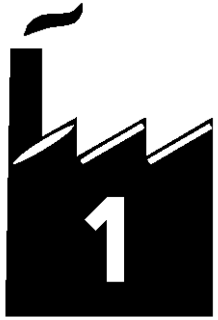
The Patching of Built Ornamental Heritage using Digital Fabrication

P5 Presentation

Ali Sarmad Khan | 4415582

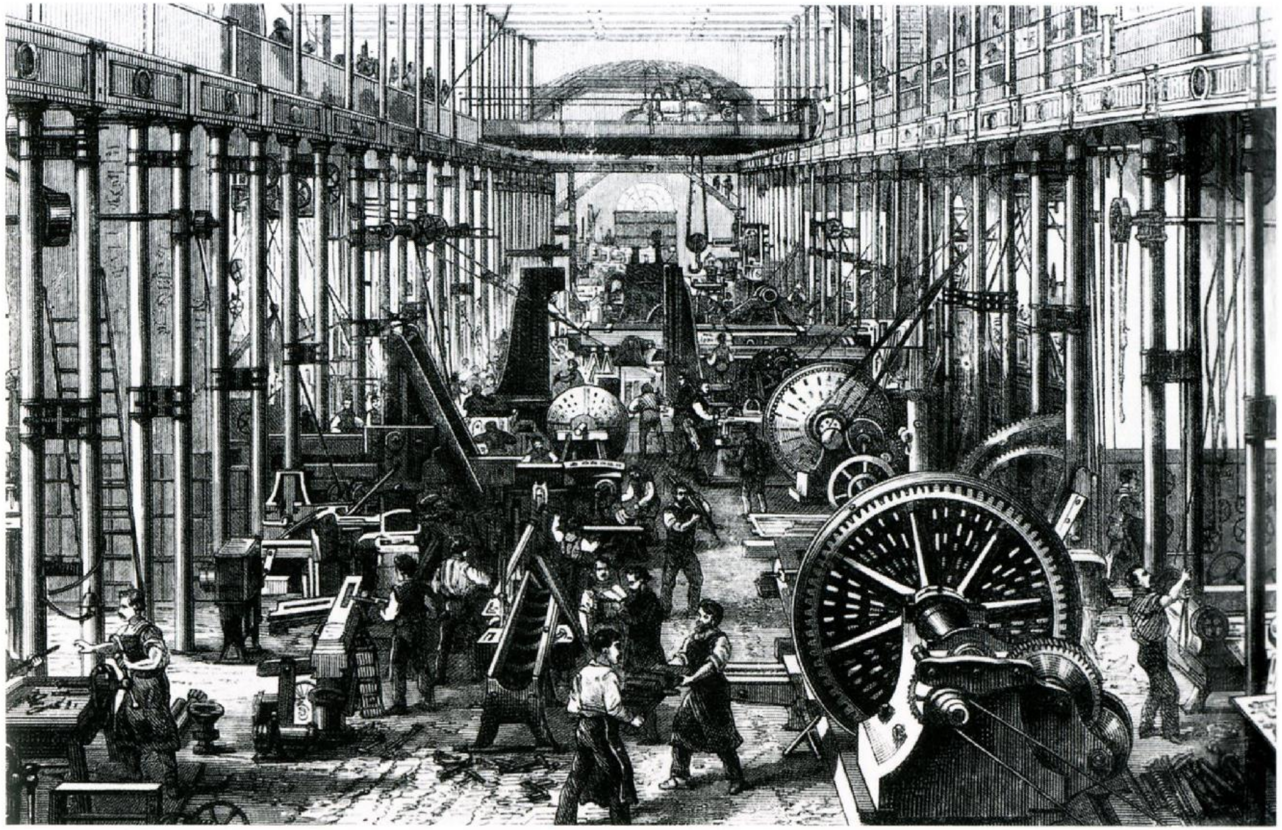
TRACK OF BUILDING TECHNOLOGY
FACULTY OF ARCHITECTURE AND
THE BUILT ENVIRONMENT



First Industrial Revolution
1760 - 1820

First Industrial Revolution
1760 - 1820

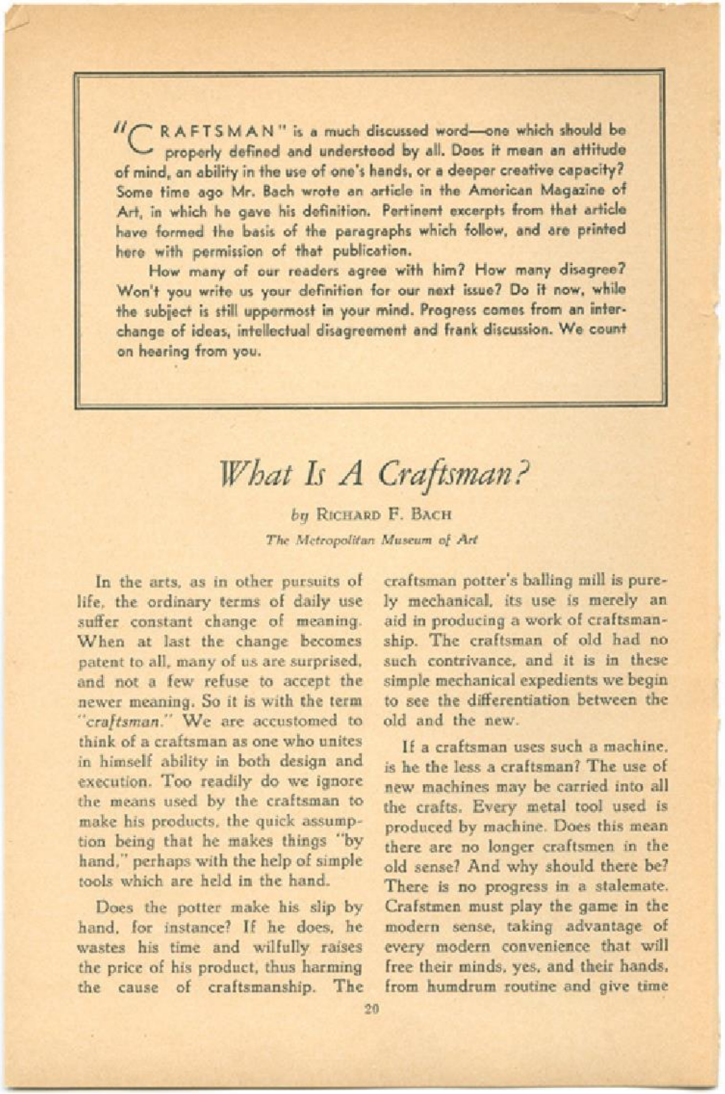
- Alternative Sources of Energy
- Mostly limited to Britain
- Shift from hand held tools and domestic manufacturing to water, steam and wind power amongst others.



First Industrial Revolution
1760 - 1820

Second Industrial Revolution
1870 - 1914

- Electricity
- Introduction of powered personal vehicles
- Faster transportation led to mass production.
- Re-evaluation of definition of craftsman
- Richard F. Bach



"CRAFTSMAN" is a much discussed word—one which should be properly defined and understood by all. Does it mean an attitude of mind, an ability in the use of one's hands, or a deeper creative capacity? Some time ago Mr. Bach wrote an article in the American Magazine of Art, in which he gave his definition. Pertinent excerpts from that article have formed the basis of the paragraphs which follow, and are printed here with permission of that publication.

How many of our readers agree with him? How many disagree? Won't you write us your definition for our next issue? Do it now, while the subject is still uppermost in your mind. Progress comes from an interchange of ideas, intellectual disagreement and frank discussion. We count on hearing from you.

What Is A Craftsman?

by RICHARD F. BACH

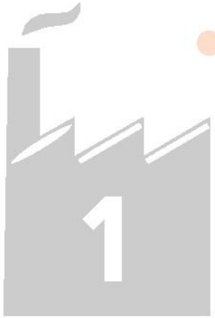
The Metropolitan Museum of Art

In the arts, as in other pursuits of life, the ordinary terms of daily use suffer constant change of meaning. When at last the change becomes patent to all, many of us are surprised, and not a few refuse to accept the newer meaning. So it is with the term "*craftsman*." We are accustomed to think of a craftsman as one who unites in himself ability in both design and execution. Too readily do we ignore the means used by the craftsman to make his products, the quick assumption being that he makes things "by hand," perhaps with the help of simple tools which are held in the hand.

Does the potter make his slip by hand, for instance? If he does, he wastes his time and wilfully raises the price of his product, thus harming the cause of craftsmanship. The craftsman potter's balling mill is purely mechanical, its use is merely an aid in producing a work of craftsmanship. The craftsman of old had no such contrivance, and it is in these simple mechanical expedients we begin to see the differentiation between the old and the new.

If a craftsman uses such a machine, is he the less a craftsman? The use of new machines may be carried into all the crafts. Every metal tool used is produced by machine. Does this mean there are no longer craftsmen in the old sense? And why should there be? There is no progress in a stalemate. Crafstmen must play the game in the modern sense, taking advantage of every modern convenience that will free their minds, yes, and their hands, from humdrum routine and give time

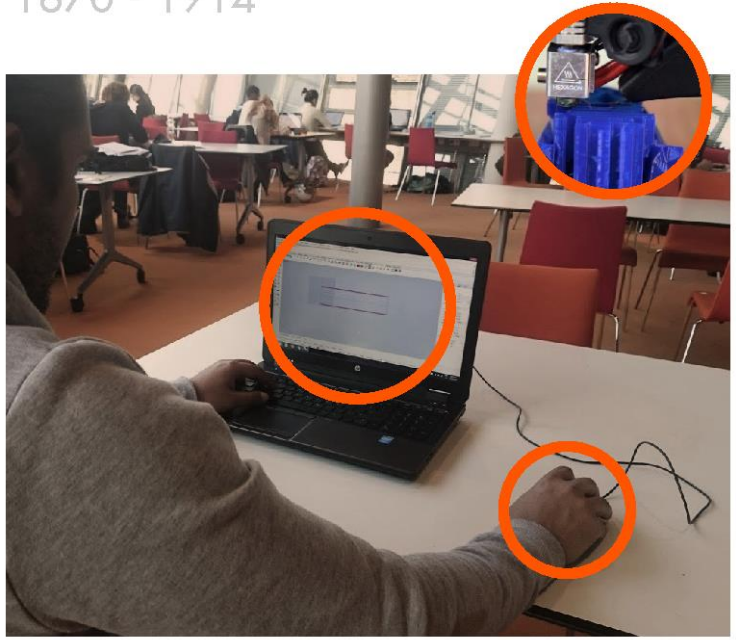
20



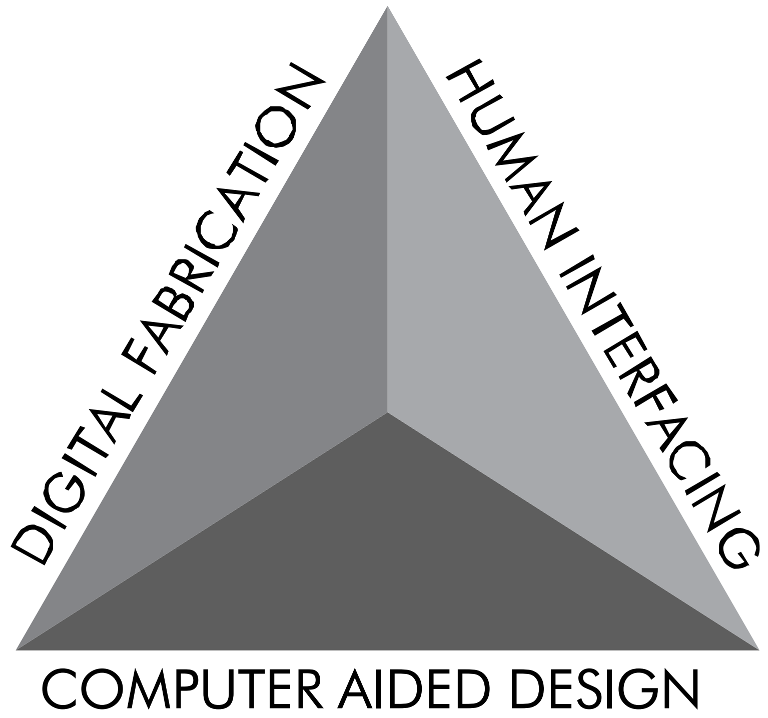
First Industrial Revolution
1760 - 1820

Second Industrial Revolution
1870 - 1914

Third Industrial Revolution
1970s - Now



- Personal Computers
- The Internet
- Digital Fabrication
- The 'Neo-Craftsman'


DIGITAL FABRICATION
HUMAN INTERFACING
COMPUTER AIDED DESIGN

COST

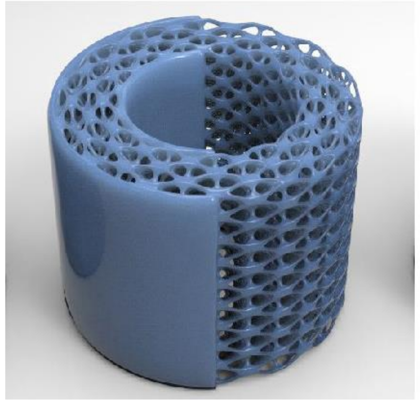
TIME

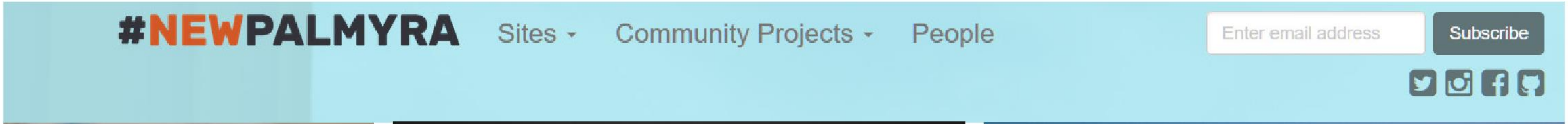
DAMAGE

DISTANCE

COMPLEXITY

MASS





Bassel Khartabil, Syrian Open-source Developer, Jailed since 2012

Model of the Temple of Bel, destroyed in 2015

Replicas of the entrance arch are being planned for Trafalgar Square, London and Times Square, NYC

Objective

To create a **guide** for the use of **digital fabrication** techniques for the restoration of damaged ornaments in the field of architectural **conservation** and thereby explore the role of the craftsman.

