

# Unwrapping History with Mathematics

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# The Invisible Library

*En Gedi Scroll, damaged by fire, c. 600CE*



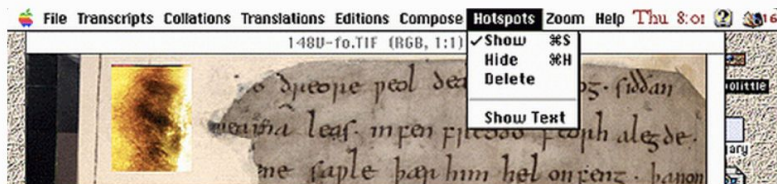
*Herculaneum Scroll, damaged by Vesuvius eruption, c. 79CE, further damaged by physical unwrapping in 1883-4CE*



**Problem:** How do we determine what these scrolls contain without irreparably damaging them?

# Timeline

## 2D Digitization of Burned Pages

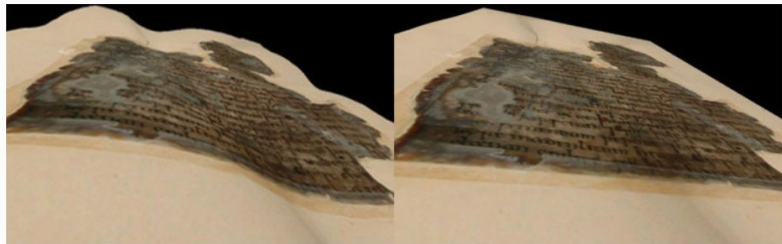


Beowulf, The British Library

1999

2000

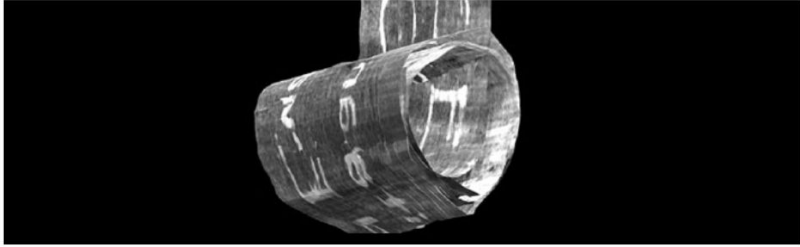
## Digital Flattening of Warped Pages



The Cotton Collection, The British Library

# Timeline

## Virtual Unwrapping



Egyptian Scroll Prototype, The University of Kentucky

2003

2006

## Non-invasive Reading



Ecclesiastes Book Binding, The University of Michigan

[View Video](#)

# Timeline

## Multi-spectral Images Across Time



The St. Chad Gospels: Diachronic Manuscript Registration and Visualization  
[View Paper](#)

2009

## Digital Rendering of Internal Structures



2011

Herculaneum Scroll, Institut de France  
[View Video](#)



# Timeline

2013

## Restoration Using Layers

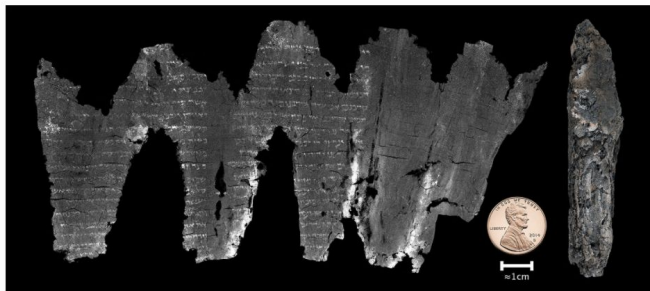


Chinese Dynastic Texts, National Palace Museum (Taiwan)

[View Video](#)

2015

## Complete Virtual Unwrapping and Reading



The Scroll from En-Gedi, The Israel Antiquities Authority

[View Project](#)

