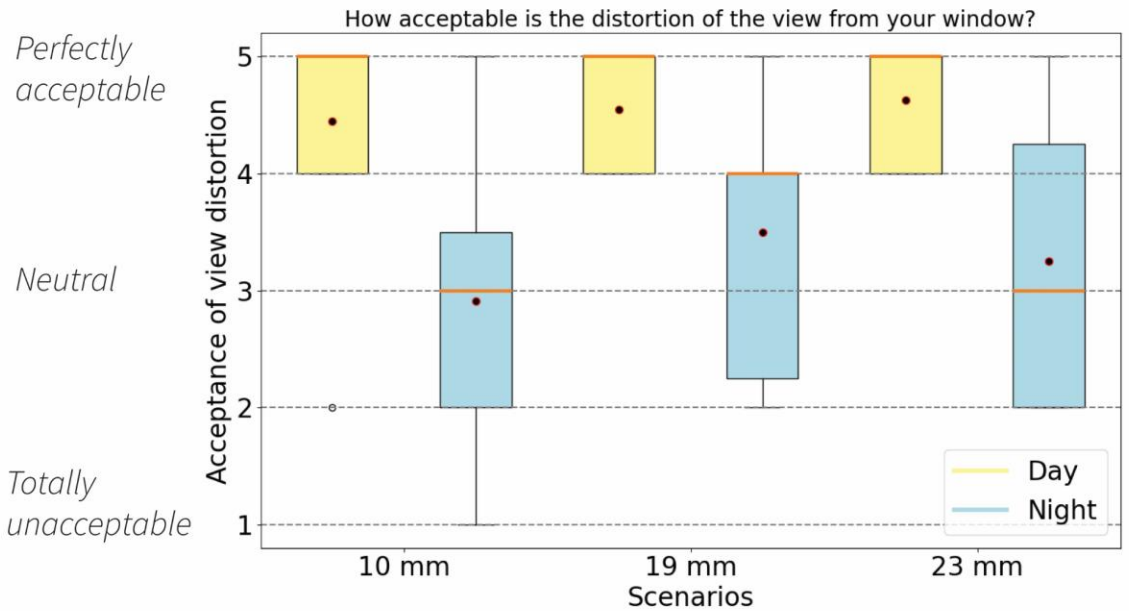
Strongly disagree: there is no distortion in my view of the outside. → *Strongly agree: there is a significant distortion in my view of the outside.*

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Perception and Acceptance of View distortion



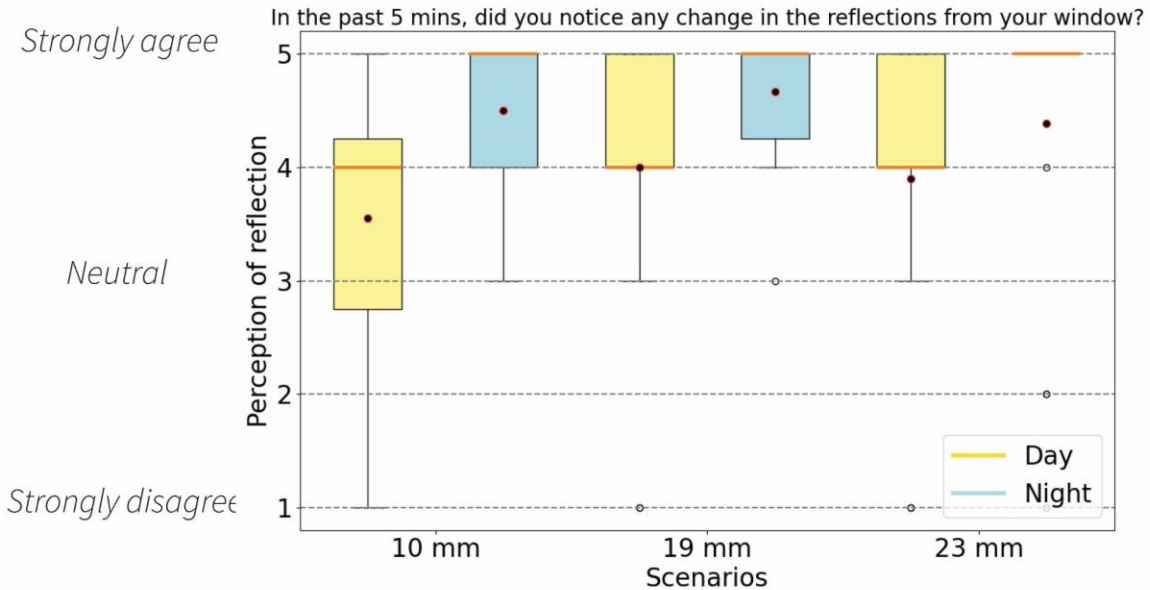


Strongly disagree: there is no distortion in my view of the outside. → *Strongly agree: there is a significant distortion in my view of the outside.*

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Perception and Acceptance of Change in reflection

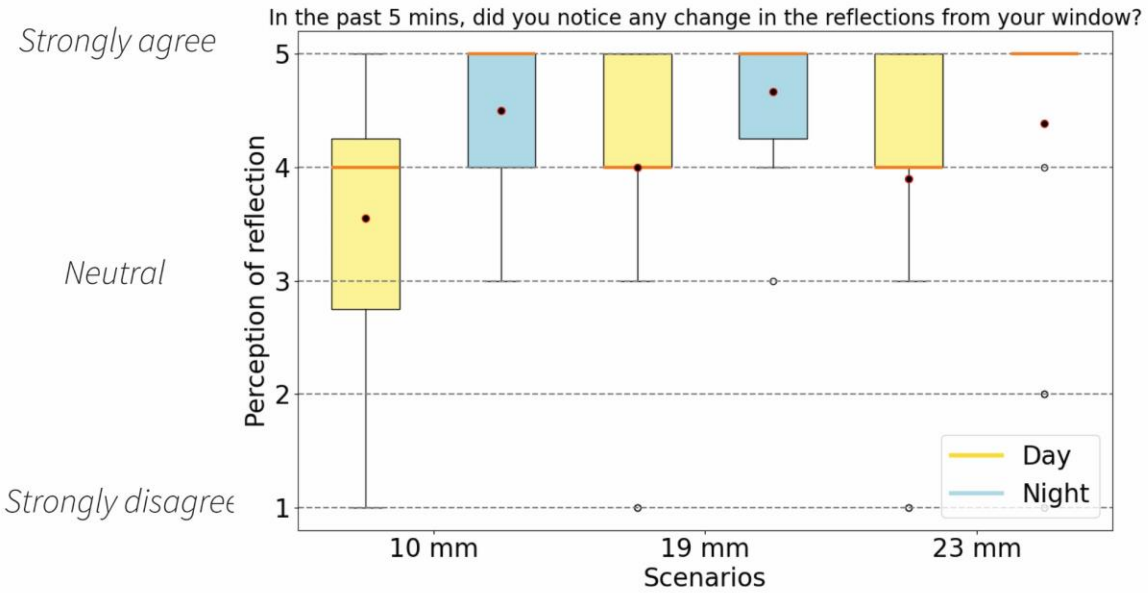


Strongly disagree: there is no change in reflection → *Strongly agree: there is a significant change in reflection*