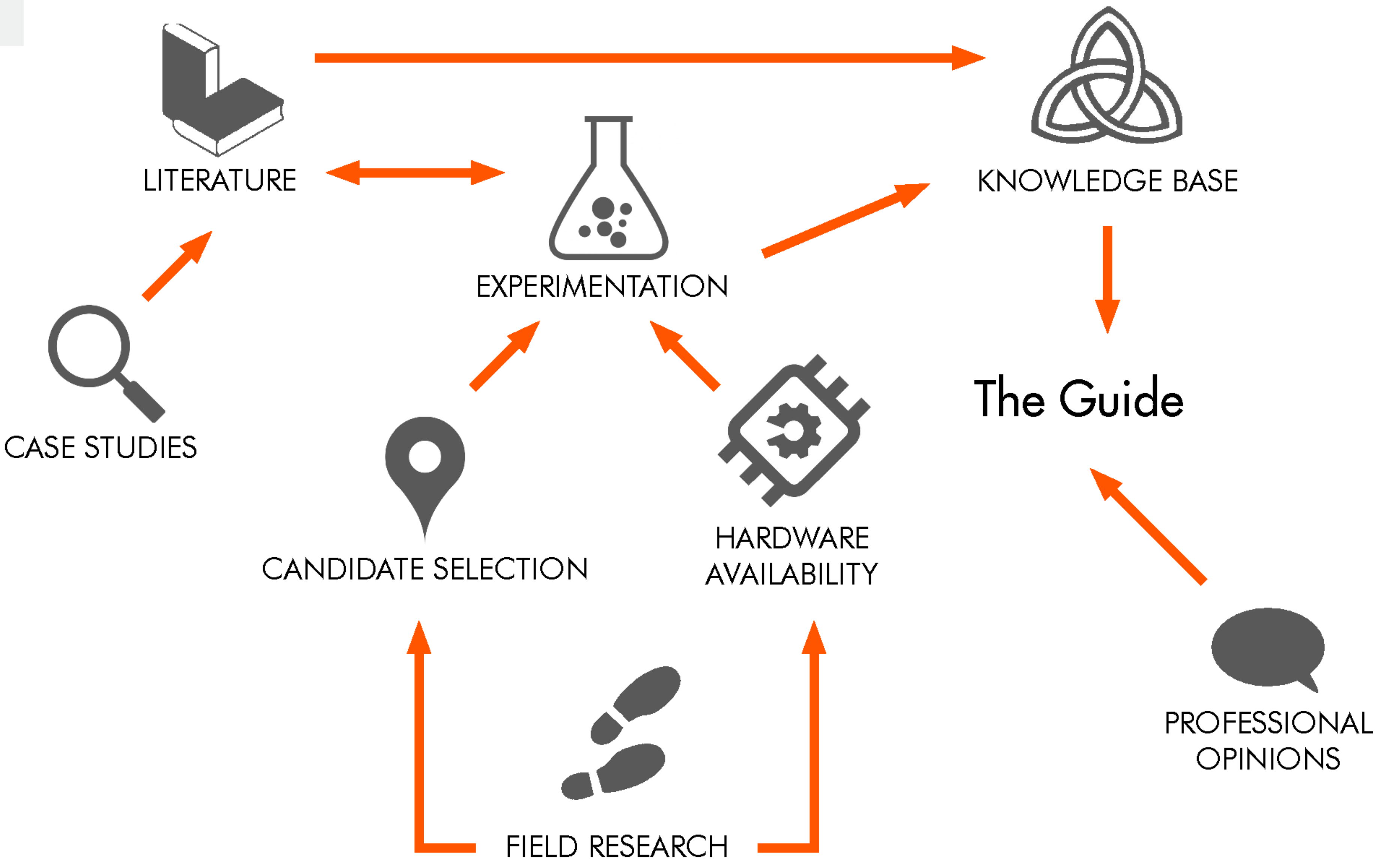
Primary fields of research:

Architectural Conservation +	3D Scanning +	Digital Fabrication
- Determining Candidates	- Scanning to Document	- Finding Best Solution
- Comparing with existing techniques	- Scanning to Modify	- Comparing Techniques
- Professional Opinions (Subjectivity)	- Comparing Techniques	- Hybridization
	- Interpolating new geometry	- Post-processing
	- Troubleshooting	- Optimization
		- Troubleshooting

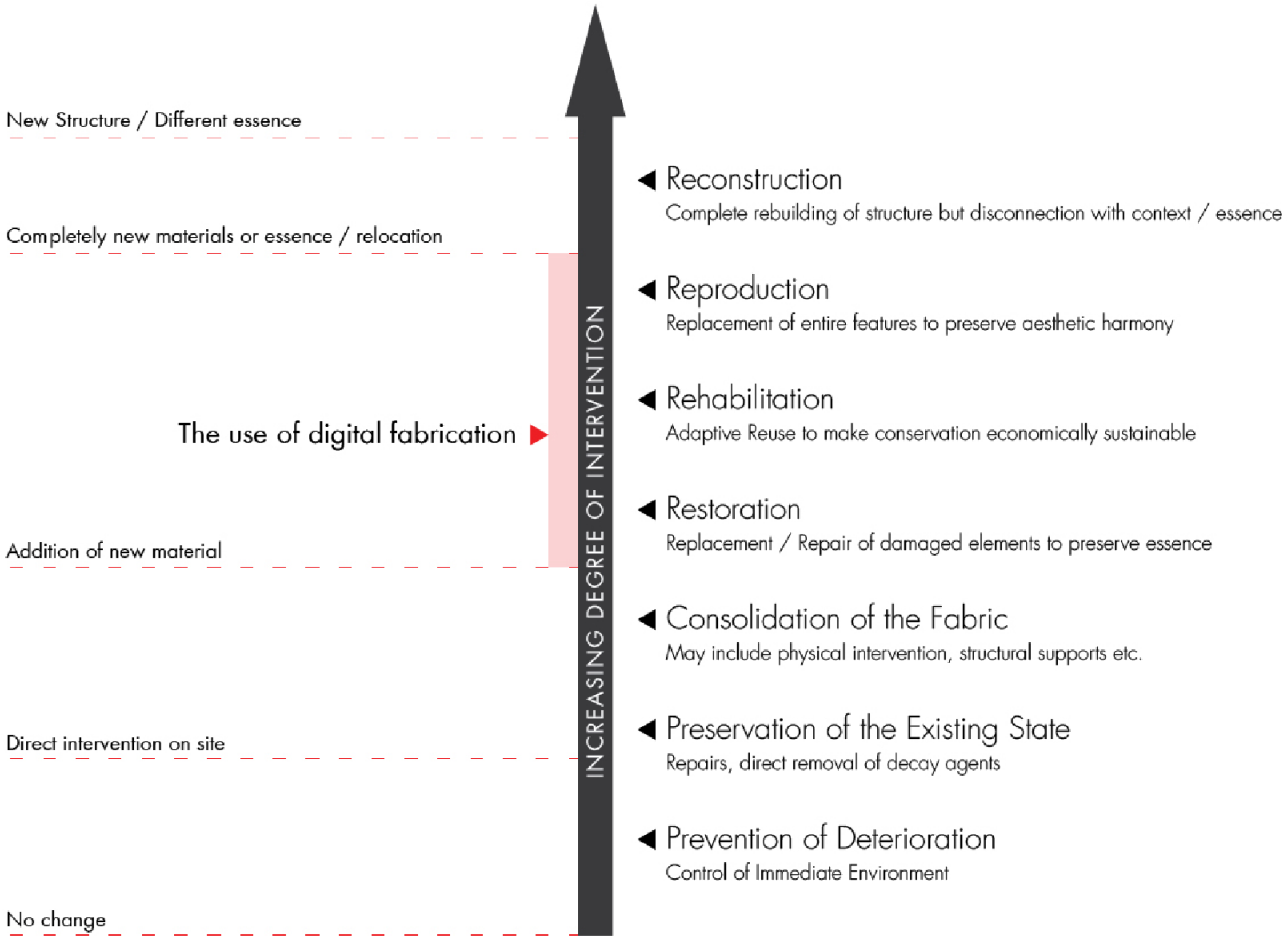
Research Question

‘What are the influencing factors in the use and selection of LIDAR and Digital Fabrication for the patching of ornamental heritage?’

Methodology



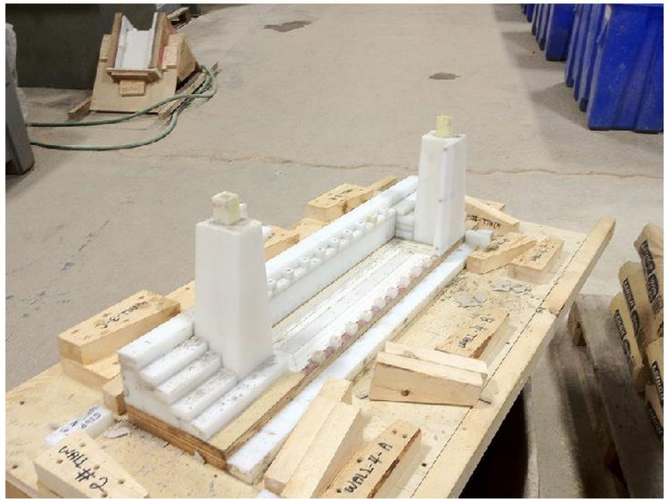
Degrees of Intervention



Case Study 1:
Annie Pfeiffer Chapel

Located in Florida Southern College, Lakeland, Florida, USA is a structure designed by architect **Frank Lloyd Wright** and completed in **1941**.

Restoration being carried out by **Mesick Cohen Wilson Baker Architects** (MCWB) via the use of 3D printing.



The Teflon was combined with wood (handcrafted) to recreate the molds, an example of hybridization.

The prototype tile was successfully casted using an unspecified concrete mixture.

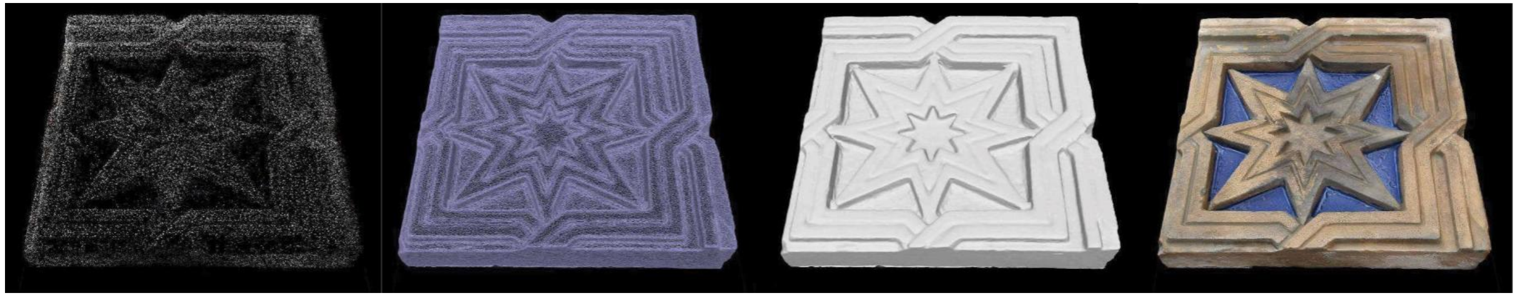
Case Study 2:
Great Synagogue of Timisoara (Ceramic Tile)

Pro-Jet - Powder Infiltrate

(Most expensive but colored and accurate)

Fused Deposition Modeling (FDM) - PLA material

(Low quality but cheap)



Scanned using photogrammetry

Selective Laser Sintering (SLS) - Nylon 12

(Comparatively expensive but accurate)

Traditional Patching Methods

The Dutchman Repair

Step 1
Identification :
Concentrated Damage

Step 2
Relief cuts for removal

Step 3
Material chiseled out

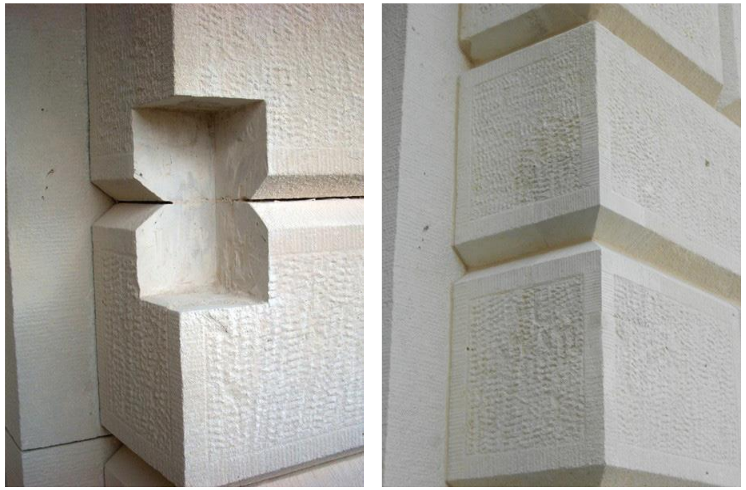
Step 4
Steel rods with complementary grooves (2cm offset)

Step 5
Dry fitted and then bound with hydraulic lime or epoxy

Stone Ionic Capital (Canadian Atlantic Sandstone)

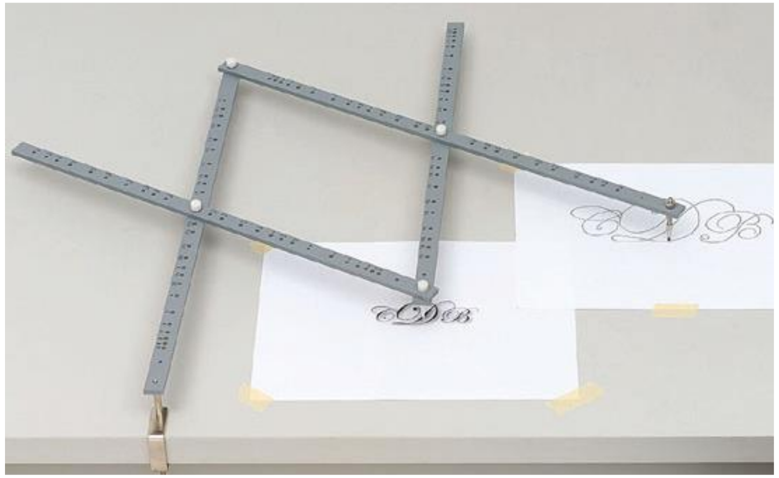
Stone Fluted Column (Tradesman Group)

Fluted Column (Wooden)



Stone Corner Repair (Treanor Architects)

Stone Pantographic Infills (Acropolis)



Stonemason's Pantograph

Stereo-pantograph (Acropolis)

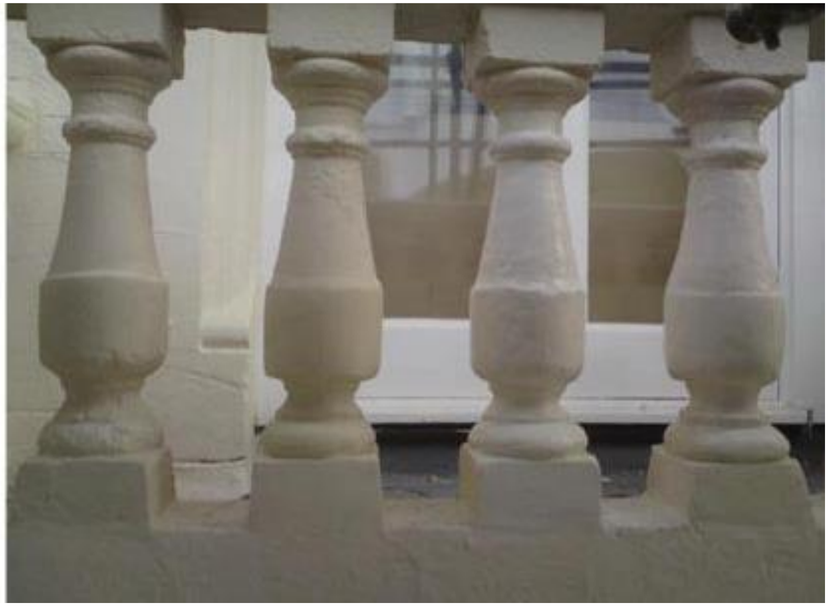
Various Steel Bars (Titanium)