# Timeline

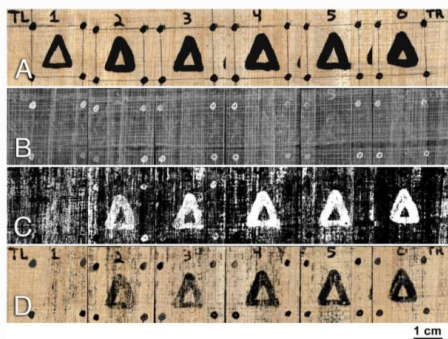
2018

## 3D Registration to 2D Images



Herculaneum  
Papyrus Scrolls –  
PHerc. 118  
[View Project](#)

## Machine Learning Reveals Carbon Ink



From Invisibility to  
Readability:  
Recovering the Ink  
of Herculaneum  
[View Project](#)

2019

# The Volume Cartographer

A computer program for virtually unwrapping ancient scrolls while keeping them intact

Developed at the University of Kentucky by Dr. Brent Seales





# The Process of Unwrapping the En-Gedi

1. Noninvasive volumetric scan
2. Segmentation
3. Texturing
4. Flattening
5. Merging and visualization



# Volumetric Scan

Can be done with a variety methods

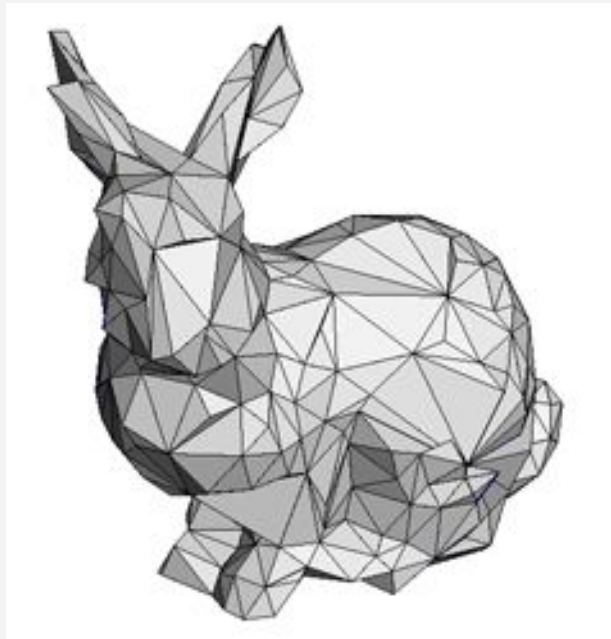
Dependent on the scale and the material and physical properties of the object.