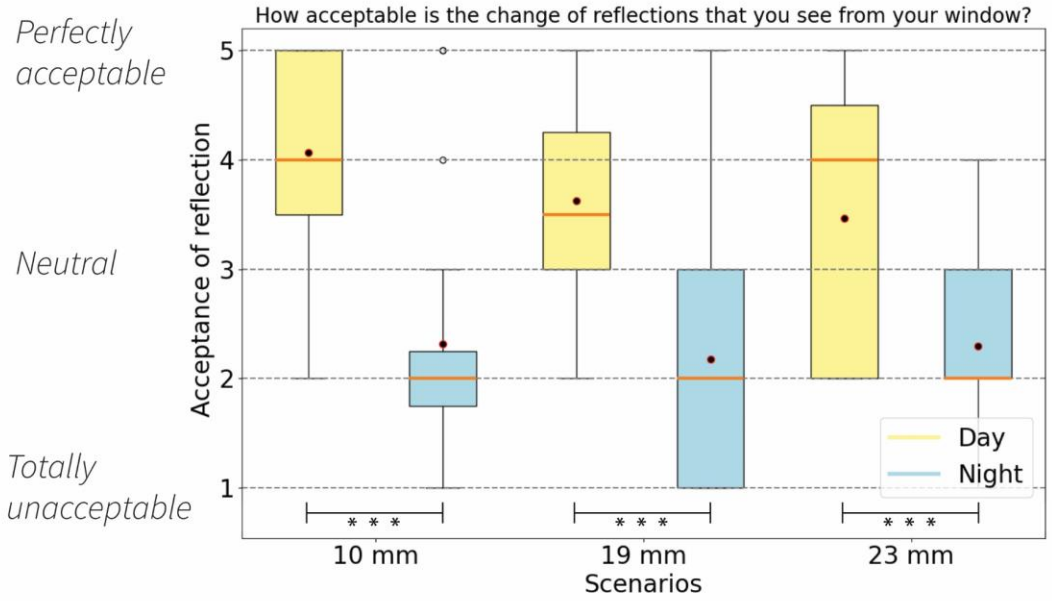
Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Perception and Acceptance of Change in reflection



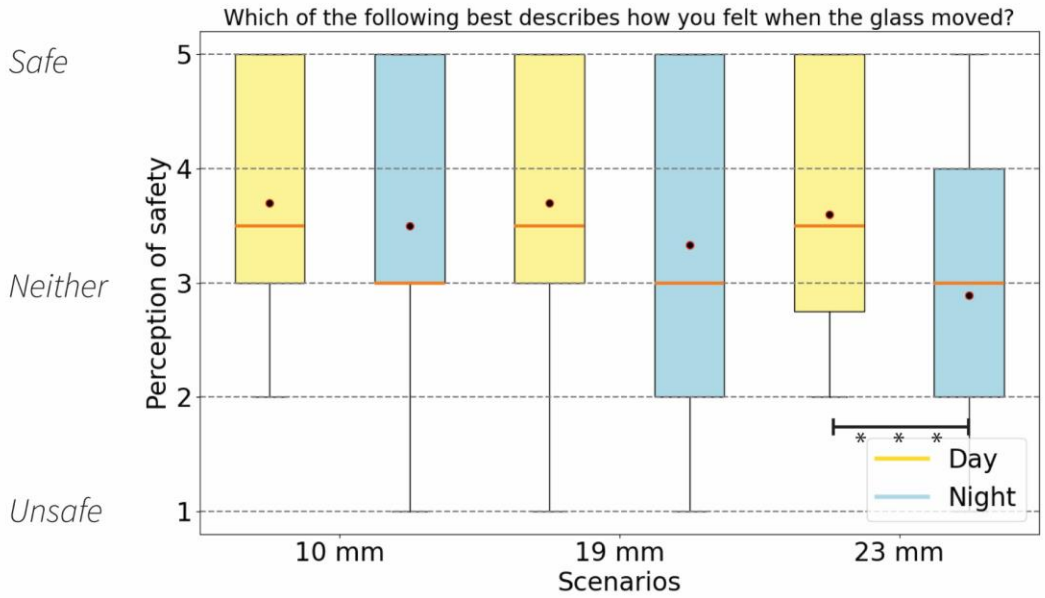
Strongly disagree: there is no change in reflection → *Strongly agree: there is a significant change in reflection*

