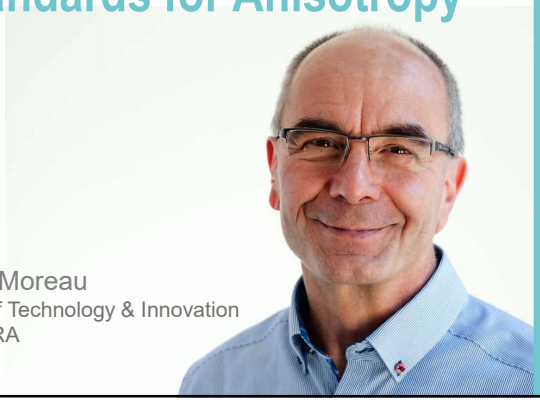
NGA

thirsty THURSDAY

Quench your thirst for knowledge!

Standards for Anisotropy



Louis Moreau
Head of Technology & Innovation
AGNORA

MARK YOUR CALENDAR FOR THESE OTHER UPCOMING EVENTS

Thirsty Thursday – Designing for School Security
June 17, 2021, 1:00 pm ET

NGA Glass Conference: July 2021
July 20, 2021, 3:00-5:00 pm ET | Zoom

Thirsty Thursday
August 26, 2021, 1:00 pm ET

GlassBuild America
Sept 13-15, 2021 | Atlanta, GA
- Glazing Executives Forum: Sept 13
- NGA Glass Conference: Sept 13-15

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NGA Glass Conference: Summer & Fall 2021

Online via Zoom

July 20, 2021 | 3:00 – 5:00 pm ET

- Committee Chair Updates
- Hot Topics Wish List development
- Networking + Happy Hour

In person at the Omni Hotel, *with GlassBuild America*

Sept 13, 2021 | 2:30 – 3:30 pm ET
Economic Outlook session at Glazing Executives Forum

Sept 14, 2021 | 4:00 – 5:00 pm ET
Opening Reception

Sept 15, 2021 | 8:00 am – 2:00 pm ET

Breakfast + Glass Magazine Top Trends Report

Glazing Industry Stakeholder Discussion:
engage our partners outside the industry to promote, educate and advocate for glazing and glass building products

Lunch + Technical Codes & Standards Update

Glazing Industry Contributor Discussion:
focus on promoting, educating and advocating for our industry

glass.org / event / nga-glass-conference-july-2021

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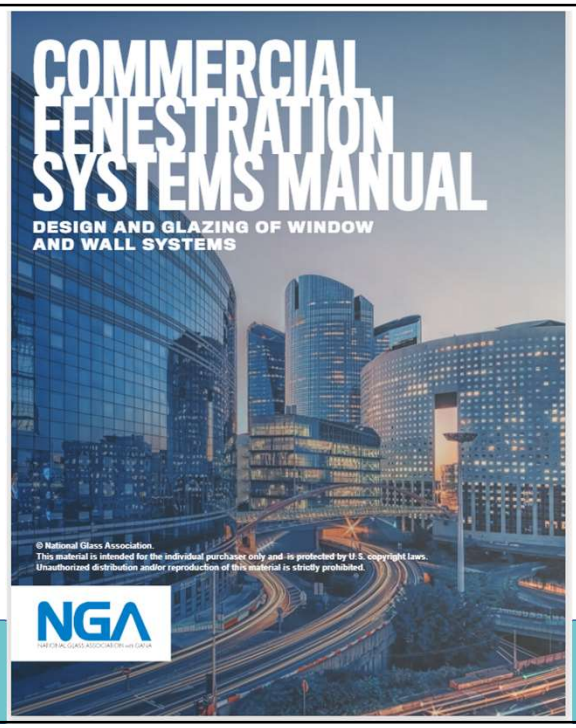

42 Individual Volunteer Contributors

16 Member Companies provided photos and graphics

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Commercial Fenestration Systems Manual glass.org/store

4

glassbuild.com | jwatson@glass.org

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AIA Continuing Education Provider

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This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions will be addressed at the conclusion of the presentation.

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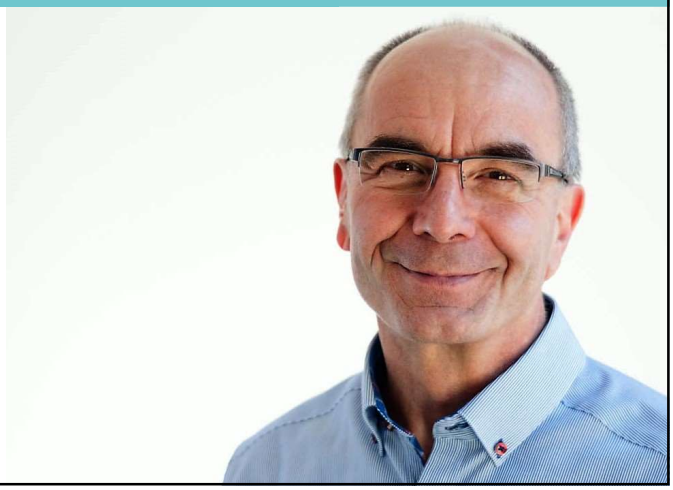
thirsty THURSDAY

Quench your thirst for knowledge!

Standard for Anisotropy



Louis Moreau
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Learning Objectives

- Define anisotropy
- Define retardation
- Identify two essential conditions required to see leopard spots
- Explain which unit of measure is used to define anisotropy in architectural glass
- Describe two environmental risk factors that will influence anisotropy.

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Today's agenda

- Basic vocabulary
- The physic behind
- Explain the unit of measure
- Identify the conditions that reveals iridescence
- Describe C1901 and how you can use it

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WHO WE ARE:

AGNORA is an award-winning glass fabricator providing the largest, high-quality architectural glass in North America.

