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Textile digitisation tools & methods for cultural heritage

George Ioannakis

WORKSHOP #8: OPPORTUNITIES AND TOOLS FROM THE CULTURAL HERITAGE CLOUD FOR DIGITAL ARCHAEOLOGY

Monday, May 5th, 2025, Athens

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Outline

- TEXTaiLES Vision and Objectives
- Use-Cases, Scenarios and Associated Challenges
- Technical Solutions for Digitising Textiles

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Overview

- **Topic:** HORIZON-CL2-2023-HERITAGE-ECCCH-01-02 A European Collaborative Cloud for Cultural Heritage – Innovative tools for digitising cultural heritage objects
- **Type of Action:** Research and Innovation Action (RIA)
- **Project Number:** 101158328
- **Project starting date:** 1st September 2024
- **Project duration:** 36 months (31st August 2027)
- Max. EU Contribution: € 3,622,156.31

Consortium

1. Athena Research Center (ARC), Greece
2. Sapienza University of Rome (SUR), Italy
3. Center For Research & Technology Hellas (CER), Greece
4. University of Warsaw (UWA), Poland
5. University of Oulu (OUL), Finland
6. TechnAI (TAI), Spain
7. Nubis PC (NUB), Greece
8. The Fraunhofer Society (FRA), Germany
9. ACCELIGENCE Ltd (ACC), Cyprus
10. Textile Museum St. Gallen (TSG), Switzerland

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Consortium

10 Partners: 7 EU and **1** non-EU countries

x3 Research and Technology Organisations

x3 Higher Education Institutions

x3 Small and Medium-sized Enterprises

x1 Non-profit Organisation

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Management Structure

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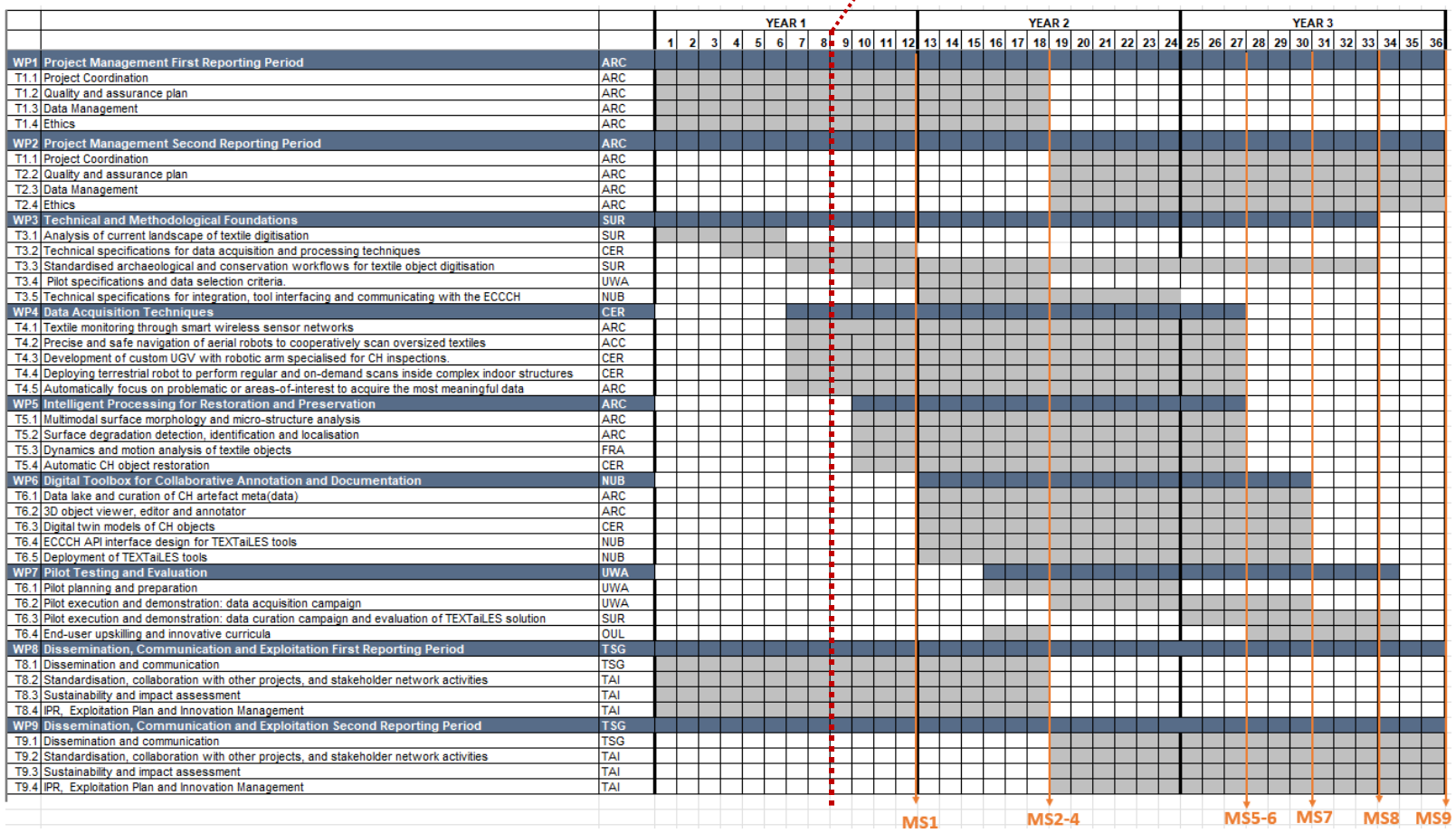
Timeline

We are here



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Problem Statement

Despite recent methodological advances in European textile research, digitisation of textile CH objects has:

- **Not received sufficient attention** in comparison to other Cultural Heritage artefacts
- This lack of attention can be attributed to the **significant technical challenges** posed by textile Cultural Heritage artefacts
- Need for **specialized tools and methodologies** for digitising textile artefacts

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Concept (1/3)

Building the foundations for CH textile digitisation standards for ECCCH:

- **Our goal:** TEXTaiLES builds the methodological foundations for digitising CH textile objects and producing a standardised protocol in terms of technological means and methodological workflows that are offered to the scientific communities as part of the ECCCH.
- **Learn from the past:** Utilize current practices in textile digitisation in all of its phases

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Concept (2/3)

Building the foundations for CH textile digitisation standards for ECCCH:

- **Standardise:** Tools and methods for the lifecycle of the digitisation process of textile objects which should be standardised by carefully examining and documenting all of these phases.
- **Innovative research:** AI tools specialised in analysis of textile objects for their deeper understanding and for unlocking their hidden and non-visible characteristics

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Concept (3/3)

Building the foundations for CH textile digitisation standards for ECCCH:

- **Offer to the communities:** We propose how these tools are deployed and integrated to archaeological research in a systematic manner through the ECCCH, we build innovative interdisciplinary research communities, and we provide upskill activities for the textile CH scientific community.

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Main Goals

Building the foundations for CH textile digitisation standards for ECCCH:

- Universal portable and affordable textile **data acquisition**
- Large-scale, low-cost **digitisation**
- Accurate **3D digital replicas** accompanied by heterogeneous and multi-level information
- Delivery of **digital tools** for research/study and dissemination purposes
- Promote our **textile tradition** and history within and outside Europe
- Enhance the **understanding** of our textile tradition

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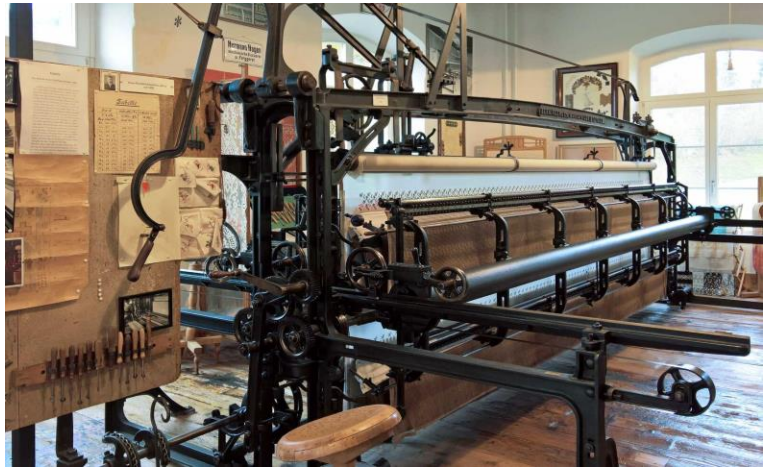

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Educational activities

For humanities professionals, including archaeologists, museum curators, conservators, historians, art historians, and more. The curricula will encompass: 1) manuals for selecting textile cultural heritage (CH) objects suitable for digitisation; 2) guidelines for evaluating available methods and their outcomes; 3) as well as cost and time estimations.

For students we will provide comprehensive training in AI cloud-based tools for textile analysis, recording of digitisation sessions to share the experience as open-laboratory, digital imaging techniques and cultural heritage digitisation hands on activities, available also to be incorporated to summer school curricula.

For industry professionals the trainings will concentrate on practical applications of AI tools in CH and textile digitization for commercial purposes.

For scientists in digital technologies we will provide training in advanced imaging and analysis techniques with AI and other key emerging technologies.

