# The card-based tool for co-design workshop on smart material applications in automotive interiors

Front side

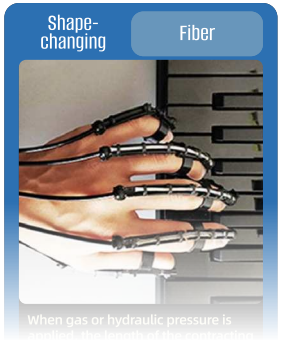
Back side

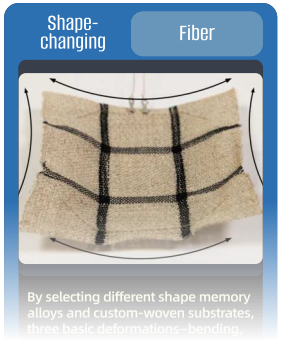
# Material Card
# (Technology Card Set)

Each card is printed in real size.

Fiber | Membrane | Surface | 3D structure

Shape-changing



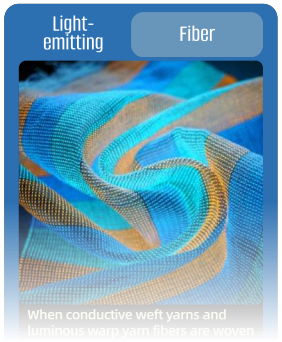



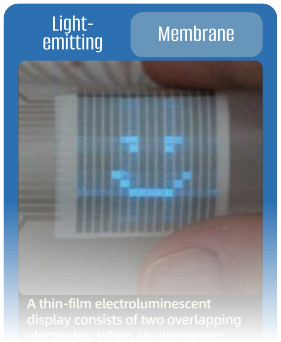




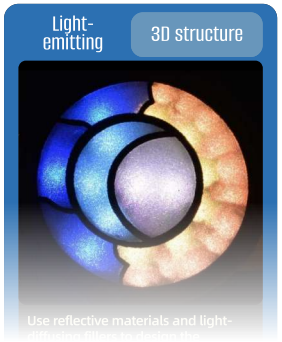


Light-emitting

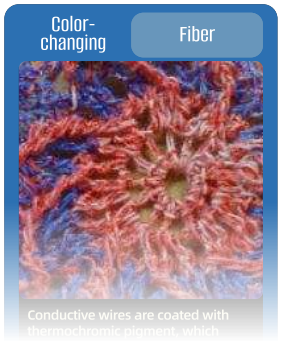


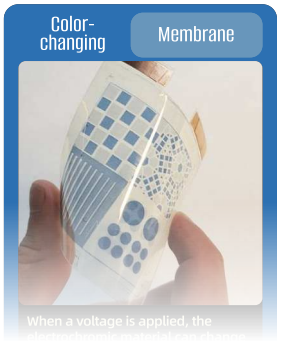





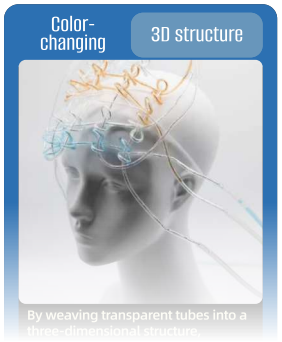



Color-changing

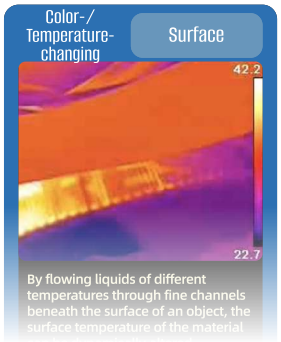







Temperature-changing


# An illustration of the “material palette”

Shape-changing

Fiber

When gas or hydraulic pressure is applied, the length of the contracting (stretching) muscle fibers shortens (elongates), generating linear force in the direction of tension.

## Material

**Soft tube**

## Actuation

**Pneumatics/Hydraulics**

## Fabrication

**Weaving, knitting**

Shape-changing

Fiber

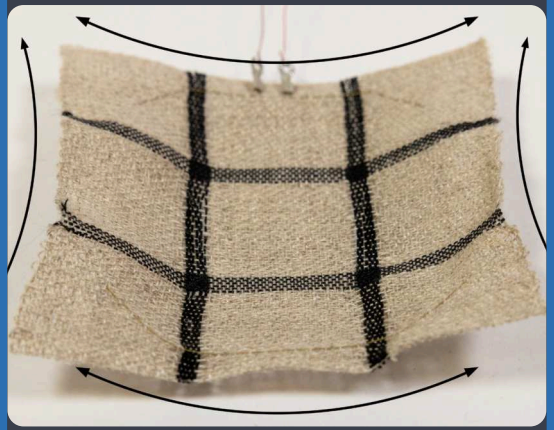
## Application Space


- Under a tensile strain rate of 18 mm/sec, the sensor's resistance can reach a strain of 130% over 10 iterations. In a ø=0.9 mm, 53A fiber configuration, the supply pressure is incrementally changed by 100 kPa, ranging from 100 kPa to 600 kPa. The maximum contraction ratio obtained from the vertical displacement rail is 32%, and the force generated at 600 kPa is 8.8 N.

OmniFiber, Afsar. et al, ACM UIST'21

Shape-changing

Fiber



By selecting different shape memory alloys and custom-woven substrates, three basic deformations—bending, expansion, and contraction—can be achieved.

## Material

**SMA, textile**

## Actuation

**Electricity**

## Fabrication

**Weaving**

Shape-changing

Fiber

## Application Space

- The rated standard driving voltage for the SMA wire is 20.7 V/m, and the standard driving current is 340 mA, generating a force of 1.47 N and a dynamic strain of 4%. When the ratio of constrained SMA length to flexible SMA length is 6, the bending angle is approximately 90°.
- A tubular patch sample was made using silk yarn on a 3-inch wide loom setup, with an initial thickness of 0.561 mm, an increased height of 36.5 mm, and an expansion force of 0.1619 N.
- A 16-turn SMA spring with an initial length of 43 mm was installed in a linen × silk × plain weave fabric patch. The patch was powered with 1.7 V and 1 A, providing an average pulling force of 3.94 N on a weight.
- On a 266.8 g/m$^2$ 100% polyester fleece, the patch exhibited an expansion length of 20-25 mm, a bending angle of 10-20°, and a contraction ratio of 0.4.

Patch-O, Ku. et al, ACM CHI'22

Light-emitting

Fiber

When conductive weft yarns and luminous warp yarn fibers are woven with cotton yarn, each interwoven warp and weft forms an EL unit, which emits light when an alternating voltage is applied.