Known as an industry leading, team-based customer service company, AGNORA employs innovative production processes and invests in leading-edge machinery to push the boundaries of what is possible in architectural glass fabrication and meet challenging design objectives brought by their customers.

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Milwaukee, WI
USA
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Apple Store Yorkdale
Toronto, ON Canada
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12


Apple Store Legacy
Boston, MA USA
PAPER+SOURCE
LEGAL
LEGAL
AGNORA

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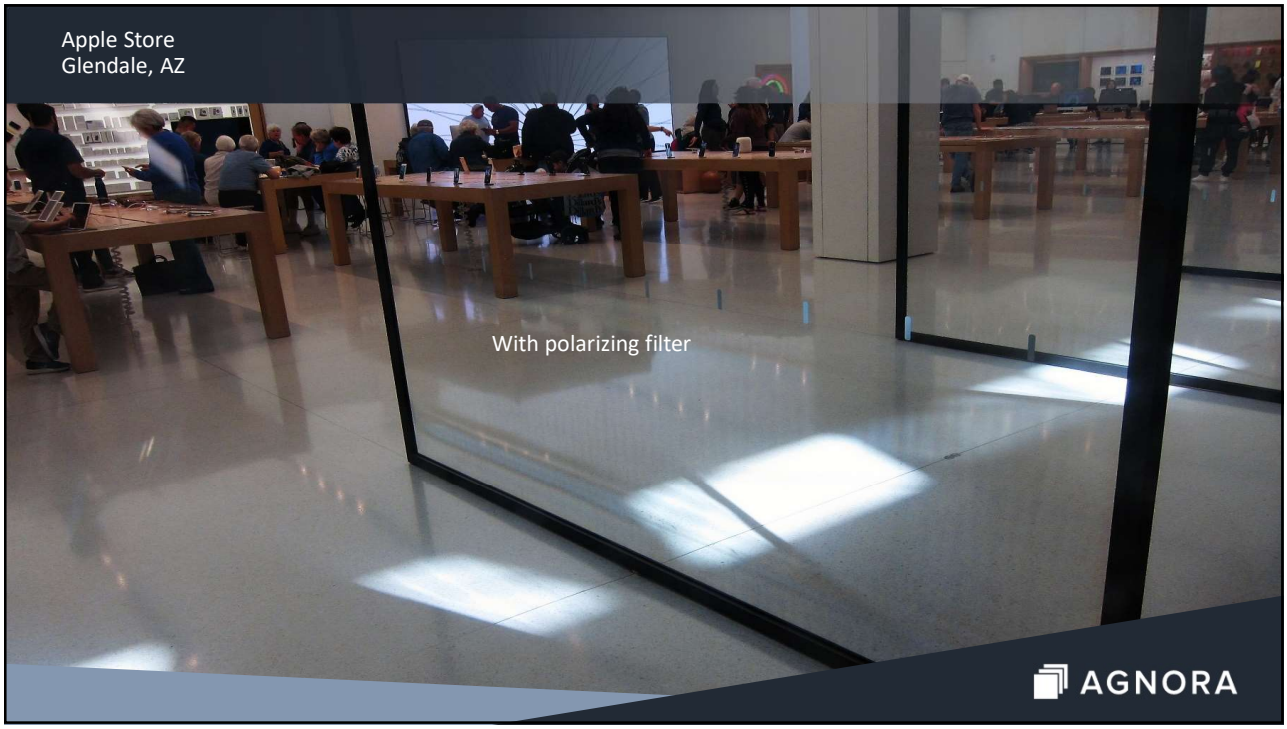
Apple Store
Glendale, AZ
With polarizing filter
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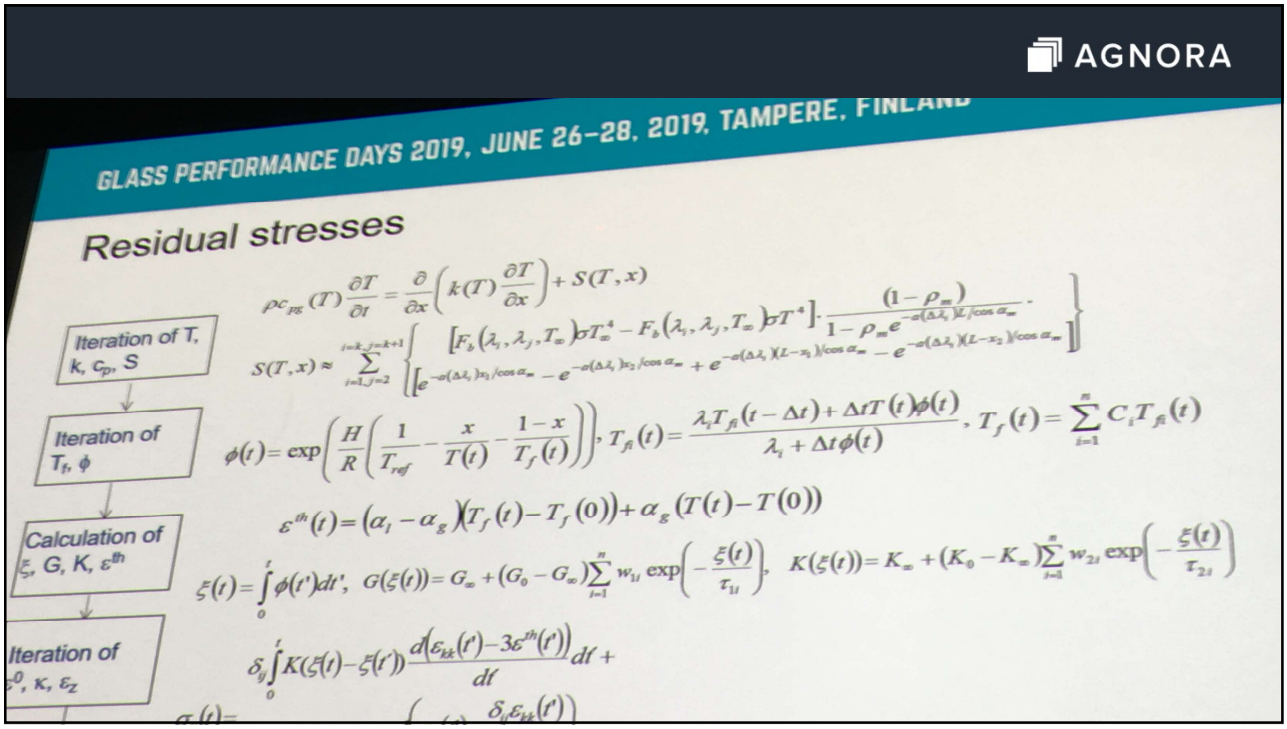
AGNORA
GLASS PERFORMANCE DAYS 2019, JUNE 26–28, 2019, TAMPERE, FINLAND
Residual stresses
Iteration of T, k, c_p, S
Iteration of T_f, ϕ
Calculation of ξ, G, K, ε^{th}
Iteration of σ^0, κ, ε_z
$\rho c_{pg}(T)\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(k(T)\frac{\partial T}{\partial x}\right)+S(T,x)$
$S(T,x)\approx\sum_{i=1,j=2}^{i=k,j=k+1}\left\{\begin{array}{l}[F_b(\lambda_i,\lambda_j,T_\infty)\sigma T_\infty^4-F_b(\lambda_i,\lambda_j,T_\infty)\sigma T^4]\cdot\frac{(1-\rho_\infty)}{1-\rho_\infty e^{-\alpha(\Delta\lambda_i)L_j/\cos\alpha_\infty}}\cdot\\ \left[e^{-\alpha(\Delta\lambda_i)x_1/\cos\alpha_\infty}-e^{-\alpha(\Delta\lambda_i)x_2/\cos\alpha_\infty}+e^{-\alpha(\Delta\lambda_i)(L-x_1)/\cos\alpha_\infty}-e^{-\alpha(\Delta\lambda_i)(L-x_2)/\cos\alpha_\infty}\right]\end{array}\right\}$
$\phi(t)=\exp\left(\frac{H}{R}\left(\frac{1}{T_{ref}}-\frac{x}{T(t)}-\frac{1-x}{T_f(t)}\right)\right),\ T_{fi}(t)=\frac{\lambda_i T_{fi}(t-\Delta t)+\Delta t T(t)\phi(t)}{\lambda_i+\Delta t\phi(t)},\ T_f(t)=\sum_{i=1}^{n}C_i T_{fi}(t)$
$\varepsilon^{th}(t)=(\alpha_l-\alpha_g)(T_f(t)-T_f(0))+\alpha_g(T(t)-T(0))$
$\xi(t)=\int_0^t\phi(t')dt',\ G(\xi(t))=G_\infty+(G_0-G_\infty)\sum_{i=1}^{n}w_{1i}\exp\left(-\frac{\xi(t)}{\tau_{1i}}\right),\ K(\xi(t))=K_\infty+(K_0-K_\infty)\sum_{i=1}^{n}w_{2i}\exp\left(-\frac{\xi(t)}{\tau_{2i}}\right)$
$\delta_{ij}\int_0^t K(\xi(t)-\xi(t'))\frac{d(\varepsilon_{kk}(t')-3\varepsilon^{th}(t'))}{dt}dt'+$