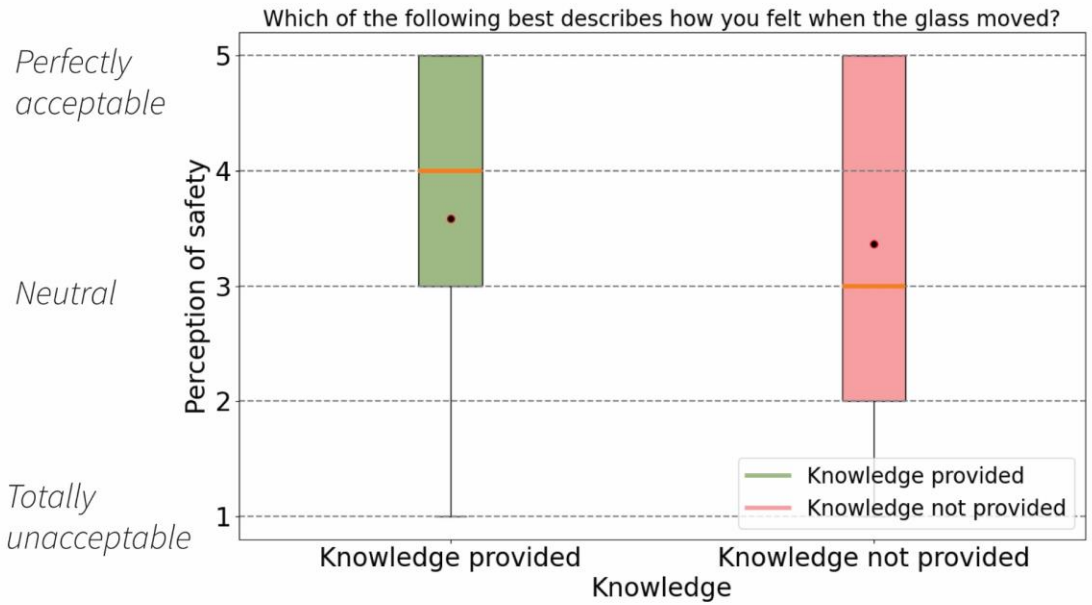


Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

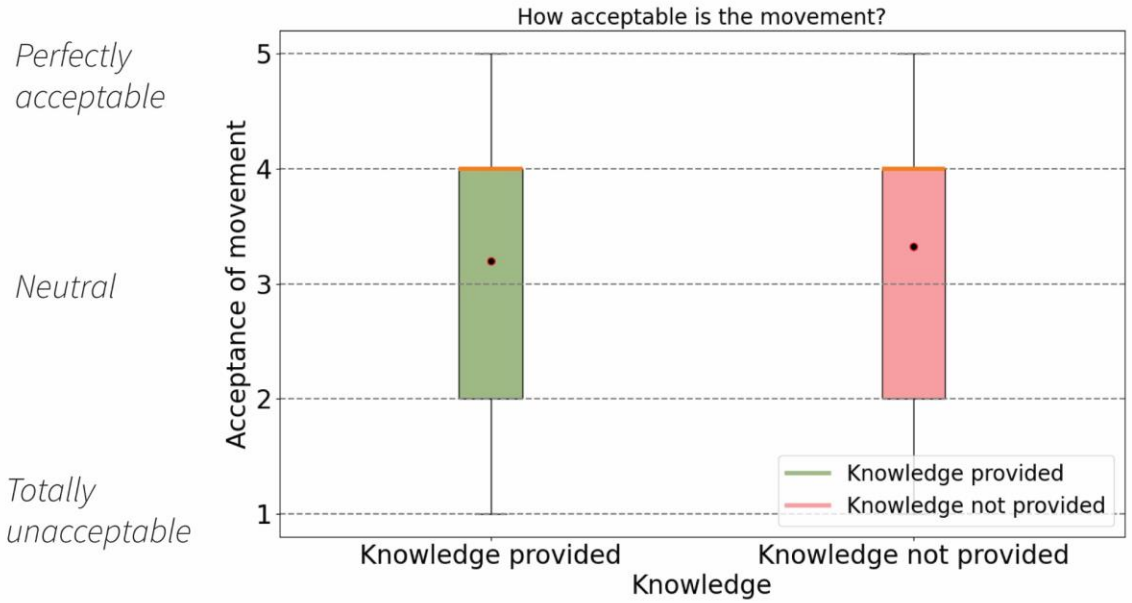
Perception of safety and Effect of knowledge

