CAPTURING AND 3D RENDERING OF OPTICAL MATERIAL BEHAVIOR

The **physical** approach to **realism**

- Towards **high-end** automated **geometry & color** acquisition
- Optical **material behavior** acquisition & 3D rendering

Martin Ritz
Martin.Ritz@igd.fraunhofer.de

Deputy Head
Competence Center
Digitization of Cultural Heritage
Fraunhofer Institute for
Computer Graphics Research IGD

Fraunhoferstrasse 5
64283 Darmstadt, Germany

www.igd.fraunhofer.de
www.cultlab3d.de

WHY 3D DIGITIZATION?

Natural and man-made disasters, flow of time,…

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POTENTIAL USE CASES OF FAST & HQ 3D DIGITIZATION
…both for **Cultural Heritage** and the **Industry**

- **Cultural Heritage**: Many more use cases for 3D digitization beyond „**Digital Conservation**":
  - **Documentation** of preservation status over time
  - Virtual/real **reconstruction** of fragmented or destroyed artifacts
  - Offering science and the public **worldwide access** through digital libraries and archives
  - New **exhibition** concepts (e.g., hybrid exhibitions, virtual/real restitution of geograph. disjunct collections)
  - **Reproduction** instead of transporting fragile originals (e.g., 3D print)
  - Entertainment and **tourism** (e.g., games, documentaries)
- **Industry**: Equally challenging objects (highly reflective, cavities):
  - Tracking of **material integrity** or **geometrical changes** to tools **over time** (e.g., car manufacturing)
  - **Quality assurance**: CAD model vs. real manufactured part (set-actual comparison)
  - Reconstruction of **missing 3D/CAD models** from parts (e.g., cars/old timers)
  - **Guiding robotic systems** along real object surfaces w/o known geometry (e.g., painting, coating)

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A VISION FORMING FROM PRESSING NEED

- Situation
  - Huge numbers of artifacts waiting to be digitized
  - Need for sustainable digitization
    - Sufficient quality, different aspects / dimensions, e.g. optical material behavior
  - Manual digitization: too much time and effort
  - No commercial autonomous and color-calibrated 3D scanning systems available

- Our vision:
  - Fully automatic system, one-button solution
  - High throughput, high quality
    - Geometry+texture, also acquisition of optical material behavior
  - Tradeoff to solve: digitization time vs. hardware cost
    - Single camera on robotic system ⇔ dome-like structure with hardware redundancy

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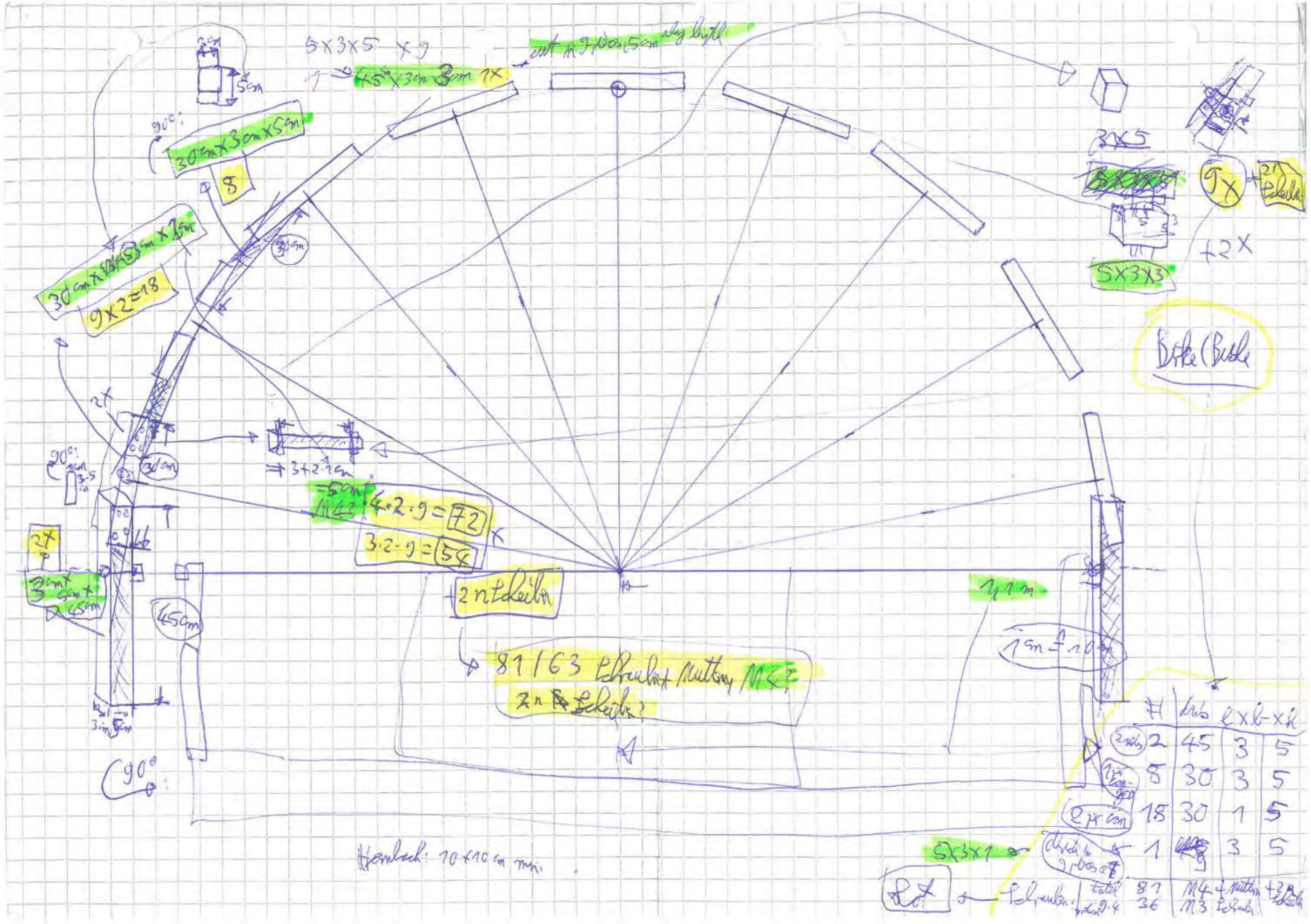
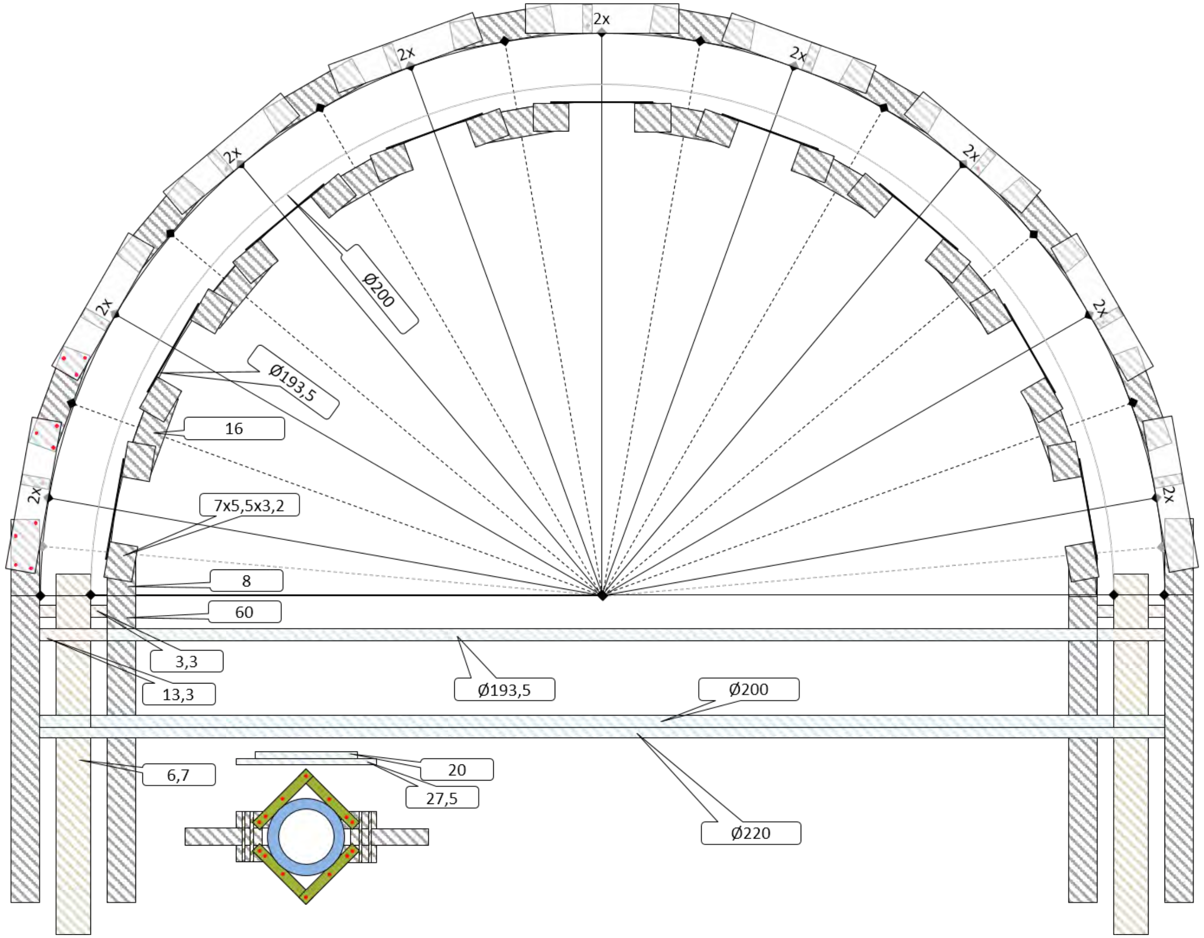
REALIZING OUR VISION