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The Word…

Anisotropy

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The Word…

Anisotropy

What does it mean?

- ≠ Isotropy
  - Water
  - Vacuum
  - Annealed glass

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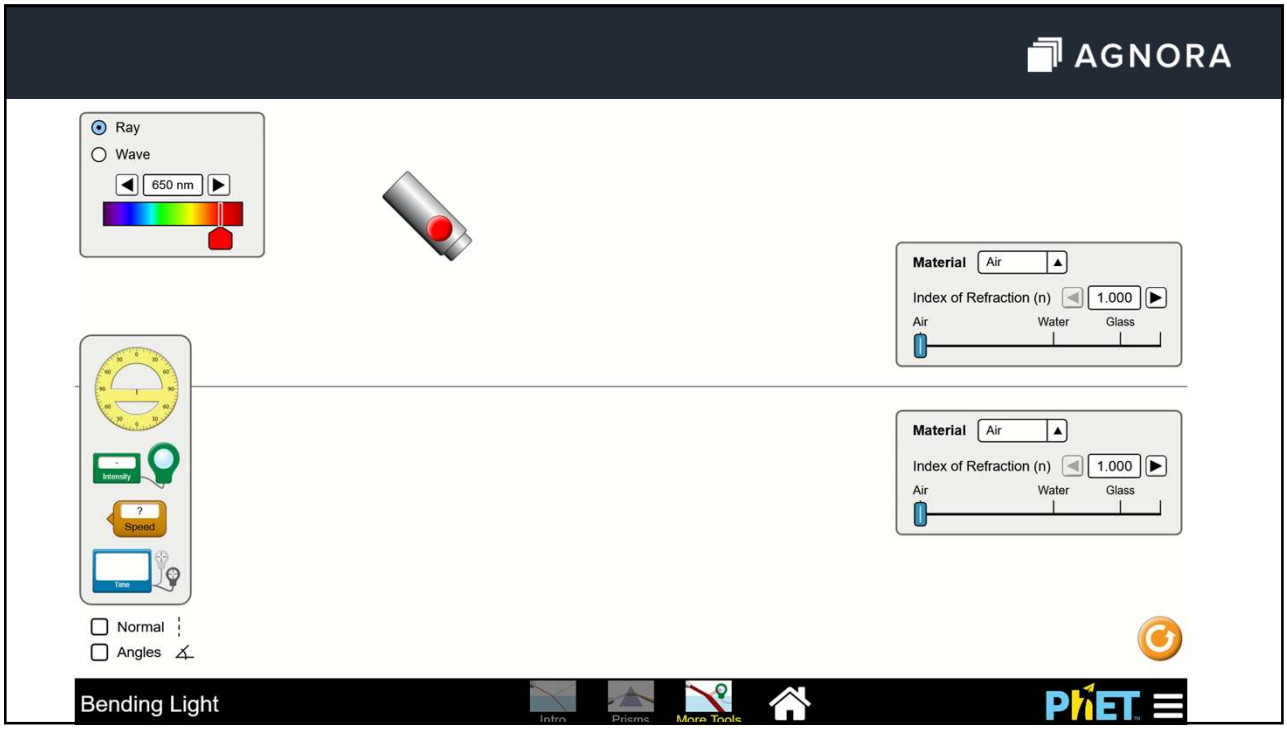
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Ray
Wave
650 nm
Material
Air
Index of Refraction (n)
1.000
Air
Water
Glass
Material
Air
Index of Refraction (n)
1.000
Air
Water
Glass
Intensity
Speed
Time
Normal
Angles
Bending Light
Intro
Prisms
More Tools
PhET