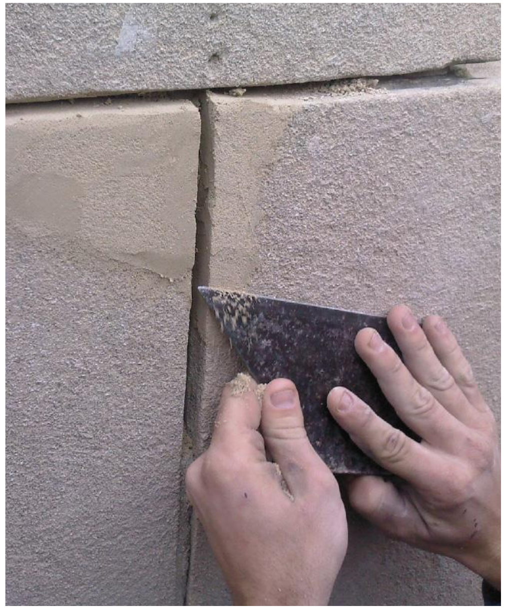
Fitting of new pieces

Geometric Contrast (Offset and Color)

Slots for Steel Bars

In-situ Mortar Patching





Stone Balustrades (Plastic Surgeon Fine Finishers)

Comparison with Digital Fabrication

METHOD	LEVEL OF INTERVENTION (LOWER IS HIGHER)	ECONOMY (LOWER IS MORE EXPENSIVE)	TIME REQUIRED (LOWER IS HIGHER)	LEARNING CURVE (LOWER IS HIGHER)
DUTCHMAN REPAIR	1	2	2	2
PANTOGRAPHIC INFILL	3	1	1	1
MORTAR PATCHING	2	4	4	3
DIGITAL FABRICATION	3	3	3	2

Professional Opinions: Digital Fabrication

prof.ir. Rob van Hees

Professor of Heritage & Technology,
Conservationist and Researcher

"…traditional craftsman important for **final touch**…"

"…**too perfect** may become visible…"

…useful when only **photographic evidence** is left…

…limitation of **variety of materials** is holding digital fabrication back…

Hugo van Milt

Restoration Architect & Manager at
Van Milt Restorers

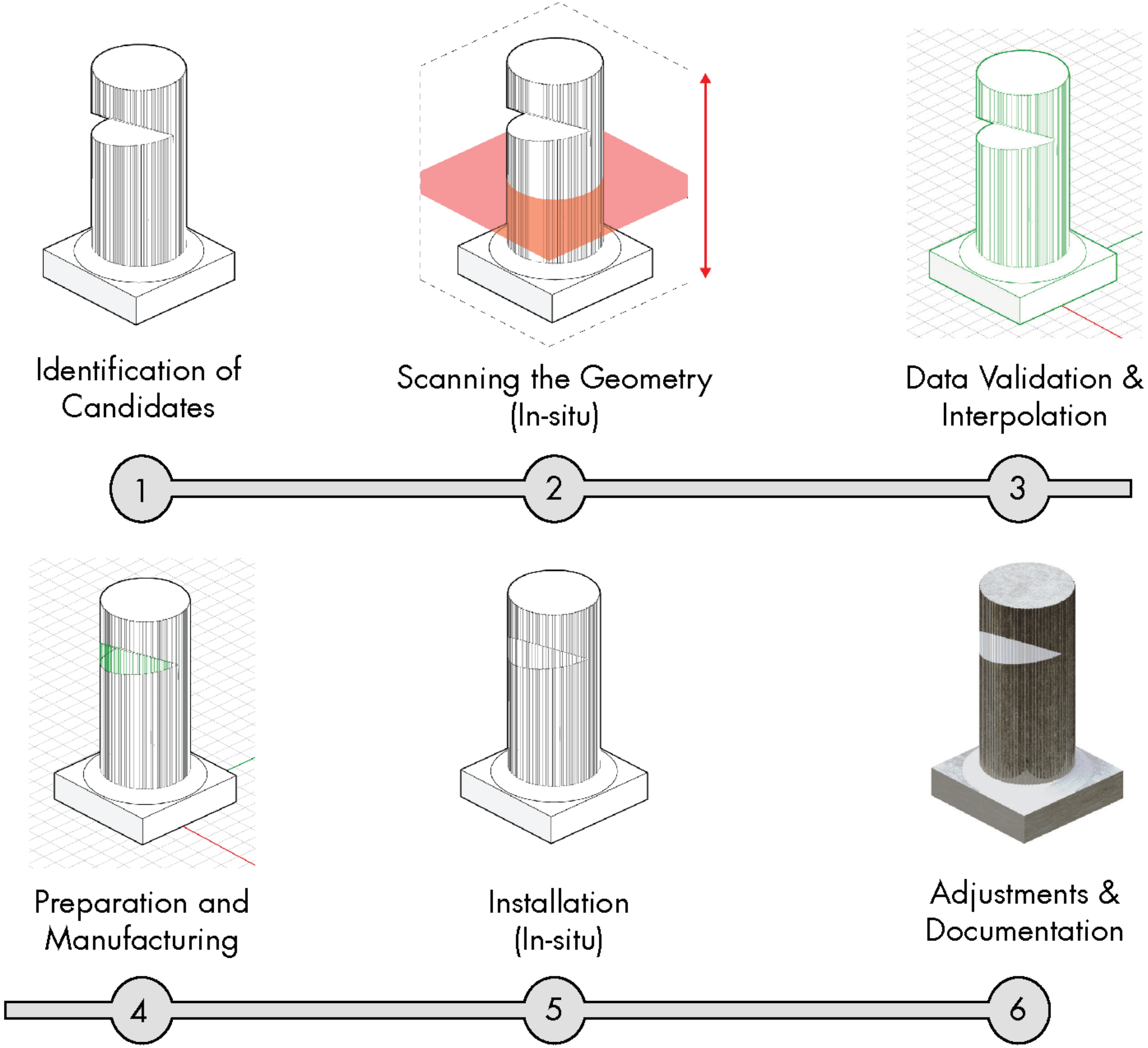
"…machine does not look at the **quality of stone**, it does not look at cracks for example, while a craftsman can…"

"…we use digital fabrication to make molds but have trouble finding the **correct materials**…"

…**authorities** prefer traditional materials and old technologies…

…there's a risk that with increasing digital technologies restoration may become **fake and artificial**…

Modus Operandi



3D Scanning
(LIDAR)

Laser Scanner: Zoller + Fröhlich Imager 5010C

- **Phase Comparison** Scanner

- Manufactured by German engineering firm Zoller + Fröhlich.

- Also includes a rotating mirror to increase Field of View.

- Integrated CMOS camera.

- Dust and water proof and allows wireless communication.

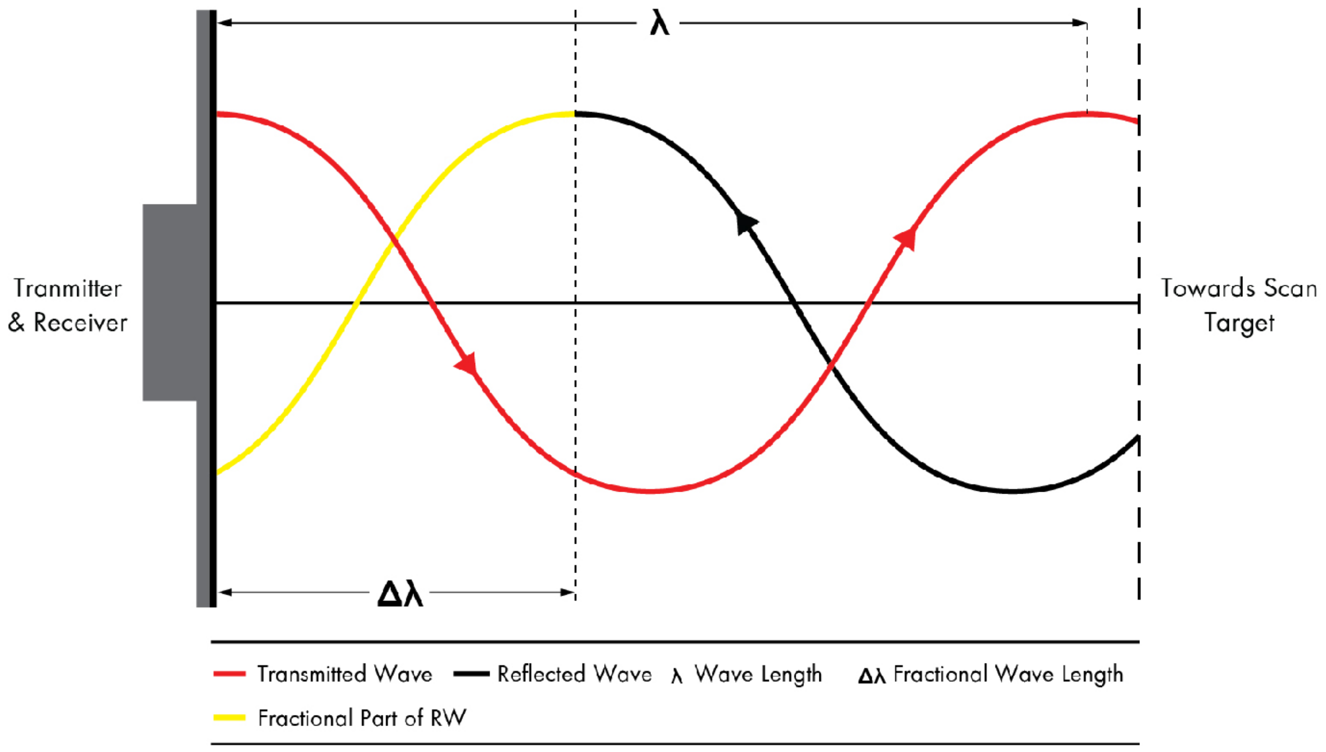
- Scan Range: 187.3m

- Spot Size: At 0.1m range, 3.5mm

- Sourced from Delft based scanning company Delfttech.

Phase Comparison

- Higher rate of capture than other active scanning techniques.
- Lesser range, at around 100 m.
- Produce denser point clouds.



$$R = \frac{(M\lambda + \Delta\lambda)}{2}$$

Where,

R is the distance from the surface,

M is the number of wavelengths (integer),

λ is the known value of the wavelength,

Δλ is the fractional part of the wavelength.

Ideal Laser Scanning Conditions

- **Optimal lighting conditions**
  Preferably indirect light of medium intensity to reduce glare.

- **The material of the object**
  Matte finish is ideal since it has minimal glare, can be temporarily coated with special paint.

- **The object color**
  Red or dark colors in poor lighting conditions or bright colors in bright lighting conditions can affect the reflectivity.

- **The shape of the object**
  Cavities, hidden faces, furry surfaces can drastically affect the result.

Preparing the Site (According to Delfttech)

i. Clean lens and mirror, Charge battery

ii. Place reference targets

iii. Place and level tripod

iv. Attach the tribrach

v. Recheck mirror and lens, clean if necessary.

vi. Mount scanner on tribrach, adjust if necessary.

vii. Turn on scanner, tweak parameters.

viii. Clean lens and mirror again, recharge.

Mesh Generation

Meshing Software

MESHLAB

- Freeware
- Highest level of control
- Least user friendly
- Higher learning curve
- No mesh editing tools

CLOUDCOMPARE

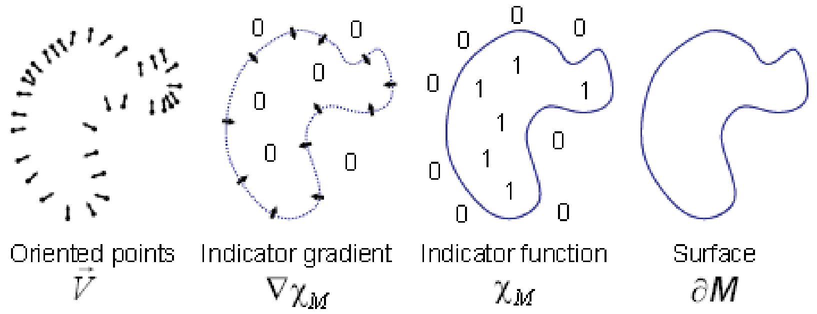
- Freeware
- High level of control but limited tweaking
- Third party plugins have to be used
- Relatively user friendly
- No mesh editing tools

GEOMAGIC WRAP

- Proprietary
- Relatively high level of control
- Very user friendly
- Powerful mesh editing tools