REALIZING OUR VISION

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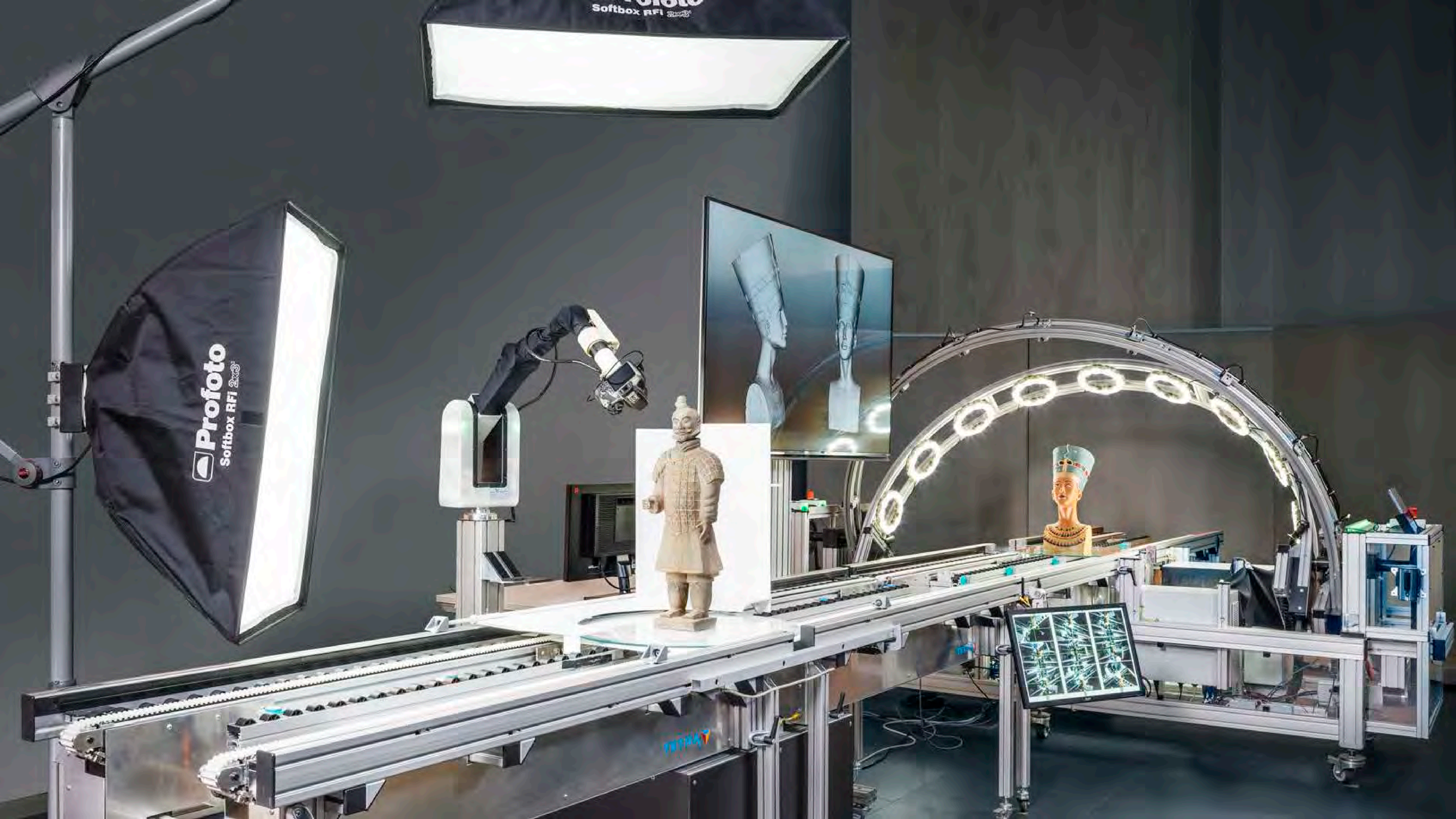

Softbox RFi 2x3'
Profoto
Softbox RFi 2x3'

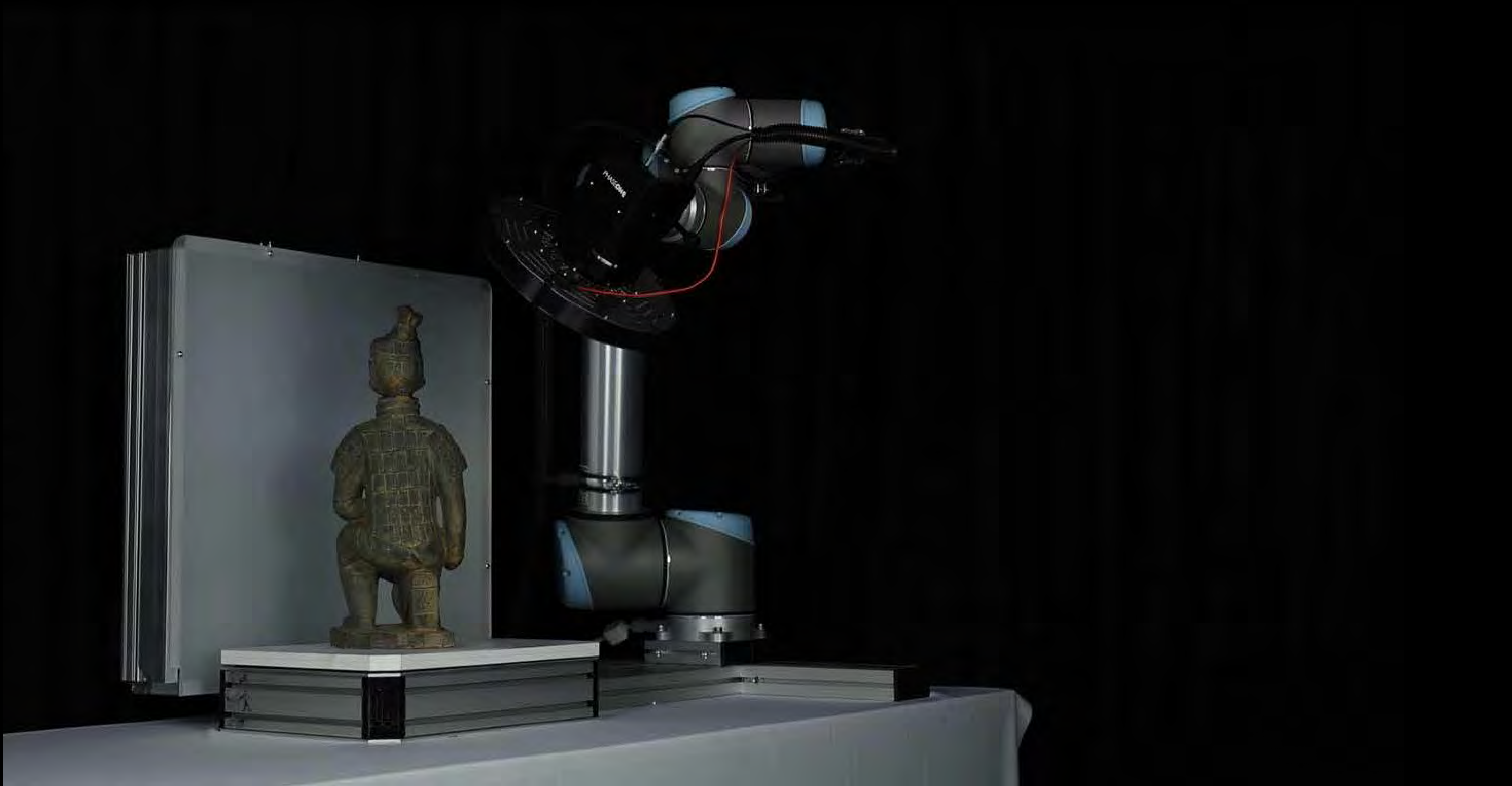
EU PRIZE FOR CULTURAL HERITAGE / EUROPA NOSTRA AWARD 2018 FOR CULTLAB3D


EUROPEAN UNION
PRIZE FOR
CULTURAL HERITAGE
EUROPA NOSTRA
AWARD
2018

TOWARDS HIGH-END AUTOMATED GEOMETRY ACQUISITION
Scanning shiny/complex objects directly

- No coating/spraying
- Hardly any post-processing
- Using optical and algorithmic tricks
  - Optically decoupling diffuse from specular
  - Next-best View Planning: automatically avoiding angles of total reflection

© CES / 3D-model: Fraunhofer IGD, rendering: United Screens GmbH




TOWARDS HIGH-END AUTOMATED GEOMETRY ACQUISITION

Scanning shiny industrial objects in real-time

- Laser-line scanning
- Result geometry appears instantly after laser line sweeps over object