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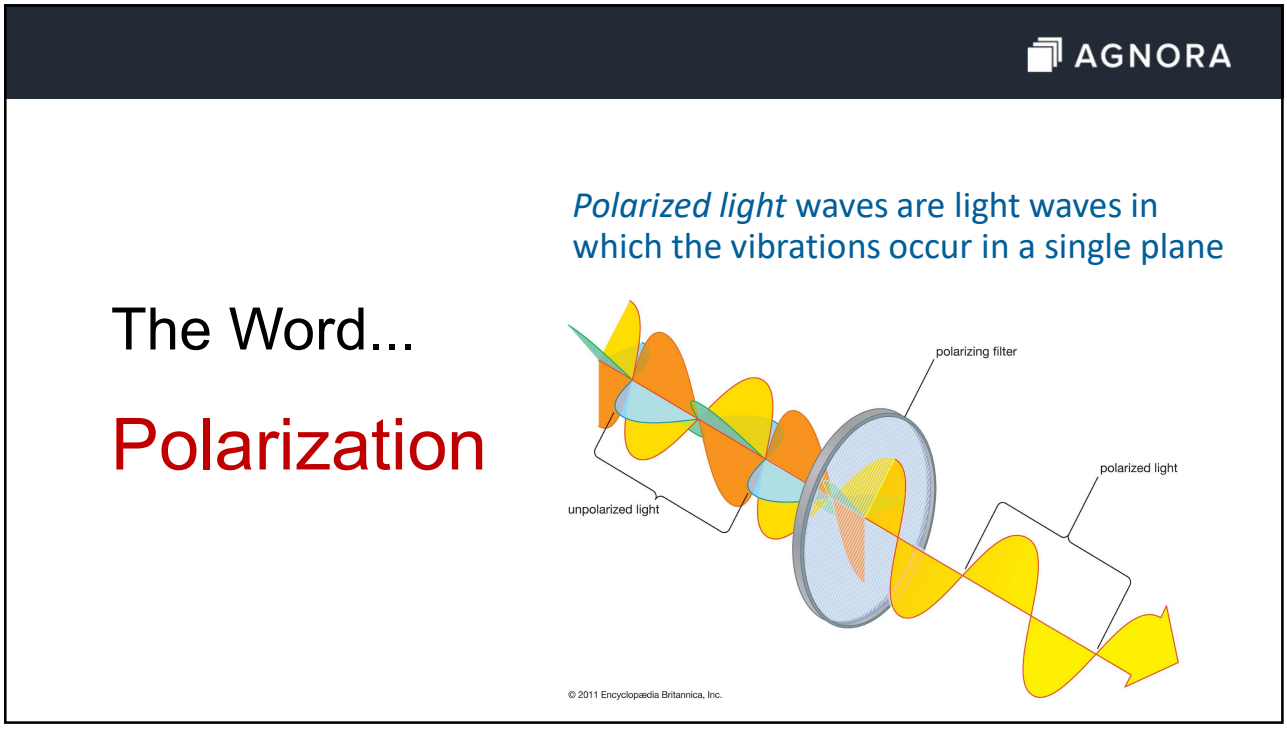
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The Word...
Polarization
Polarized light waves are light waves in which the vibrations occur in a single plane
polarizing filter
polarized light
unpolarized light
© 2011 Encyclopædia Britannica, Inc.

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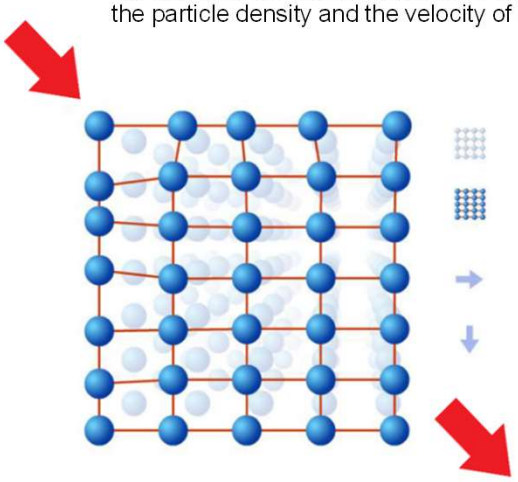
The Word...

Birefringence

What does it mean?