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*persons appear in random order

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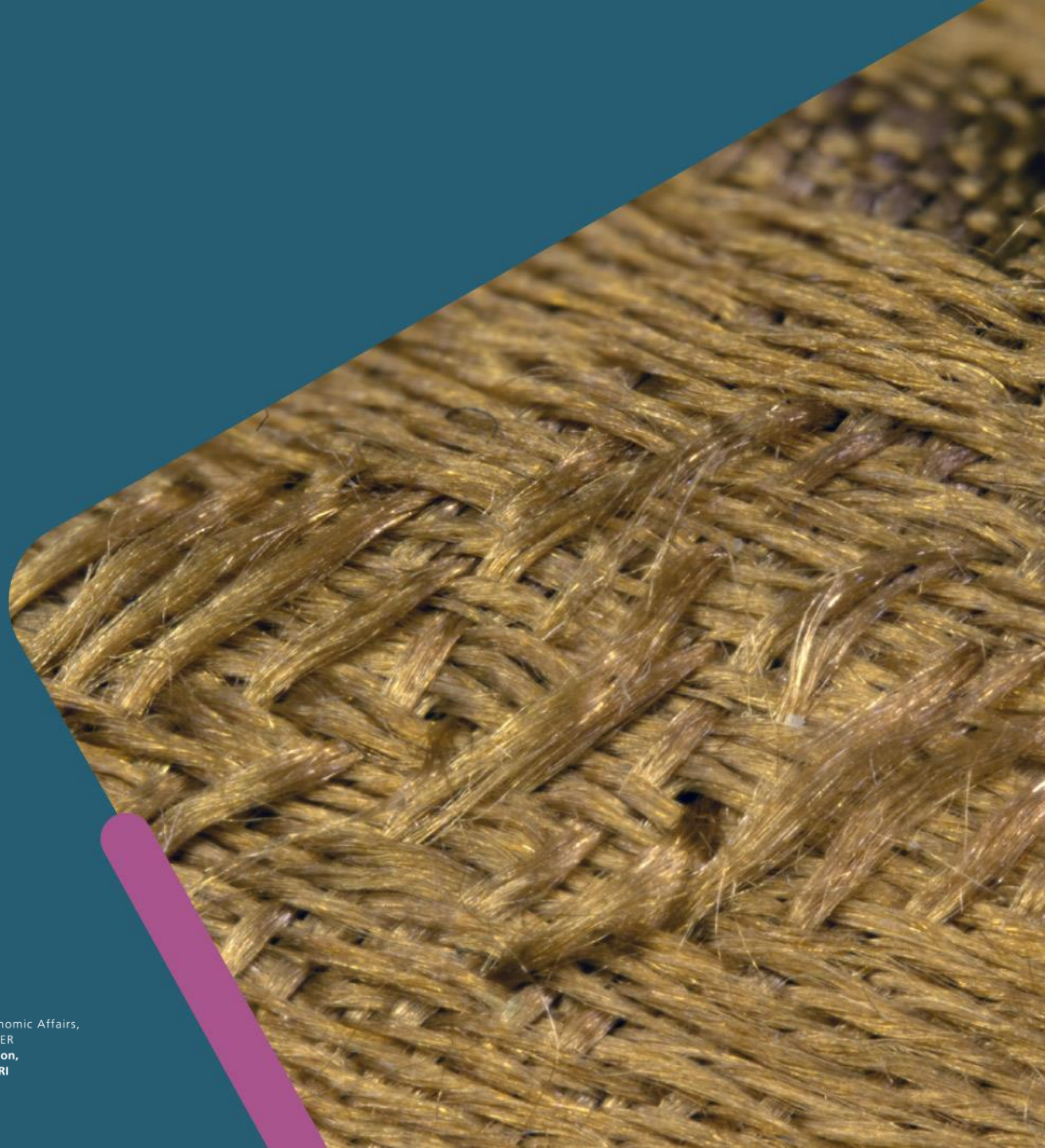
TEXTaiLES use-cases, scenarios and associated challenges



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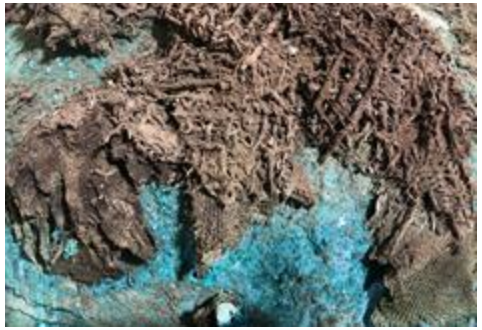
Use cases

- Eight use cases representing a large variety of textile objects
- Collection owners are participating as associated partners
- Use cases:
  - Use case 1 - Greek ancient textiles
  - Use case 2 - Textiles collection from Pompeii (Italy)
  - Use case 3 - Greek Bronze Age clay sealings
  - Use case 4 - Textile imprints on the human plaster casts from Pompeii
  - Use case 5 – Benaki Museum collection (Greece)
  - Use case 6 - Turku Cathedral Museum collection (Finland)
  - Use case 7 - Collection of the Opera Theatre Archive in Rome (Italy)
  - Use case 8 - Hand- and machine-made embroidery and laces Textile Museum St. Gallen Collection (Switzerland)



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Challenges

- Textile structures and decorative techniques (e.g., embroidery) are typically small-scale and intricate. Examples include tapestries and lace.
- Poor condition of textiles often results in loss or obscurity of features. Issues include fading, discolouration, carbonisation, missing parts, or complete loss. Only imprints may be preserved on foreign materials.
- Silk and metal threads for fine textiles are highly reflective. These threads are often difficult to analyse with traditional tools.
- Textiles designed for interior decoration, such as furnishings, tapestries and carpets, can be markedly oversized.
- Textiles are soft and elastic. Movement is a characteristic property; modelling motion dynamics is demanding.
- Textiles are sensitive materials; highly susceptible to deterioration from burial (excavated) or ageing (historical). Safe handling for digitisation is challenging.
- Evidence of textiles may be indirect, with evidence being preserved through imprints. Imprints lose pliability and undergo alterations. Preservation on 3D surfaces like ceramics makes accurate digital representations challenging using common tools.

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Title: Use Case 1 – Greek ancient textiles

Description: Textiles excavated in different regions of Greece, from 10th c BCE to 11th c CE

Object Categories: Mainly mineralised excavated textiles, at different states of preservation.

Challenges: Very fragile three-dimensional textile finds consisting of more than one type of textiles based on construction and decoration. Fragmentary textiles of minute dimensions decorated with glossy gold threads. The poor condition of the finds inhibits their aesthetic appreciation.

TEXTaiLES solution: Acquisition of multi-sensor data with advanced imaging: 3D scanning and photogrammetry to capture high-resolution geometry and fine construction/decoration details. For the glossy gold fabrics, multispectral and RGB cameras with cross-polarisation filters in combination with microscope images will be used to record the textiles' structure and construction details

Key Performance Indicators (KPIs)
▪ 3D documentation quality ▪ Multimodality and data fusion efficacy ▪ AI-powered tools for digital reconstructions

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Title: Use Case 2 – Textile collection from Pompeii (Italy)

Description: The mineralised, carbonised and gold textile fragments are part of one of the largest collection of Roman time (I century AD), stored in the Archaeological Park of Pompeii. Offer a unique opportunity to study Roman textile technology and fashion.

Object Categories: Excavated textiles in different preservation condition, mainly carbonised and mineralised.

Challenges: All textiles are heavily altered and fragmentary due to post-depositional processes. Their fragility makes handling and transport difficult. Carbonised samples are dark and often glossy, complicating digital recording—an issue also seen in gold ribbons and mineralised textiles with highly reflective surfaces. Recording is further challenged by complex structures and the minute scale of technical and decorative details.

TEXTaiLES solution: Acquisition of multi-sensor data with advanced imaging: Multispectral imaging and photogrammetry to capture high-resolution geometry and fine texture details, enhancing the digital replicas' and improving the examination and visualisation of complex structures, alternated and fine textile details, which are often hidden and cannot be identified by traditional tools. To address challenges in capturing obscure or reflective fabrics, multispectral and RGB cameras with cross-polarisation filters will be used to record the textiles' full volumetric structure and construction details

Key Performance Indicators (KPIs)

- Digital replicas' reliability and improving the examination, documentation and visualisation of complex structure and altered surfaces
- Reveal hidden fine textile

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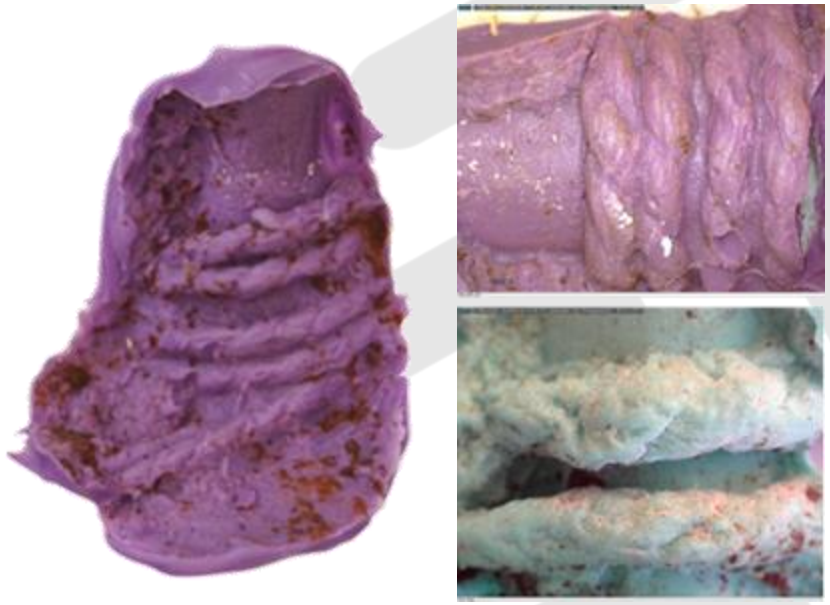

Title: Use Case 3 – Greek Bronze Age clay sealings

Description: Modern casts of Bronze Age clay sealings from Greece (c. 2650–1200 BCE), stored in the Corpus der minoischen und mykenischen Siegel (CMS) Archive in Heidelberg. Sealings, used for administrative and storage purposes, often bear impressions of textiles and other organic products left during the sealing process.