## Material

**Electroluminescent fiber, conductive fiber**

## Actuation

**AC electricity**

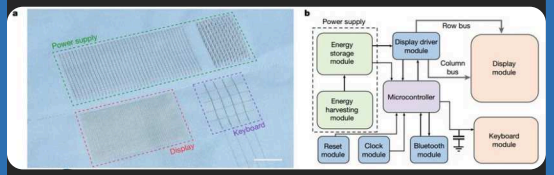
## Fabrication

**Weaving, knitting, embroidery**

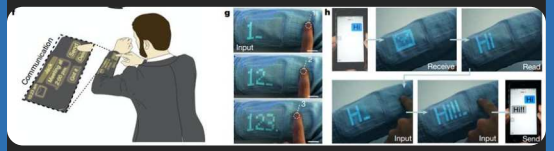
Light-emitting

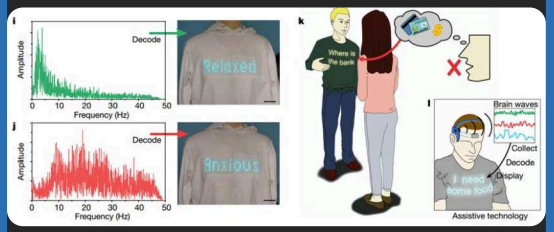
Fiber

## Application Space








- At a voltage of 3.7 V $\mu m^{-1}$ and a frequency of 2000 Hz, the current density is 1.8 $mA \cdot cm^{-2}$, the power consumption is 363.1 μW, and the brightness is 115.1 $cd \cdot m^{-2}$.

Large-area display textiles integrated with functional systems, Shi. et al, Nature volume 591(2021)

Color-changing

Fiber

Conductive wires are coated with thermochromic pigment, which generates heat when powered, causing the pigment to change from an opaque state to a transparent state. When the pigment cools down, it returns to its opaque state.

## Material

**Thermochromic fiber**

## Actuation

**Electricity**

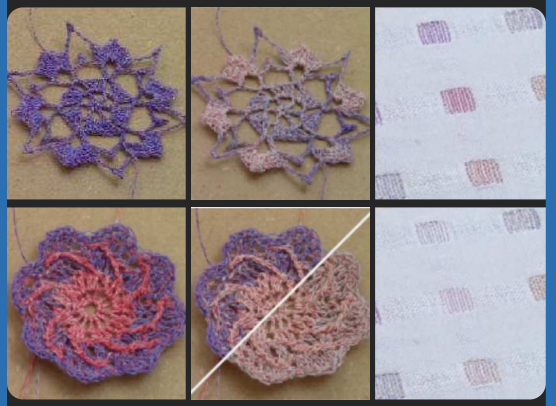
## Fabrication

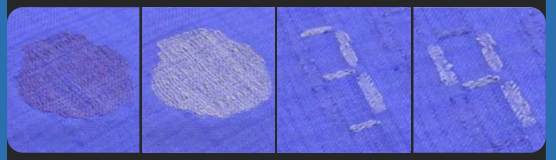
**Knitting, weaving, embroidery**

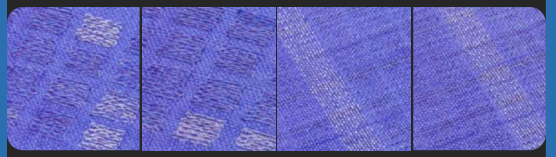
Color-changing

Fiber

## Application Space







- A 20-inch yellow wire requires a voltage of 1.6V and a current of 515mA to induce a color change.

"I don't want to wear a screen" , Devendorf. et al, ACM CHI'16

Shape-changing

Membrane

The membrane is welded into a specific pattern to form a membrane-like airbag. When the airbag inflates, the internal pressure increases, causing the airbag to bulge and drive the membrane to deform.

## Material

**Flexible membrane**

e.g., TPU, silicone

## Actuation

**Pneumatics**

## Fabrication

**Welding, hot pressing, adhesive bonding, etc.**

Shape-changing

Membrane

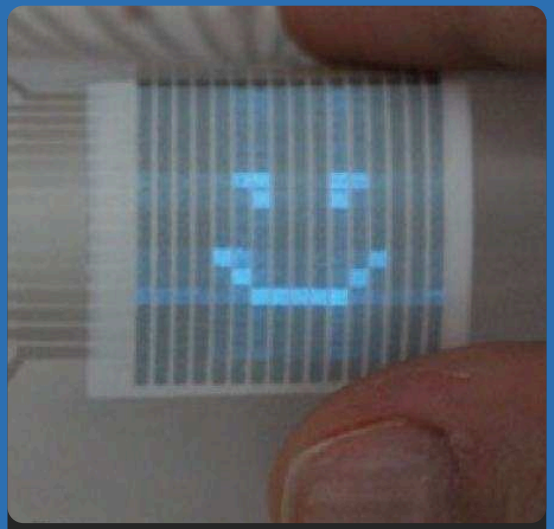
## Application Space


- A single joint can generate approximately 40 mN·m of torque at 270 kPa pressure, and changing the material can enhance the output capability.

Aeromorph, Ou. et al, ACM UIST'16

Light-emitting

Membrane



A thin-film electroluminescent display consists of two overlapping electrodes. When an alternating signal is applied, the electroluminescent coating between the electrodes lights up, causing the display to emit light.