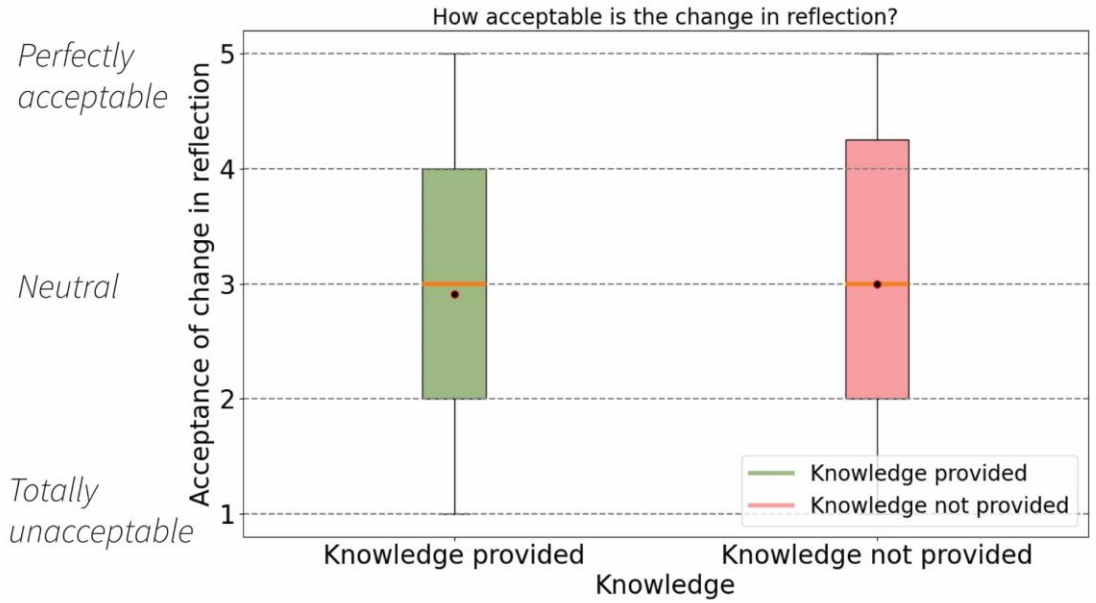




Results and Implications

Effect of Knowledge on acceptance of movement and change in reflection

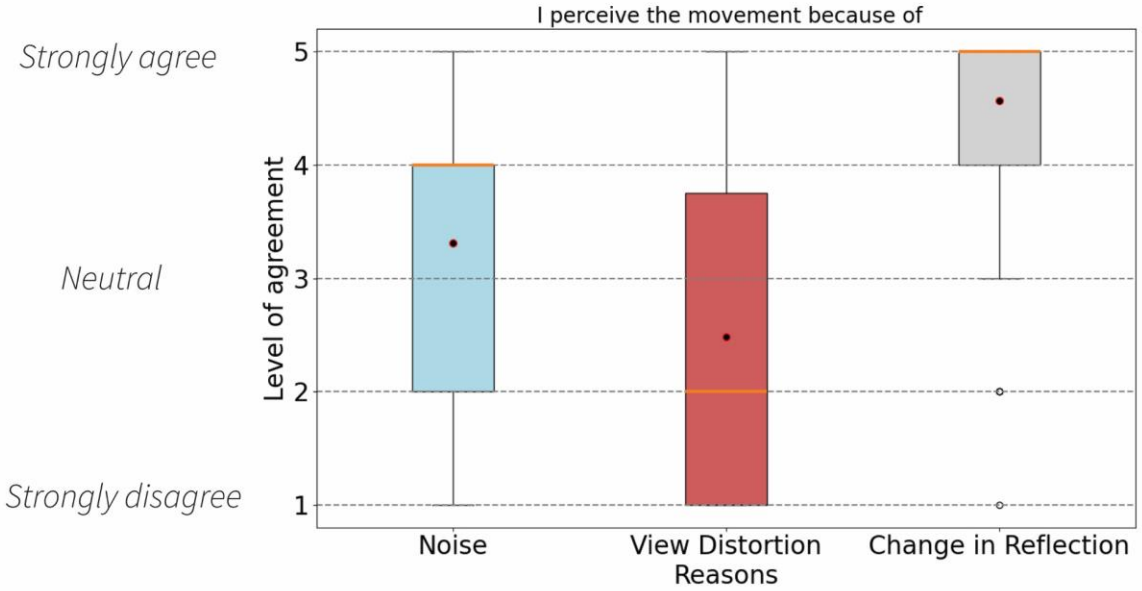


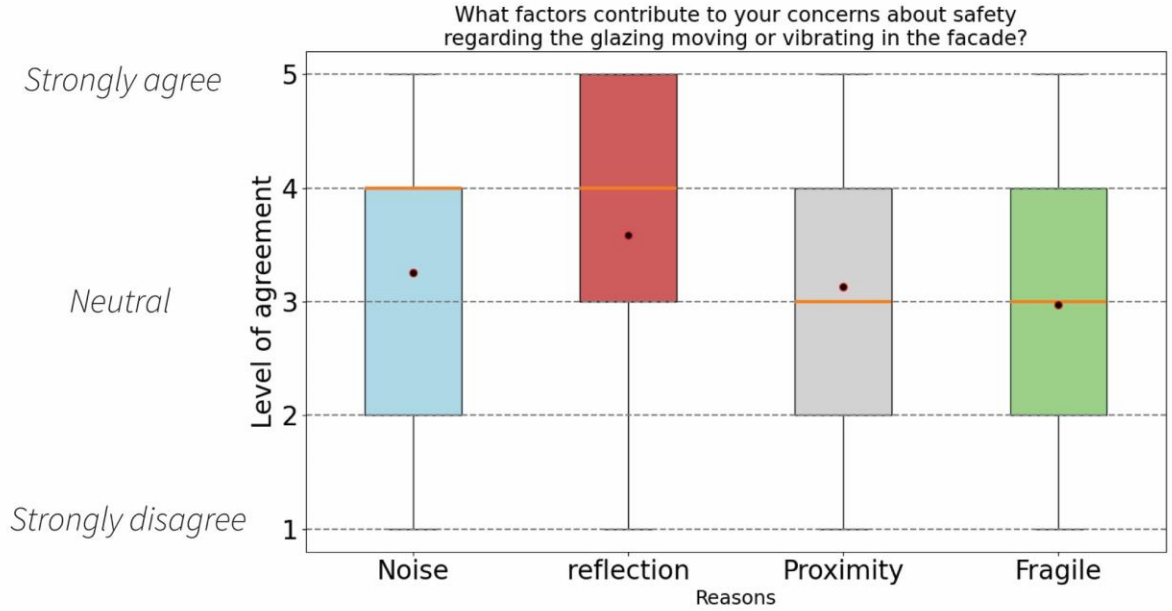


Experimental Setup → Design of Experiment → Results and Implications → Method → Analyzing the Questioner → Material Savings and Design

Results and Implications

Why do occupants percieve glass deflection?





Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

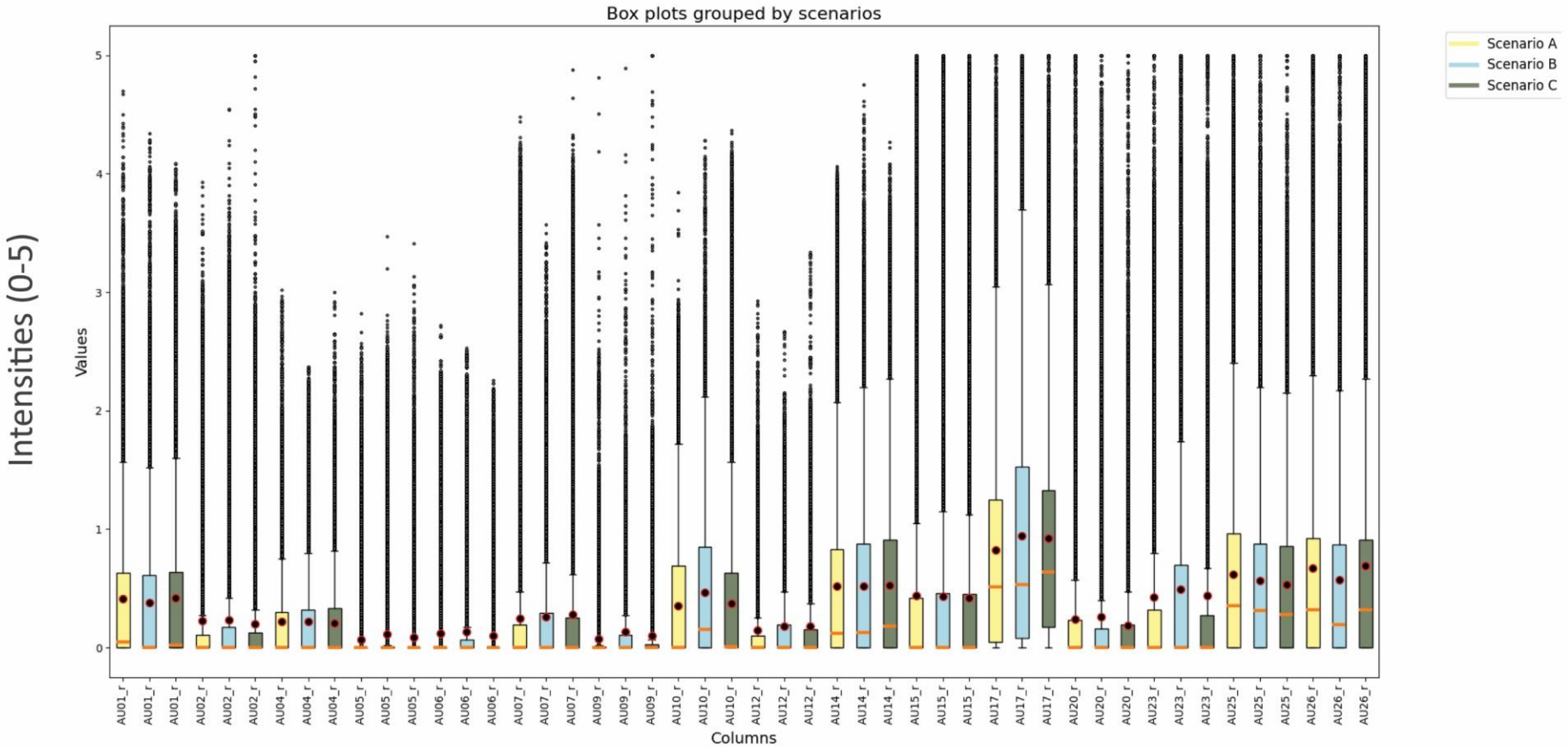
Results and Implications

Summary

- Setup proved to be effective in capturing human response to varying deflections of glazing
- Changes in reflections are the main way users perceived the glass deflecting
- User acceptance at higher deflections is similar than at lower deflections
- During the day is much higher than during the night
- Regardless of knowledge, safety was not a concern