Mechanical stress leads to deformation of the material structure and therefore changes the particle density and the velocity of light



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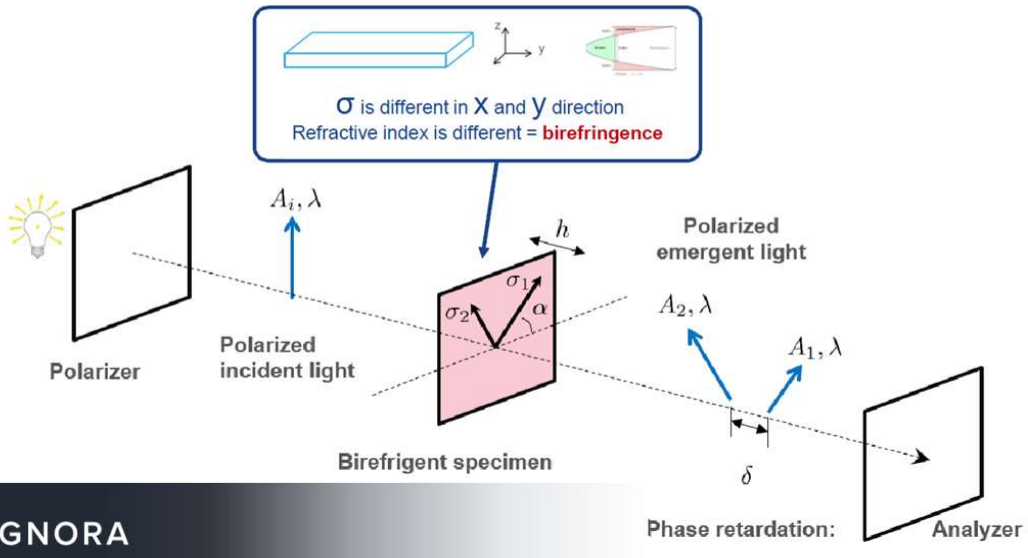
BIREFRINGENT PROPERTIES OF HEAT TREATED GLASS

- POLARIZED LIGHT + STRESS-INDUCED BIREFRINGENCE = PHOTOELASTICITY



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The Word...

Birefringence

When polarized light hits a birefringent material

- Refracts a single incoming ray in two perpendicular directions
- Corresponding to two different polarizations

Optically Anisotropic Material

Having differences of index of refraction

Heterogenous Stress

Caused by imperfect homogeneous heating and cooling in the tempering furnace.

This phenomenon can also exist in interlayers

Caused by cooling differences in the autoclave

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Area Stresses

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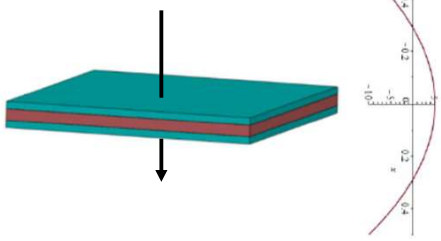
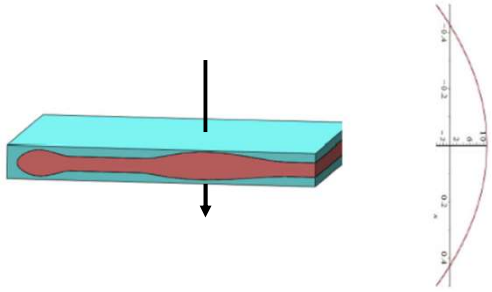
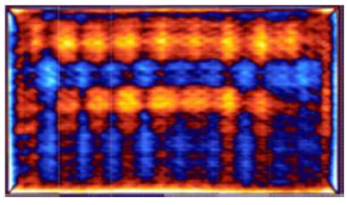


"Ideal" tempered glass



"Real" tempered glass



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The Word…

Retardation

What does it mean?

- In a birefringent material, the light waves propagate in the horizontal and vertical directions at different speeds, resulting in an optical path difference or optical retardation
- Measure of birefringence: Expressed in nanometer - nm

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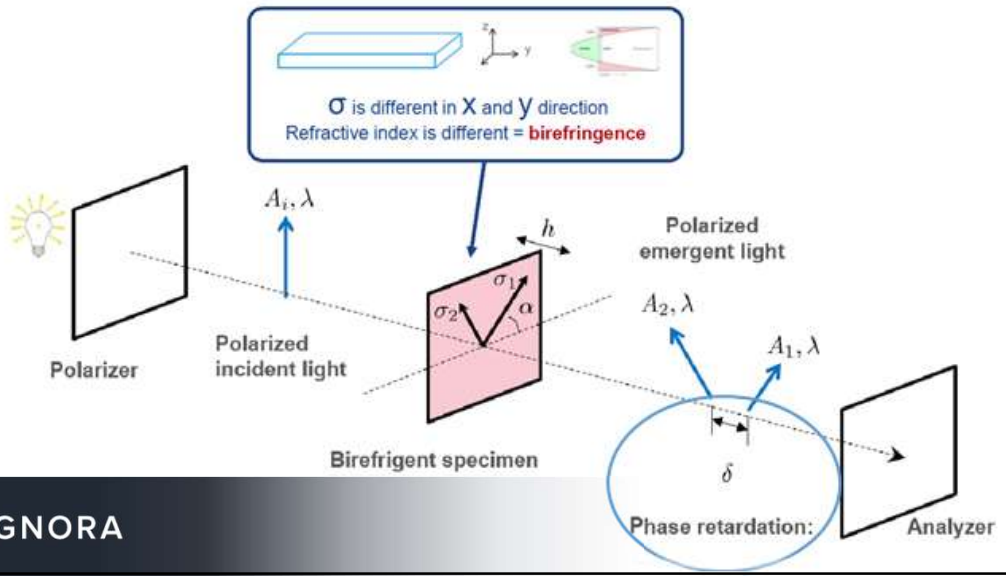
BIREFRINGENT PROPERTIES OF HEAT TREATED GLASS