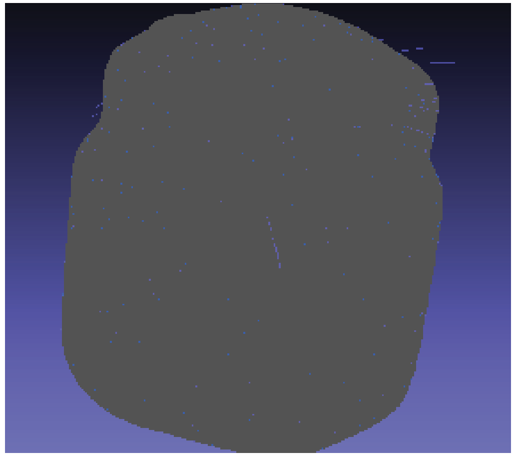
Meshing

- **Chosen meshing algorithm:** Poisson Surface Reconstruction

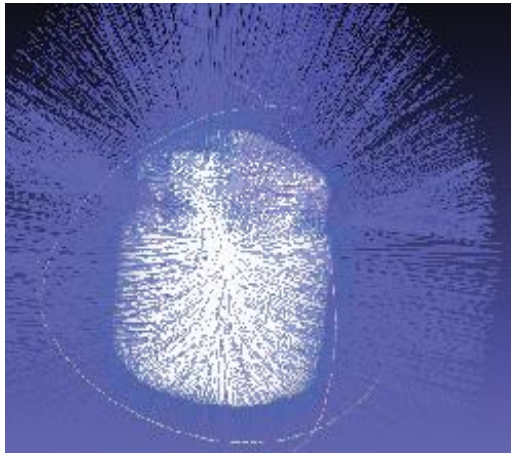


- **Primary Parameters**
  - Octree Depth
  - Solver Divide
  - Samples per Node

- **Competing parameters:** Time – Detail – Processing Power



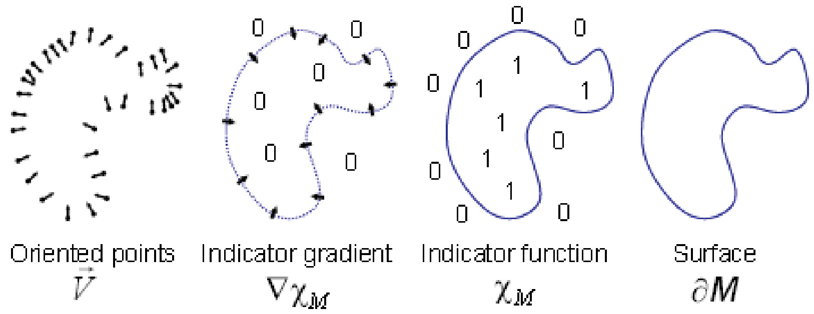
Unoriented Normals



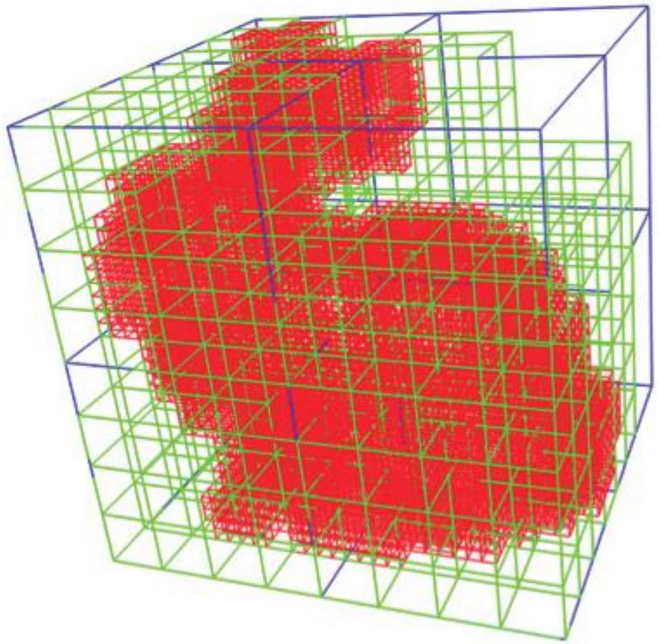
Oriented Normals

Meshing

- **Chosen meshing algorithm:** Poisson Surface Reconstruction



- **Primary Parameters**
  - Octree Depth
  - Solver Divide
  - Samples per Node

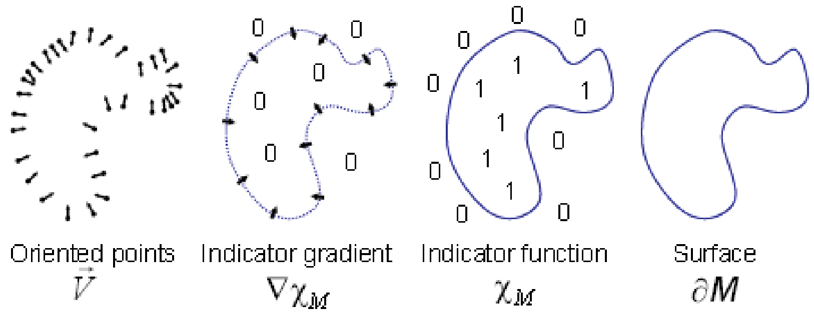


- Determines resolution of 3D Grid
- Universal optimum value of 12
- Diminishing results

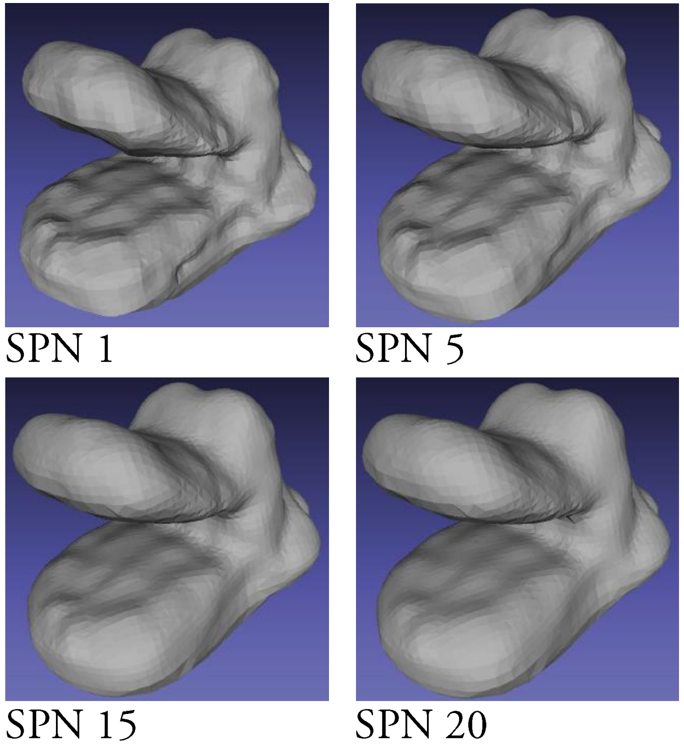
- **Competing parameters:** Time – Detail – Processing Power

Meshing

- **Chosen meshing algorithm:** Poisson Surface Reconstruction



- **Primary Parameters**
  - Octree Depth
  - Solver Divide
  - Samples per Node



- Higher values exclude anomalous data
- Values 1 – 5 optimum for low noise data
- Higher values reduce noise at the expense of detail.

- **Competing parameters:** Time – Detail – Processing Power

Candidate 1: Stone Column Segment

Location: Department of Architecture, TU Delft

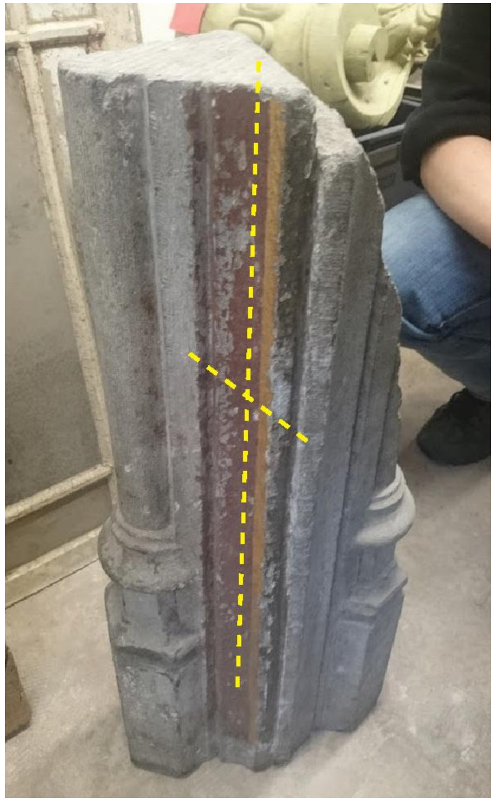
Date: Unknown

Focus: Regeneration of missing fragment

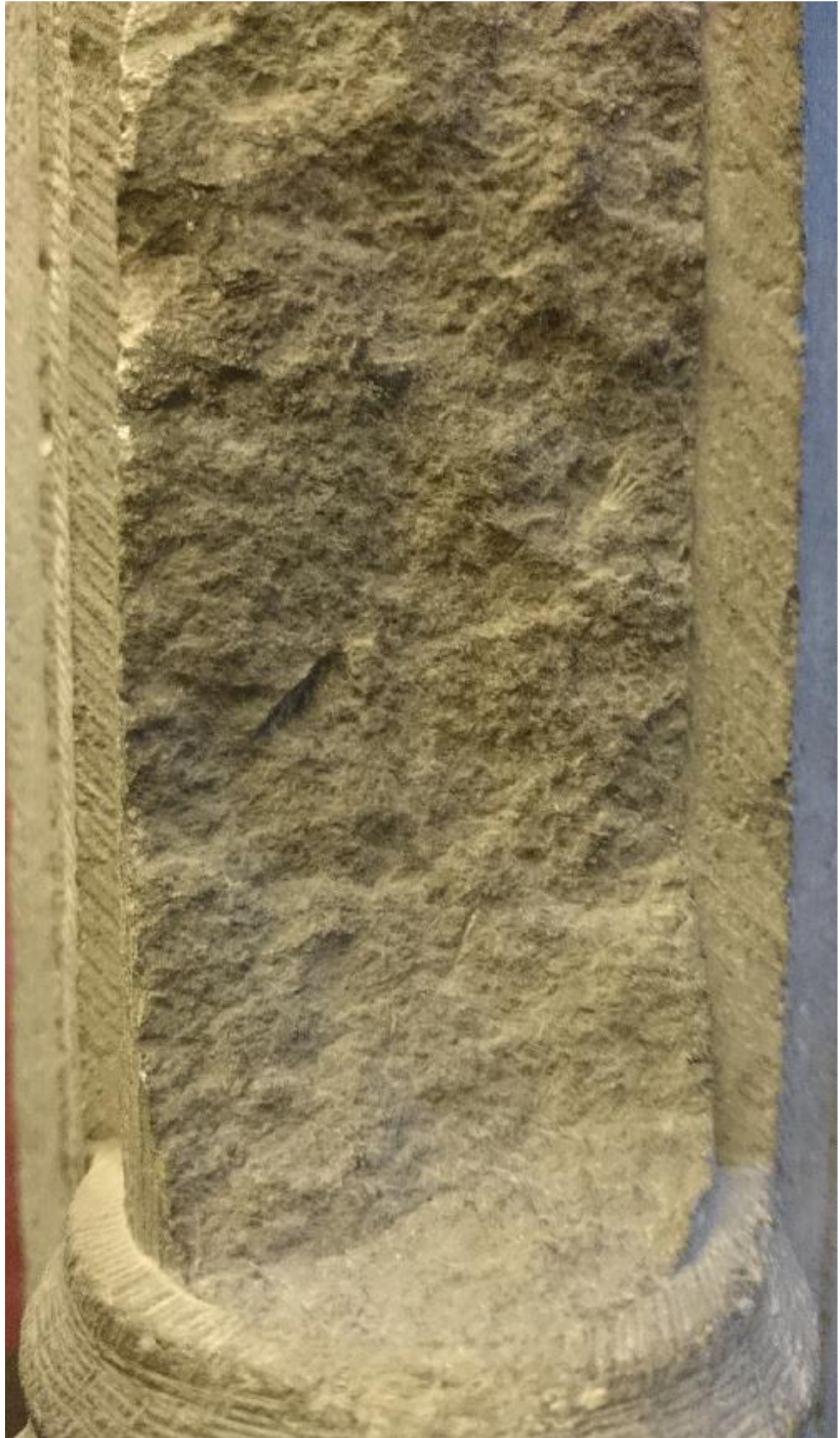
Function: Column (Possibly Mullion)

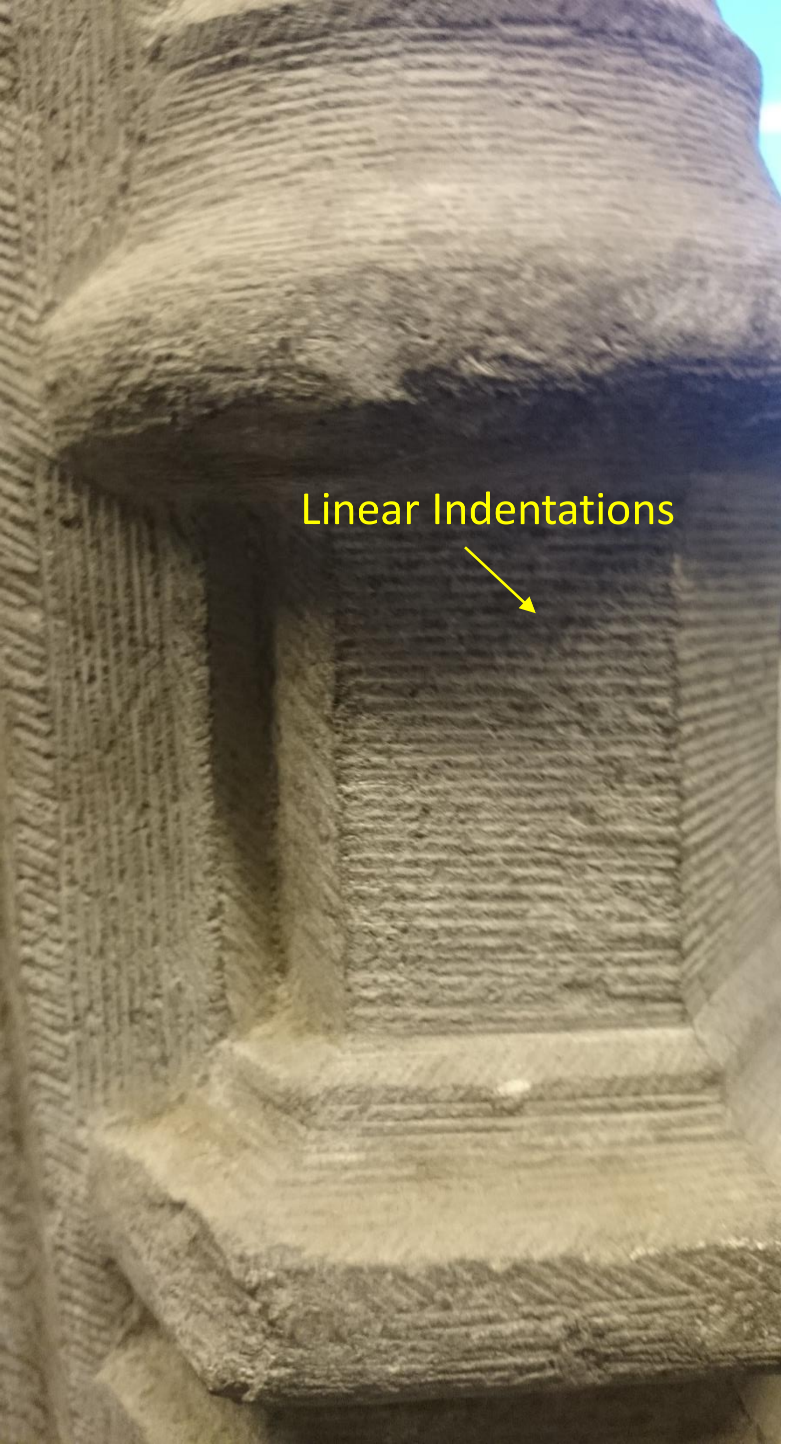
Conjecture:

- Acid test produced **effervescence**, possibly limestone or calcite containing stone.
- Possibly **Belgian Blue Limestone** (Dense)
- Possibly column with inserts for **windows**.
- Unbroken side shows more **erosion** than broken, could give insight into orientation of element.