Artec Space Spider 3-D scanner →



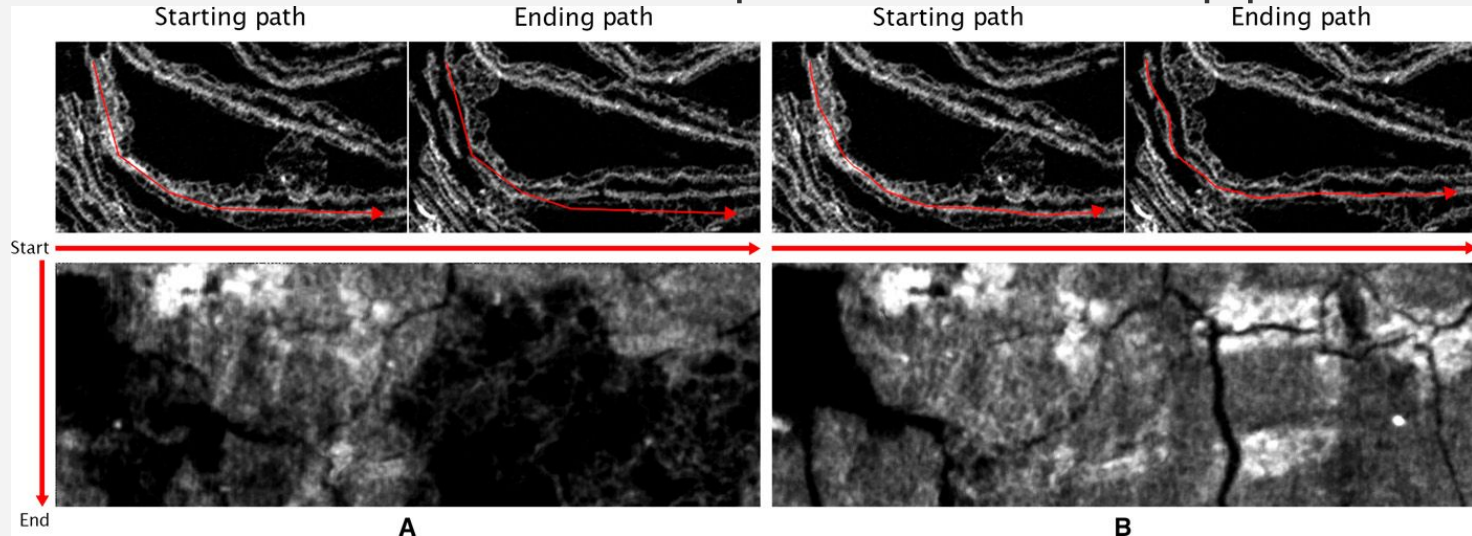
# Background Information

Mesh: a set of 3D points connected in faces



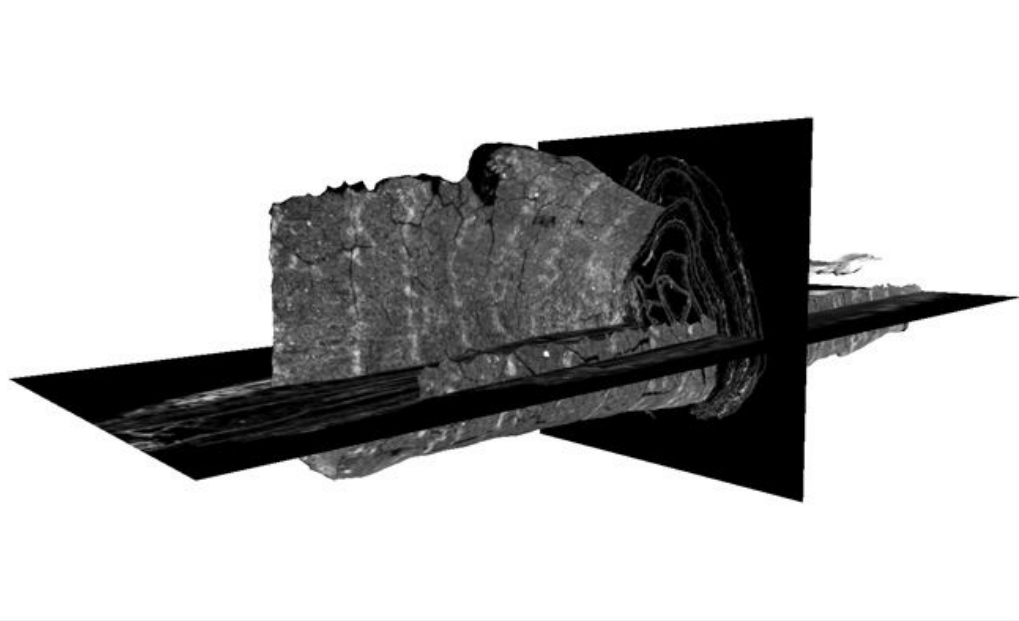
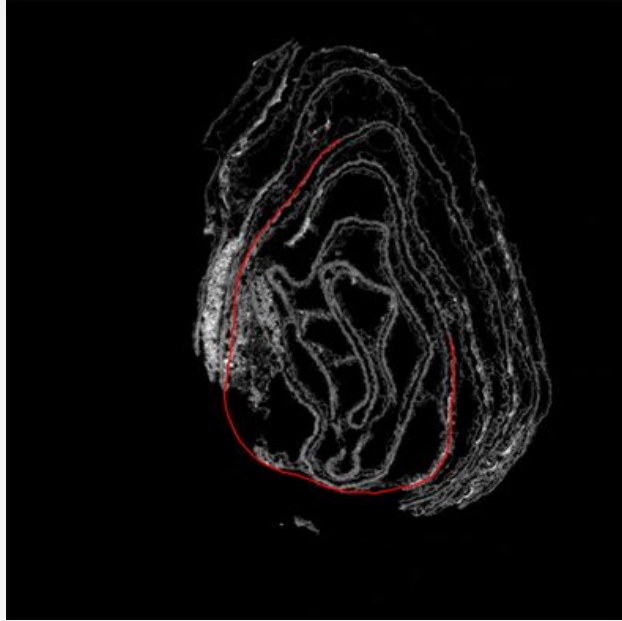
# Segmentation