POLARIZED LIGHT + STRESS-INDUCED BIREFRINGENCE = PHOTOELASTICITY



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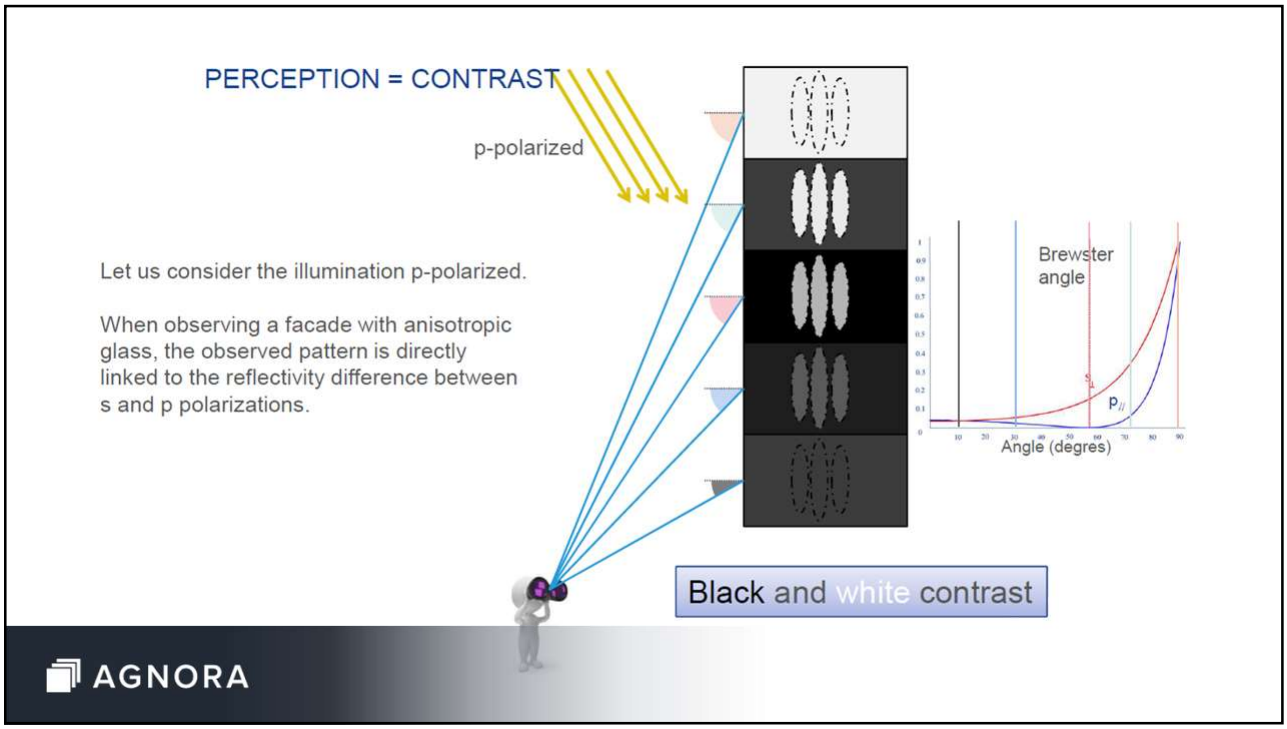
PERCEPTION = CONTRAST
p-polarized
Let us consider the illumination p-polarized.
When observing a facade with anisotropic glass, the observed pattern is directly linked to the reflectivity difference between s and p polarizations.
Brewster angle
Angle (degres)
Black and white contrast
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A typical example of iridescence
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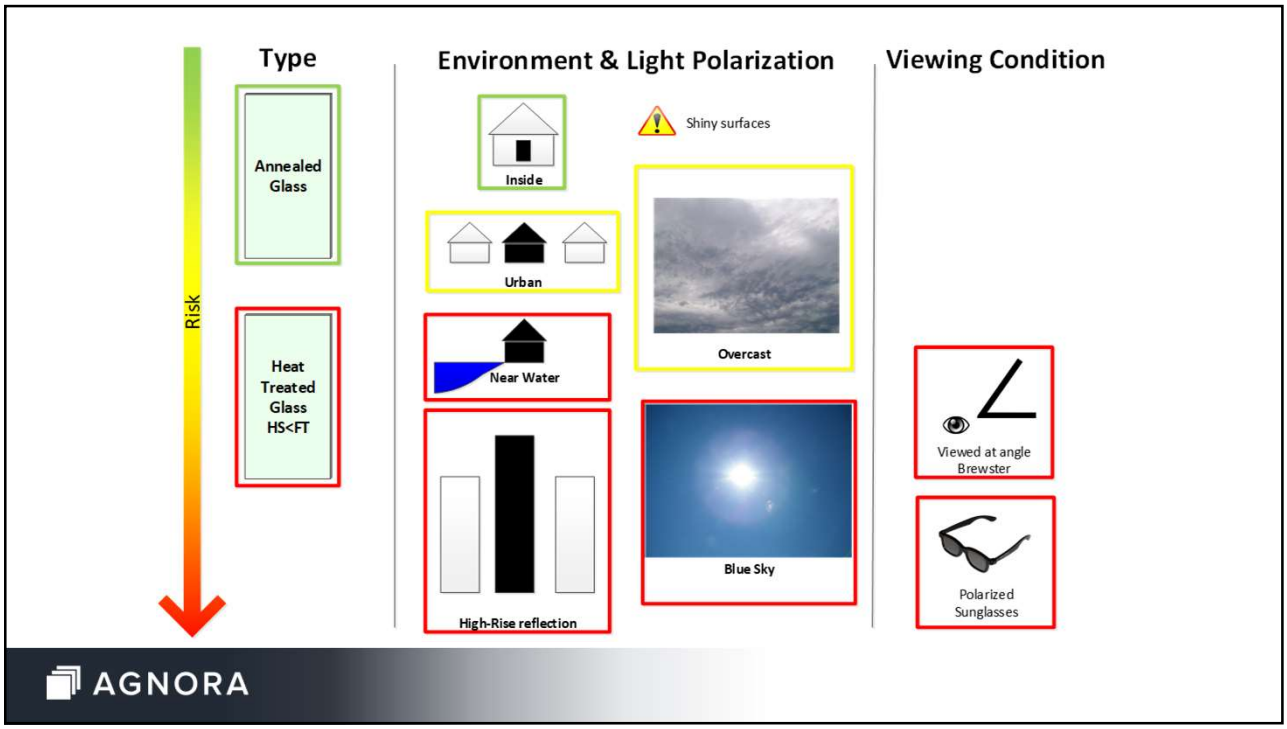