Object Categories: Modern imprints and casts of the undersides and insides of clay sealings and nodules from Bronze Age Greece.

Challenges: 1. Photographic and digital microscope documentation. 2. Capturing detailed weave and thread features, including additional elements such as knots or loops. 3. Identifying raw materials, production techniques, and related aspects.

TEXTaiLES solution: 1, 2 - high-quality imaging techniques (e.g. 3D scanning, photogrammetry, Reflectance Transformation Imaging) to enhance low-relief impressions, reveal fine details, enable the creation of 3D reconstructions of impressed textiles and 3D cast replicas. 3 - AI technologies to potentially identify raw materials and production techniques, detect textiles reuse/recycling practices, trace individual-specific patterns of textile handling during the sealing process.

Key Performance Indicators (KPIs)
▪ Enhance textile details visibility via high-resolution imaging techniques and 3D imaging. ▪ Identification of raw materials, production techniques, reuse/recycle patterns, and individual textile handling behaviors during sealing processes via AI technologies.

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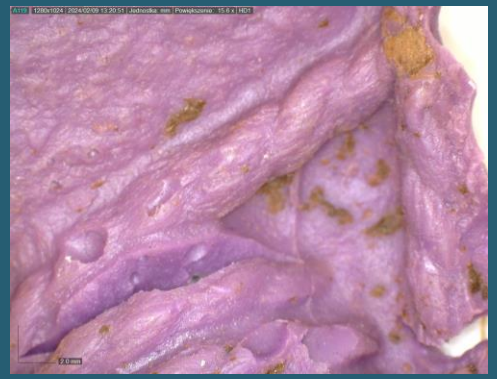
Challenges – use case 3



- Traditional photography and digital microscopes often struggle to capture detailed weave and thread features, as well as additional elements such as knots, loops, or fringes, due to the properties of the modern cast materials and the characteristics of the impressions themselves.
- The casts are very small, yet highly three-dimensional objects with irregular shapes and surfaces, often including shadowed areas or glossy finishes.
- The imprints are typically low reliefs, sometimes with poorly reproduced textures or structures, which can cause focus issues.
- The physical properties of silicone and plasticine (e.g., shrinkage, malleability), along with the varying quality of the impressed materials, often present challenges in identifying, e.g., used raw materials or production techniques.

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Title: Use Case 4 - Textile Imprints on Human Plaster Casts from Pompeii (Italy)

Description: Plaster casts of human bodies, which preserve detailed imprints of garments and textiles. Provide a unique opportunity to study Roman fashion and textile technology from the 1st century AD.

Object Categories: human plaster casts with textile imprints.

Challenges: Traditional photography and microscopy cannot capture the fine, low-relief textile details. The casts are monochrome and have irregular, glossy surfaces, making it difficult to record the intricate imprints.

TEXTaiLES solution: Advanced Imaging: Use of Reflectance Transformation Imaging (RTI) and multispectral imaging to capture fine details and enhance low-relief structures. Multispectral scanning to detect hidden accessories and remains of organic materials. AI and Digital Twin Technology: AI tools to separate garments from body casts, revealing their 3D structure and movement.

Key Performance Indicators (KPIs)
▪ Accurate representation of fabric and garment structure and movement using AI and digital twin technology. ▪ Enhance textile details visibility via high-resolution imaging techniques and 3D imaging.

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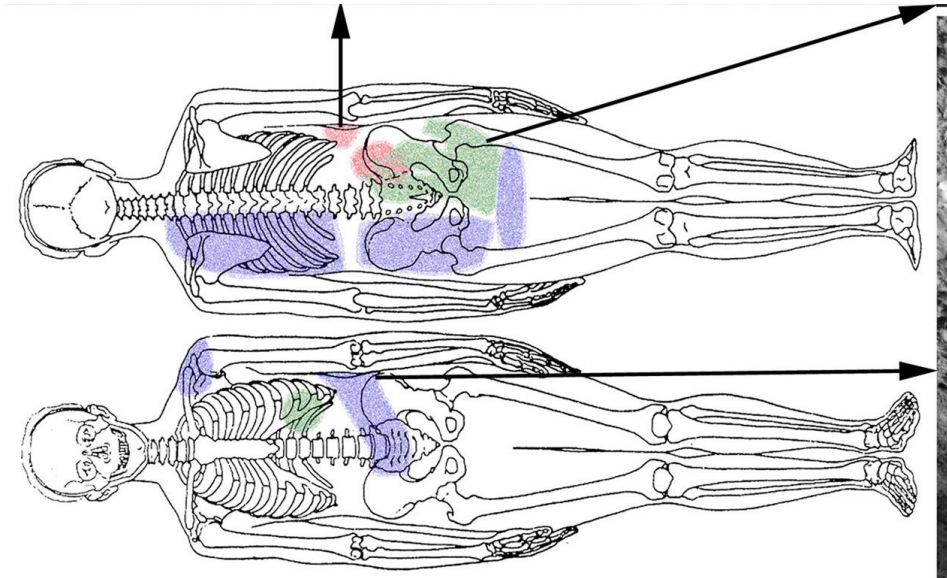

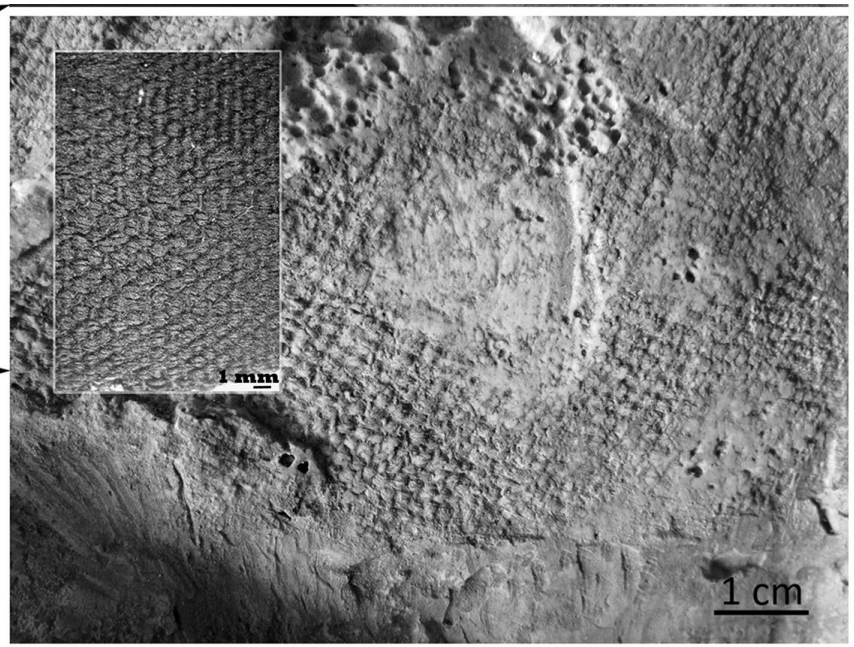

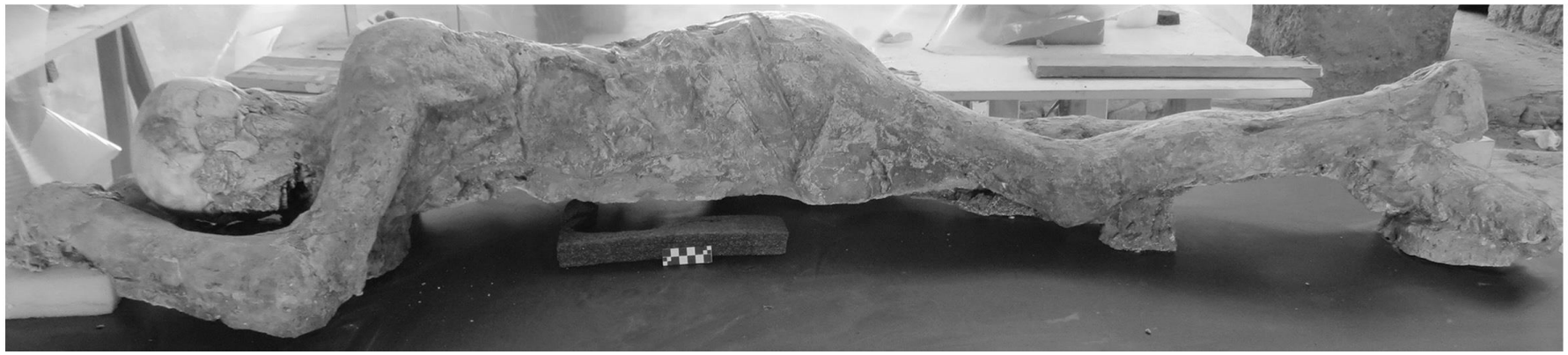

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Title: Use Case 5 – Benaki Museum collection (Greece)

Description: This use case involves western fashion and Greek traditional costumes and accessories (18th–20th centuries).

Object Categories: three-dimensional pieces of clothing and accessories

Challenges: The objects have sophisticated cut and construction and decorative patterns. They are decorated with shiny embellishments, like beads and gold-thread embroidery. Motion, which is an important inherent property of textiles is missing from these objects that are now museum artifacts.

TEXTaiLES solution: Computational imaging and 3D scanning coupled with photogrammetry and microscopy imaging, to produce 3D models that will include all the fine details of construction and decoration.