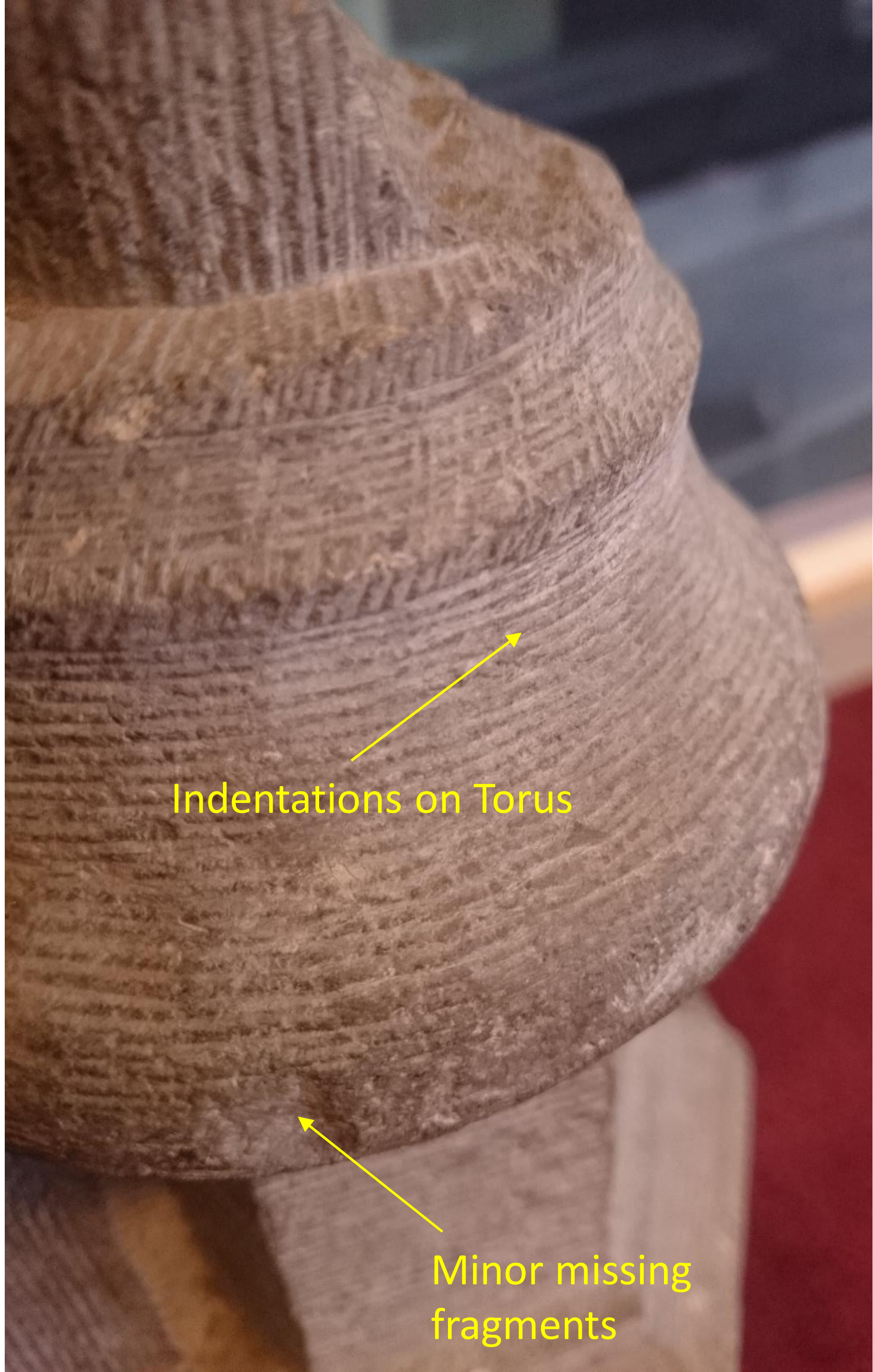




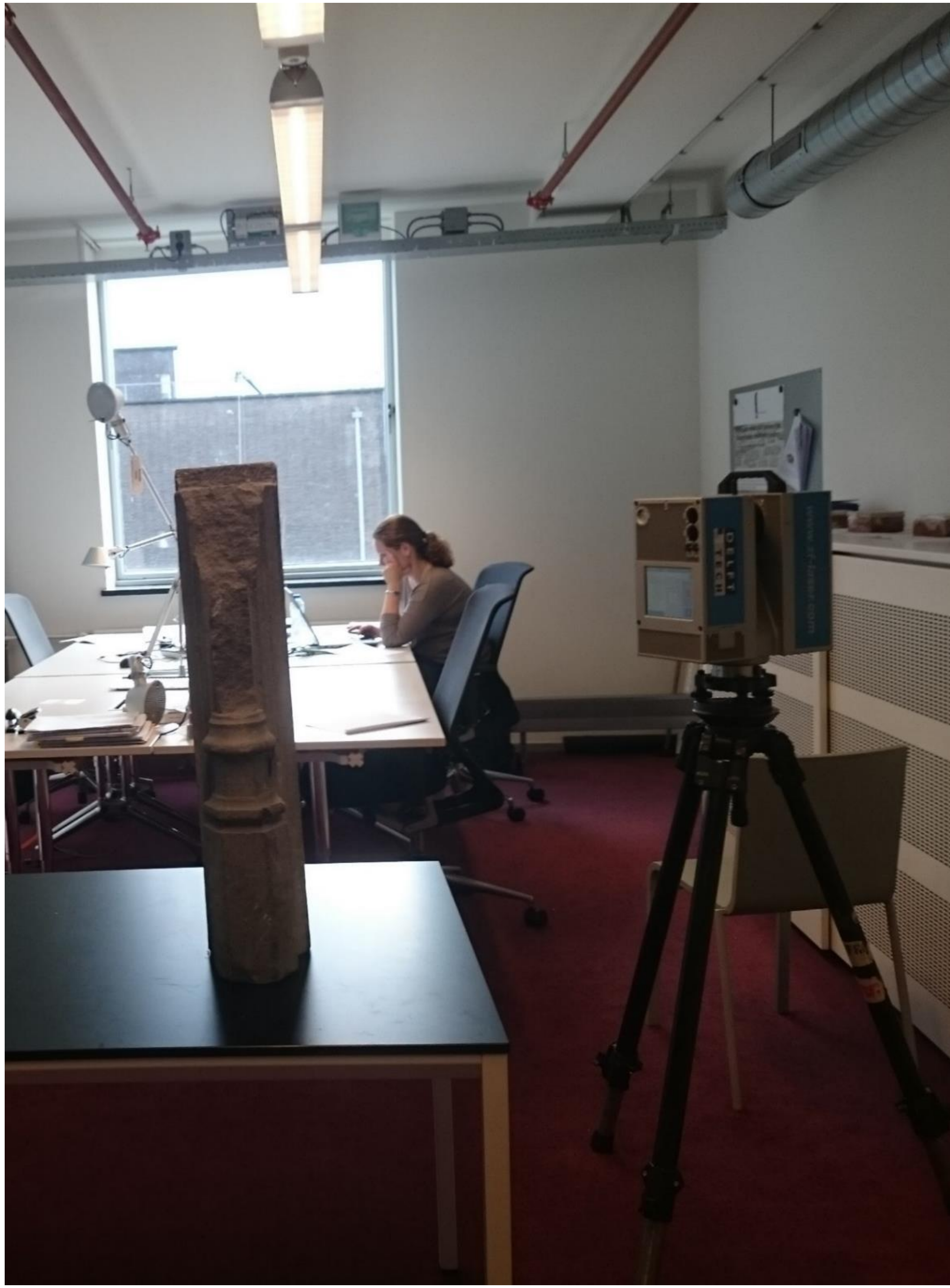



Linear Indentations


Signs of Faded Paint

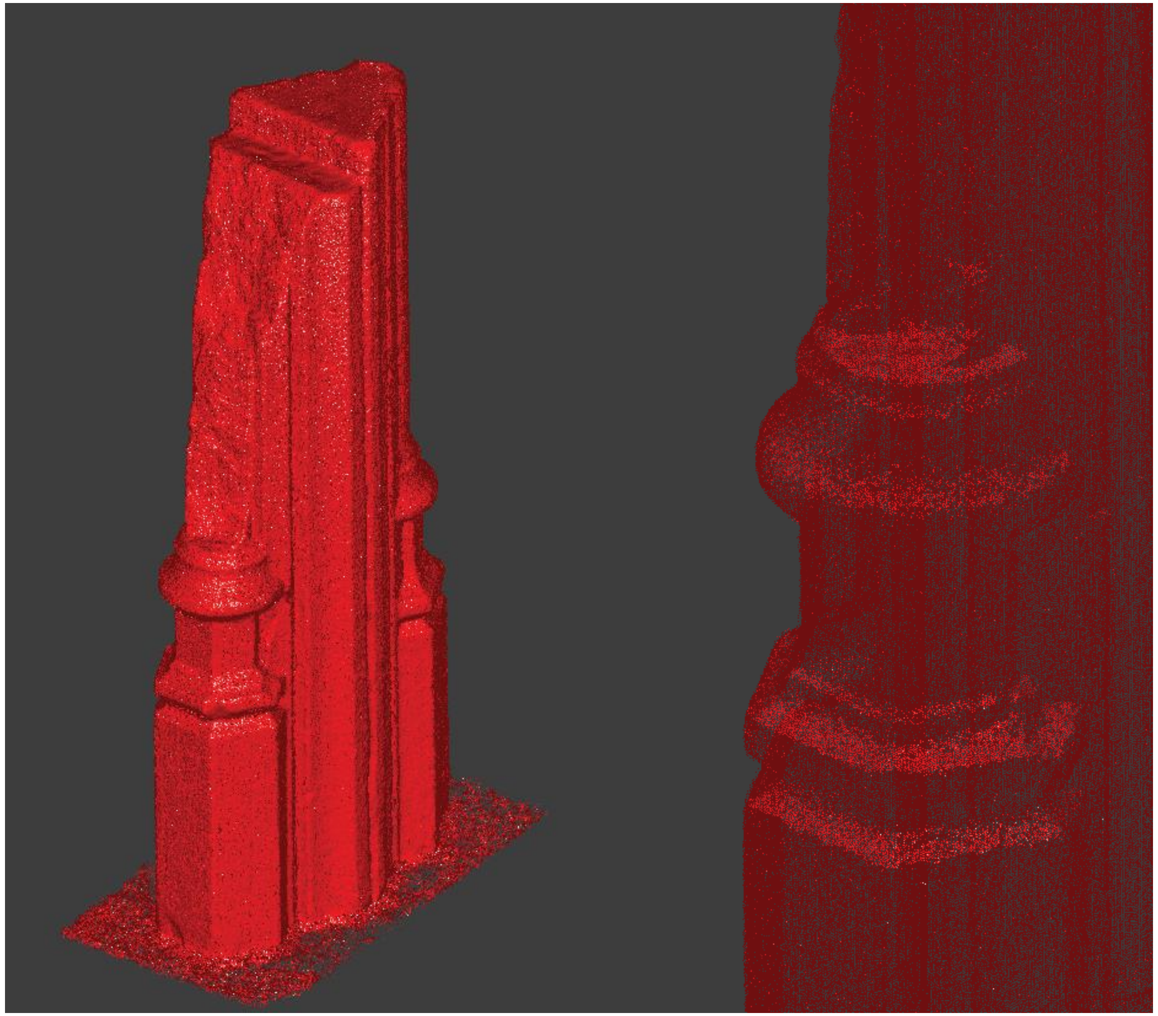

Indentations on Torus
Minor missing fragments

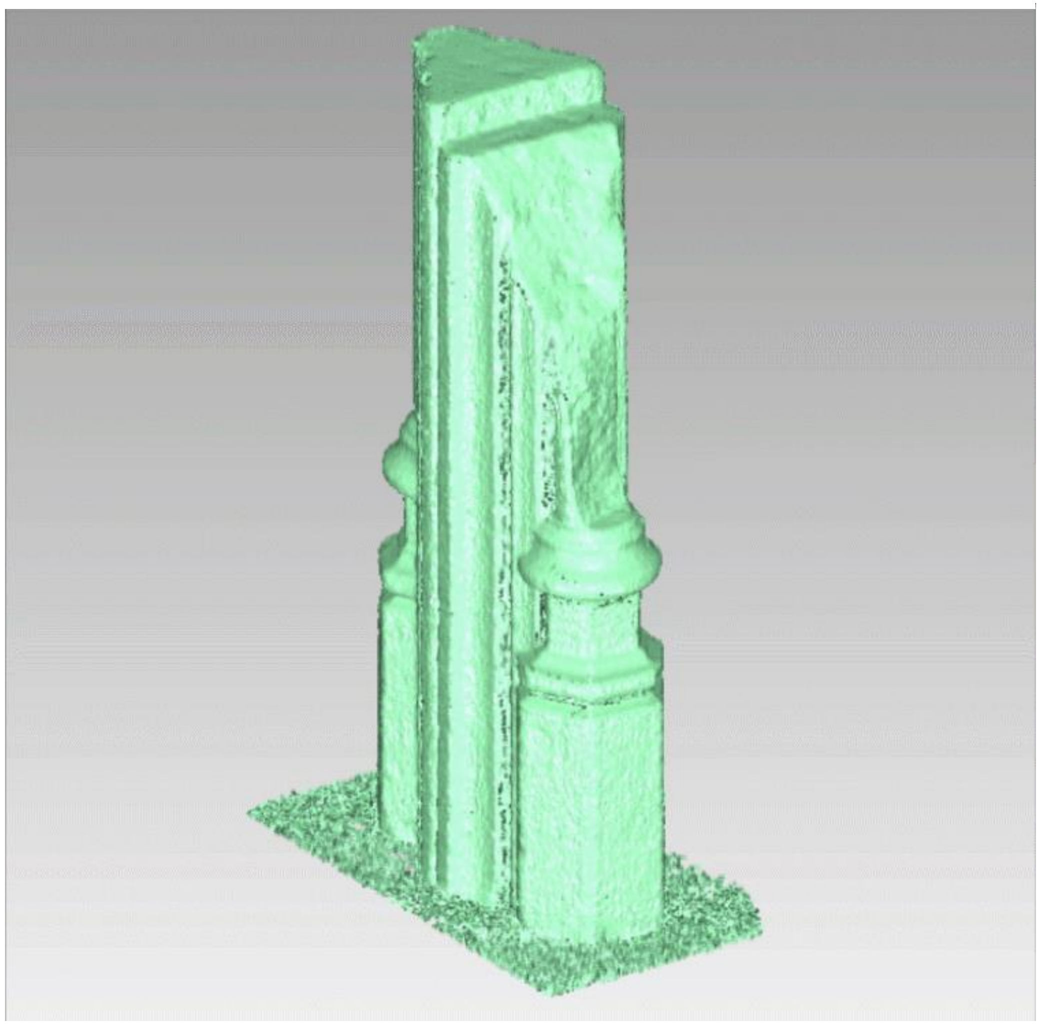

IMAGER 5010C
DELFT TECH

1
BKCity

DELFT TECH

4
5
6

Imported Geometry



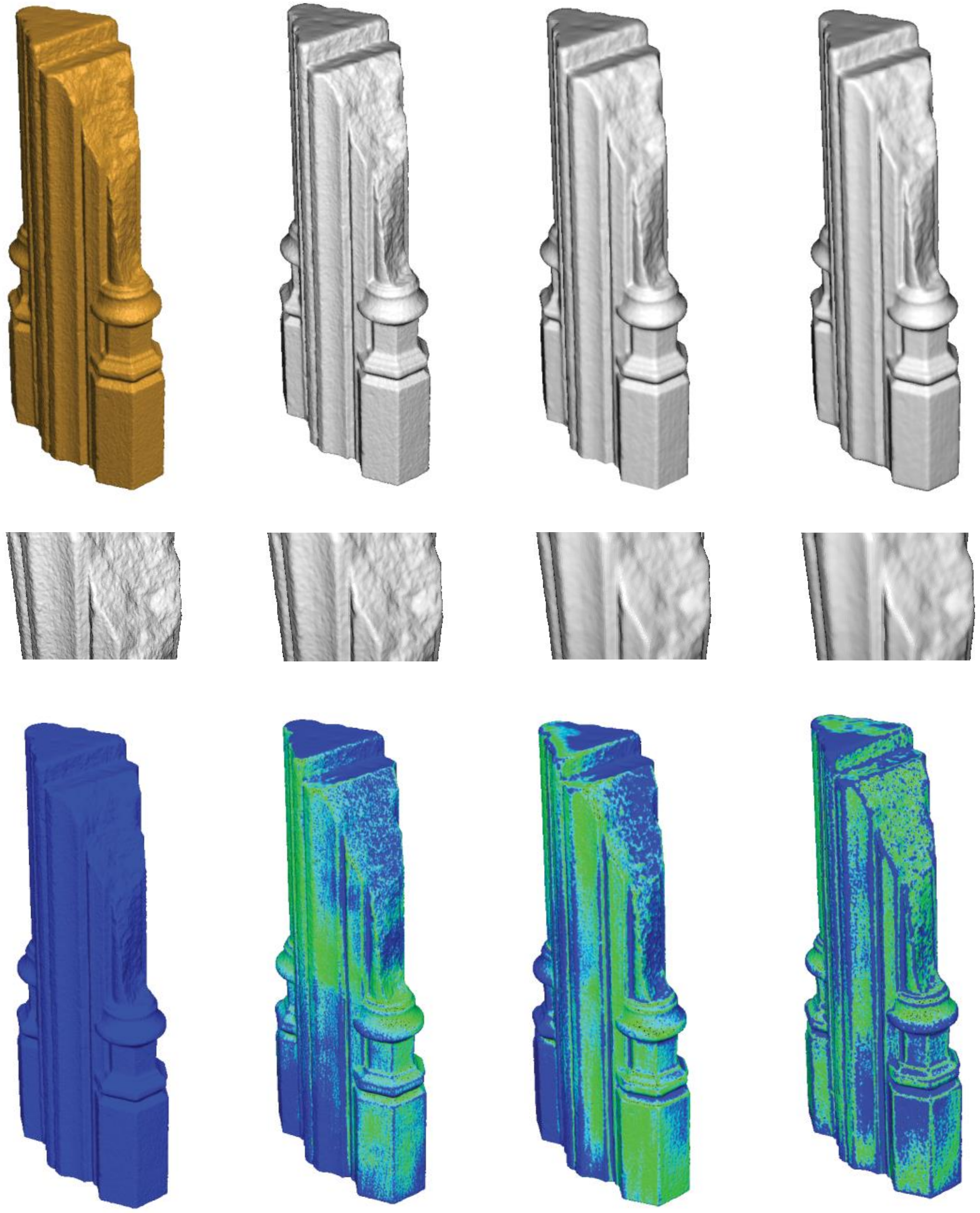


1,528,925 Points Imported

Mesh Generation: Meshlab

- More meshing algorithms available
- Memory management issues **limit Octree Depth to 12**
- **Samples per node** above 15 causes changes on fracture surface
- Excess smoothing even between 10 - 15 range

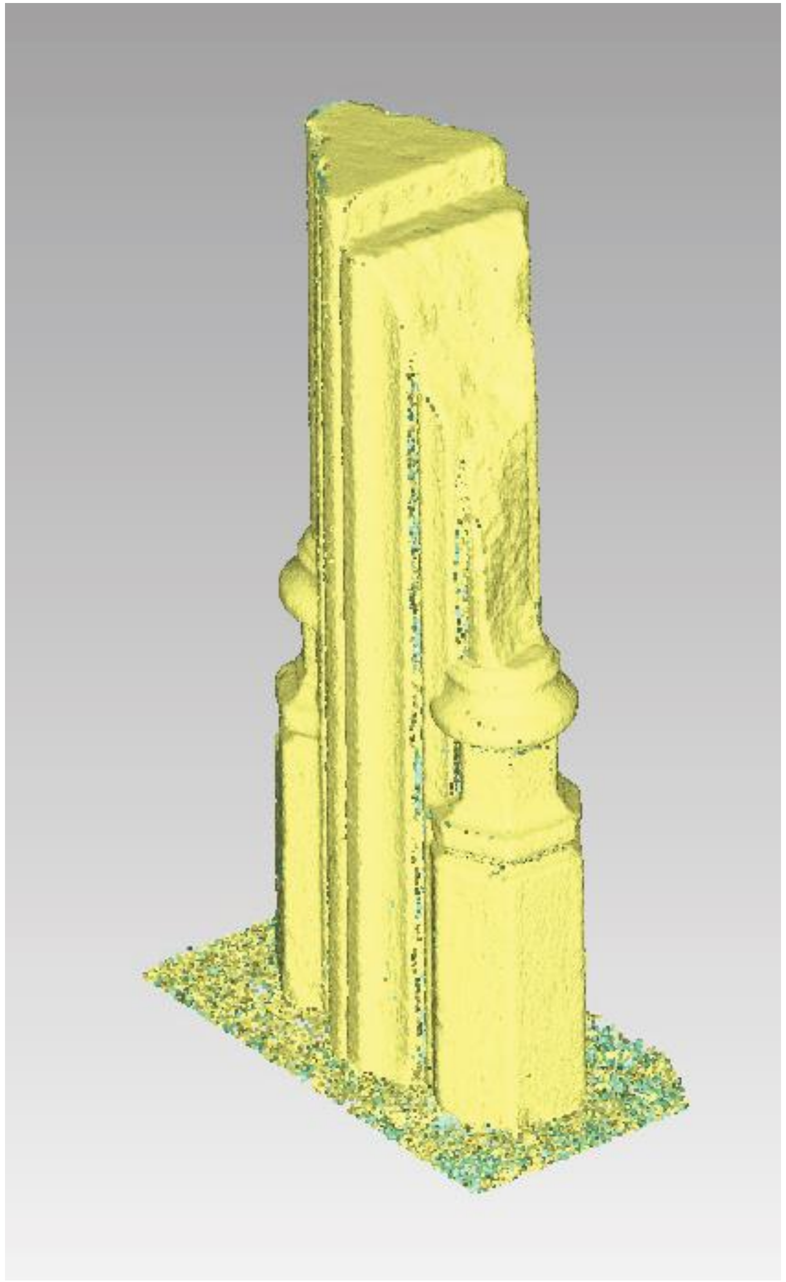
- Frequent failure of meshing calculation

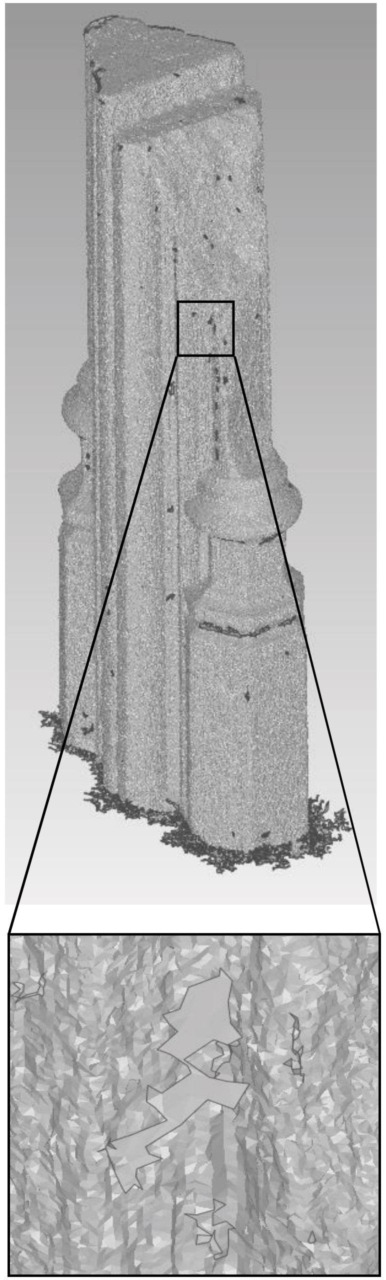


Samples per node: 1 *Samples per node: 4* *Samples per node: 15* *Samples per node: 20*

Mesh Generation: Geomagic Wrap

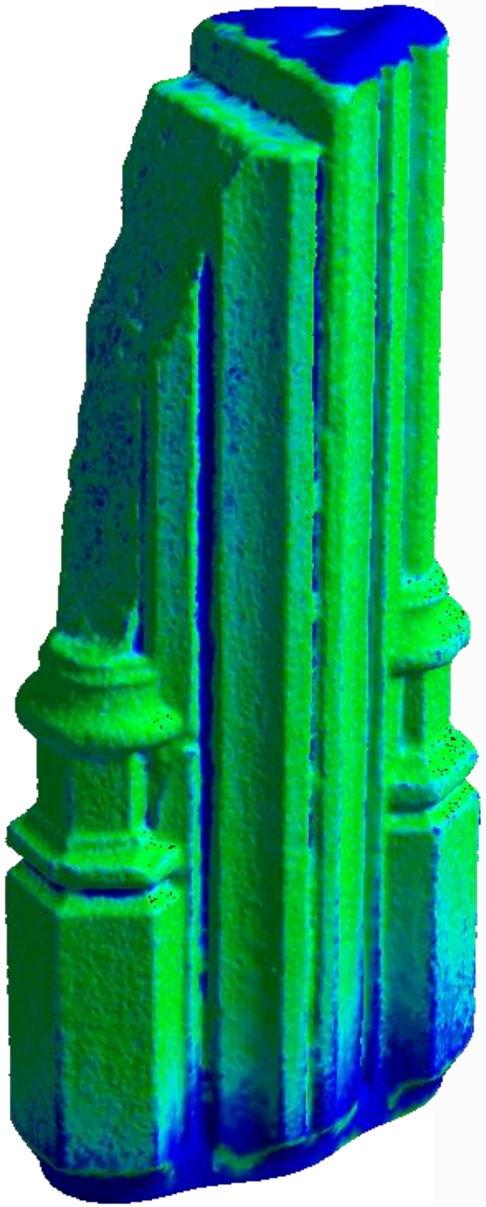
- Only one meshing algorithm ‘Wrap’