construction of a geometric model localizing the shape and position of the substrate surface within the scan on which text is presumed to appear



(A) Texture generated when the surface is only partially localized. (B) Texture generated when surface is accurately localized.

# Segmentation

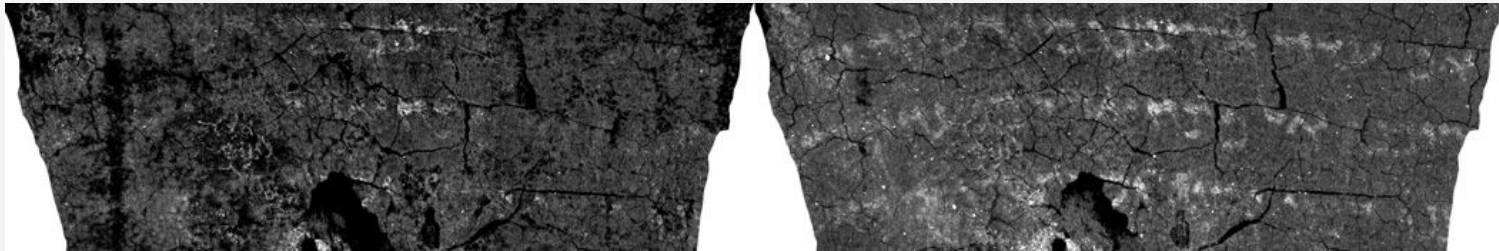


# Texturing

assignment of an intensity, “or brightness” to each point on the surface

neighborhood-based directional filtering method

The texture intensity is calculated from a filter applied to the set of voxels within each surface point's local neighborhood