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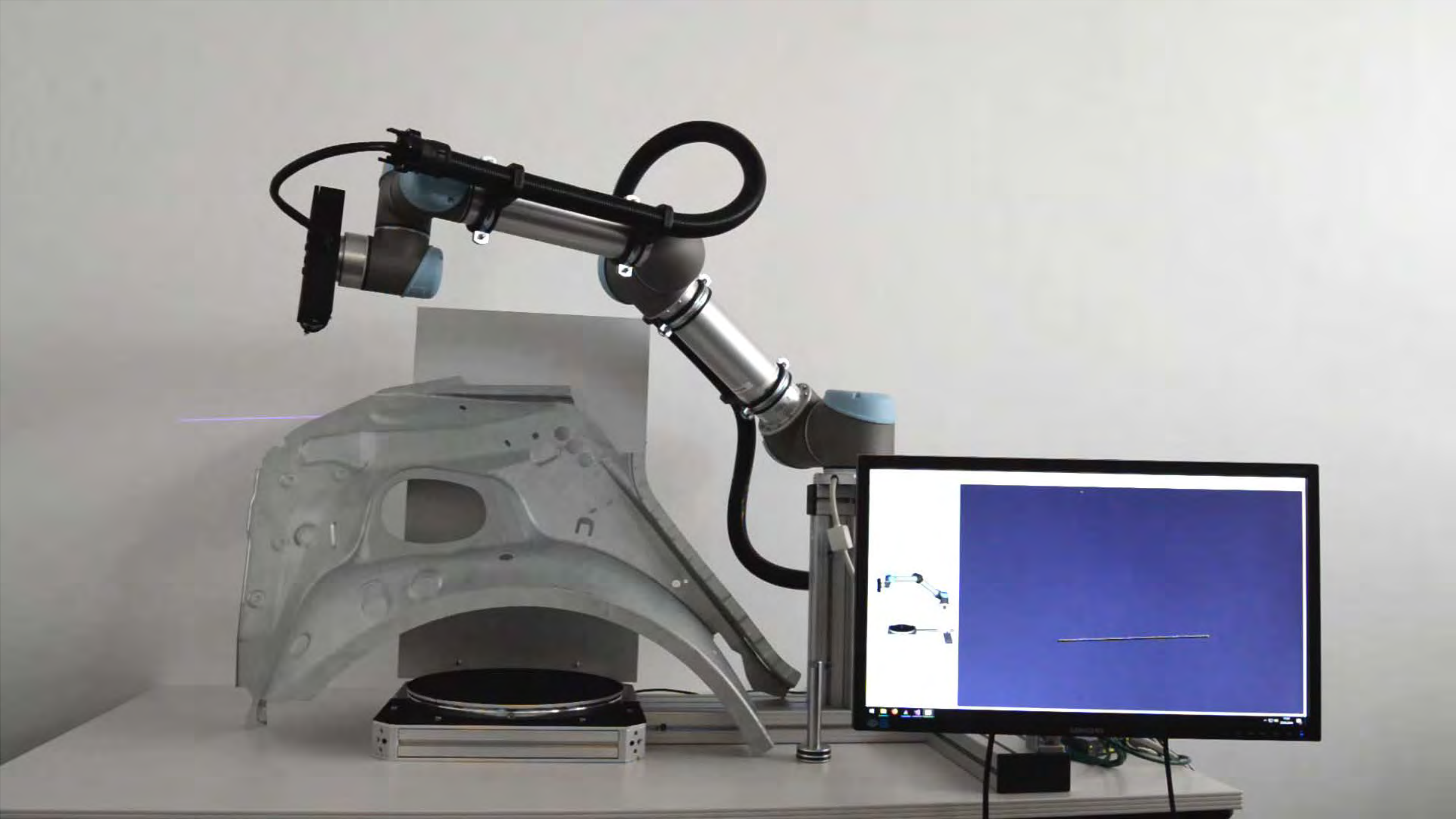
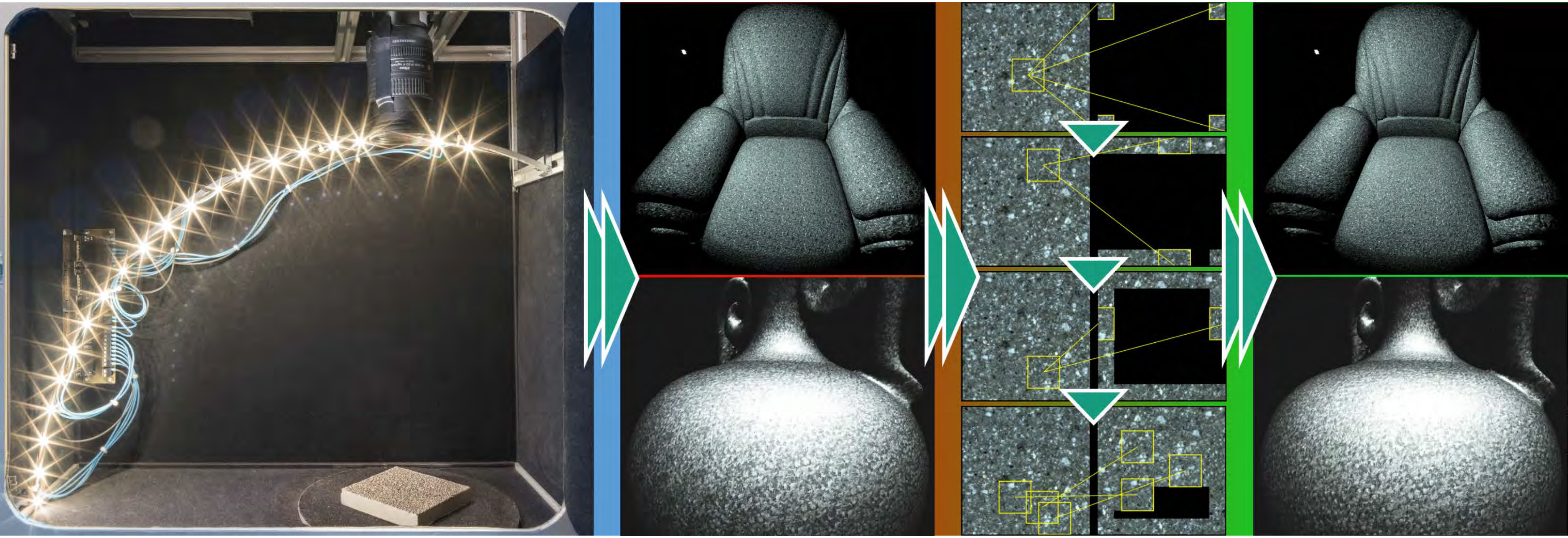


OPTICAL MATERIAL BEHAVIOR ACQUISITION & RENDERING of flat surface samples



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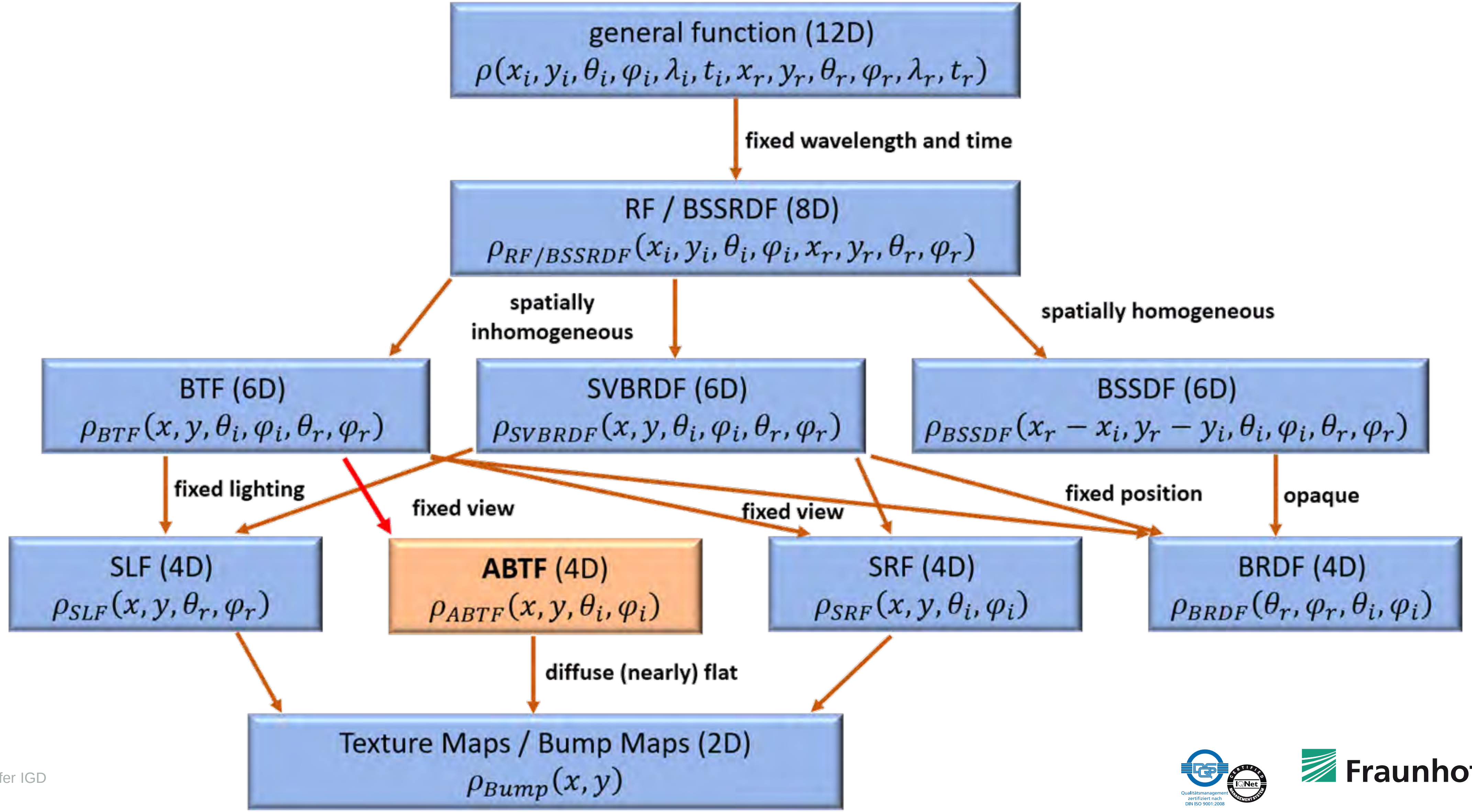
Physically Measured Optical Material Behavior



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Physically Measured Optical Material Behavior

BTF vs. A(pproximate)-BTF

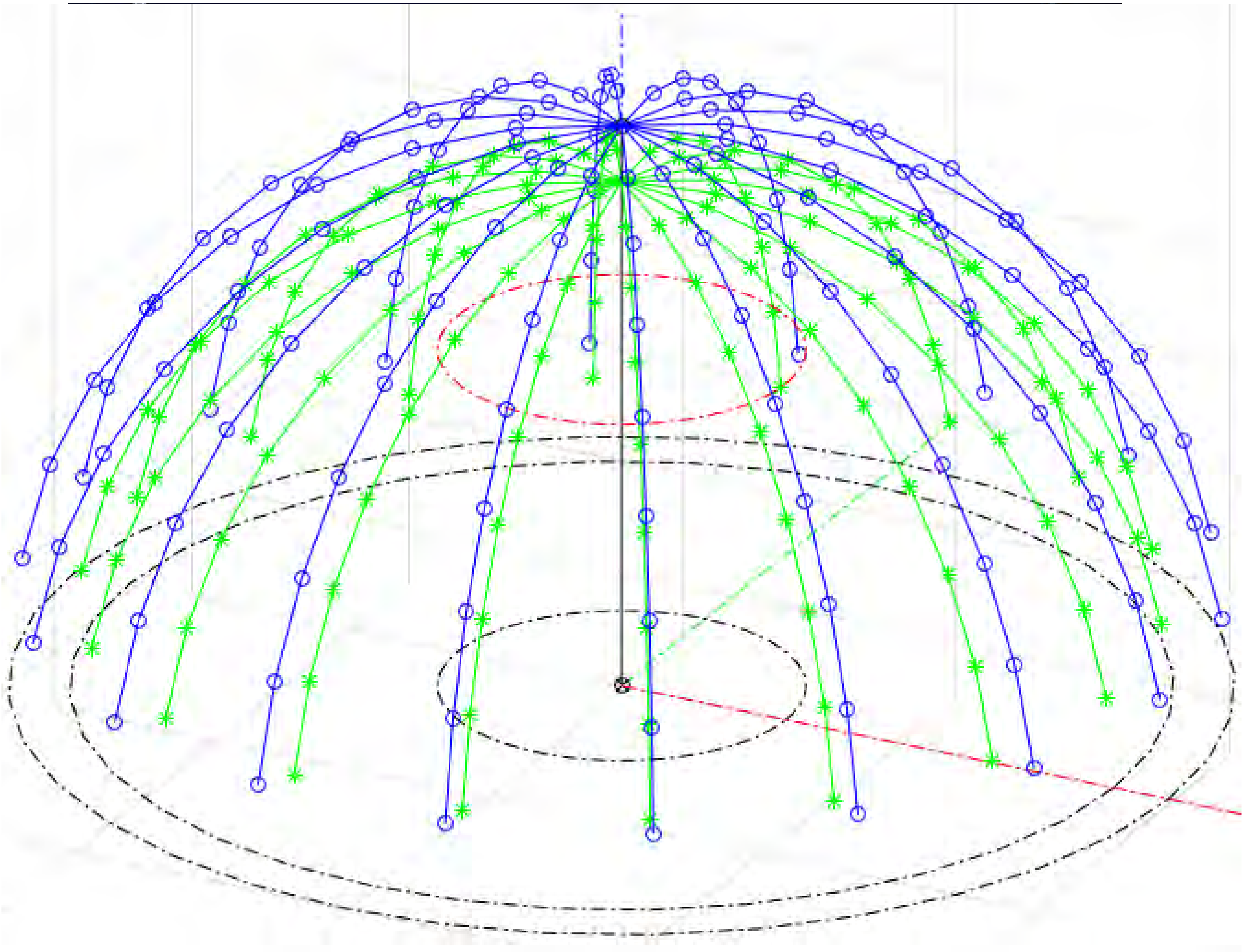
BTF (6D)