Results and Implications

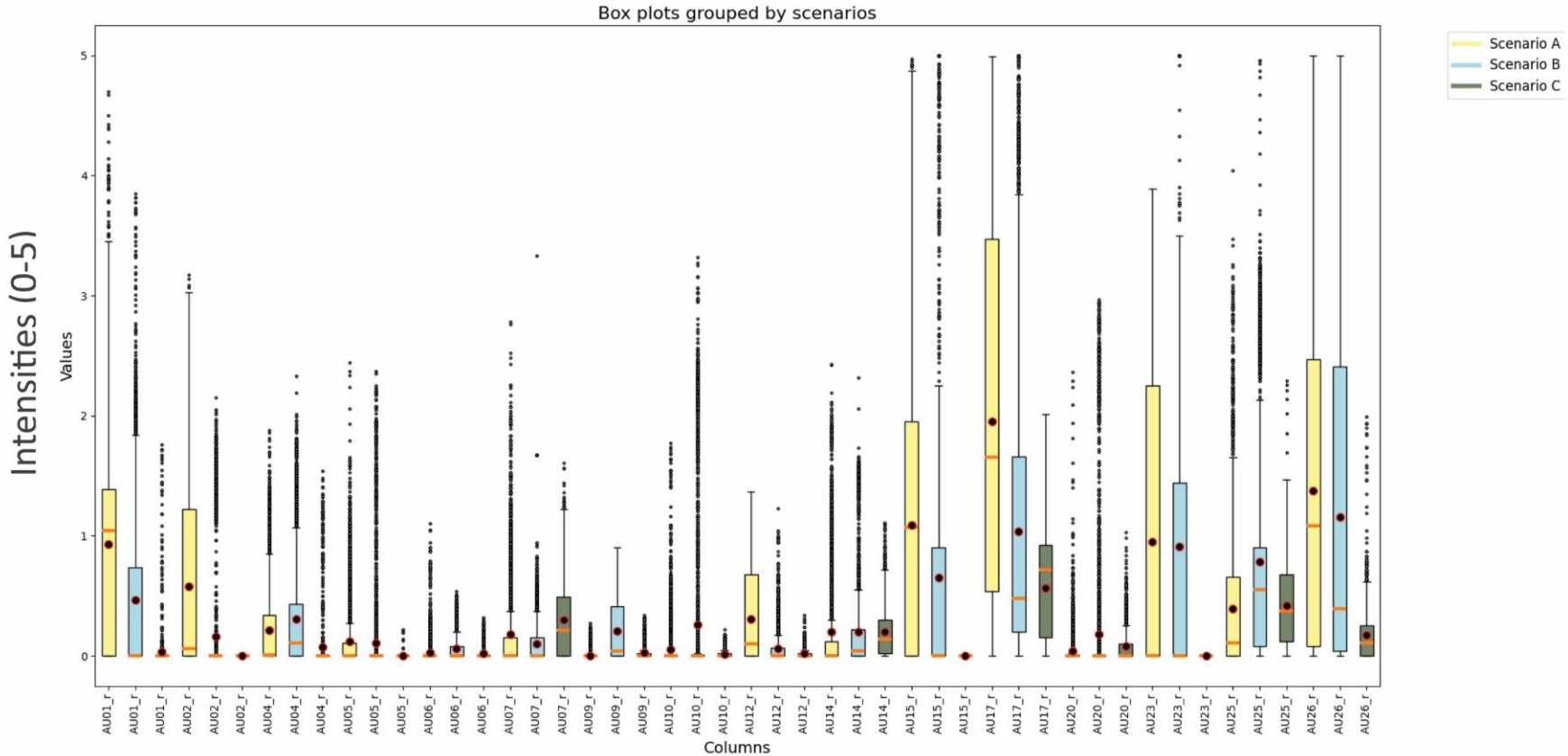
Action units



Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Action units



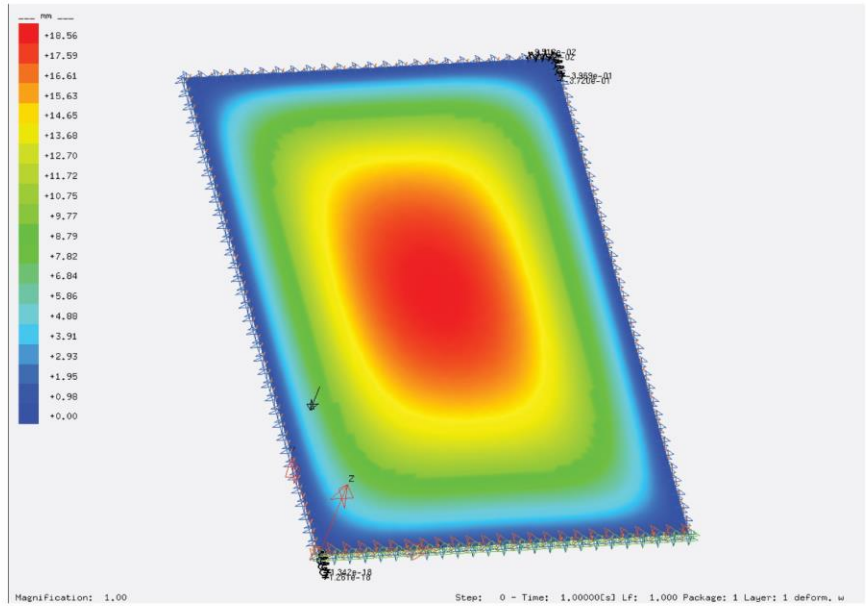
Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

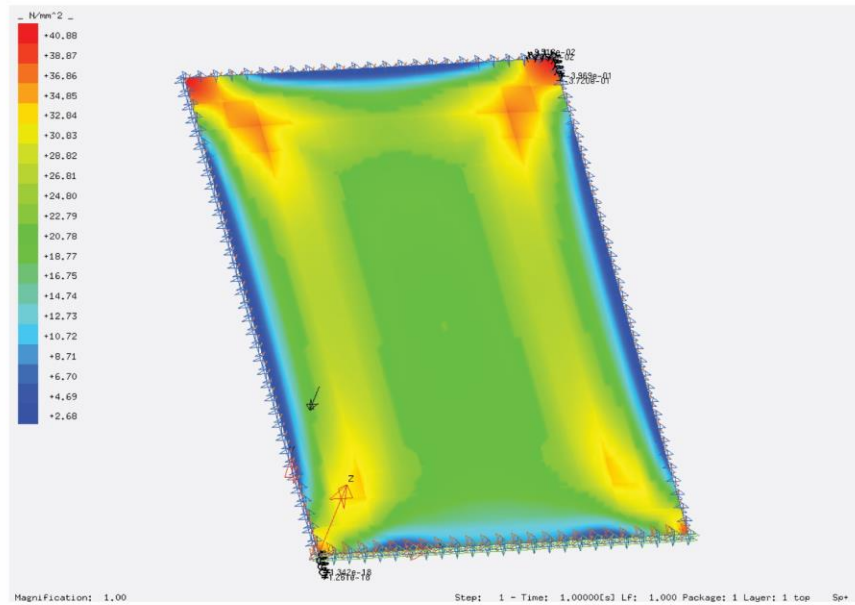
Results and Implications

Material savings

- SJ Mepla

  -Nonlinear analysis
  -IGU Construction
  -Simply suppoeted system
  -Load sharing effext





Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Material savings

	Glass type	Pressure (Mpa)	SLS	Size of pane	Number of panes in the model	Air gap	Maximum principal pressure (Mpa)	Minimum thickness of glass required
SJ Mepla	Fully toughened glass	1.43 x e^{-2}	L/50=19 mm	1476mm x972 mm	2	16	51.47	6 mm
SJ Mepla	Fully toughened glass	1.43 x e^{-2}	L/40=23 mm	1476mm x972 mm	2	16	67.17	4.9 mm

18 % Material reduction

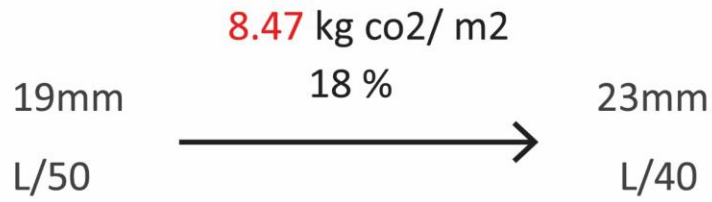
carbon footprint reduction

8.47 kg co2/ m2 of glass

Results and Implications

Design considerations

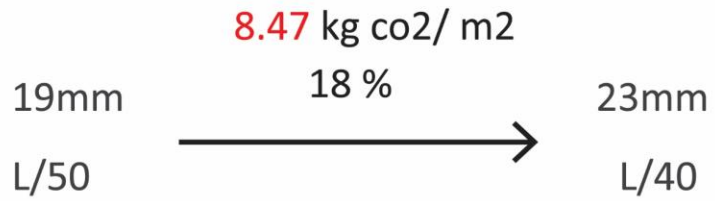
- Edge rotation
- Air and Water tightness
- Local stress from edge of glass touching the framing

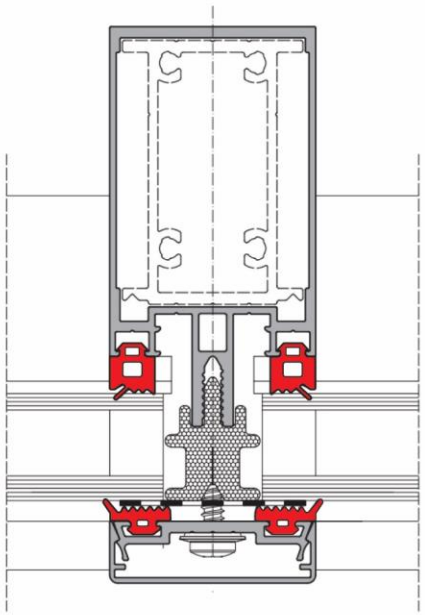


Results and Implications

Design considerations

- Edge rotation
- Air and Water tightness
- Local stress from edge of glass touching the framing

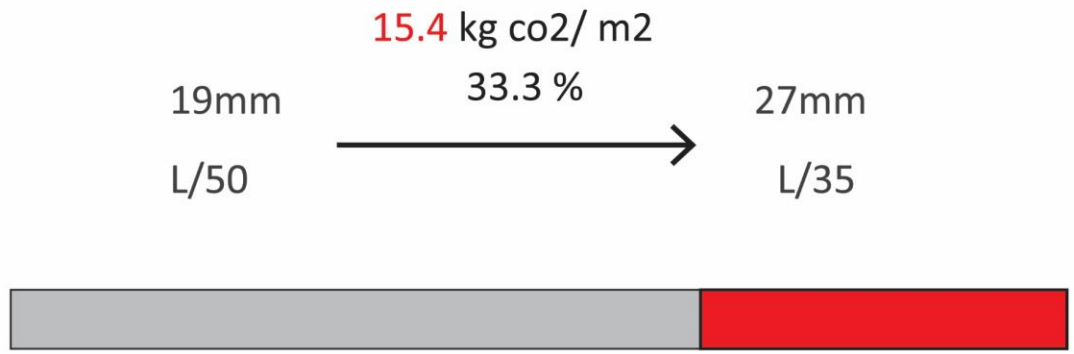




Results and Implications

Design considerations

- Air and Water tightness
- Local stress from edge of glass touching the framing
- Loss of function in Gasket
- Draught
- Anti-reflection film from 30% to 4 %