# Flattening

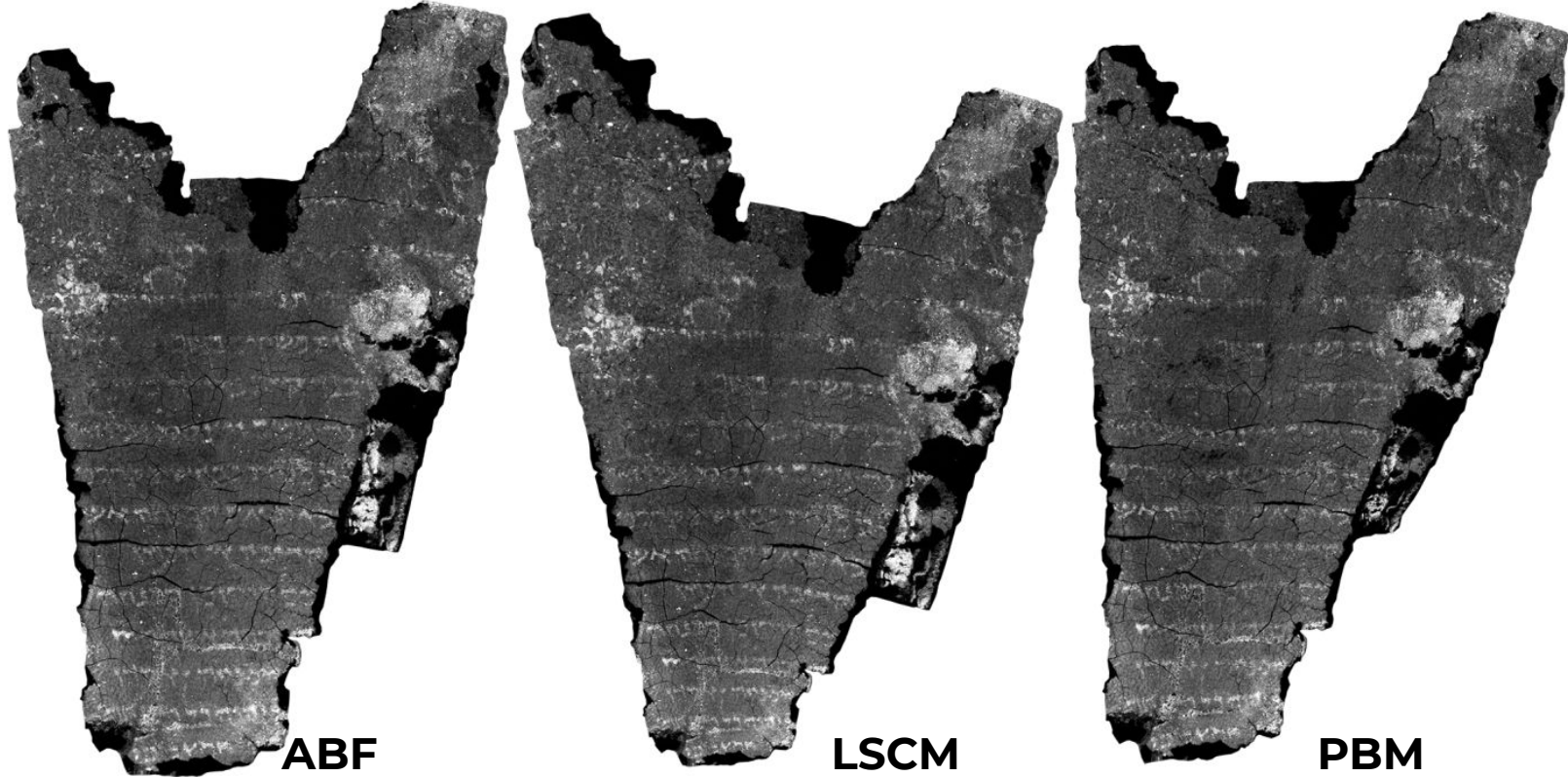
Necessary to create a readable document

Different Methods could be used:

- Least Squares Conformal Mapping
- Area-Based Flattening
- Physics-Based Modeling