$\rho_{BTF}(x, y, \theta_i, \varphi_i, \theta_r, \varphi_r)$

fixed view

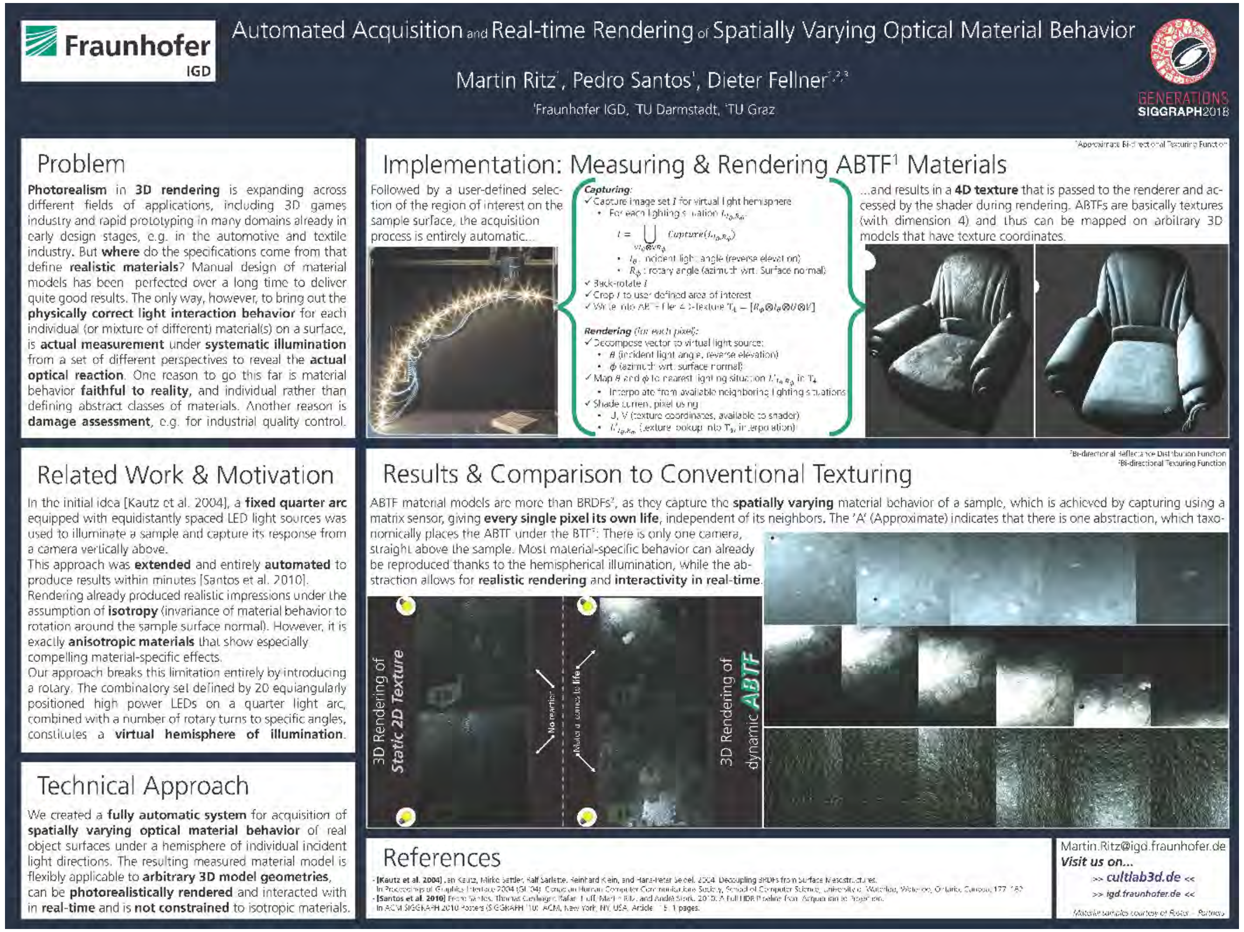
ABTF (4D)

$\rho_{ABTF}(x, y, \theta_i, \varphi_i)$

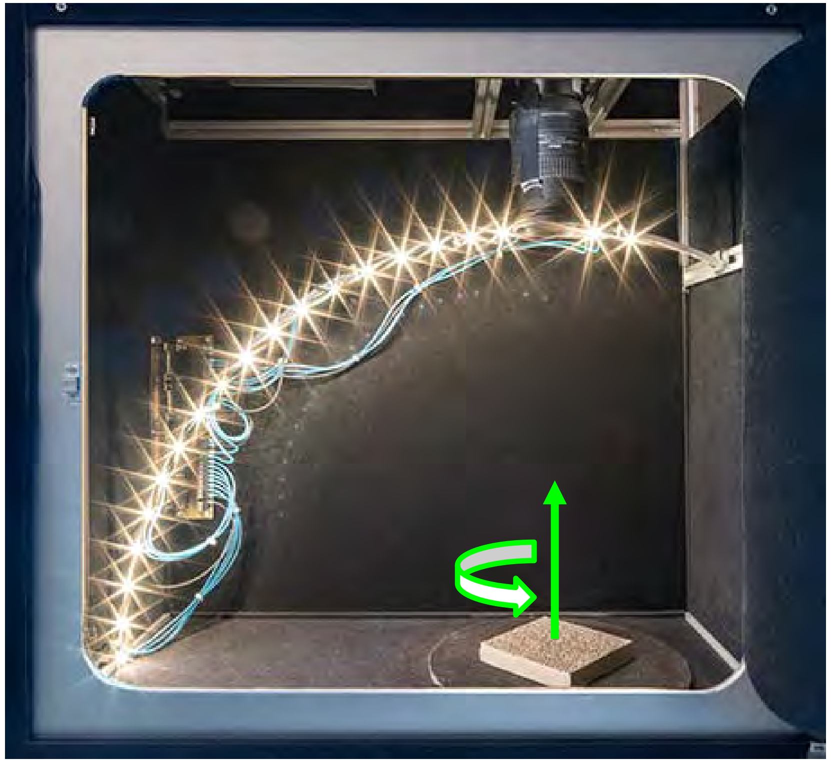


Physically Measured Optical Material Behavior

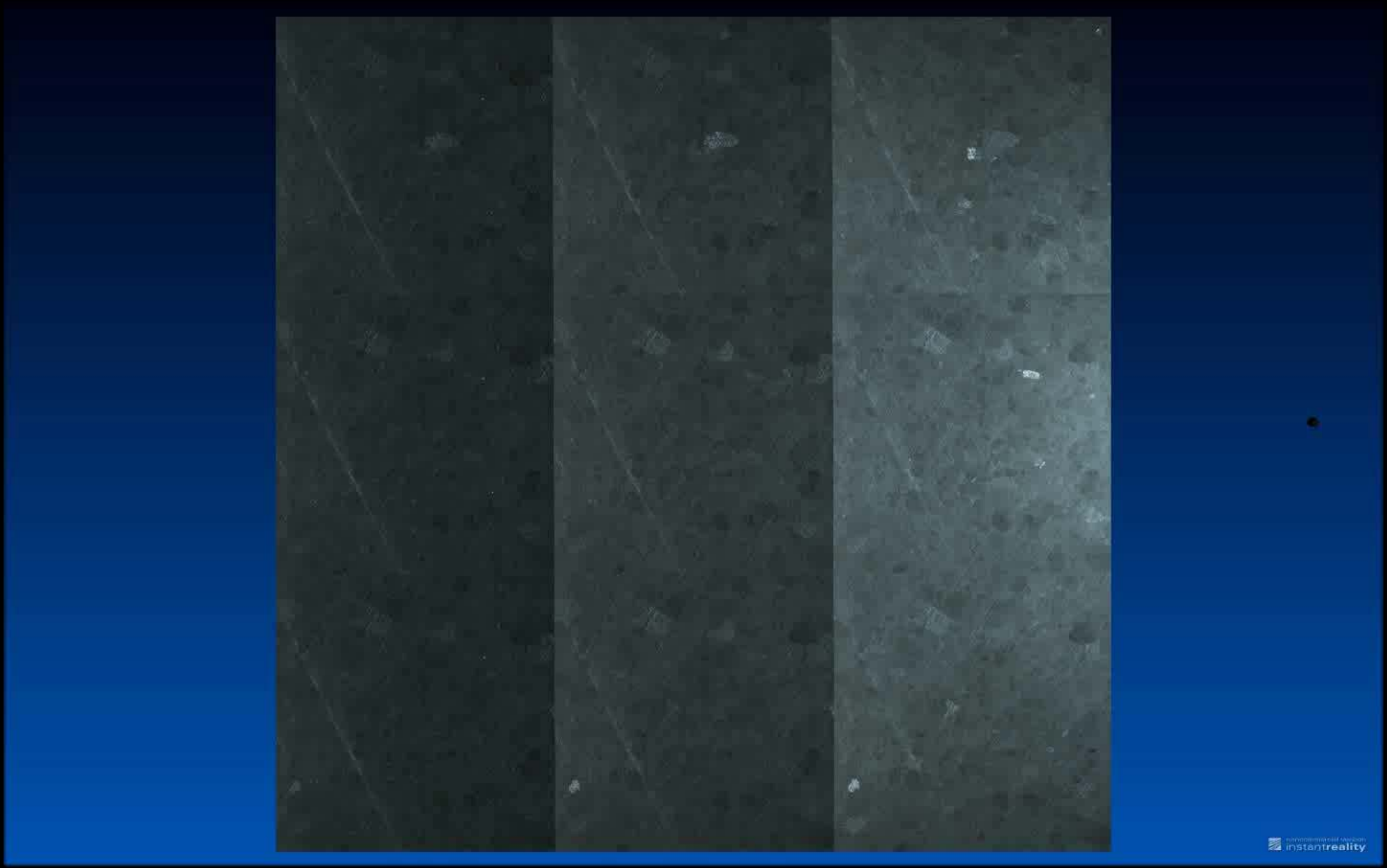
A(pproximate)-BTF



- SIGGRAPH 2018 Canada:
  - Measuring & Rendering ABTF Materials



White reflective stone (before texture periodization)