Key Performance Indicators (KPIs)
▪ 3D documentation quality ▪ Motion and dynamics modelling simulation accuracy

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Title: Use Case 6 – Turku Cathedral Museum Collection (Finland)

Description: The funerary attire in the collection from Turku Cathedral was excavated between 1922 and 1925. These items belong to people who lived in Turku (Finland) during the 17th and 18th centuries. Complete garments, and coffin furnishings, such as pillows, as well as accessories like silk caps, stockings, gloves, and floral wreaths.

Object Categories: Six items: caps, a child's slipper, a headdress, and a box with unconserved fabric

Challenges: The complexity of individual artefacts, such as caps with silver-coated yarn and silk laces, reflecting surfaces of silk and metal, and black-and-white surfaces makes documentation and conservation of the collection challenging. Understanding items necessitates the study of reverse sides and internal structures.

TEXTaiLES solution: Utilizing photogrammetry and Reflectance Transformation Imaging (RTI) to capture fine details of complex patterns. Micro-computed tomography allows for viewing internal structures. AI and Digital Twin Technology: AI weaving pattern analysis helps identify textile weaving or lacing patterns.

Key Performance Indicators (KPIs)
▪ Reveal hidden internal structures ▪ Degradation detection efficiency ▪ 3D documentation quality ▪ Elimination of unreconstructable highlights through polarisation

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Challenges – use case 6

Accomplishing an evenly lit surface

- Pores and creases on textile lead to under-exposed areas. Flooding with light is not always feasible due to reflective qualities. Highlights can be a bigger problem than under-exposed areas.
- Solutions: Single- and cross-polarisation effects on photogrammetric recording. Use of polarising camera lens filters and polarising screens on light sources
- Current: Lack of accurate, user-friendly ways to assess 3D model quality

Magnification

- Challenges: Yarns and fibers are not visible in digital 3D models at standard magnifications. Increasing magnification creates new challenges: small depths of focus result in blurry images, higher skill requirement for the modeller, and increased data sizes. At macro-level magnifications, small and flat objects require focus stacking. Increased time required for modeling delicate items
- Solution: apply magnifications up to 2:1 on key textile details. Identify feasible ranges for real-world recording scenarios

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Title: Use Case 7 – Collection of the Opera Theatre Archive in Rome (Italy)

Description: Stage costumes worn by distinguished opera and ballet performers from the 19th century to the present day. Significant contributions from renowned costume designers and visual artists. The collection provides elaborate costumes with different raw materials (fibres, feathers, sequins, metal threads, beading) and techniques for realising complex constructions and patterns.

Object Categories: Complete costumes

Challenges: 1. the recording of the cut, construction and designs of the costumes as well as intricate and high-reflective surfaces; 2. the management of the collection by keeping together digital twins and associated metadata - designers, artists, date and performance - and the valorisation and conservation over time.

TEXTaiLES solution: Computational imaging and 3D scanning enable the creation of digital twins for research, conservation, and public engagement. AI-powered tools offer innovative restoration solutions, such as reconstructing missing elements through generative methods. Energy-efficient, wireless sensor networks ensure continuous, non-invasive, and cost-effective monitoring.

Key Performance Indicators (KPIs)
▪ 3D documentation quality ▪ Degradation detection efficiency and monitoring ▪ AI-powered tools for restoration solutions

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Title: Use Case 8 – Textile Museum St. Gallen Collection (Switzerland).

Description: collection of European lace, hand and machine-made, 14th-20th centuries, incl. objects from the Leopold Iklé (1838–1922) and John Jacoby (1869–1953) collections. Diversity of structures and techniques, materials and object types.

Object Categories: Fragments, costume, textile accessories and oversized interior textiles. Often translucent, designed for light to pass through and creating a see-through effect yet having a strong pattern. Raised 3d relief.

Challenges: 1. Delicate and complex 3D structures with pattern of holes ; 2. Transparency; 3. Low and high relief; 4. Loss of shape of garment when stored flat; 5. Oversized textiles that are difficult to handle. 6. Great diversity of lace techniques (hand and machine) making identification challenging.

TEXTaiLES solution: high quality imaging techniques to capture relief, patterns and motifs; reconstruction of garment's shape via digital twins; safe automatisation of digitization of oversized textiles.

Key Performance Indicators (KPIs)
▪ 3D documentation quality ▪ Enhance textile details visibility ▪ Representation of structure, shape and movement ▪ Safe and non-invasive methods

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textailes

Thank you!

Textilmuseum St.Gallen

SAPIENZA UNIVERSITÀ DI ROMA

A3TEX
SAPIENZA RESEARCH CENTER
ARCHAEOLOGY AND ARCHAEOMETRY OF ANCIENT TEXTILE

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UNIVERSITY OF WARSAW

WYDZIAŁ ARCHEOLOGII
Uniwersytet Warszawski

UNIVERSITY OF OULU

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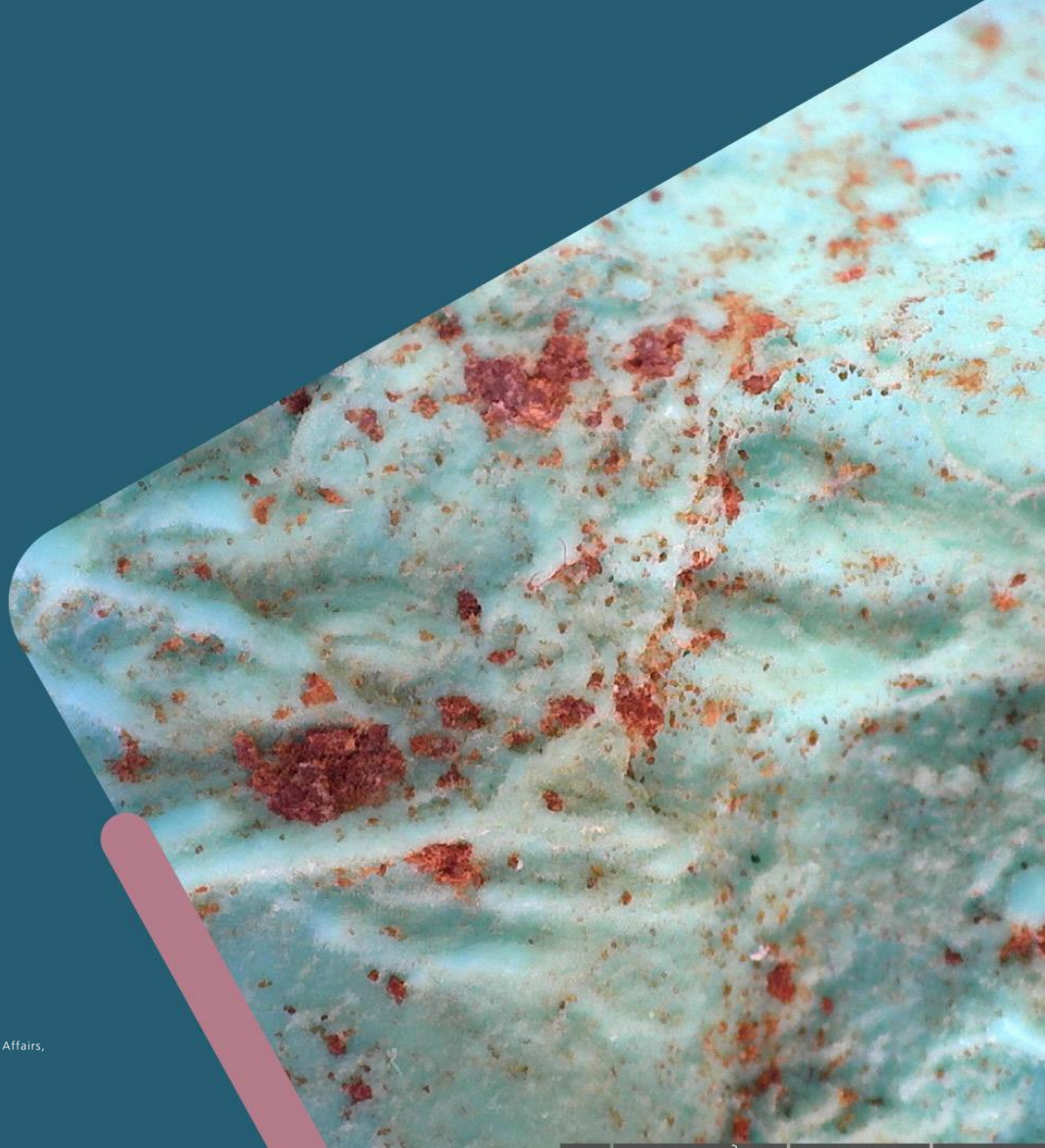
TEXTaiLES – Technical Tools

Athanasios Kapoutsis

WORKSHOP #8: OPPORTUNITIES AND TOOLS FROM THE CULTURAL HERITAGE CLOUD FOR DIGITAL ARCHAEOLOGY

Monday, May 5th, 2025, Athens



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Outline

- 3 Technical Work Packages
- 14 Tools developed
- Based on
  - Data aquation technologies
  - Data storage and visualization
  - Data processing for generating knowledge

WP4	**Data Acquisition Techniques**
T4.1	Textile monitoring through smart wireless sensor networks
T4.2	Precise and safe navigation of aerial robots to cooperatively scan oversized textiles
T4.3	Development of custom UGV with robotic arm specialised for CH inspections.
T4.4	Deploying terrestrial robot to perform regular and on-demand scans inside complex indoor structures
T4.5	Automatically focus on problematic or areas-of-interest to acquire the most meaningful data
WP5	**Intelligent Processing for Restoration and Preservation**
T5.1	Multimodal surface morphology and micro-structure analysis
T5.2	Surface degradation detection, identification and localisation
T5.3	Dynamics and motion analysis of textile objects
T5.4	Automatic CH object restoration
WP6	**Digital Toolbox for Collaborative Annotation and Documentation**
T6.1	Data lake and curation of CH artefact meta(data)
T6.2	3D object viewer, editor and annotator
T6.3	Digital twin models of CH objects
T6.4	ECCCH API interface design for TEXTaiLES tools
T6.5	Deployment of TEXTaiLES tools