## Material

**Electroluminescent coating, electrode coating**

## Actuation

**AC electricity**

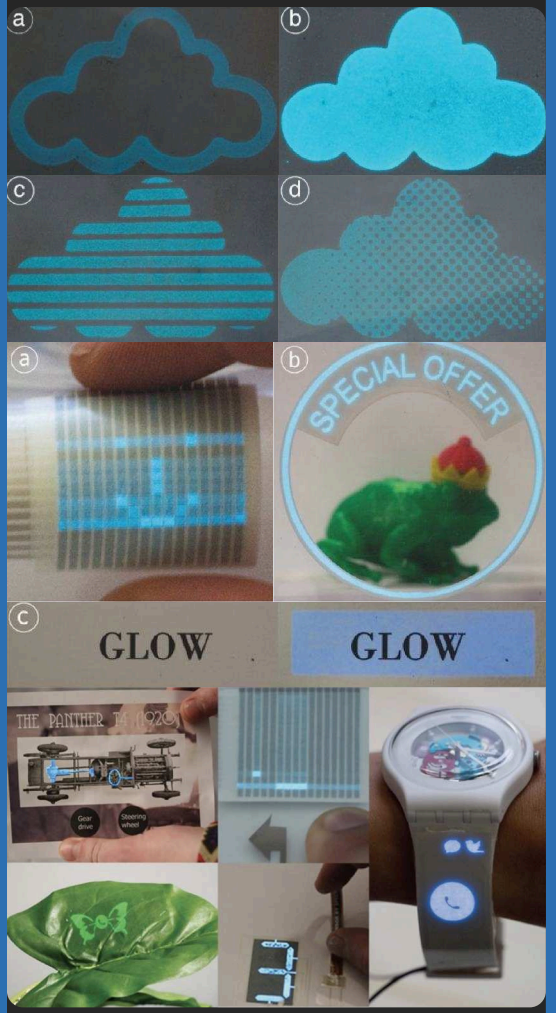
## Fabrication

**Multilayer screen printing, conductive inkjet printing**

Light-emitting

Membrane

## Application Space

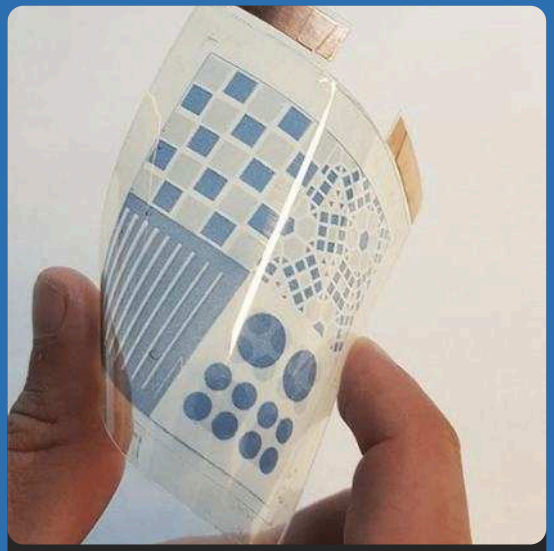



- When driven by a DC12V10M inverter with a maximum input voltage of 12V DC, the display brightness varies between 120 to 280 cd/m$^2$. The display brightness differs depending on the base material used.

PrintScreen, Olberding. et al, ACM UIST'14

Color-changing

Membrane



When a voltage is applied, the electrochromic material can change its color from nearly transparent to a deeper blue.

## Material

**Electrochromic ink, transparent electrode**

## Actuation

**Electricity**

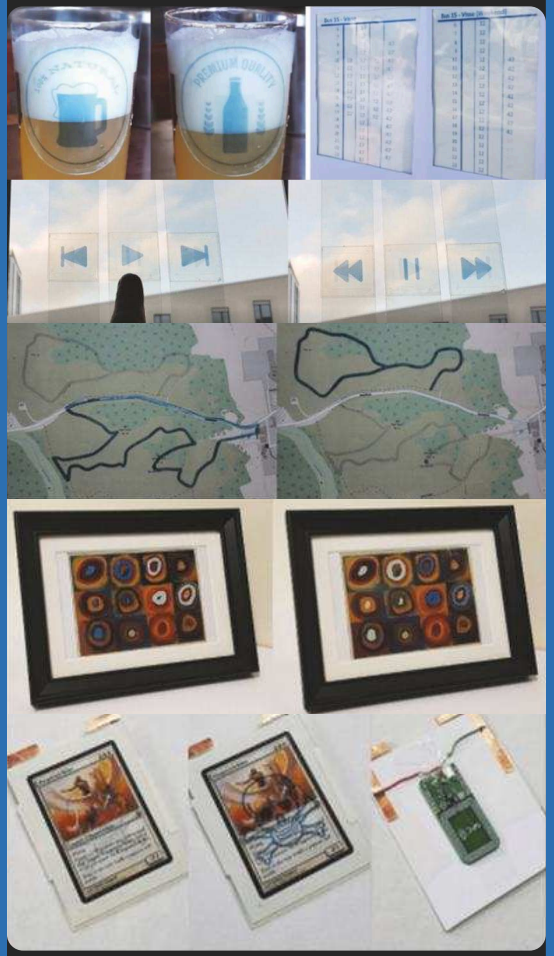
## Fabrication

**Screen printing, inkjet printing**

Color-changing

Membrane

## Application Space



- The ink will naturally fade within a few hours. The switching time ranges from 1.1s to 5.1s, with an average current consumption of 2-4 mA and a power consumption of 4-8 mW.

TransPrint, Jensen. et al,
Advances in Human-Computer Interaction Volume 2019

Temperature-changing

Membrane

A Peltier element array can heat up or cool down when powered, thereby altering the surface temperature of the object.

## Material

**Peltier element array**

## Actuation

**Electricity**

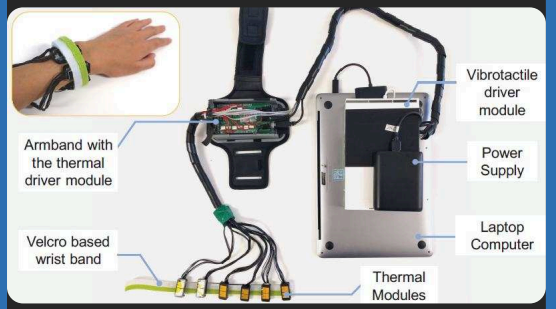
## Fabrication

**Embedded or attached onto a flexible substrate**

Temperature-changing

Membrane

## Application Space




- The component's heating and cooling time by 3°C is approximately 1 second. At a current of 1A, a single element has a maximum cooling capacity of 94 mW, with the cold side temperature reaching 8.7°C.

ThermalBracelet, Peiris. et al, ACM CHI'19

Shape-changing

Surface

Each deformation pixel consists of an electroosmotic pump. When an electric field is applied, the liquid inside the pixel flows upward, causing the top membrane layer to undergo bulging or indentation deformation.

## Material

**Electroosmotic pump**

## Actuation

**Electro-hydraulics**

## Fabrication

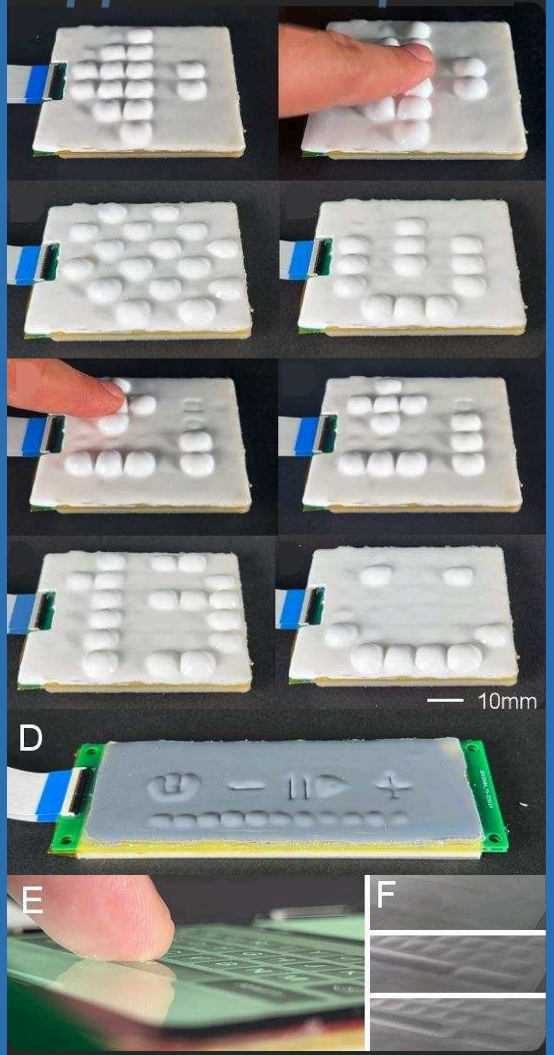
**Custom Shapes**

**Embedded Installation**

Shape-changing

Surface

## Application Space




- The electroosmotic pump can generate approximately 50 kPa of liquid pressure at 250 V.
- The size of a single deformation pixel has been validated to range from 1.6 to 10 mm.
- The power consumption has been validated to be 10-20 mW/mm².