# Flattening Methods



# Distortion Mapping

Determined by z-score

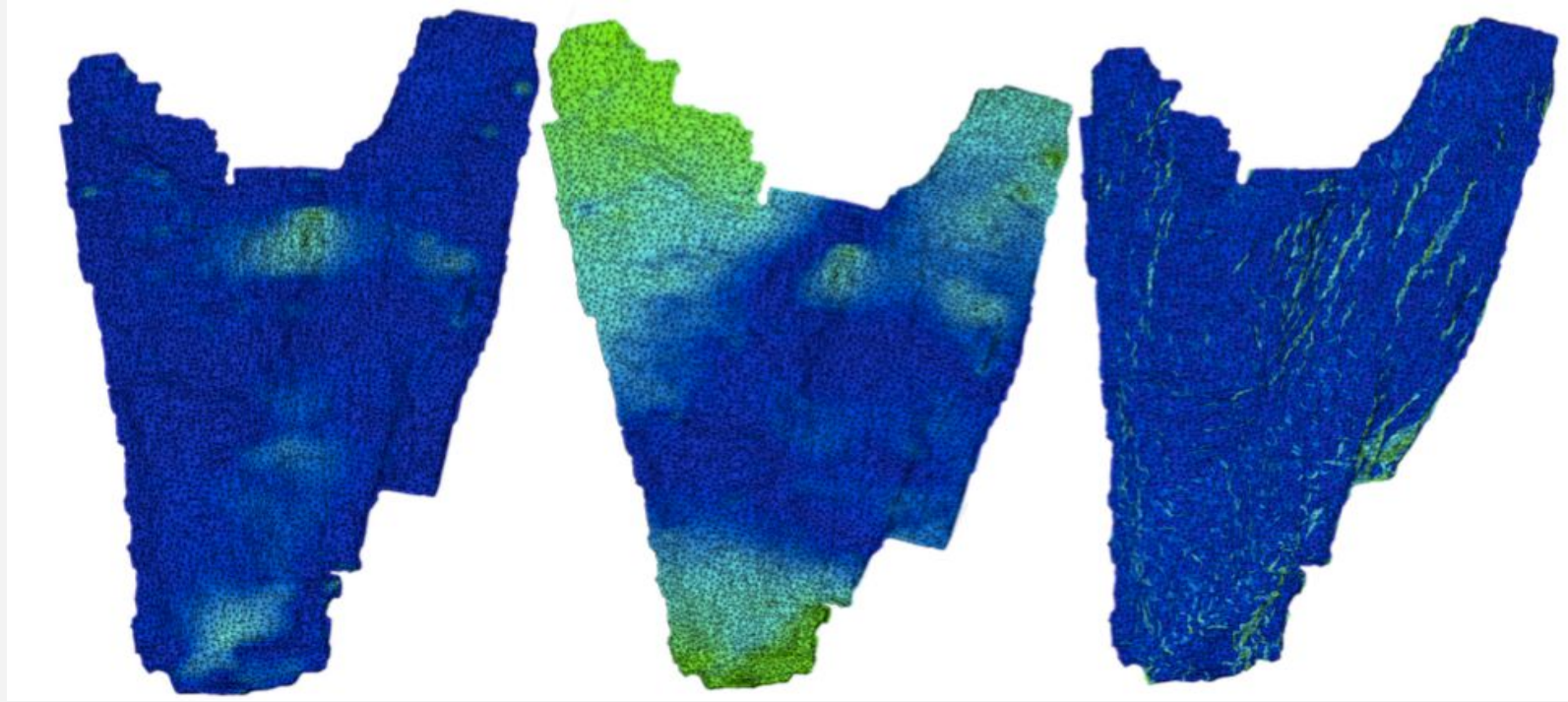
Minimum  
( $z=-1$ )

Average  
( $z=0$ )

Maximum  
( $z=1$ )