Rendering of measured ABTF material by Fraunhofer IGD using InstantReality
Material sample: Foster and Partners - thanks to Francis Aish

Metal plate with reflective patches (before texture periodization)

Rendering of measured ABTF material by Fraunhofer IGD using InstantReality
Material sample: Foster and Partners - thanks to Francis Aish

Weakness of Approach so far

4D Texture (ABTF material model)

- **Strengths**:
  - Flexible mapping of measured material behavior on **arbitrary geometry**
  - Photo-realistic rendering and interaction in **real-time**

- **Weakness**:
  - Common problems of texturing, striking in 2 levels:

1. Non-seamless textures create visible **border artifacts**
   - At transition to neighbors
2. Even perfectly seamless textures show **repetition artifacts**
   - Distribution in large numbers side by side over 3D surface

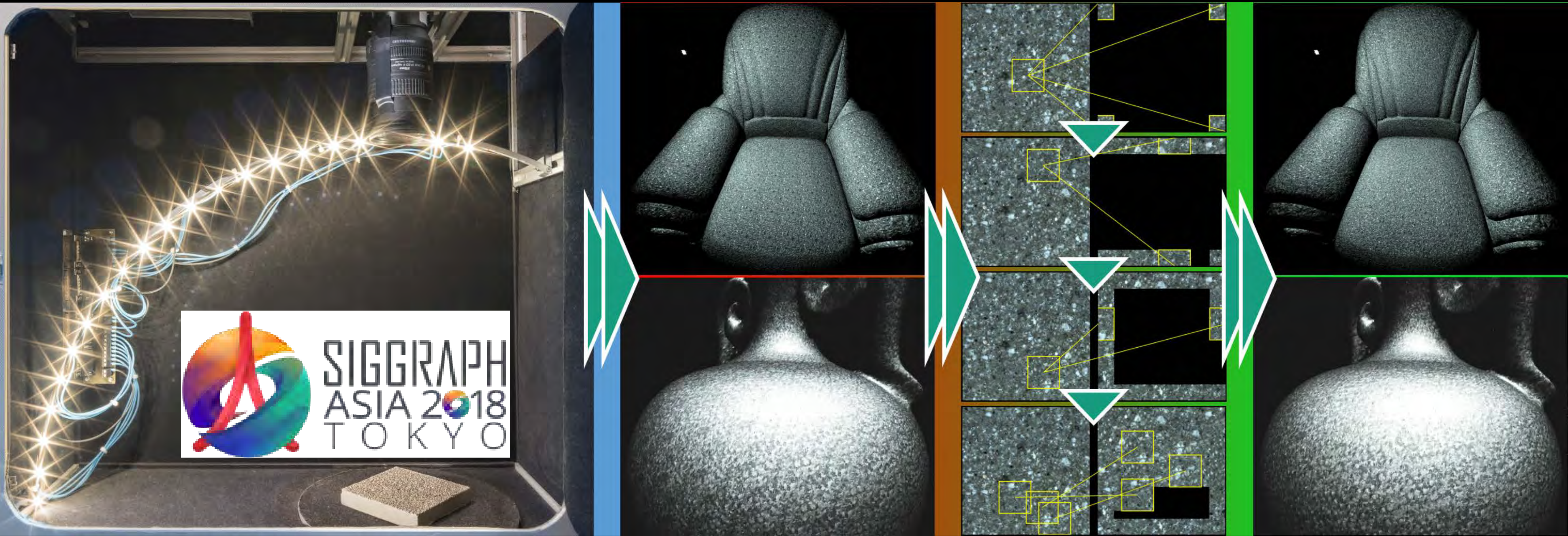
Martin Ritz,
Pedro Santos
Cultural Heritage Digitization,
Fraunhofer IGD, Germany

Simon Breitfelder
TU Darmstadt, Germany

Synthesis and Rendering of Seamless and Non-Repetitive 4D Texture Variations for Measured Optical Material Properties

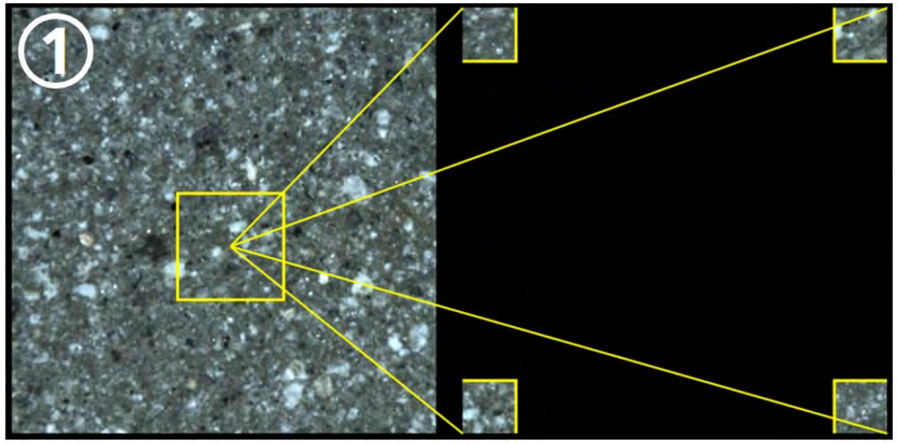
Dieter Fellner
Fraunhofer IGD, Germany
TU Darmstadt, Germany
TU Graz, Austria

Arjan Kuijper
Fraunhofer IGD, Germany
TU Darmstadt, Germany



Texture Synthesis

Establishing Seamless Transitions → Periodicity

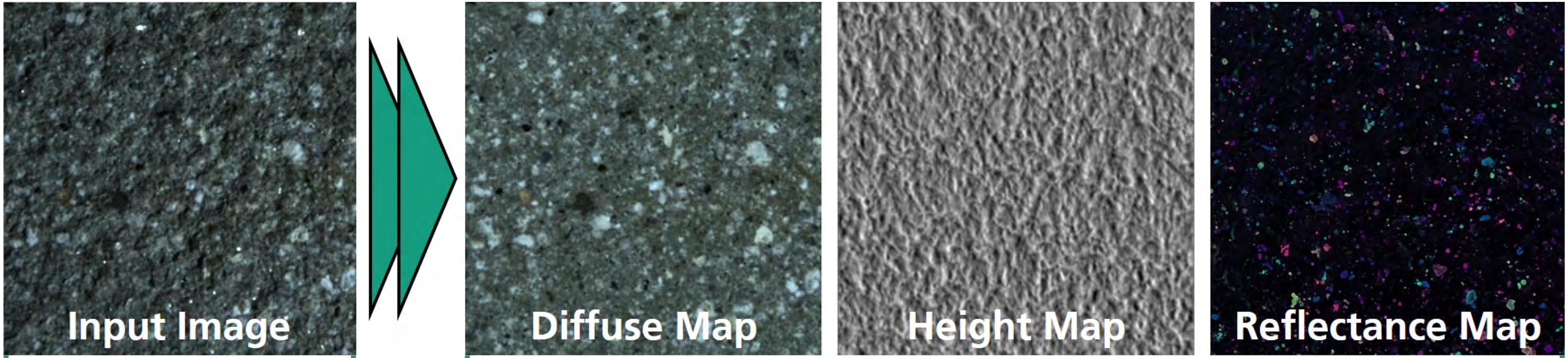


Texture Synthesis

Finding the Best-matching Patch for Transfer: Free-form Boundary Cut

Texture Synthesis

Maintaining Material Behavior Consistency across the Dimensions of Light



1 sample image
from
measured ABTF dataset

3 computed images
representing characteristics of the
entire measured ABTF dataset

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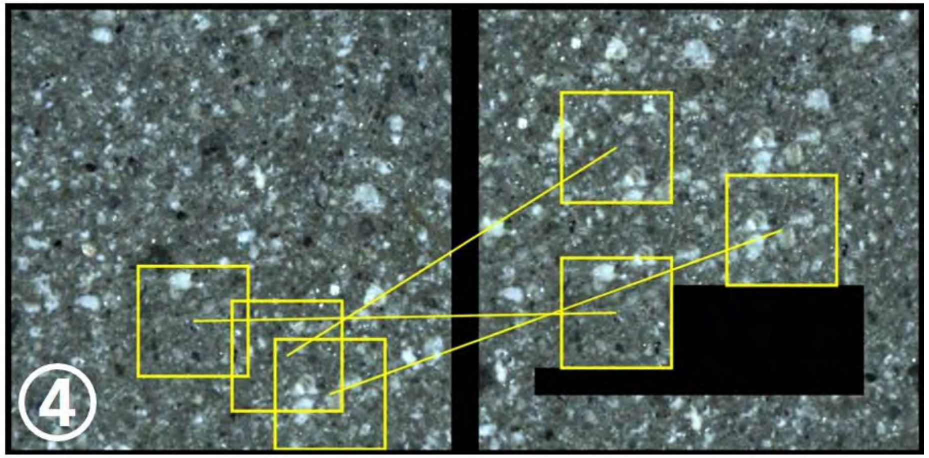
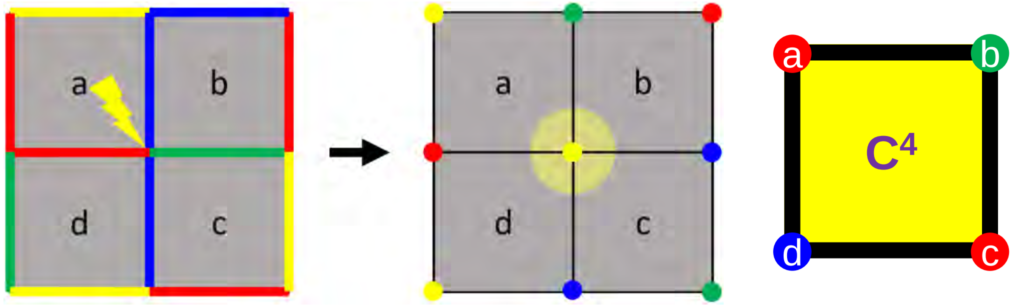
Texture Synthesis