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Commercial Anisotropy Scanners

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Osprey 9 - LiteSentry

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A New Standard…

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C1901-21

Standard Test Method for Measuring
Optical Retardation in Flat Architectural Glass

- **Standard test method** for measuring optical anisotropy
- Heat treated flat monolithic glass
- Educate stakeholders on the phenomenon and on technology available
- Establish a language, a methodology
- Confirm that numerical values are expressed in a fundamental physic unit
- Certify that measurements are consistent, repeatable and traceable
- Building block that allows you to create a **specification**

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AGNORA's LiteScanner for Anisotropy

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ASTM C1901 In Use - Requirements

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OBJECTIVES

- Guarantying an acceptable and quantifiable level of anisotropy
- Using the ASTM C1901 published standard
- Agreeing on a maximum value
- Producing within that value

2- Anisotropy (8.U)
Full size benchmark units will be ordered. The tempered component of these units will be measured on our SoftSolution anisotropy Scanner. Those panels will be brought to site for approval by architect and owner. Based on measured value obtained on this benchmark, AGNORA and Carslon will agree on a limit for anisotropy.
An optional report can be supplied for each tempered glass as per enclosed example.

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ASTM C1901 In Use - Production

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AGNORA tempered five (5) Pilkington Optiwhite lites

Visual Evaluation of Each Lite

- Naked eye
- With polarized lens
- In our viewing environment, we consider this mockup is “state of the art”

SoftSolution scanning of each

- We took a representative sample
- With a known value
- We rescan the same several times and obtained the same value
  - The measure is repeatable
  - **95 Percentile is 50 nm**

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ASTM C1901 In Use – Next Steps

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Install on site in normal viewing condition

All stakeholders need to agree that it is correct for anisotropy

- Then the 95 Percentile – 50 nm becomes the set limit

AGNORA will scan each lite during production

- Produce within that limit
- Or remake

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ASTM C1901 In Use - Report

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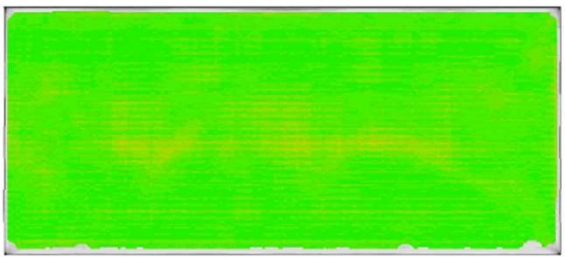
glass info:	
date/time:	12.02.2021 07:57:59
operator:	
glass area:	5m²
glass thickness:	5mm
quantile:	98% <= 58nm 95% <= 50nm
isotropy:	
min. corner distance:	55mm
min. border distance:	25mm
edge stress:	
min. corner distance:	75mm



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ASTM C1901 In Use - Results

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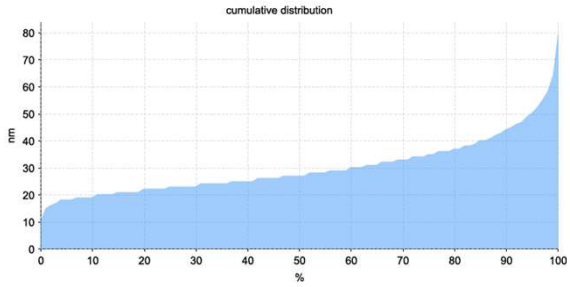

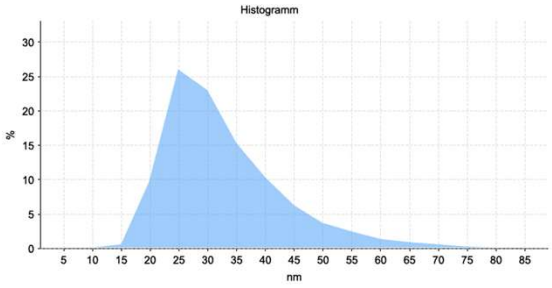

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Next Steps in Our Journey

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R&D Watch

- How to evaluate the retardation map
- How to describe the light environment
- Create realistic glass renderings

How can we measure and describe the light polarisation environment of the building and catch the environments more susceptible to anisotropy?