Flat Panel Haptics, Shultz. et al, ACM CHI'23

Light-emitting

Surface

By spraying electrodes and luminescent materials onto the surface of an object, a display can be achieved on any shaped surface when an alternating electric field is applied.

## Material

**Electroluminescent coating, electrode coating**

## Actuation

**AC electricity**

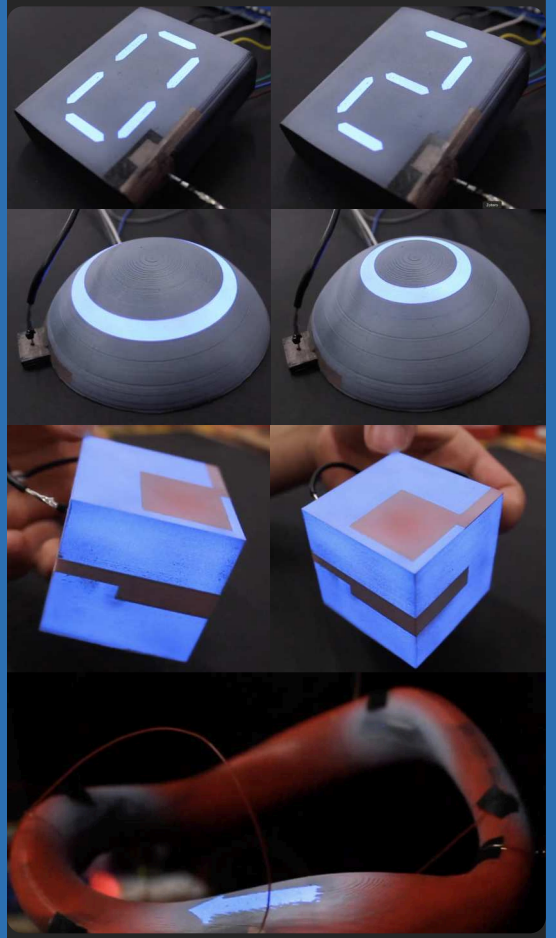
## Fabrication

**Spraying, spray painting, spray coating, etc.**

Light-emitting

Surface

## Application Space



- Electroluminescent materials can emit light when driven by 100-200V DC or AC power. A single luminescent material typically emits only one fixed color.

ProtoSpray, Ollie. et al, ACM CHI'20

Color-changing

Surface

Photochromic pigments are sprayed on the surface of an object, and when exposed to different colors of light, the pigments change to different colors.

## Material

**Photochromic pigments**

## Actuation

**Exposure**

## Fabrication

**Spraying, spray painting, spray coating, etc.**

Color-changing

Surface

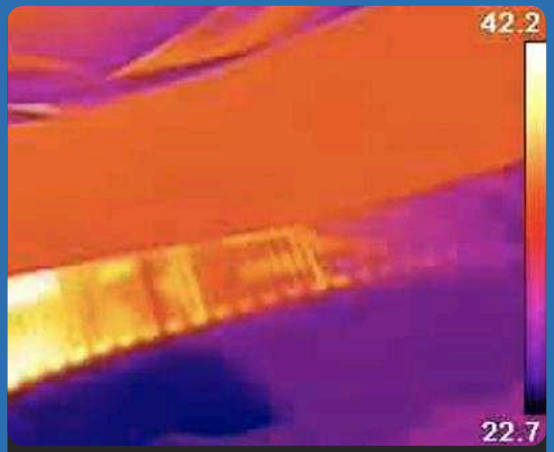
## Application Space


- Upon UV exposure, the pigment turns black; under different visible light exposures, the pigment can change to other colors. The coloration time of the pigment depends on the intensity of the exposure source, typically requiring 1-10 minutes. The natural fading time of the pigment is influenced by the ambient light intensity, usually taking 5-24 hours. The pigment has a limited color range, with green being particularly lacking in the coloration spectrum.

Photo-Chromeleon, Jin. et al, ACM UIST'19

Color-/ Temperature-changing

Surface




By flowing liquids of different temperatures through fine channels beneath the surface of an object, the surface temperature of the material can be dynamically altered.

## Material

**Fluidic channel layer**

## Actuation

**Thermofluidics**

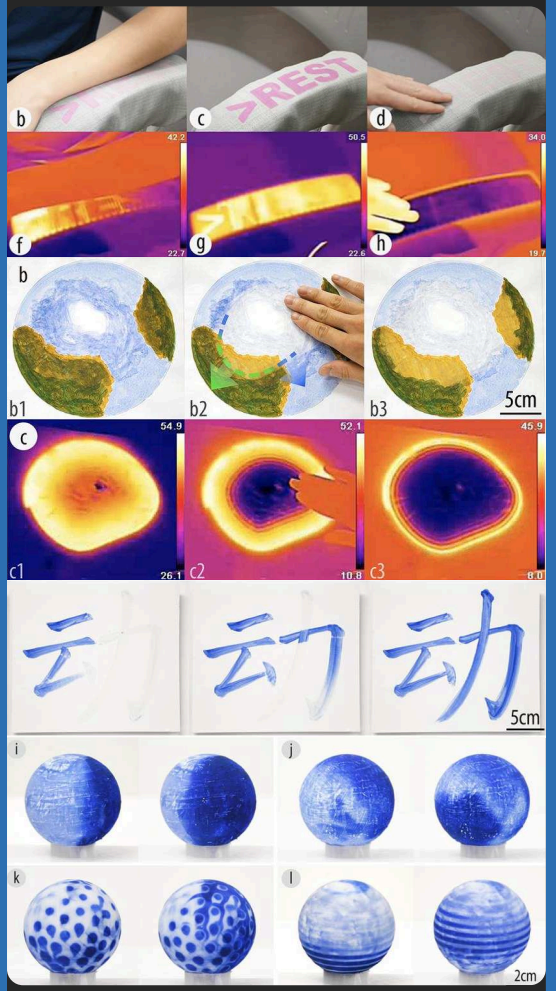
## Fabrication

**Custom shape embedded installation**

Color-/ Temperature-changing

Surface

## Application Space




- The color change and corresponding liquid-driven temperature depend on the type of thermochromic pigment used. The thinnest material thickness validated is 5 mm.