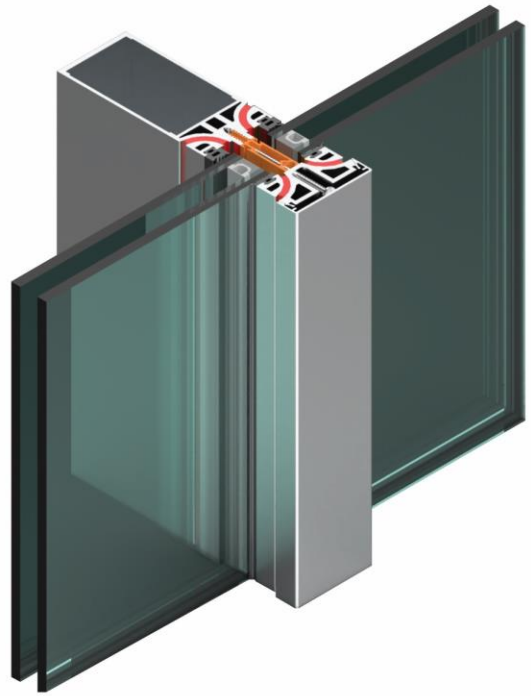
33.3 % Material reduction

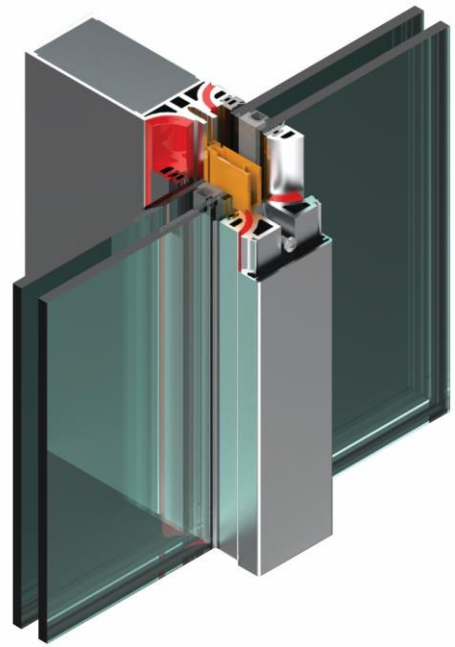
Results and Implications

Design considerations

19mm → 27mm

L/50 → L/35

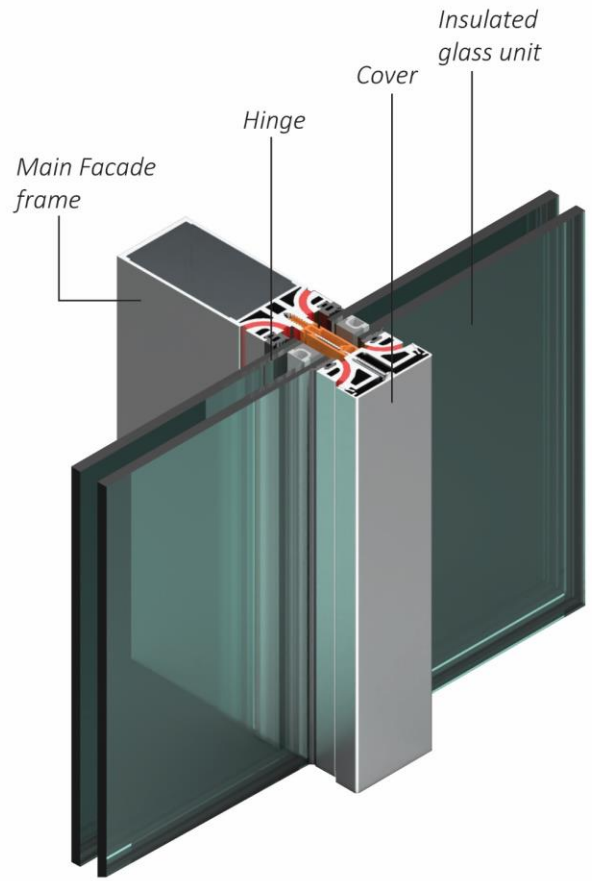


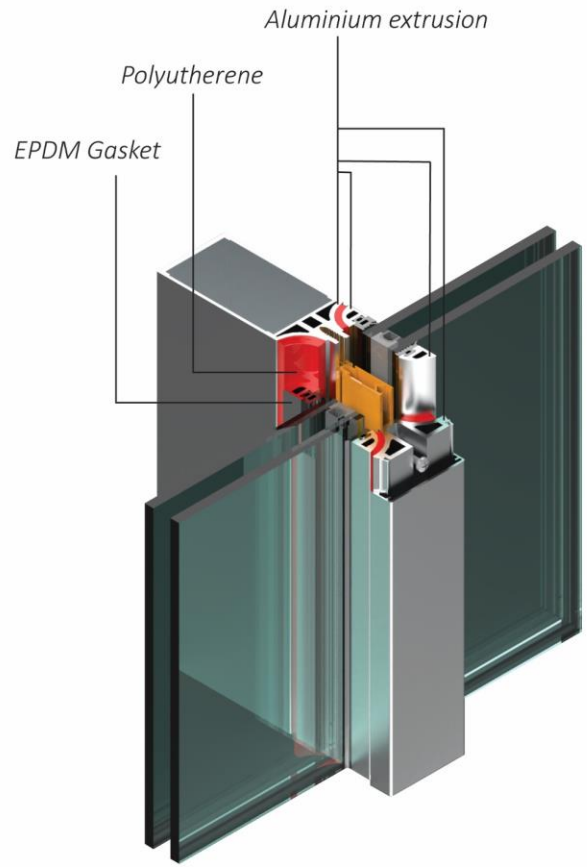


Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Design considerations

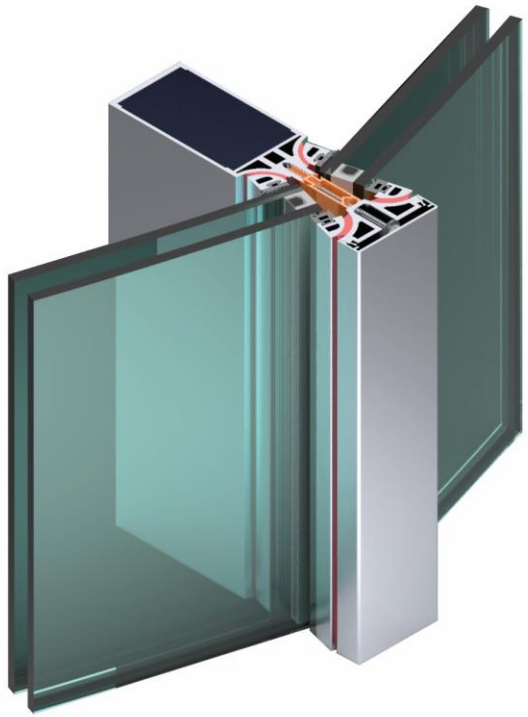




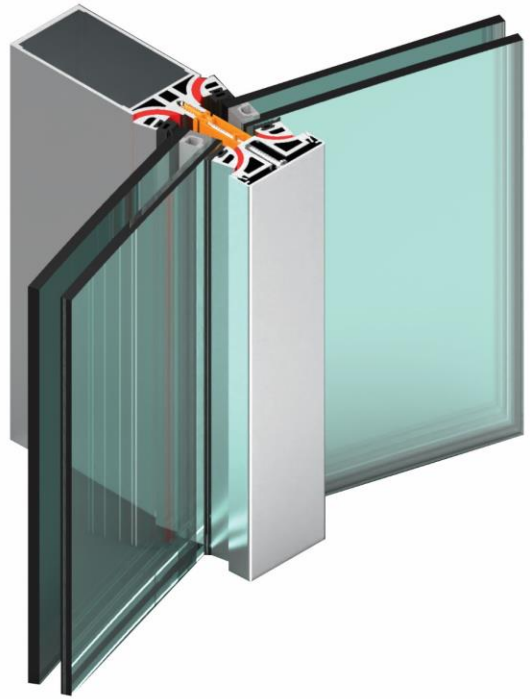
Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Design considerations