- Meshing causes **holes** in geometry
- Holes have to be **patched manually**
- Smoothing **less than Meshlab** but with more detail



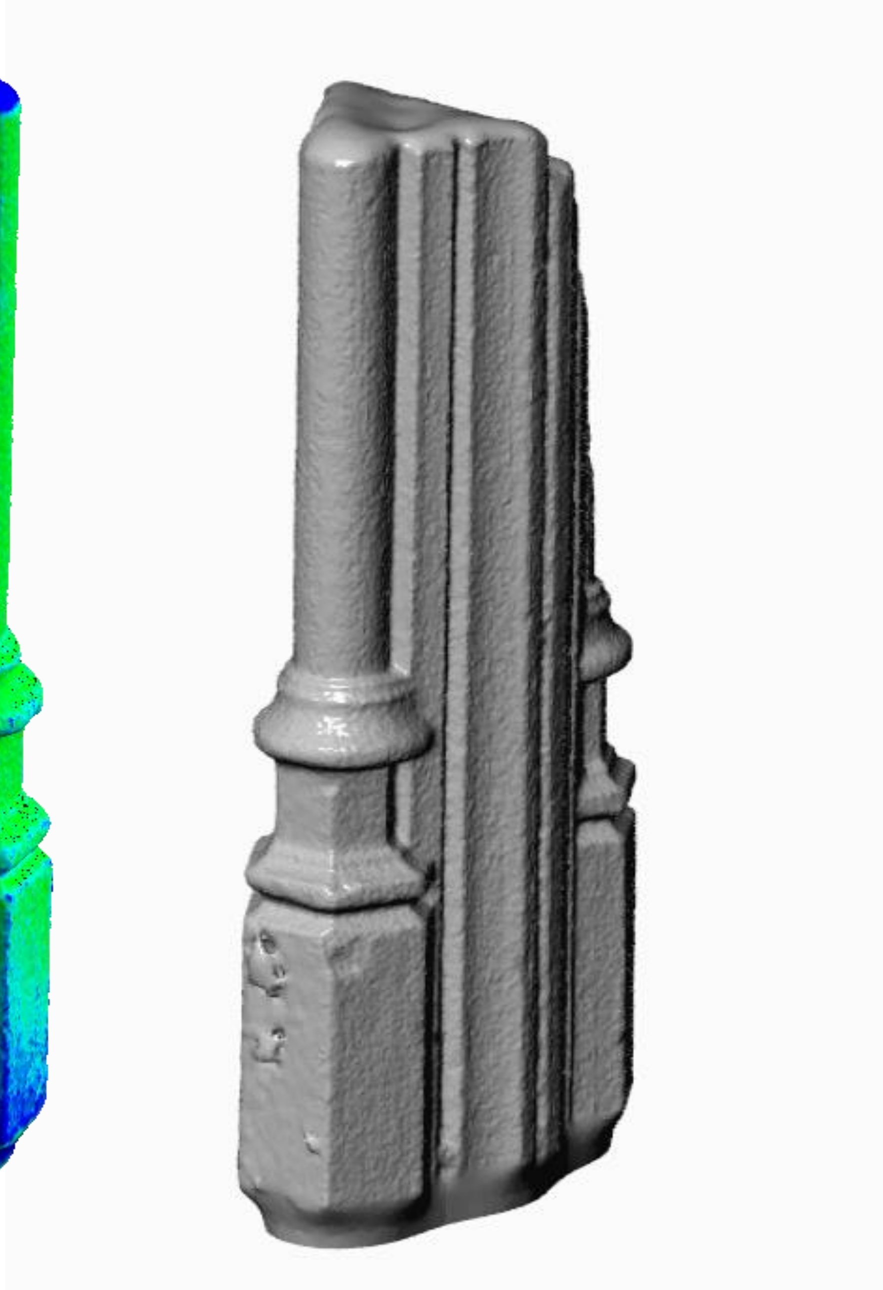


Mesh Generation: CloudCompare

- Optimized for the use of **higher Octree Dep**th.
- Some **anomalous deformations** but fixed later.
- **Balance** between noise and detail.
- Results may **vary** for different types of geometry.
- Final mesh exported from CC with settings:
  - **Octree Depth: 16, Samples per node: 8**



vs. Meshlab (same settings)

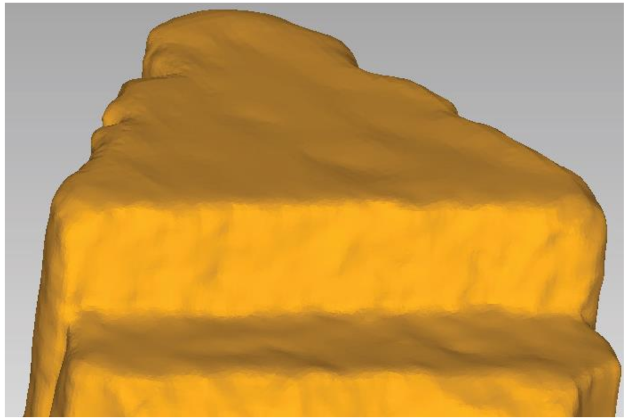


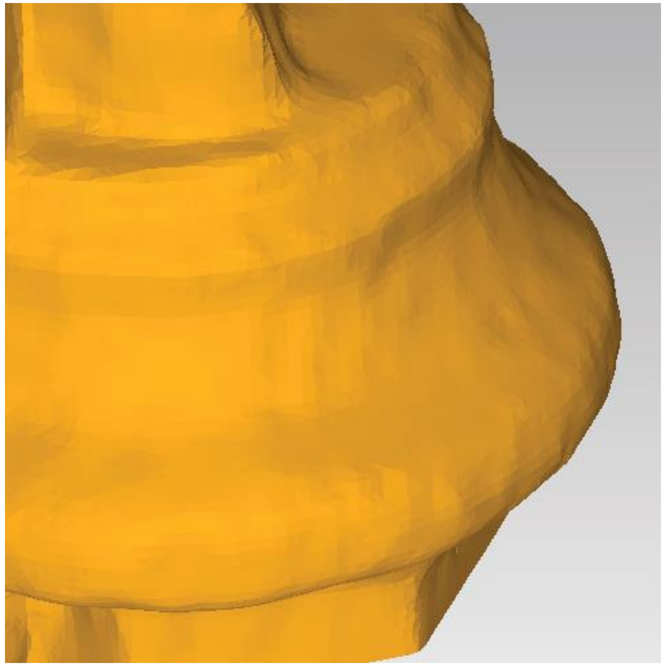
559, 794 Triangles

Mesh Generation: Conclusion

- CloudCompare mesh was chosen due to the possibility of using **higher Octree depth.**
- CloudCompare is a compromise between **lack of meshing alternatives** in Geomagic Wrap and the **user-unfriendliness** of Meshlab.
- At the end, no significant differences between Meshlab and CloudCompare meshes.