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Architecture

WP4 – Data Acquisition

UGV & Robotic Arm

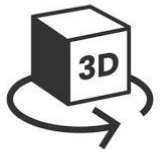
UAV & Hyperspectral Camera

WP5 – Intelligent Processing for Restoration

AI based Generative Approaches

WP6 – Documentation & Annotation

Data Lake



3D Viewer & Annotator

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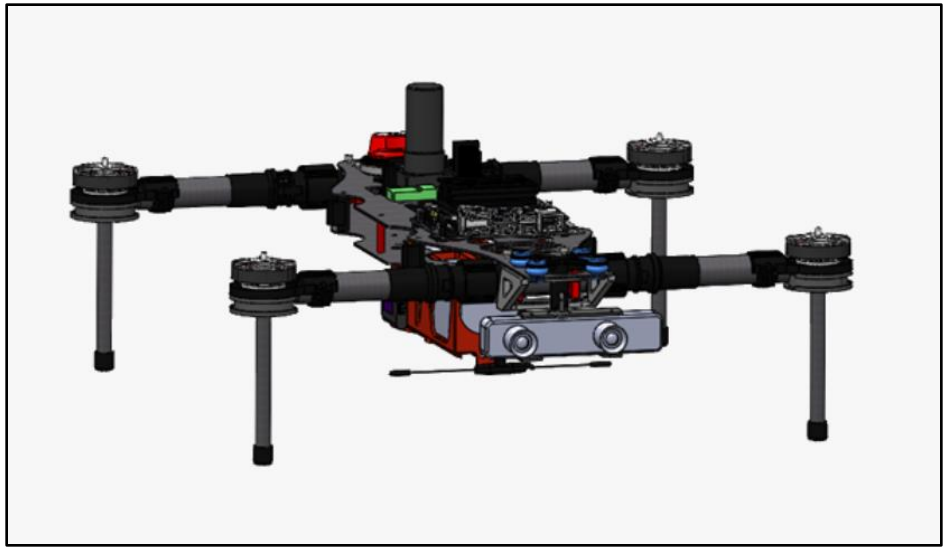
Precise and safe navigation of aerial robots to cooperatively scan oversized textiles

- Equipped with high resolution or infrared sensors
- Navigation algorithms protect textiles and avoid obstacles
- Scan oversized or hard to reach textiles
- Emergency protocols ensure safe and reliable operations



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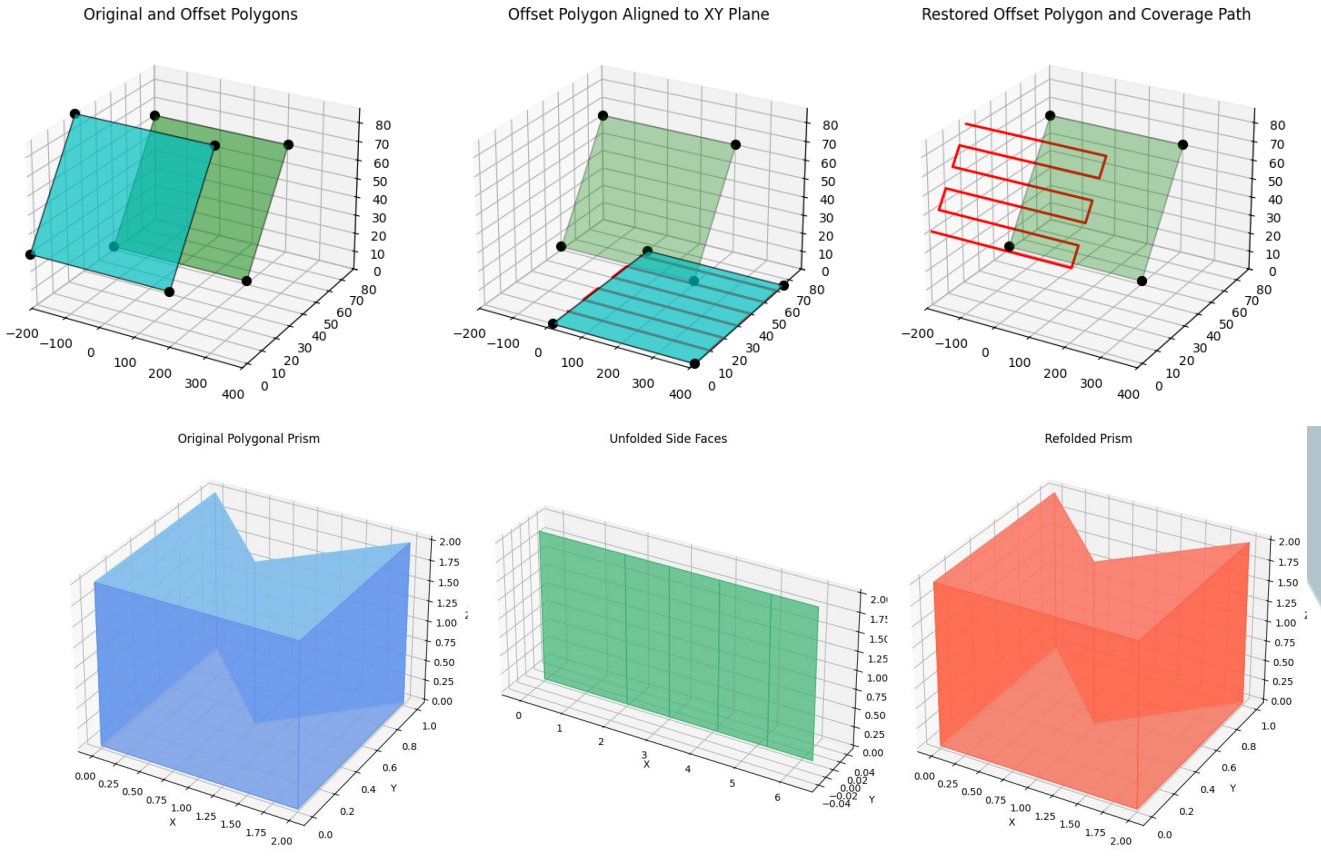
Precise and safe navigation of aerial robots to cooperatively scan oversized textiles

- **Slope Coverage**
- Cover 2D planes or polygons in a 3D space
- Apply a set of geometric transformations that allow the use of any coverage pattern
- Support WGS84 and local cartesian coordinates for both GNSS and GNSS-denied operations

- **Geometric Coverage**
- Completely cover shapes like cylinders “3D polygons” (prisms)
- Apply transformations to “unfold” the shapes and apply the coverage solutions presented in the previous slide



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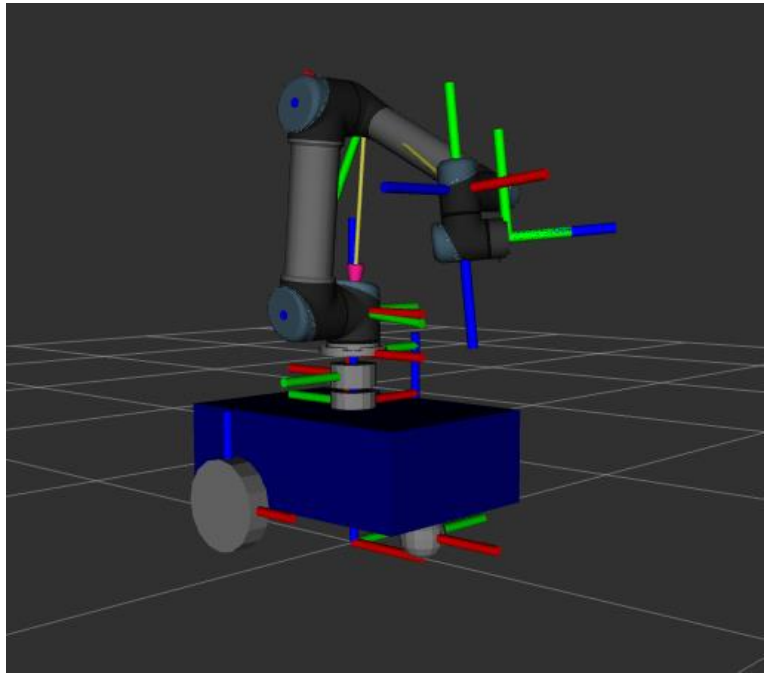
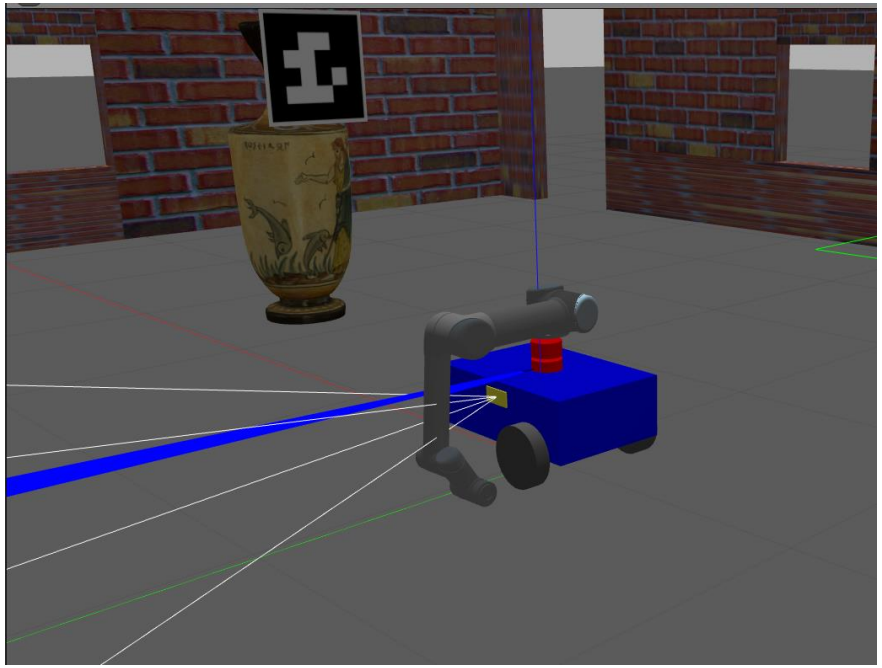
Development of custom UGV for with robotic arm specialised for CH inspections