Disrupting Repetition Artifacts





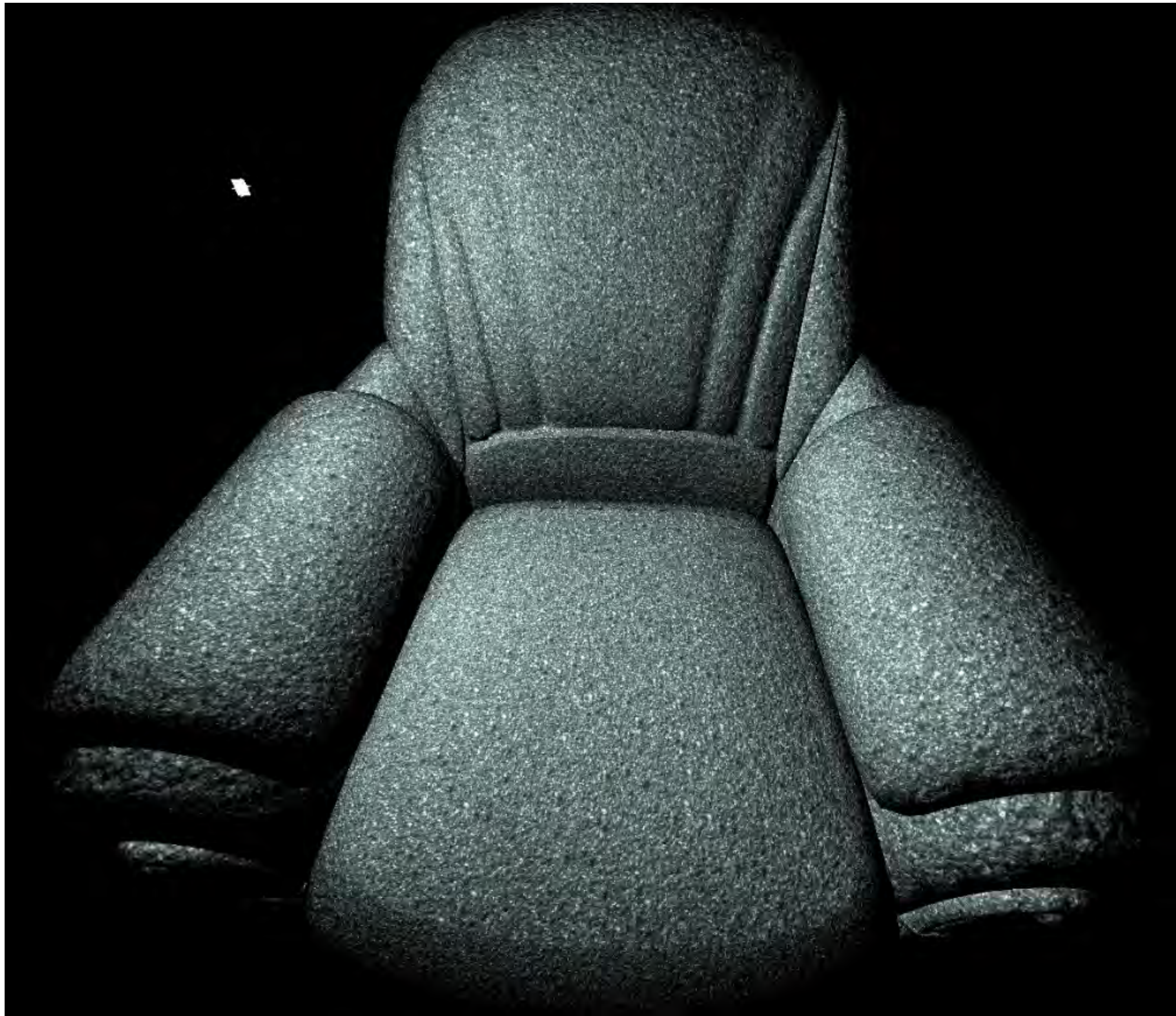
- Generation of a texture is non-deterministic
  - New distribution every time
- Set of Texture Variations
  - Compatible at edges → seamless transitions
  - C corner types → C^4 different textures
  - $C^4 =_{C=2}$ 16 variations already sufficient
- Apply <u>generating rule set</u> from each variation to the **entire ABTF dataset**

Results

Texture Synthesis stage **1** (non-periodic texturing vs. **seamless texturing**)

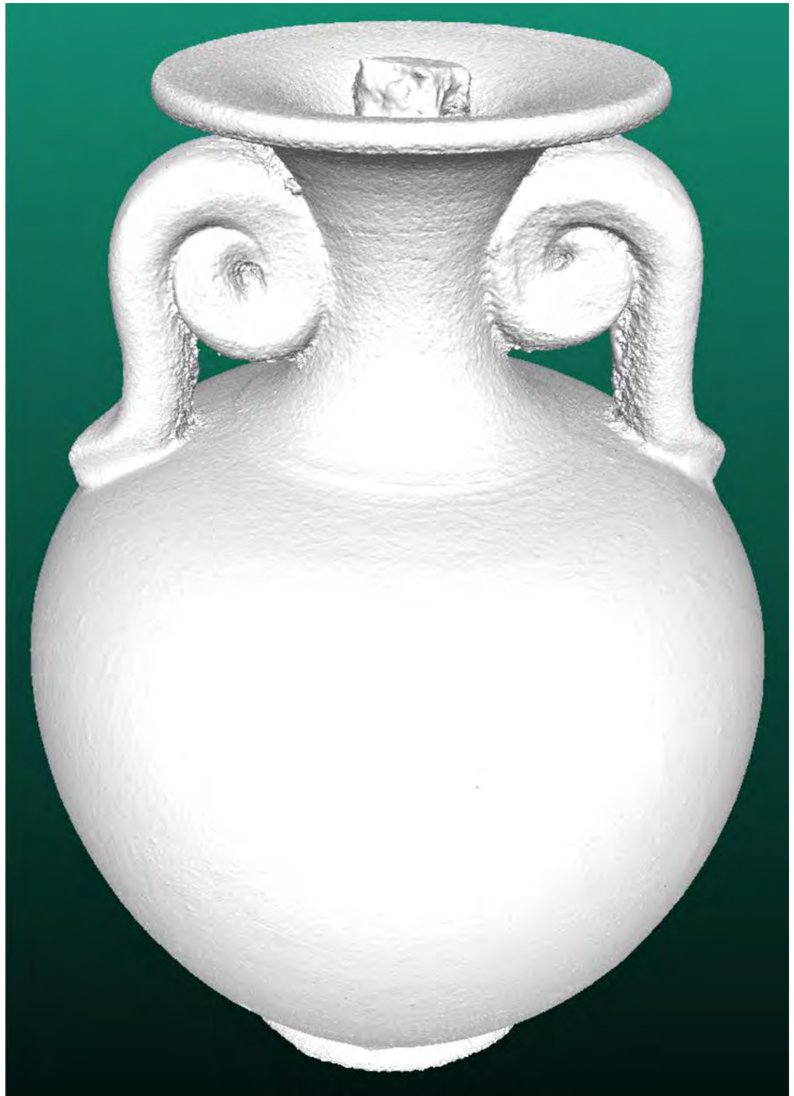
Results

Texture Synthesis stage **2** (seamless texturing with repetitions vs. **texture variations**)