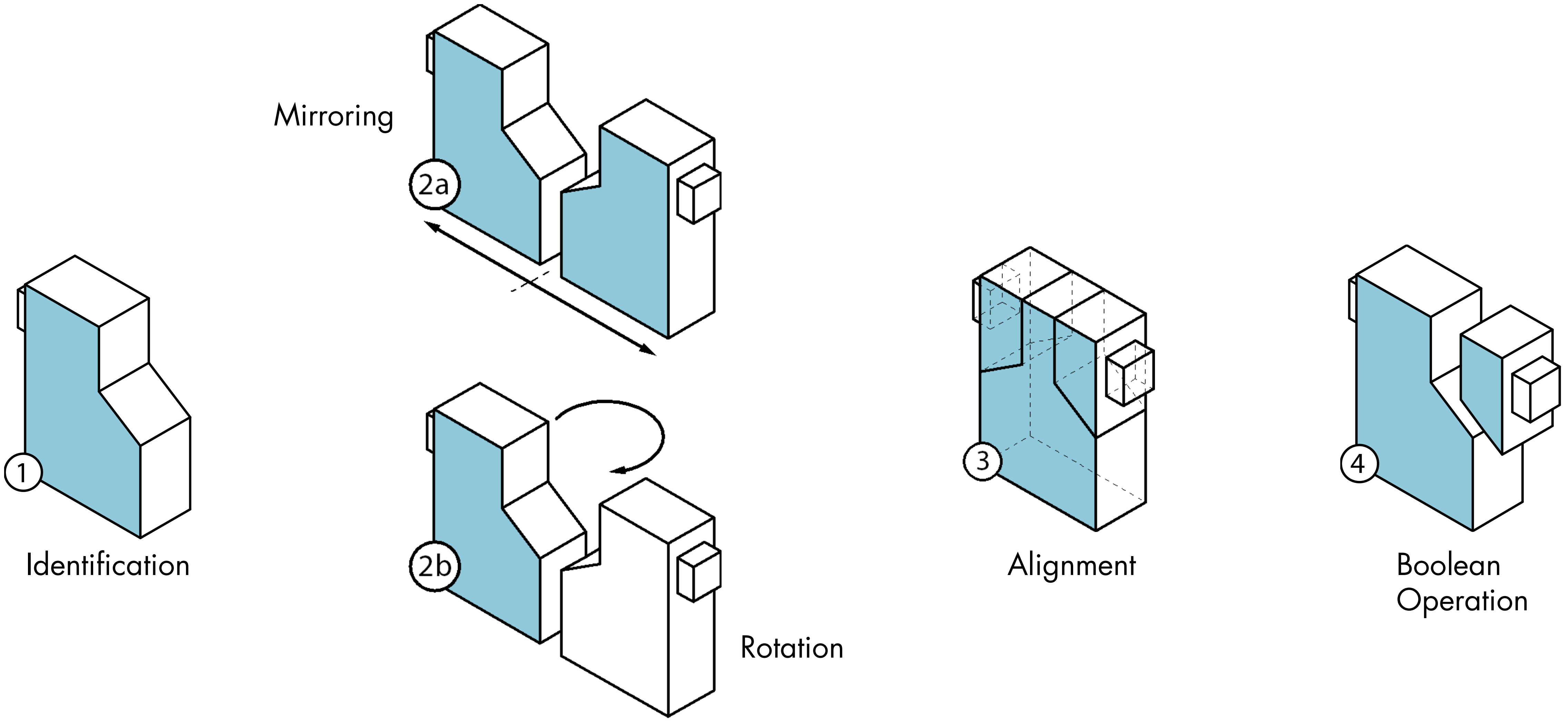
Mesh Comparison with actual surface

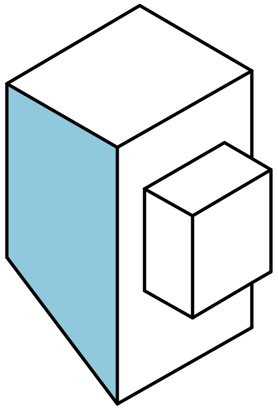




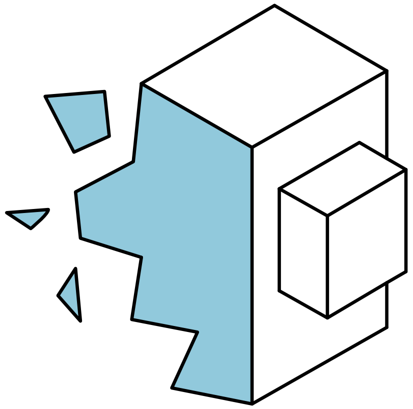
- High frequency detail was lost
- Linear indentations were lost