Better Understand Human Eye Perception

- Contrast sensitivity

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Next Steps in Our Journey

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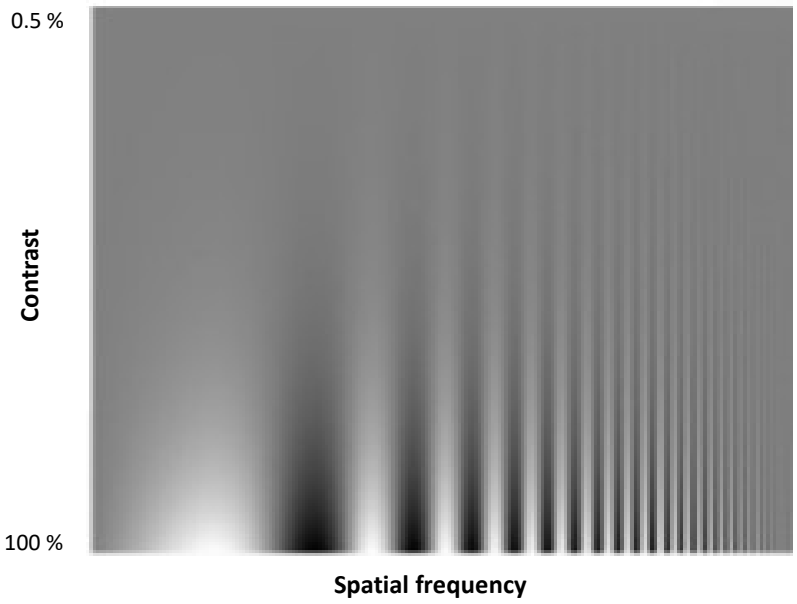

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Next Steps in Our Journey

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- Use human perception studies to see what is the most important data
  - Mathematical average
  - Island of high retardation
  - How to treat the edges, holes, notches
  - Geometry
- Define a mathematical method to work with the large array of retardation data
- Come up with guidelines per application

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Next Steps in Our Journey

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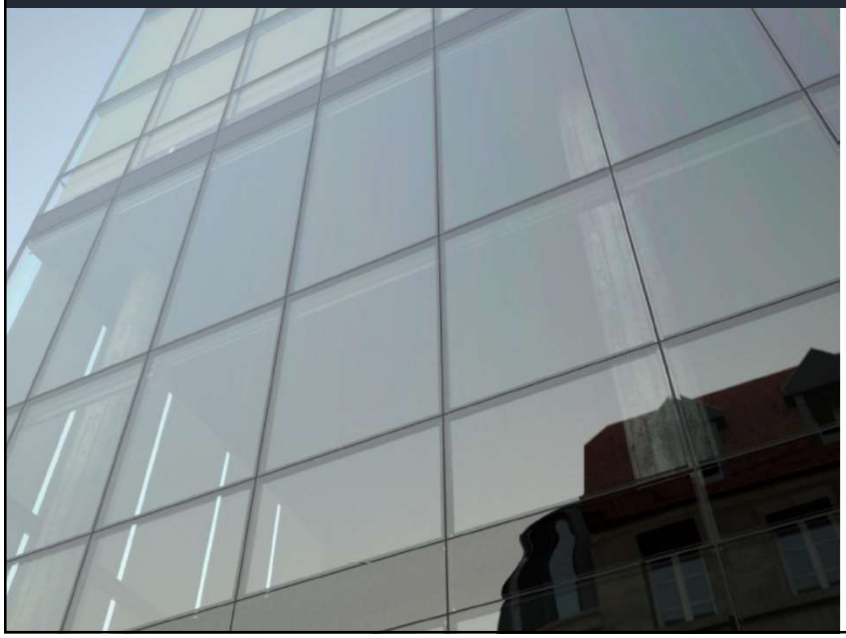

Virtual prototyping and aspect prediction with OCEAN™

Preetham-Wilkie (Polarized) Sky
Sun position Altitude = 0° Azimut = 0°

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Next Steps in Our Journey

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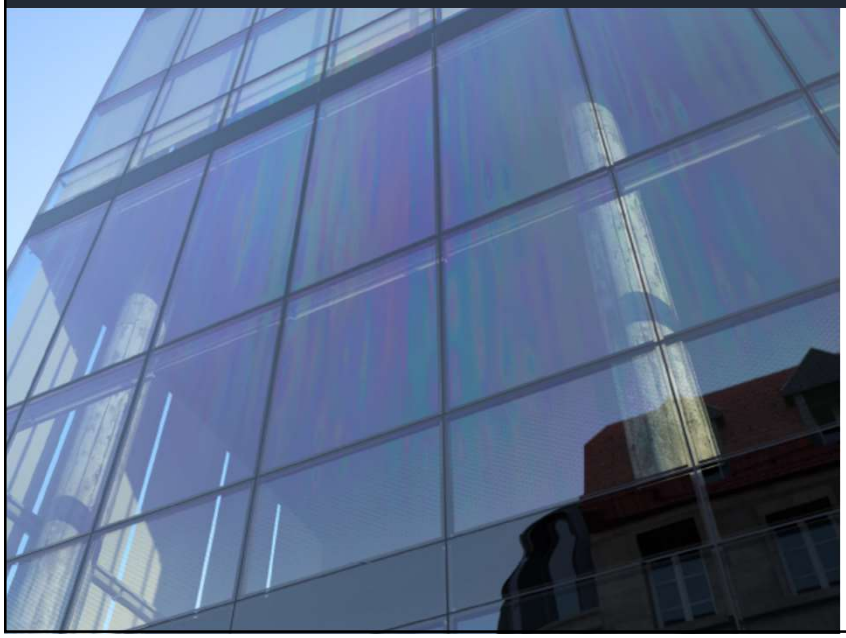

Virtual prototyping and aspect prediction with OCEAN™

Preetham-Wilkie (Polarized) Sky
Sun position Altitude = 15° Azimut = 292°

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Conclusion

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Computing power and optical technology paved the way to online scanners

Optical retardation mapping at zero degree is exact to quantify the tempering quality

With C1901 it is possible to have accurate and repeatable measurements

- Objectively improve process
- Quantify anisotropy between parties

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IT TAKES TWO TO TANGO!

1. Glass with anisotropy
2. Polarized light environment

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QUESTIONS?

Louis Moreau
AGNORA
l.moreau@agnora.com

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