Thermotion, Yu. et al, ACM CHI'23

Shape-/ Stiffness-changing

3D structure

When the material is inflated, it softens, and the structural shape can be changed through the length adjustment of the telescopic rods. When the material is vacuumed, it hardens, and the altered shape remains fixed.

## Material

**Linear actuators, Particles**

## Actuation

**Electricity, vacuum**

## Fabrication

**Custom shape installation**

Shape-/ Stiffness-changing

3D structure

## Application Space

- The deformation extent of the material depends on the telescopic range of the rods. The elongation in one direction has been validated to reach up to 170% of its original length.

xSlate, Hirai. et al, ACM CHI EA'18

Shape-changing

3D structure

The structure exhibits shape memory properties when inflated, allowing the balloon to quickly switch between several preset shapes through simple bending and adjustments.

## Material

**Plastic film (TPU, PEPA)**

## Actuation

**Pneumatics**

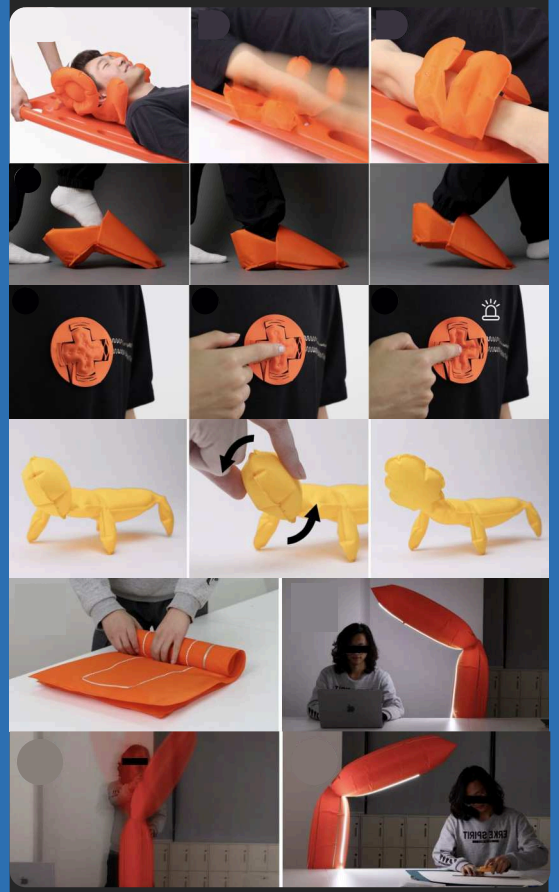
## Fabrication

**Welding, hot pressing, adhesive bonding, etc.**

Shape-changing

3D structure

## Application Space

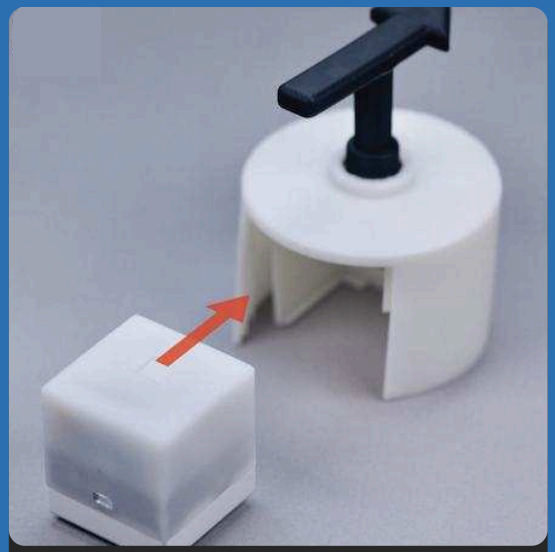


- It is possible to design a switching swing angle of 40°-100° and a switching twist angle of 30°-35°. The structural size can be designed within a range of a few centimeters to 1 meter. The higher the inflation pressure, the greater the force required for switching and the shorter the switching time.
- Reference data: A single bending joint of 14 x 6 cm, with an inflation pressure of 30 kPa, requires a switching force of 3.8 N and a switching time of 1.5 ms. Additionally, the switching force is also influenced by the plastic membrane material and structural size.

SnapInflatables, Yang. et al, ACM CHI'24

Shape-changing

3D structure



With several small robots capable of translation and rotation, along with various modular shells, different movement modes and interactive functions can be achieved.

## Material

**Modular shell**

## Actuation

**Robotics**

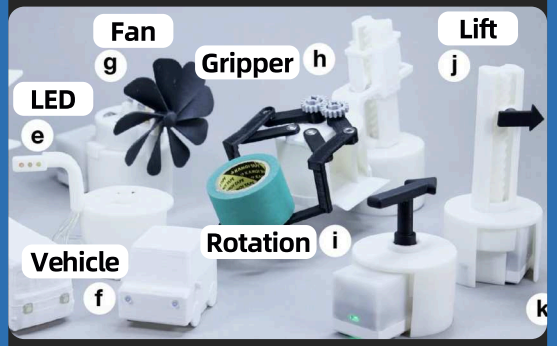
## Fabrication

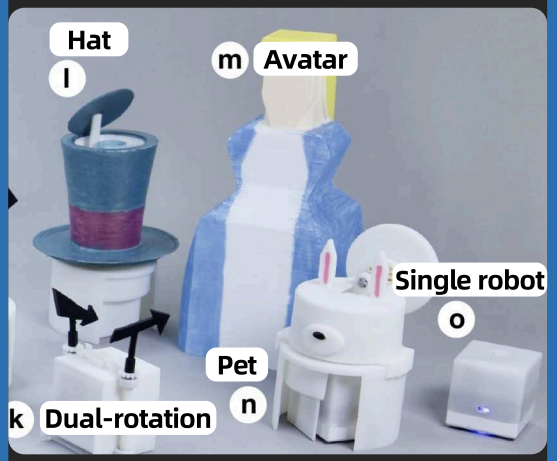
**Manual installation**

Shape-changing

3D structure

## Application Space


HERMITS, Nakagaki. et al, ACM UIST'20

Light-emitting

3D structure

Use reflective materials and light-diffusing fillers to design the distribution of LED light in three-dimensional space.

## Material

**Reflective/diffusing mirror, LED light**

## Actuation

**Electricity**

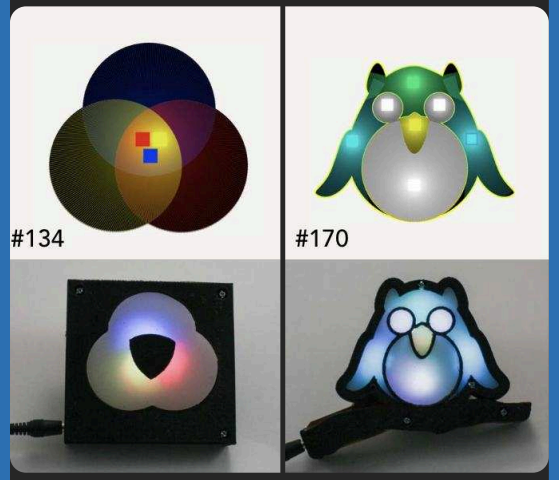
## Fabrication

**Custom shape installation**

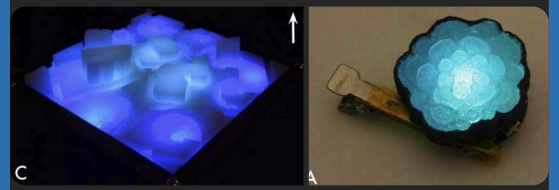
Light-emitting

3D structure

## Application Space







- The soft light angle can reach ±60°. The glare in the main direction (0°) can be reduced to 0.74.