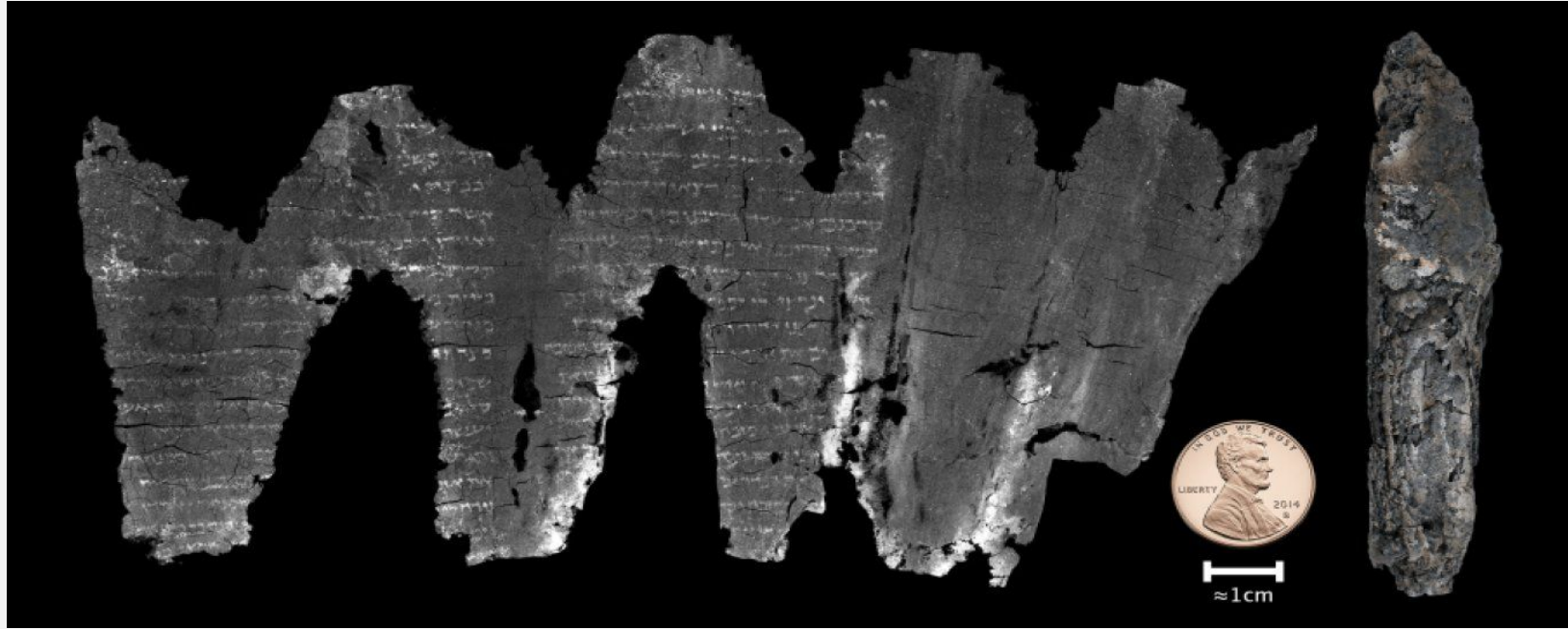


# Distortion in Flattening



Area Error Maps: ABF (left), LSCM (middle), PBM (right)

# Merging & Visualization





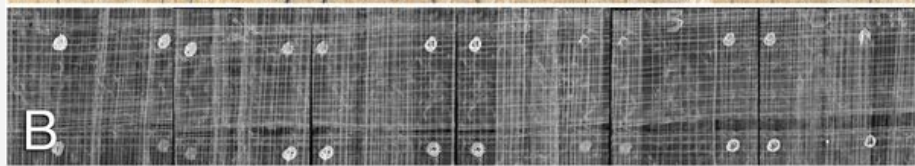
# Further Research

- Improving the pipeline to account for different paper and ink types

A: Reference photograph



B: Integral texture image



C: Network-generated carbon ink prediction image



D: Network-generated photorealistic rendering





# Bibliography

Parker CS, Parsons S, Bandy J, Chapman C, Coppens F, Seales WB (2019) From invisibility to readability: Recovering the ink of Herculaneum. PLoS ONE 14(5): e0215775. Retrieved September 2020

Parker, C. S., Seales, W. B., & Shor, P. (n.d.). Quantitative Distortion Analysis of Flattening Applied to the Scroll from En-Gedi [Scholarly project]. Retrieved September 2020.

Seales, W. B., Parker C.S.. Herculaneum Papyrus Scrolls. Digital Restoration Initiative. Retrieved September 2020.

Seales, W. B., Parker, C. S., Segal, M., Tov, E., Shor, P., & Porath, Y. (2016, September 21). From damage to discovery via virtual unwrapping: Reading the scroll from En-Gedi [Scholarly project]. In Science Advances. Retrieved September 2020.

The background is an abstract geometric pattern composed of numerous triangles of varying sizes and shades of red, pink, and magenta. The colors transition from a lighter pink in the upper left to a darker, more saturated red in the lower right.

# Questions?