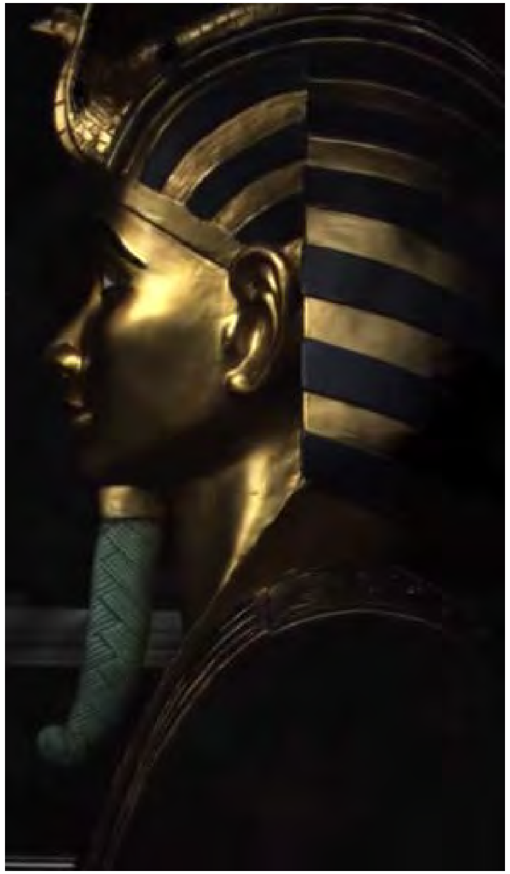


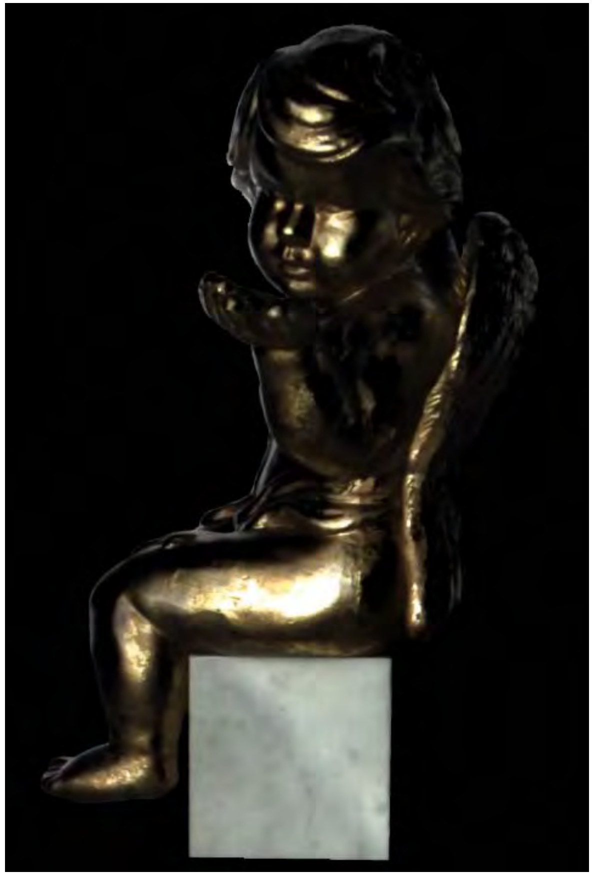
Results

Target geometry for ABTF material transfer



OPTICAL MATERIAL BEHAVIOR ACQUISITION & RENDERING of entire objects





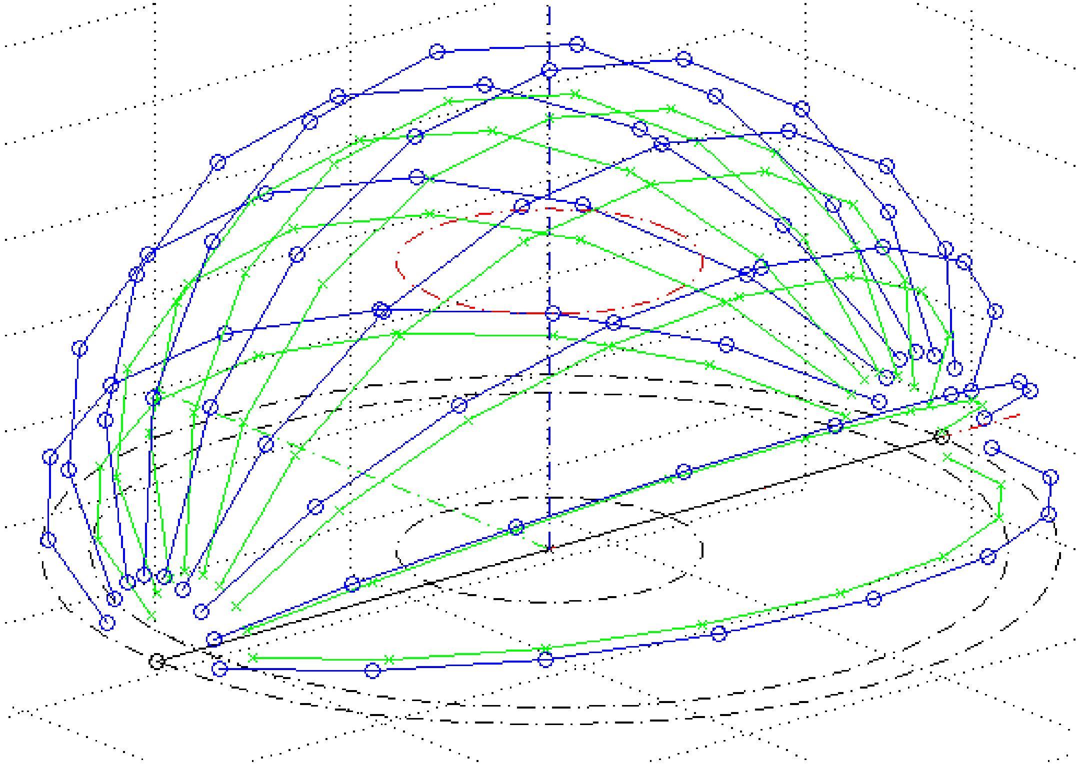
OPTICAL MATERIAL BEHAVIOR ACQUISITION & RENDERING of <u>entire</u> objects

Capture **combinatorial** set:
{**all views**} x {**all light directions**}

BTF (6D)
$\rho_{BTF}(x, y, \theta_i, \varphi_i, \theta_r, \varphi_r)$

fixed view

ABTF (4D)
$\rho_{ABTF}(x, y, \theta_i, \varphi_i)$



OPTICAL MATERIAL BEHAVIOR
ACQUISITION & RENDERING of entire objects

Capture **combinatorial** set:
{**all views**} x {**all light directions**}

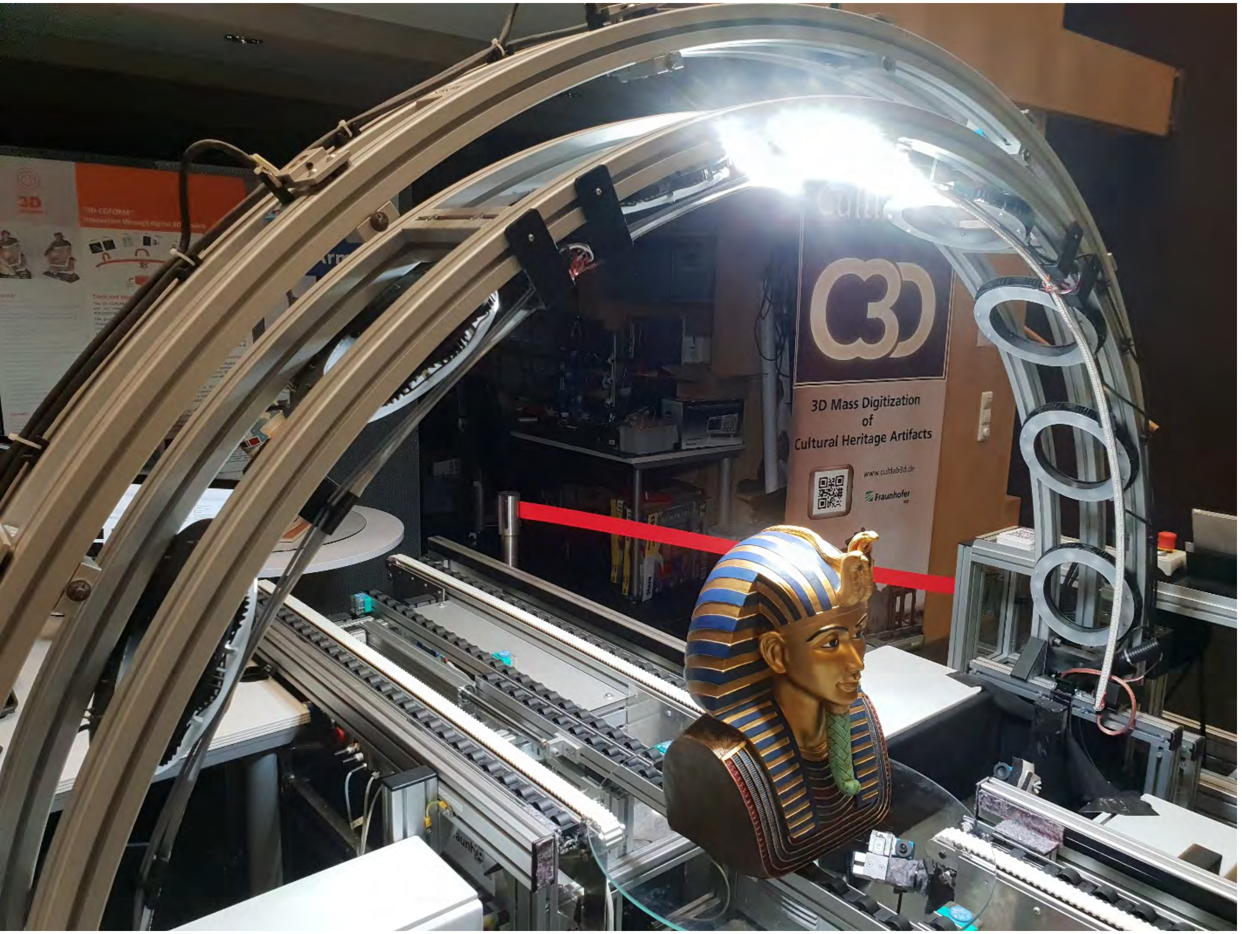
BTF (6D)
$\rho_{BTF}(x, y, \theta_i, \varphi_i, \theta_r, \varphi_r)$

fixed view

ABTF (4D)
$\rho_{ABTF}(x, y, \theta_i, \varphi_i)$

OPTICAL MATERIAL BEHAVIOR

9^2 cam perspectives x 9^2 discrete light angles



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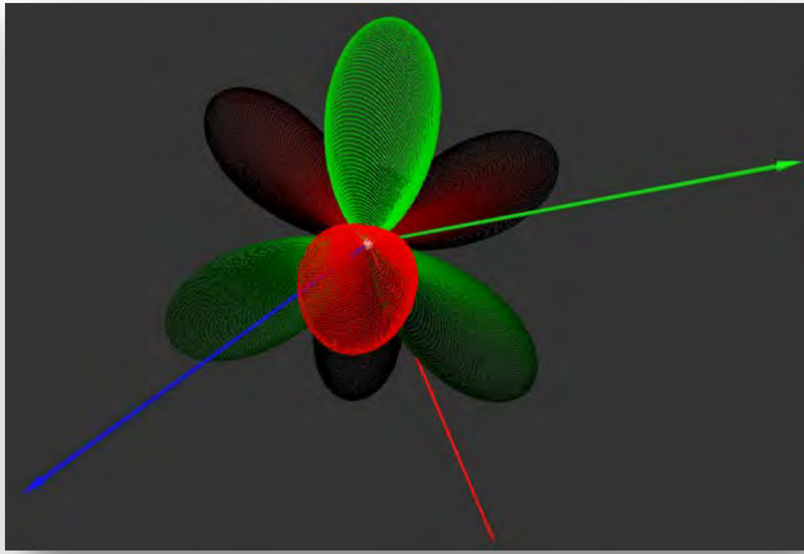
OPTICAL MATERIAL BEHAVIOR