Illumination Aesthetics, Torres. et al, ACM CHI'17

Color-changing

3D structure

By weaving transparent tubes into a three-dimensional structure, dynamic color changes in the 3D structure can be achieved by flowing different colored liquids through the tubes.

## Material

**Transparent tube, liquid**

## Actuation

**Hydraulics**

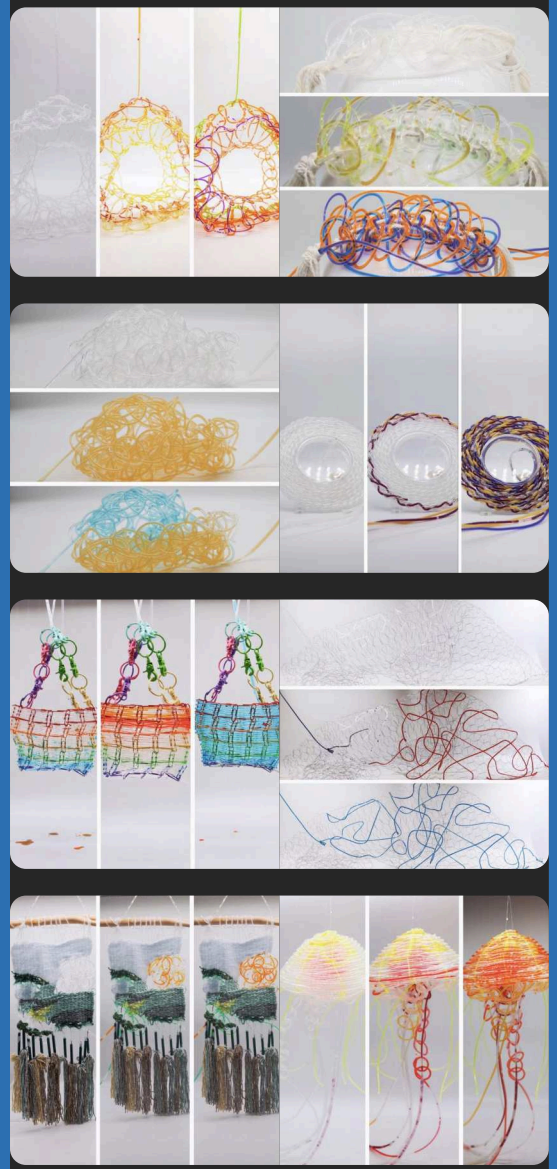
## Fabrication

**Custom shape installation, tubular weaving**

Color-changing

3D structure

## Application Space



It Puts Life into My Creations, Liu. et al, ACM CHI'22

Material

Actuation

Fabrication

Application Space

# Input Card
# (Technology Card Set)

## Long press

Hold down the specified area continuously.

## Touch

Lightly touch the specified area.

## Click

Quickly press and release the specified area.

## Double click

Quickly press the specified area twice in succession.

## Swipe

Swipe your finger across the specified area.

## Drag

Hold and move the object or icon.

## Pinch

Pinch with two fingers to zoom out or spread them to zoom in.

## Rotate

Rotate the knob or draw a circle with your finger in the specified area.

## Tap

Gently tap the screen or button.

## Voice command

Operate using voice commands.

## Air gesture

Use gestures in the air for operations, such as waving or pointing.

## Press

Press the physical button.

## Eye movement

Control the interface through eye movement.

## Body movement

Trigger operations through body movements (such as adjusting seating posture).

## Facial expression

Recognize and operate through facial expressions or movements.

## Write/draw

Write or draw in the specified area.

## Sensor

Such as temperature sensing, humidity sensing, etc.

.....

# User Card
# (Objective Card Set)

# Elderly

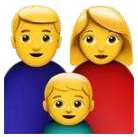
Passengers who may require a higher level of comfort and safety.

# Business professionals

Individuals who may need to handle work matters inside the vehicle.

# Children

# Pets



# Families

Including parents, children, and other family members.

# Friends

Close friends and relatives who have a tight social bond with the driver.

## Couples

Users who have an intimate relationship.

## Long-distance travelers

Users on long journeys or who are unable to get out of the vehicle for an extended period.

## Commuters

Users who commute daily.

## People with disabilities

Special groups that require individual consideration in terms of mobility.

## High-end customers

Users with a higher social status who have high demands for in-car facilities and services.

## Music enthusiasts

## Travelers

Users with a need for vehicle travel.

## Emergency personnel

Such as police officers, firefighters, and emergency medical personnel.

## Environmentalists

People who are concerned about the vehicle's environmental performance and energy-saving technologies.

## Fitness enthusiasts

Individuals who may need the comfortable space inside the vehicle for small fitness activities.

## Infants

# Emotion Card
# (Objective Card Set)

Each page is printed on A4 cardboard (real size).