Under pressure

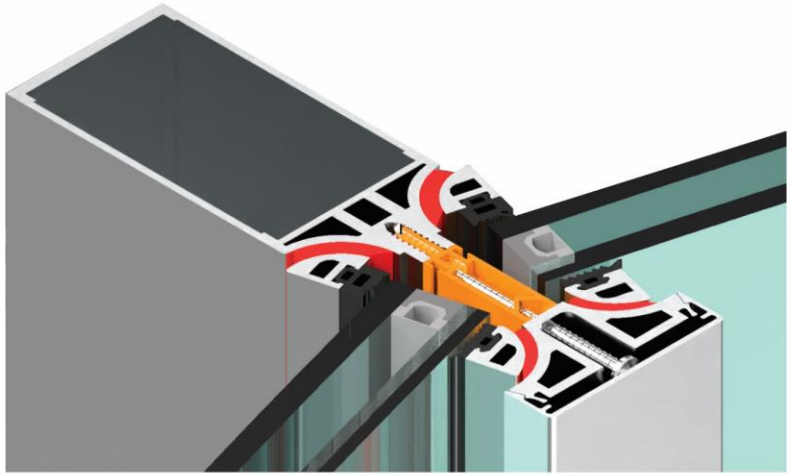


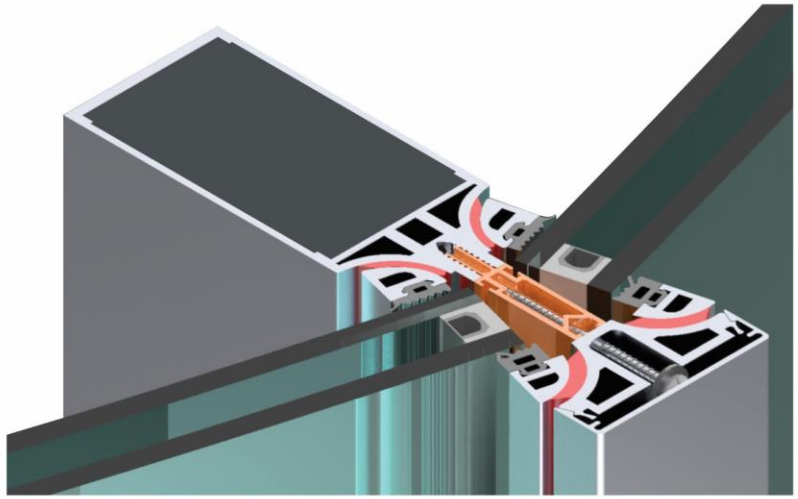
Over pressure

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Design considerations





Under pressure

Over pressure

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Sharing with the Industry

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Results and Implications

Sharing with the Industry

Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*

Research

Summary

Experimental setup

- It is possible capturing human response to varying glazing deflections

Factor

- Change in reflections plays an important role in perception

The current limit

- Regardless of knowledge, safety was not a concern
- User acceptance at higher deflections is similar than at lower deflections

Contribution

- A novel methodology

Reflections

Improvements and gap

Experimental setup

- Noise
- Deflection tested limited by specimen
- Control Frequency
- Small space: angle and distance
- Participants with different backgrounds
- Facial recognition: Action units

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Contextual impact of the study

- Long term exposure
- Activity
- Building function
- Height

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Perception from the exterior

- Pillowing

Reflections

What could next?

Improve setup

- Noise
- Deflection tested limited by specimen

Factors affecting perception

- Frequency
- Angle
- Distance
- View
- Knowledge

Contextual study

- Long term exposure
- Different activity
- Scope of participants

Reflections

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Contextual study

- Long term exposure
- Different activity
- Scope of participants

Durability of IGU

- Primary and secondary sealant

Thank you

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Thesis 2023-24| Building Technology| TU Delft

Empirical Assessment of Glazing Serviceability Limit:
Exploring Occupant Acceptance.

Mentors:

Dr. Alessandra Luna Navarro

Prof. Dr. Mauro Overend

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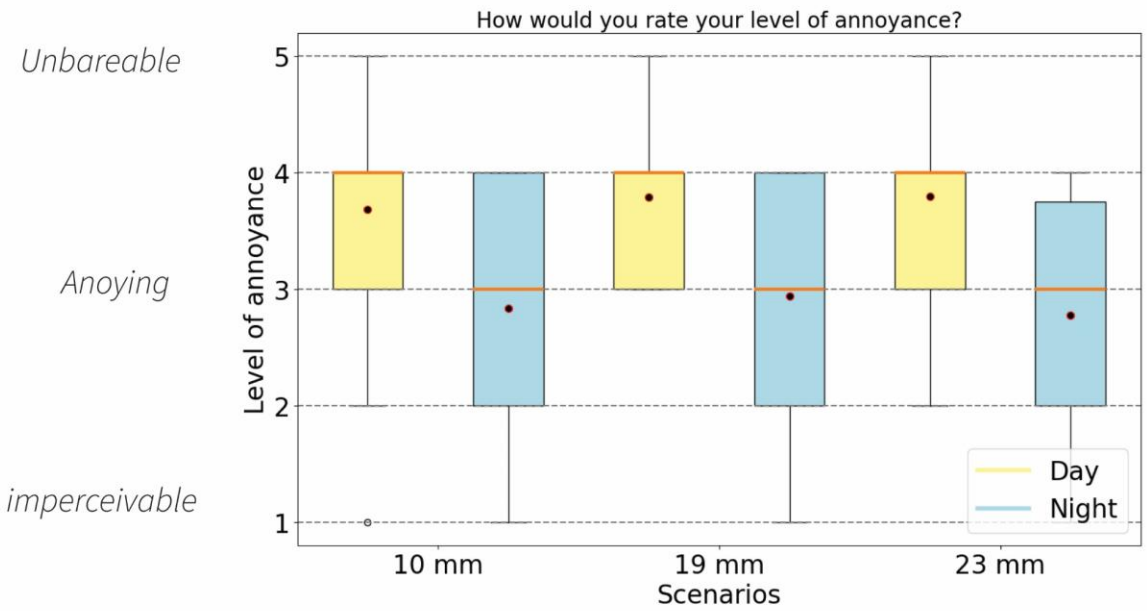
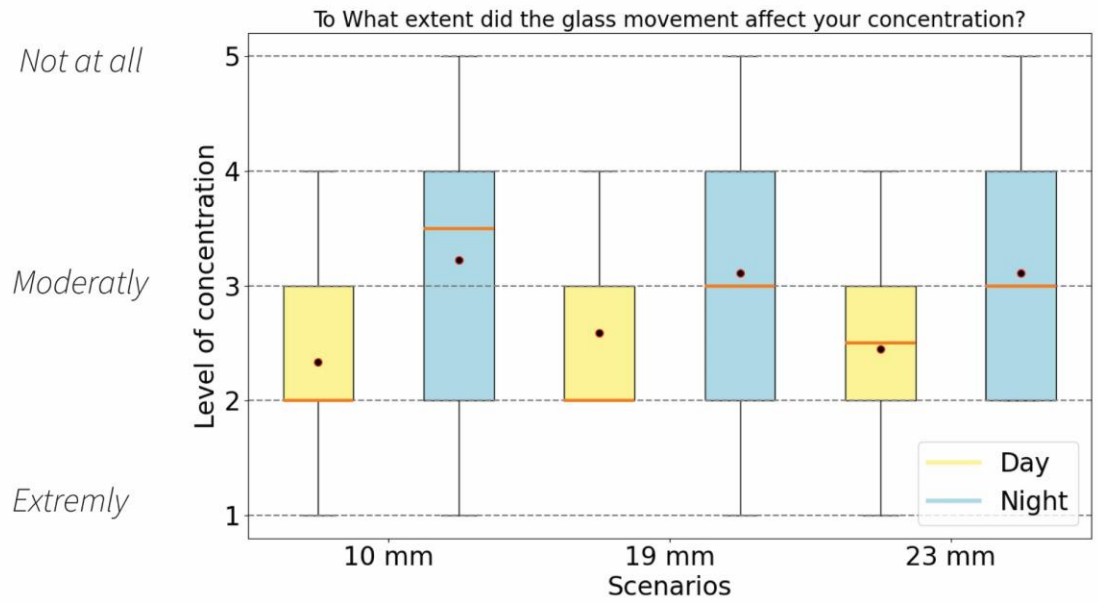
AGC

TU Delft Delft University of Technology

Results and Implications

Effect on concentration and annoyance





Experimental Setup → Design of Experiment → Results and Implications → *Method* → *Analyzing the Questioner* → *Material Savings and Design*