- Robotic arm with multiple sensors
- Low-cost
- Run for extended period

- Navigation algorithms
- Arm kinematics





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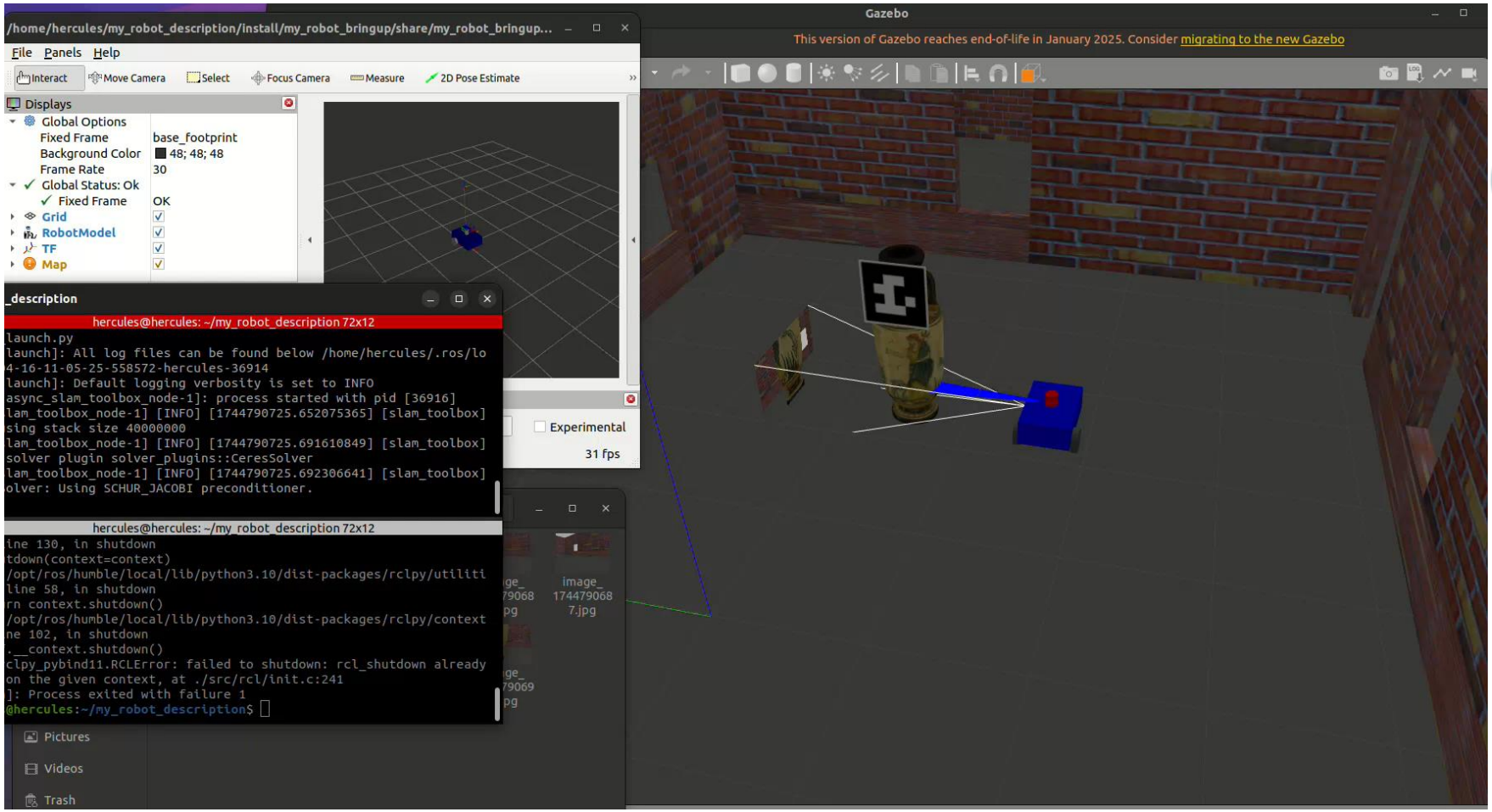
Deploying terrestrial robot to perform regular and on-demand scans inside complex indoor structures



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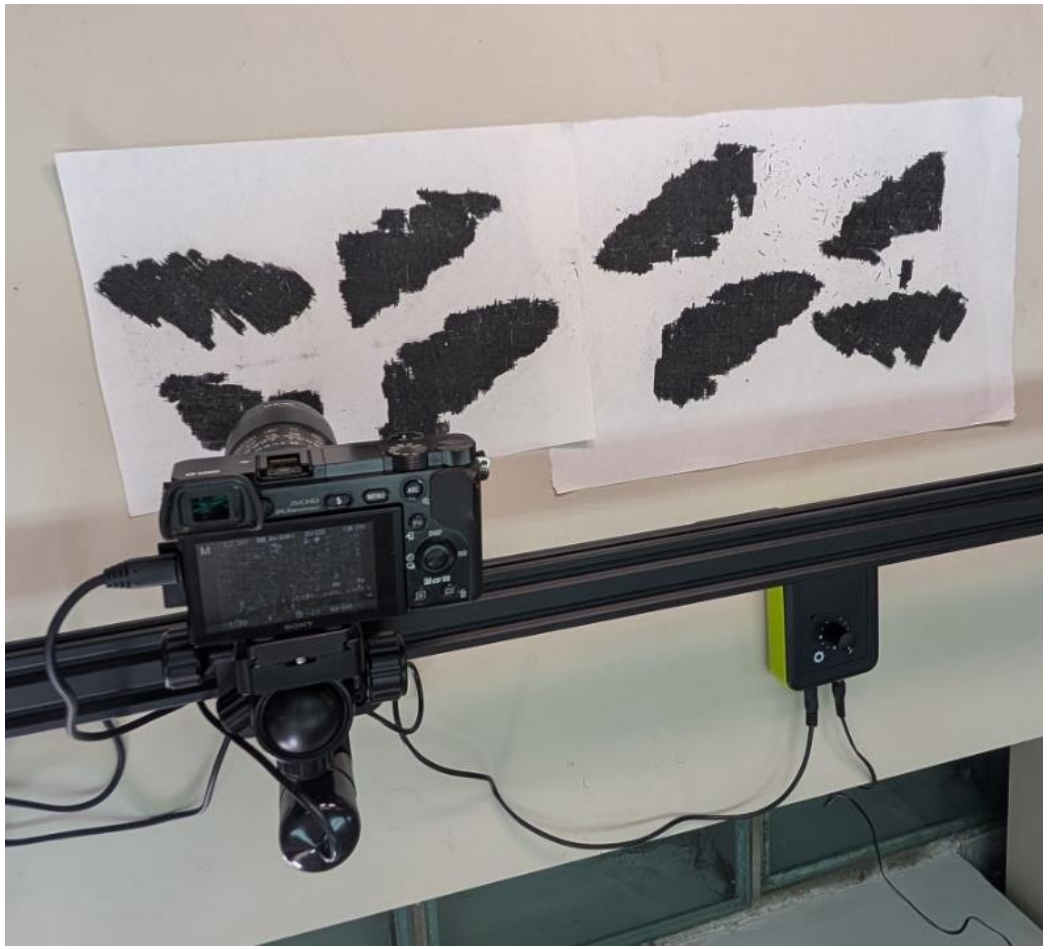
Data acquisition for the 3D reconstruction of textile samples using photogrammetry