Joy


Anger

Boredom

Relaxation

Anxiety

Sleepiness

Focus

Surprise

Nostalgia

Disappointment

Curiosity

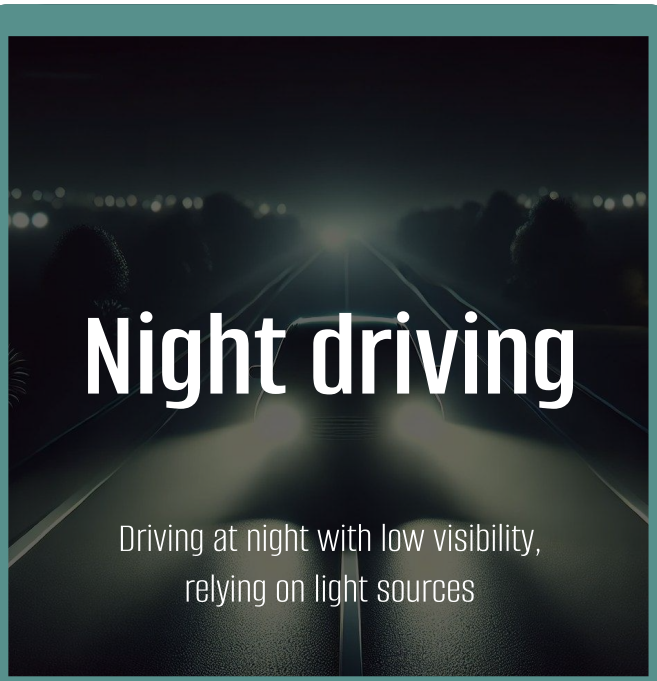
Guilt

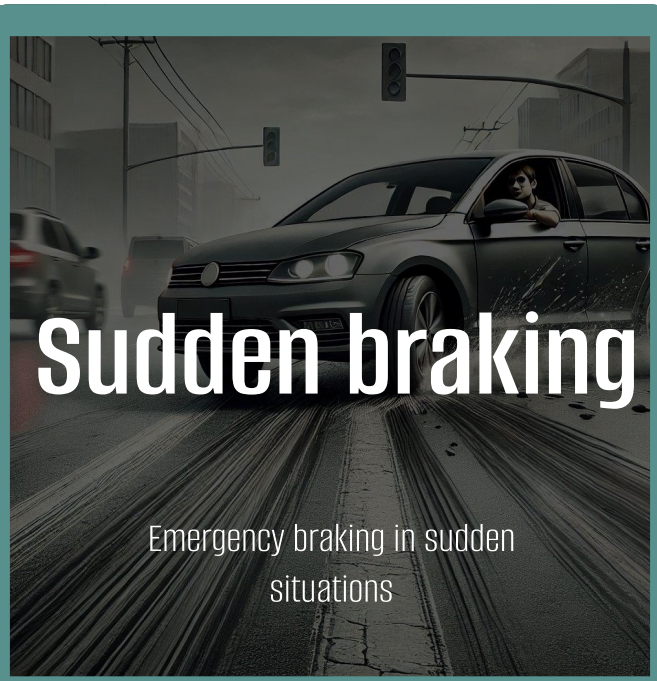
# Scenario Card
# (Objective Card Set)

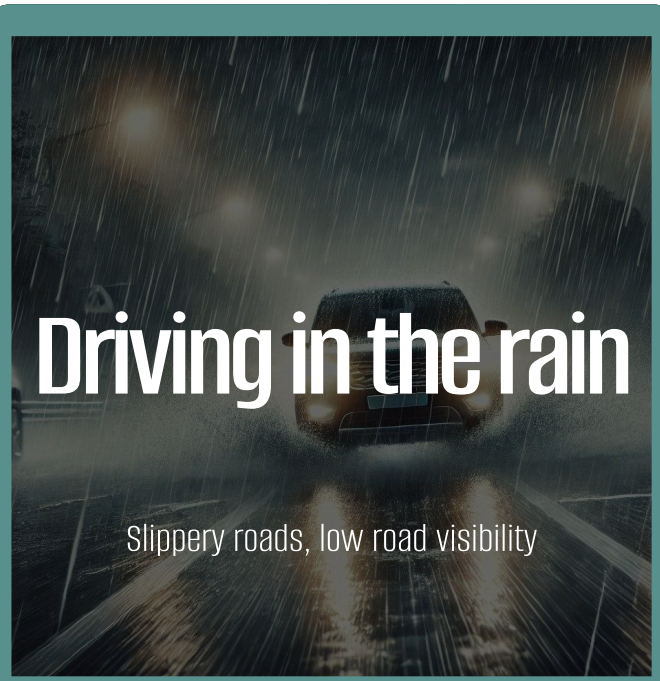

Smooth speeding
On open highways or roads with less traffic


Traffic jam
Traffic congestion due to peak hours or accidents


Sharp turn
Situations requiring sudden turns on mountain roads or city streets

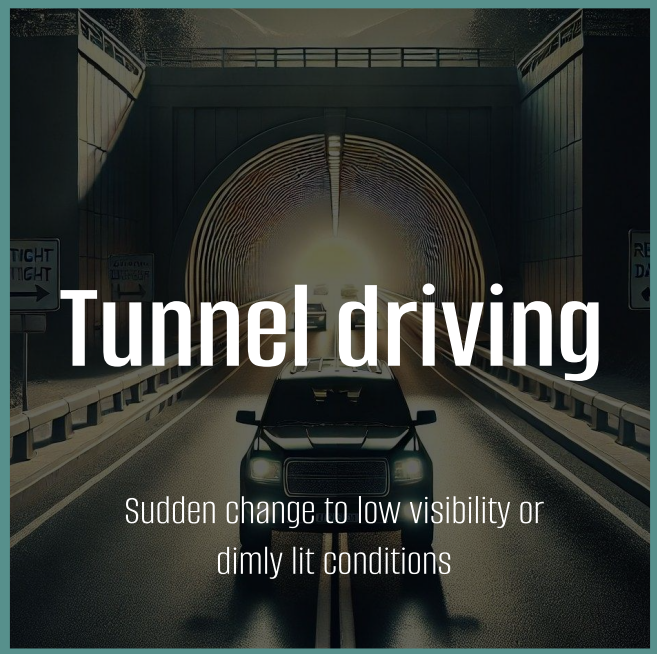

Night driving
Driving at night with low visibility, relying on light sources


Sudden braking
Emergency braking in sudden situations


Driving in the rain
Slippery roads, low road visibility

## Narrow road

On rural paths, narrow roads, or situations with obstacles

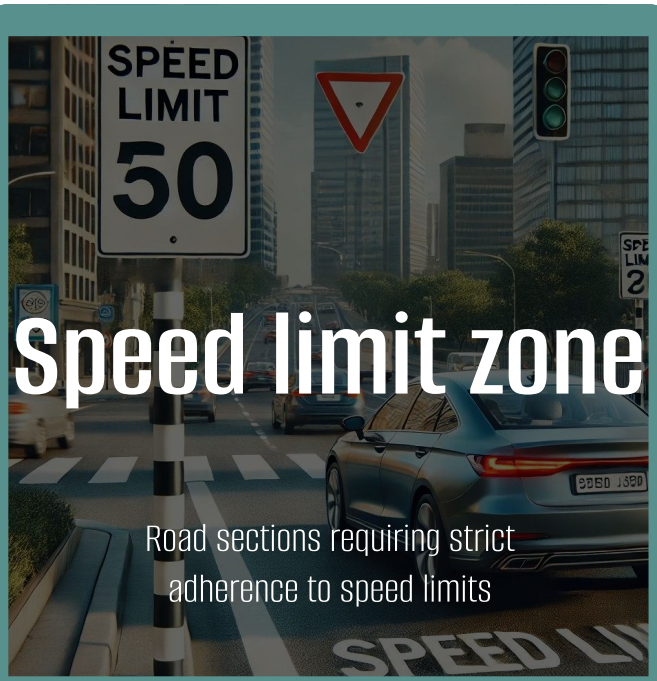


## Tunnel driving

Sudden change to low visibility or dimly lit conditions


## Emergency evasion

Need to yield to ambulances, police cars, or fire trucks




## Speed limit zone

Road sections requiring strict adherence to speed limits

## Zebra crossing

Situations requiring special attention to pedestrian movements, such as zebra crossings and intersections


## Overtaking lane

Situations requiring lane changes or overtaking

# Evaluation Card

Researcher

# Materials

Selection, substitution, and optimization of materials involve multiple performance evaluations, such as mechanical properties, thermal properties, biocompatibility, etc.