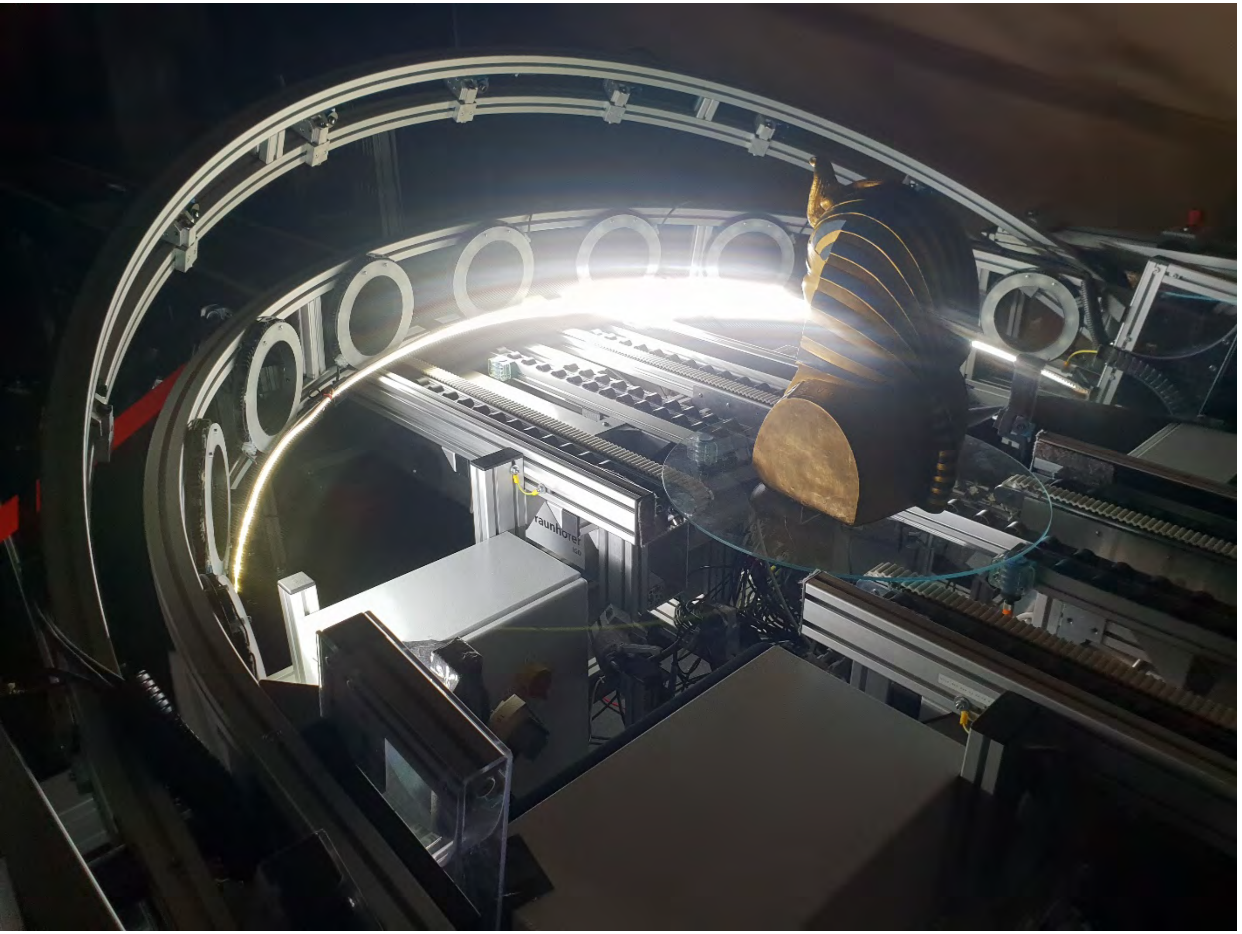
9^2 camera perspectives x continuous SH light encoding

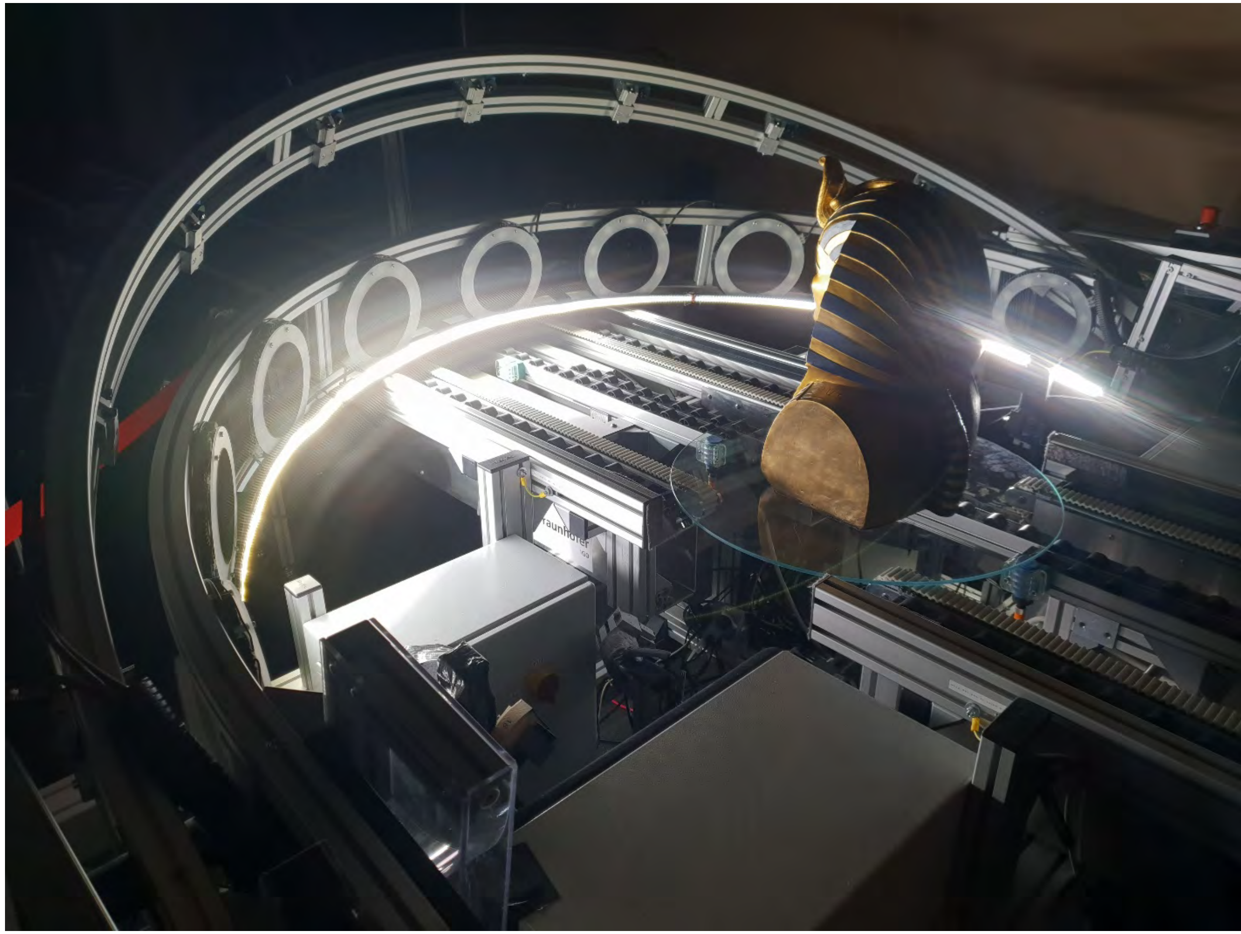
- SH = Spherical Harmonics
  - Set of base function used to efficiently encode illumination distributed over (hemi)sphere



OPTICAL MATERIAL BEHAVIOR

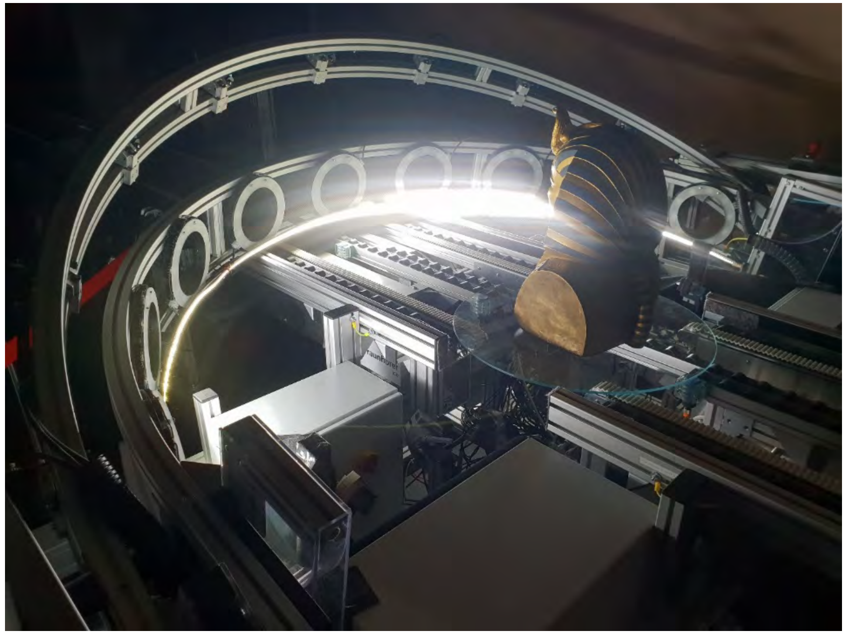
9^2 cam perspectives x <u>continuous</u> SH light encoding





The Message

- 3D digitization is important
  - Maximize **quality**
  - Minimize *human effort*
- 3D is incomplete without optical material behavior
  - Parameter-tuned models look nice, but…
  - …only methods based on **physical measurements** provide ultimate realism and reference to reality



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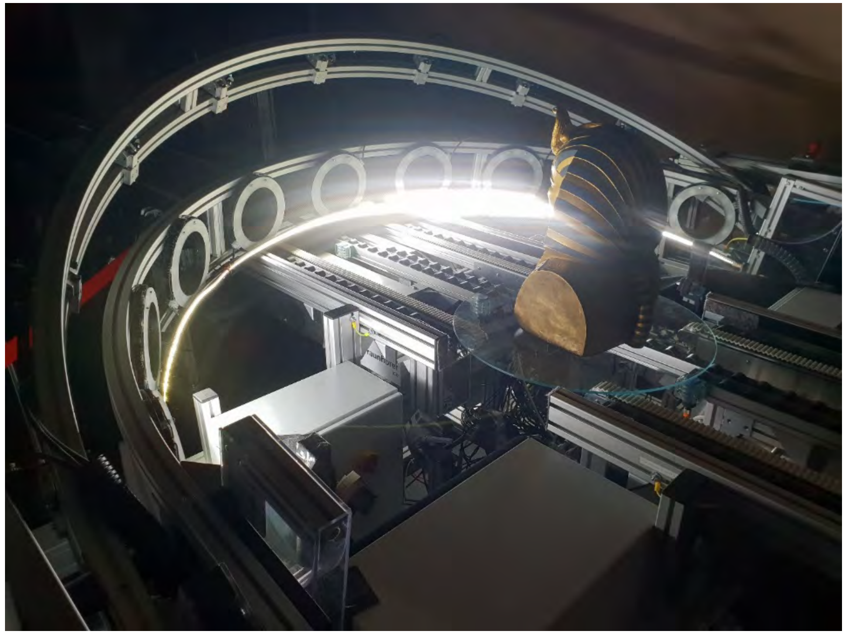
Thank you for your attention…

…please visit us…

- on www.igd.fraunhofer.de
- on www.cultlab3d.de
- or *directly* at our Fraunhofer-Institute close to Frankfurt (Germany) to see our latest developments in action.



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