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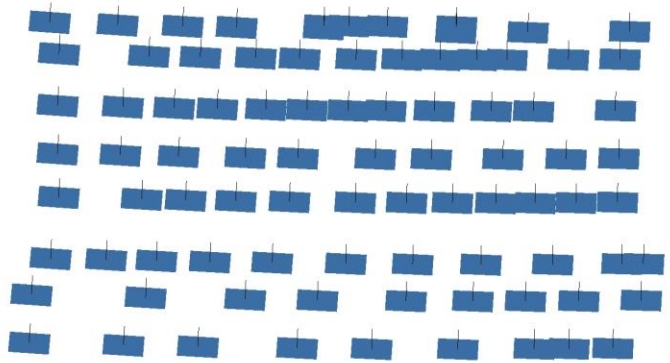
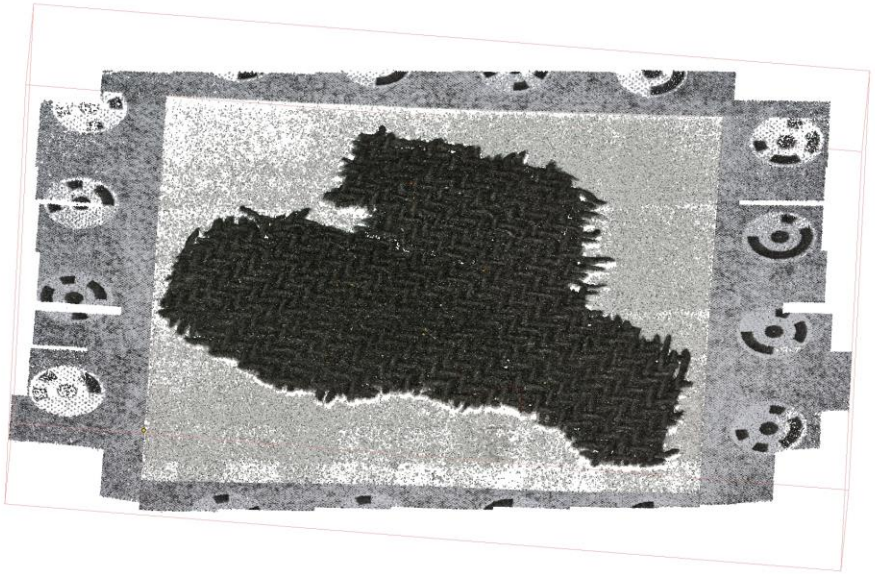
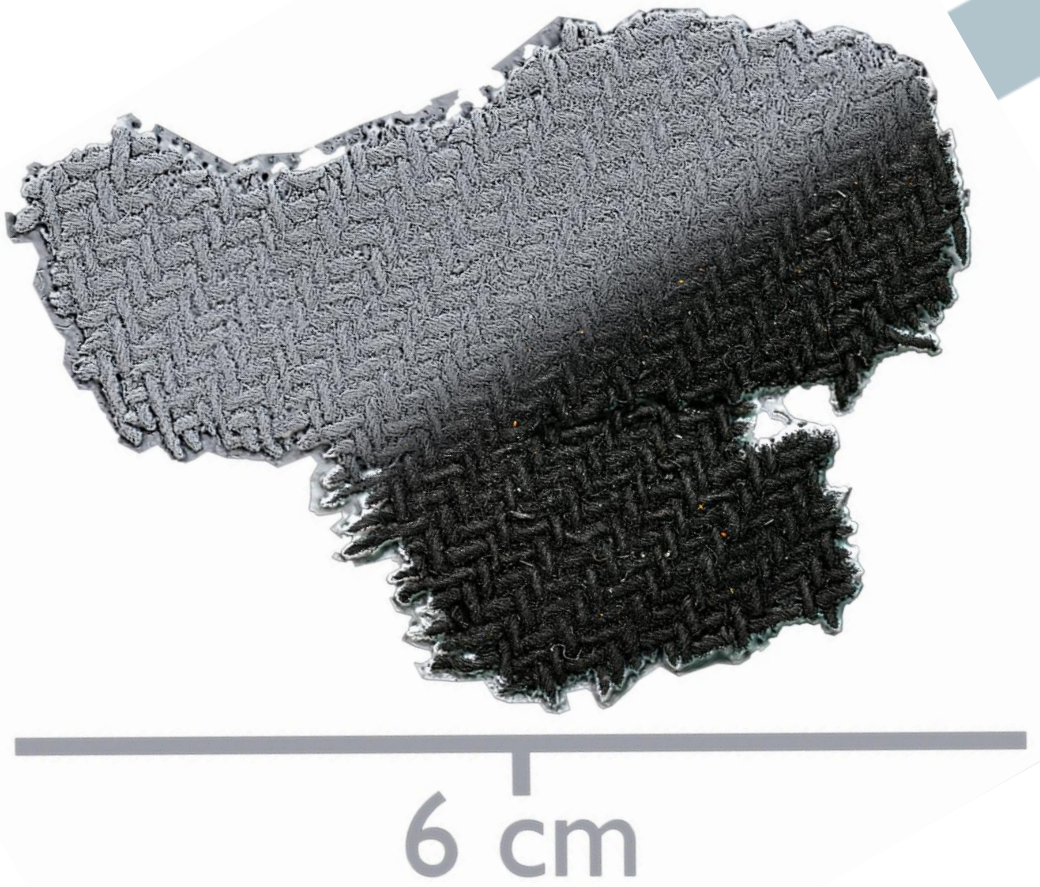
Final 3D reconstruction of a textile sample







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3D reconstruction technical details

- 24 Megapixels mirrorless camera with APS-C sized sensor.
- 65mm macro lens with 2X magnification and circular polarisation filter.
- 1.2 meters long motorised camera slider.
- 2 rectangular flood lights (17 X 11 cm led panels).
- Theoretical minimum sampling distance on the closest focal plane : 8.333 µm.
- Measured diameter of a 3D reconstructed strand (best case) : 20 µm.

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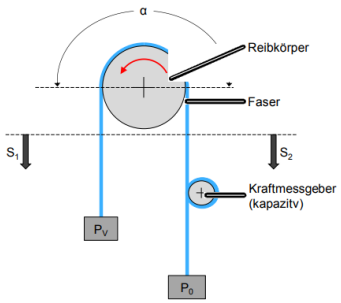
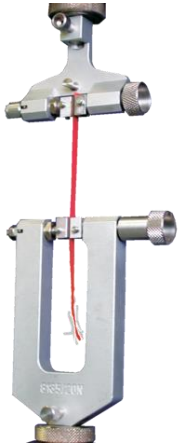
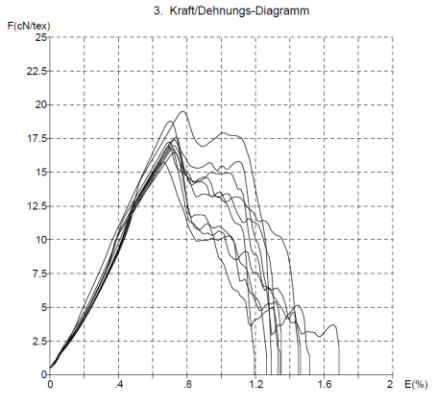
Dynamics and motion analysis

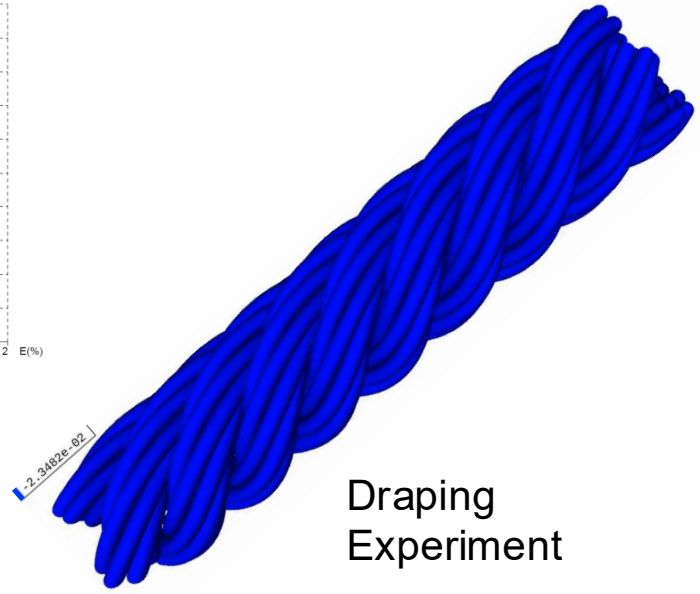
- Yarn properties
  - Cross-section, Youn's modulus or force-strain curve, friction coefficient
- Textile structure
  - Weave unit
- **Distances between yarns, real yarn length per mesh or row**
  - Input through a GUI







Shear Experiment



Draping Experiment

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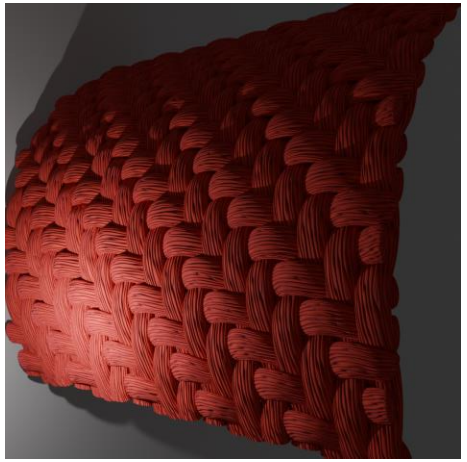
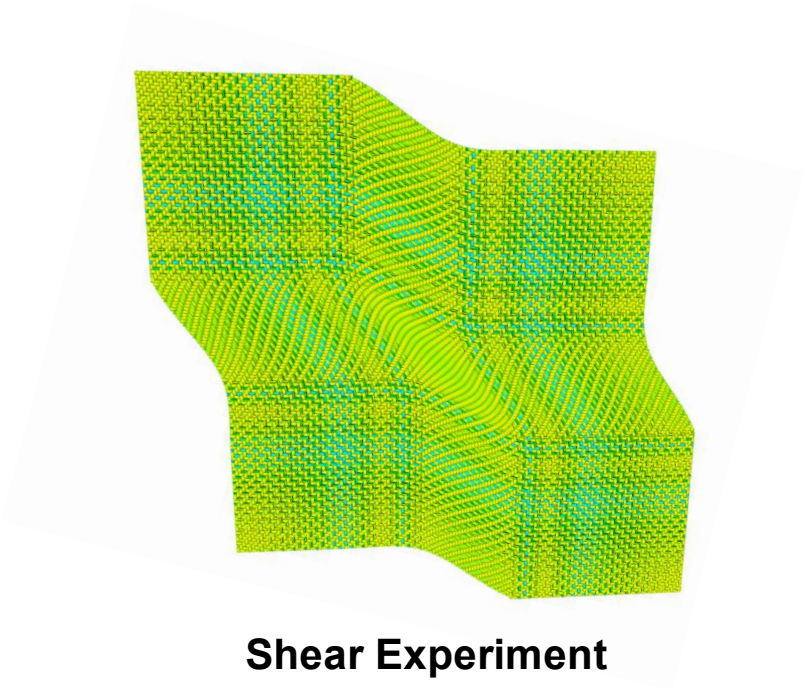
Dynamics and motion analysis