*Please provide your feedback and suggestions!*

Researcher

# Actuation mechanisms

Actuation methods, control methods, power supply methods, etc., involve energy consumption, controllability, response speed, and other factors.

*Please provide your feedback and suggestions!*

Researcher

# Manufacturing processes

Selection, substitution, and optimization of processes involve feasibility, compatibility, and cost of production processes.

*Please provide your feedback and suggestions!*

Researcher

# Design and application methods

Customization and design of various structures and functions to meet different requirements.

*Please provide your feedback and suggestions!*

Researcher

# Input methods

Triggering and response methods of system functions to form a complete interaction loop and meet various needs.

*Please provide your feedback and suggestions!*

Researcher

## Designer

# Aesthetics

Visual effects, color combinations, style consistency, etc.

*Please provide your feedback and suggestions!*

## Designer

# Creativity

Is the design innovative, inspiring users' desire to explore and curiosity?

*Please provide your feedback and suggestions!*

## Designer

# Sustainability

Are environmental protection and sustainability considered in the materials, production, and other processes?

*Please provide your feedback and suggestions!*

## Designer

# Usability

Does it meet the functions required by users? Is the product clear and easy to use?

*Please provide your feedback and suggestions!*

## Designer

# Emotional experience

Can it evoke emotional resonance in users?

*Please provide your feedback and suggestions!*

## Designer

*Please provide your feedback and suggestions!*

Industry

# Customer Benefits

Does it meet user needs?
How strong is the demand, and how much benefit does it bring to users?

*Please provide your feedback and suggestions!*

Industry

# Brand Identity

How's the brand image?Does it align with the company's attributes, values, and core strategy?

*Please provide your feedback and suggestions!*

Industry

# Market Competitiveness

Compared to competitors, how are its innovation, advantages, and disadvantages?
Does it align with future market trends?
Compared to competitors, how are its innovation, advantages, and disadvantages?
Does it align with future market trends?

*Please provide your feedback and suggestions!*

Industry

# Production Process

What changes will it bring to existing production processes? Does it match the supply chain? Is it stable and feasible? If it needs to be converted into a product, how long will it take?

*Please provide your feedback and suggestions!*

Industry

# Engineering Feasibility

*Please provide your feedback and suggestions!*

Industry

*Please provide your feedback and suggestions!*

# Evaluation Board

User Perspective

Positive Judgment

Company Perspective

Positive Judgment

User Perspective

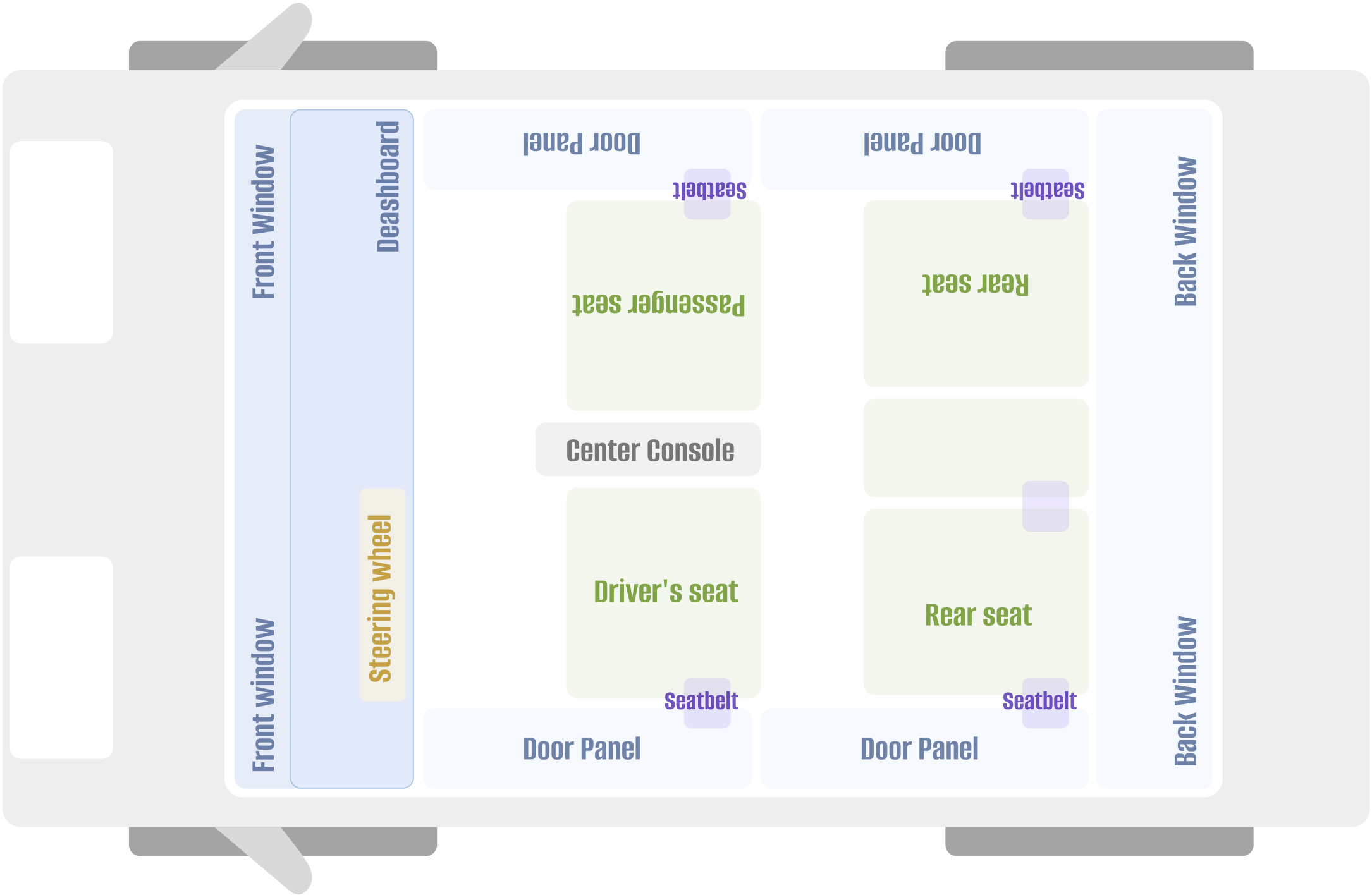
Negative Judgment

Company Perspective

Negative Judgment

This board is printed on A2 cardboard.

# Interior Layout Board




This board is printed on A0 cardboard.