- **Extrapolate to more advanced & complicated structures**
  - **Simulation across different length scales**
- **Fiber-scale → Yarn-scale → Textile-scale**



Bending Experiment



Shear Experiment

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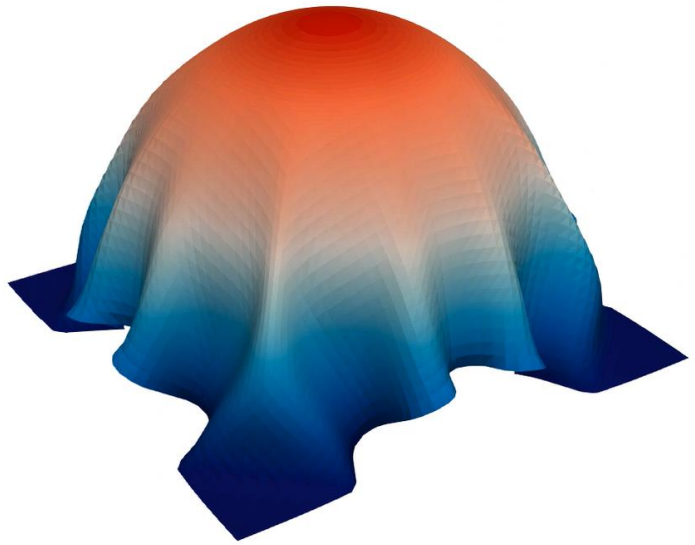
Dynamics and motion analysis

- **Capturing of textile motion through mechanical simulation**
- **Prediction of physical properties for archeological samples**



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Automatic CH object restoration

- Digital restoration of damaged textile areas
- Reproduction of missing colors/weaving patterns
- Integration of textual, visual and depth priors

<u>Image inpainting with generative AI approach:</u>

Input image + mask **Original image** **Image inpainting**

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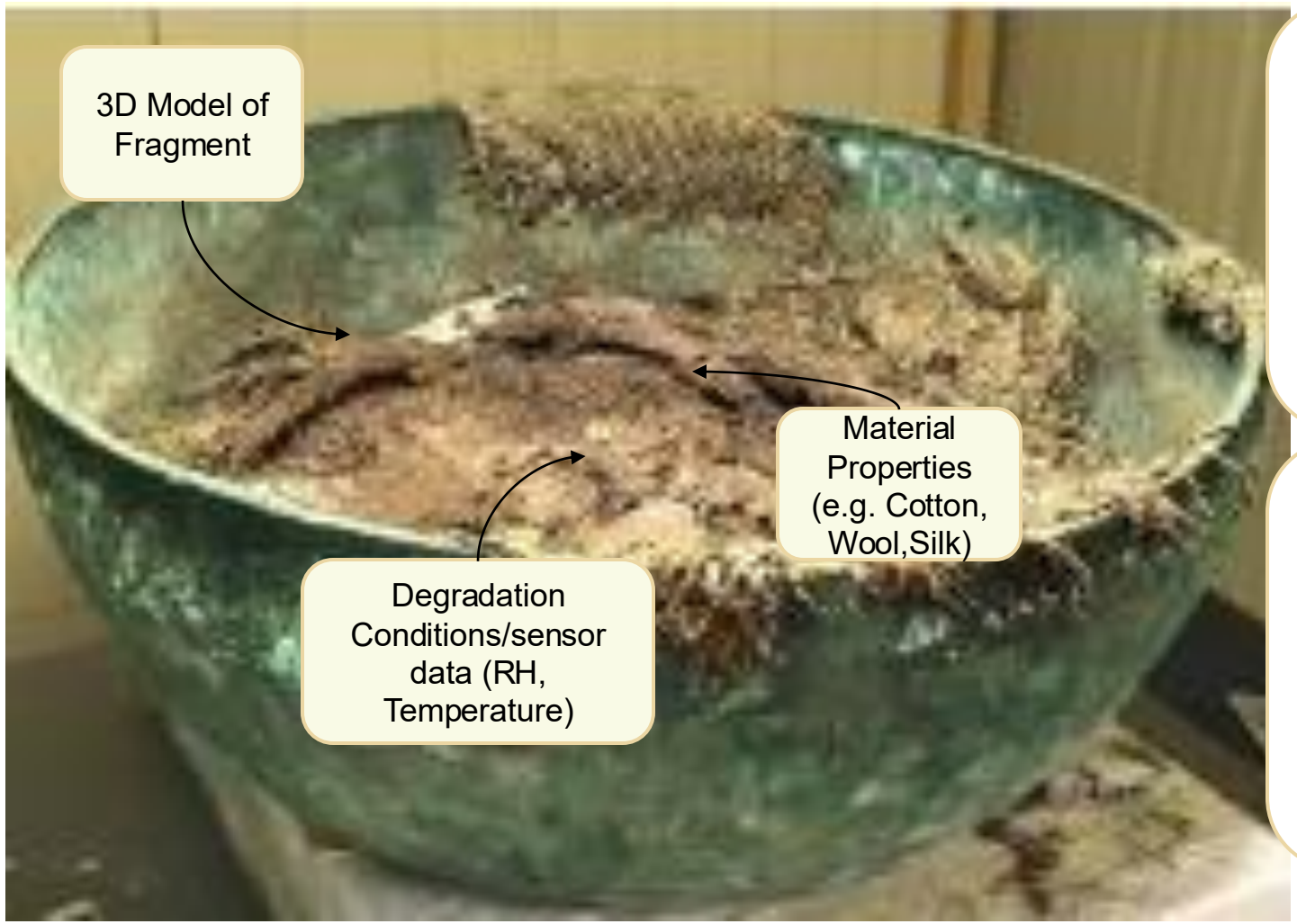
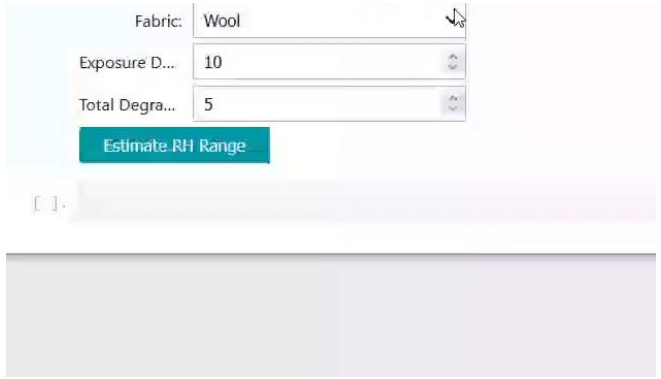
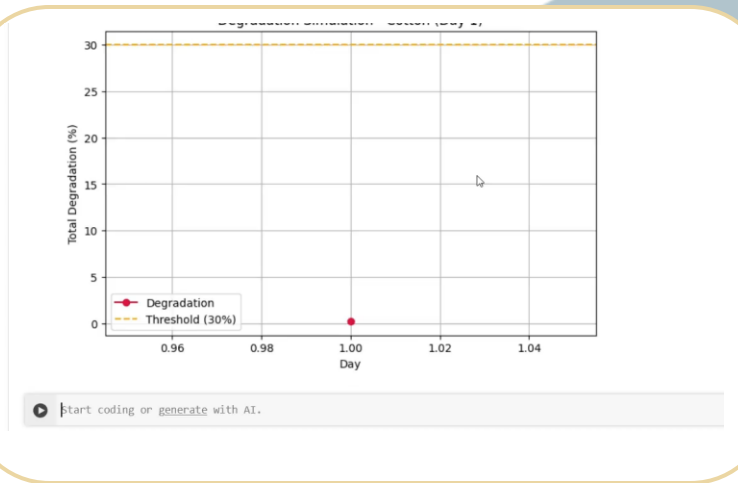
Digital twin models of CH objects

please replace all these photos with high standart quality images, it is very bad







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End-to-End Machine Learning Platform

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3D Viewer and Annotator

three.js

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API Interface design for TEXTaiLES tools

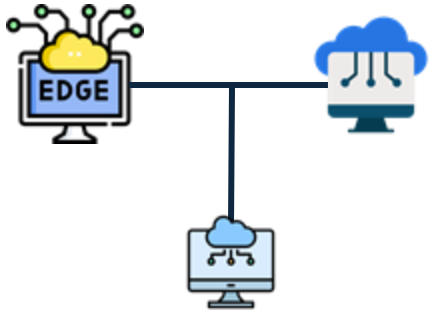
Build a scalable and robust data infrastructure that safely hosts heterogeneous data types:

- interface with ECCCH
  - facilitate interoperability between web-based 3D visualisation annotation platform and data stored at ECCCH
  - provide interactive updates to retrieve and store data related to the 4D digital twin platform developed as part of TEXTaiLES

Deployment of TextTaiLES tools

Primary goal: Facilitate the deployment of TEXTaiLES digital toolbox:

- data retrieval
- data processing
- data visualization



Containerize:

- build once, deploy everywhere
- sandbox (protect data/users/infra)
- secure interactions with ECCCH

Example schema

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{
  "$schema": "http://json-schema.org/draft-
    07/schema#",
  "title": "Artefact",
  "type": "object",
  "properties": {
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    "name": { "type": "string" },
    "origin": { "type": "string" },
    "age": { "type": "string" },
    "material": { "type": "string" },
    "digitalRepresentations": {
      "type": "array",
      "items": {
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  "format": "uri" }
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  "resolution", "fileURL"]
      }
    }
  },
  "required": ["id", "name", "origin", "age",
    "material", "digitalRepresentations"]
}
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https://www.instagram.com/textailes.eu/

https://www.linkedin.com/company/textailes

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