Interpolation Principle





Expectation



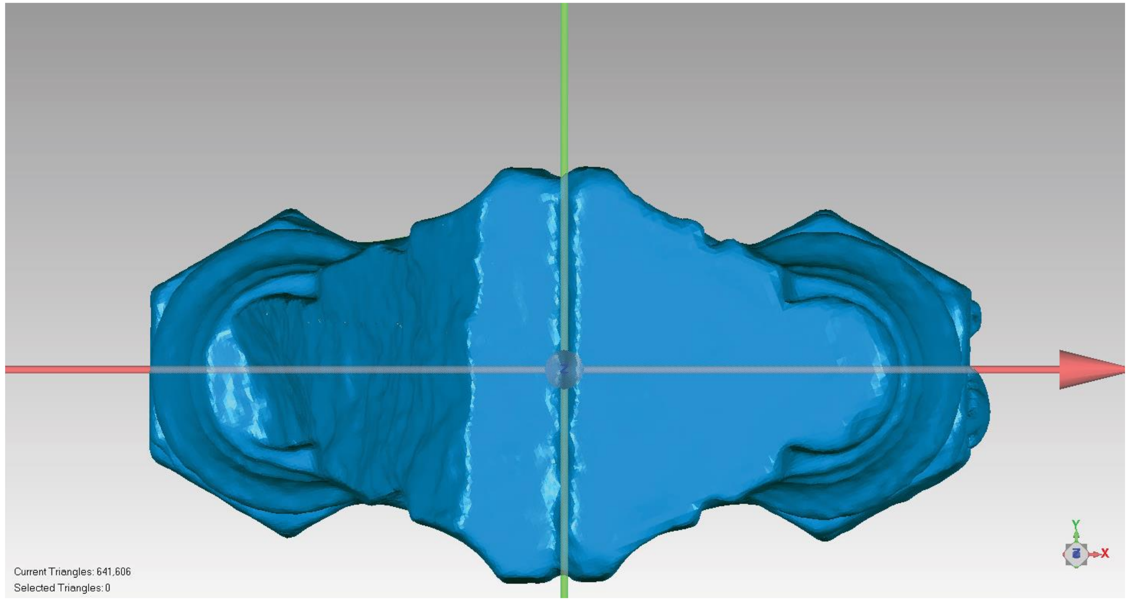
Reality

Interpolation
with

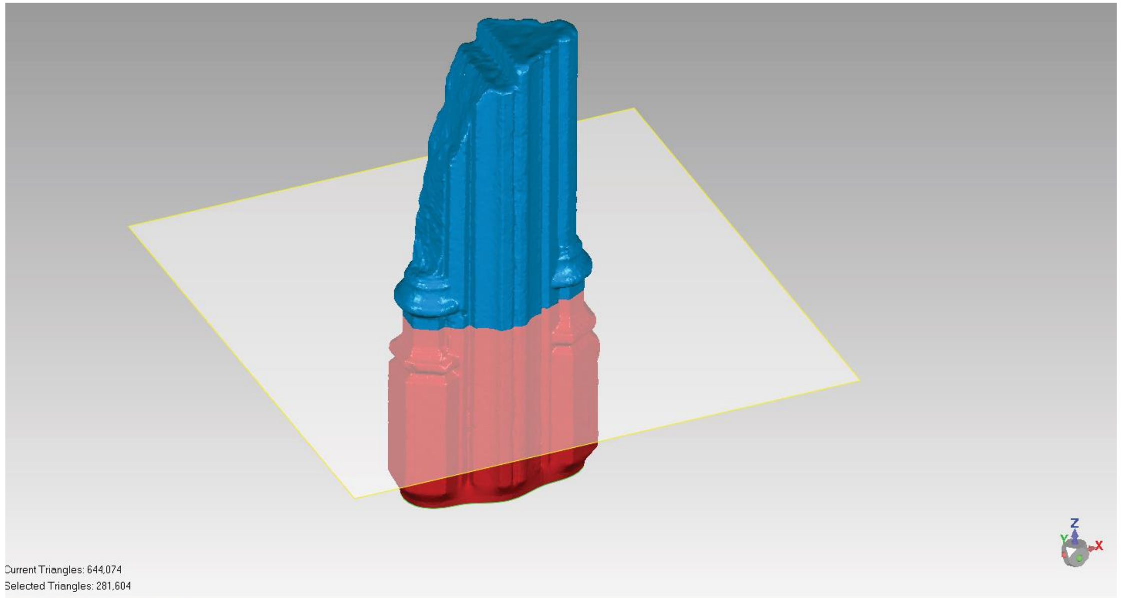
Geomagic

Wrap®

Mesh Manipulation: Interpolation

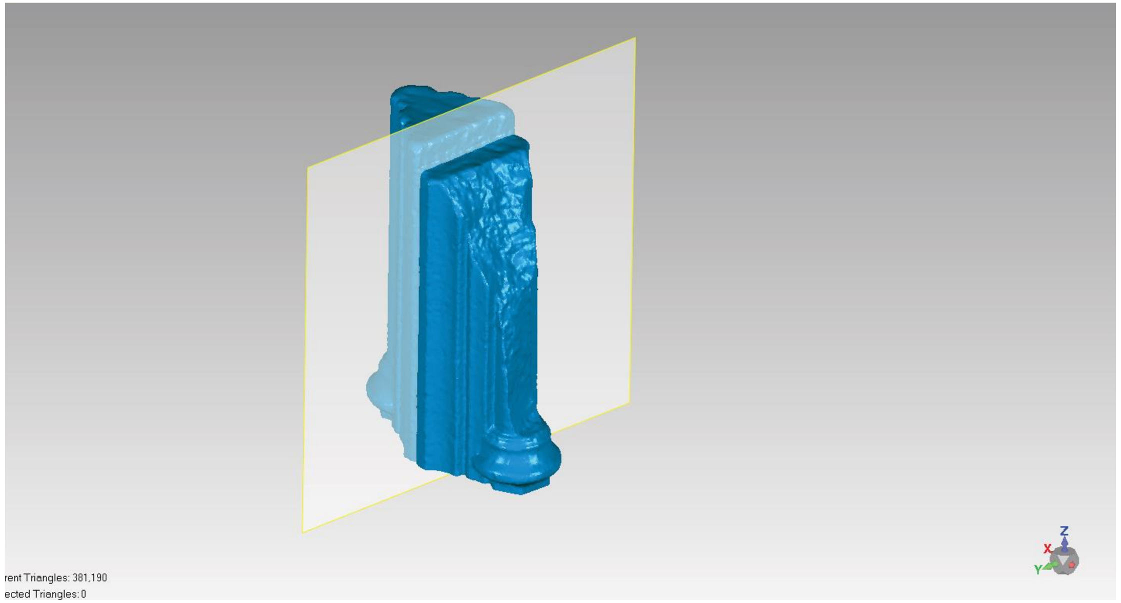


1. Alignment with local coordinate system

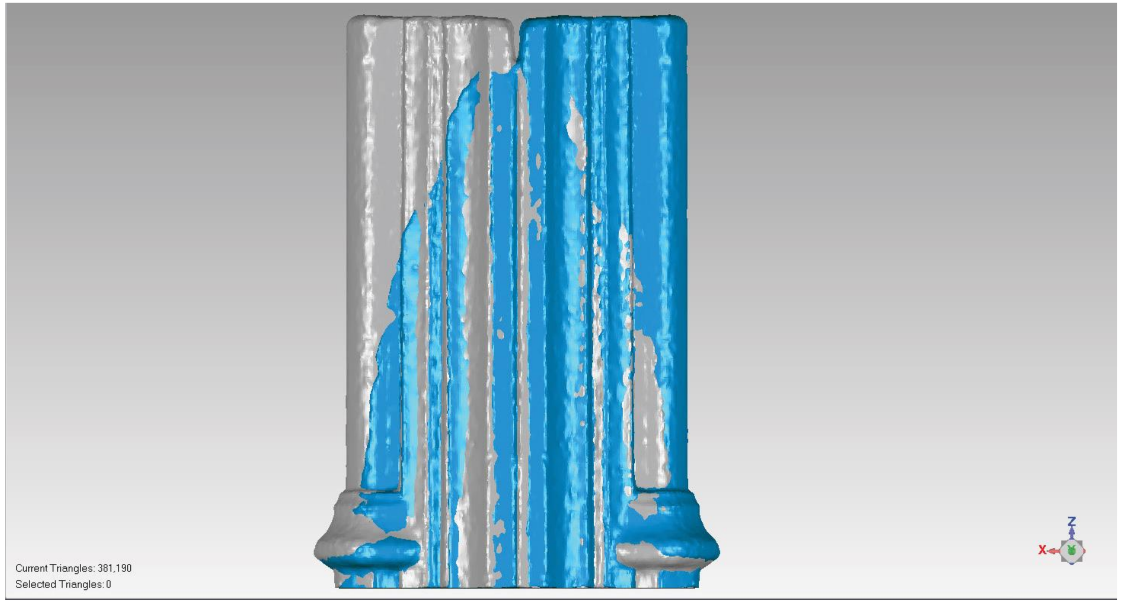


2. Cropping unnecessary geometry

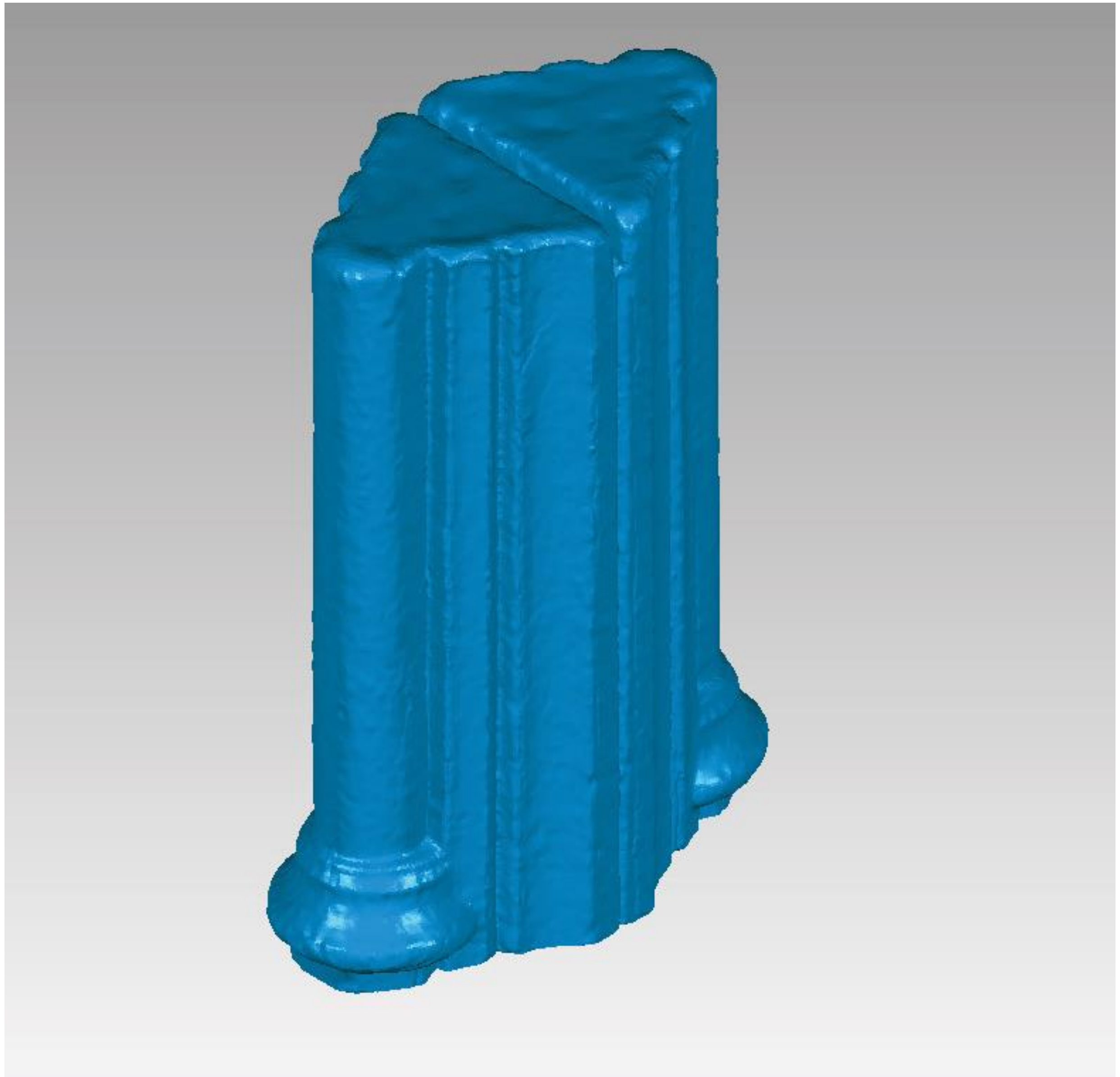
Mesh Manipulation: Interpolation



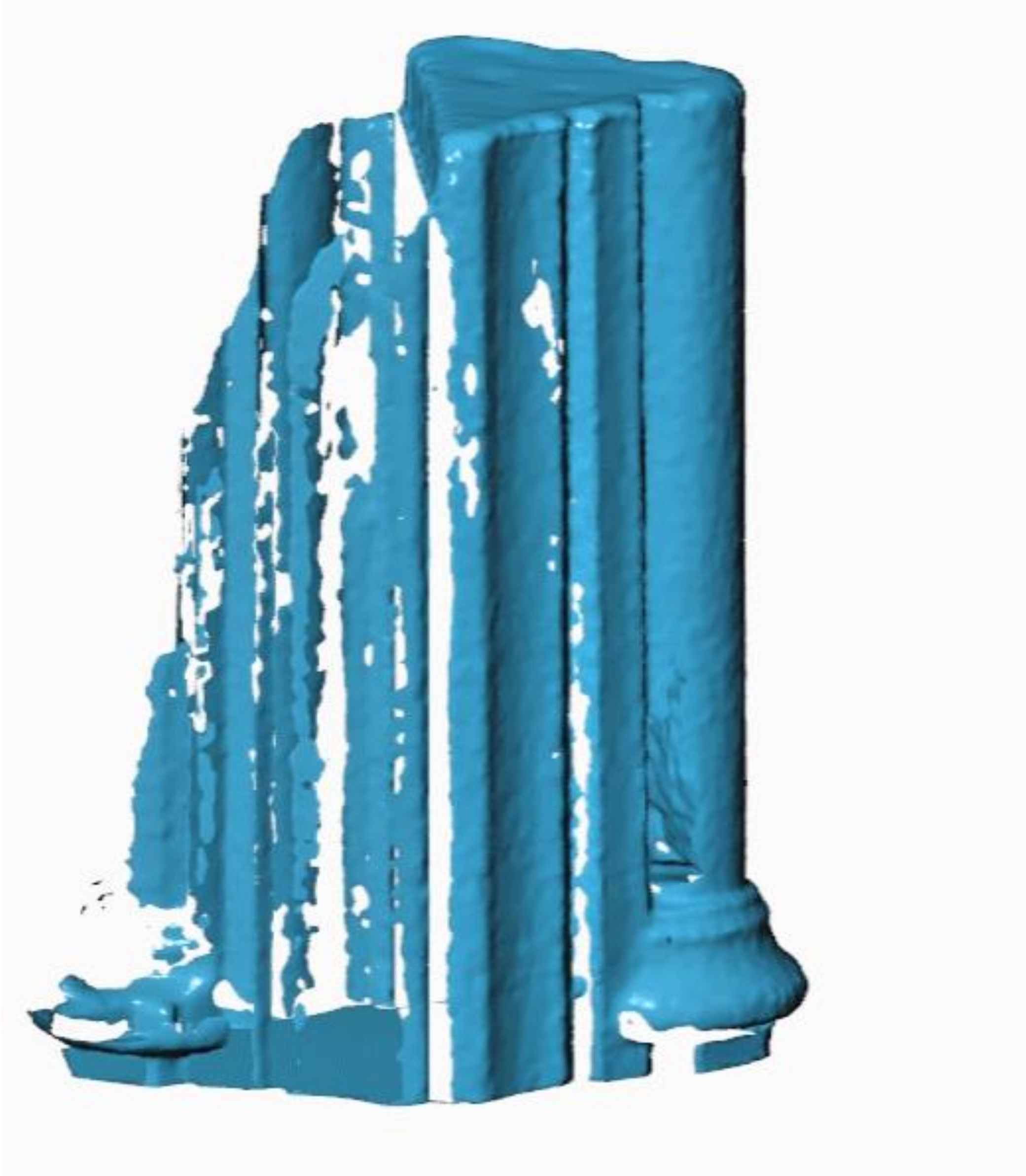
3. Mirroring Geometry



4. Aligning geometry for Boolean

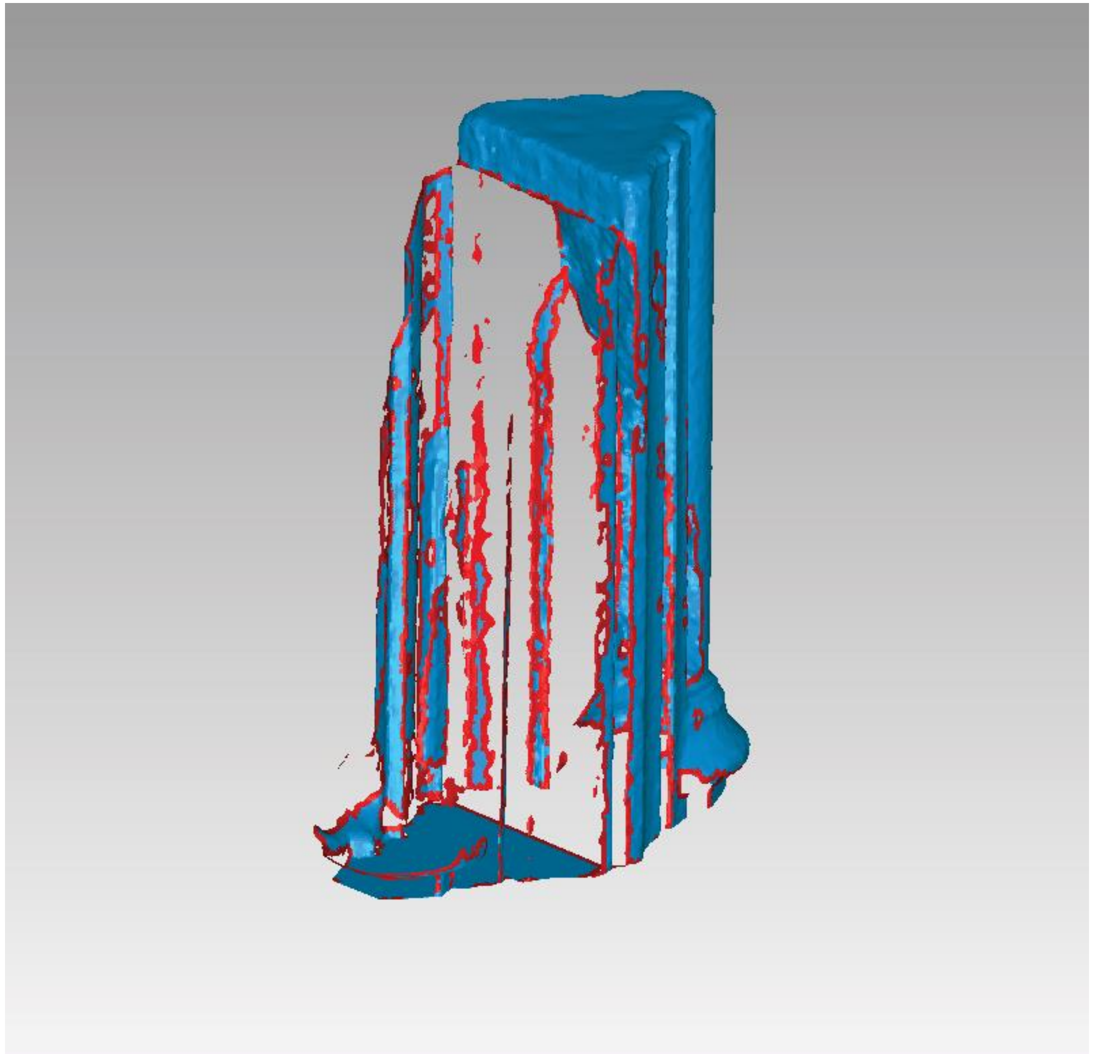


5. Subtractive Boolean Operation

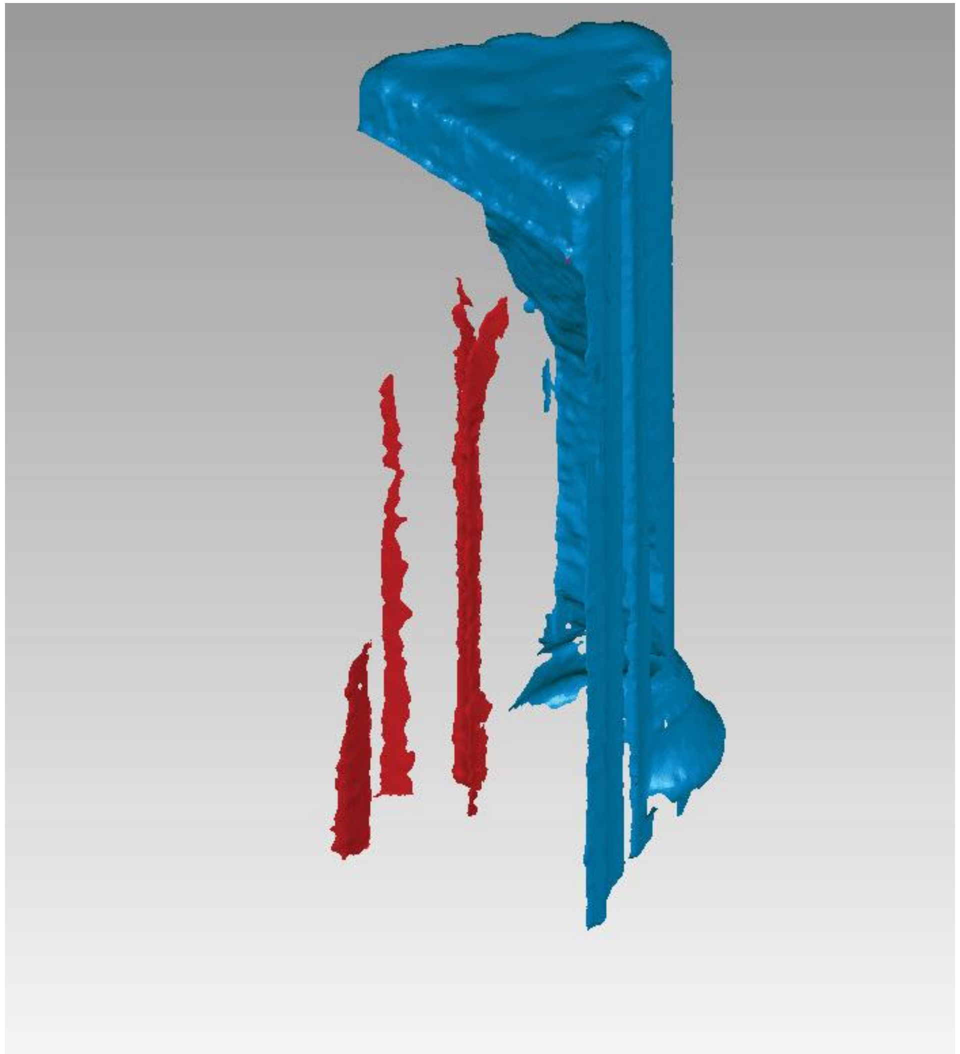


6. Boolean Result

Mesh Manipulation: Cleaning

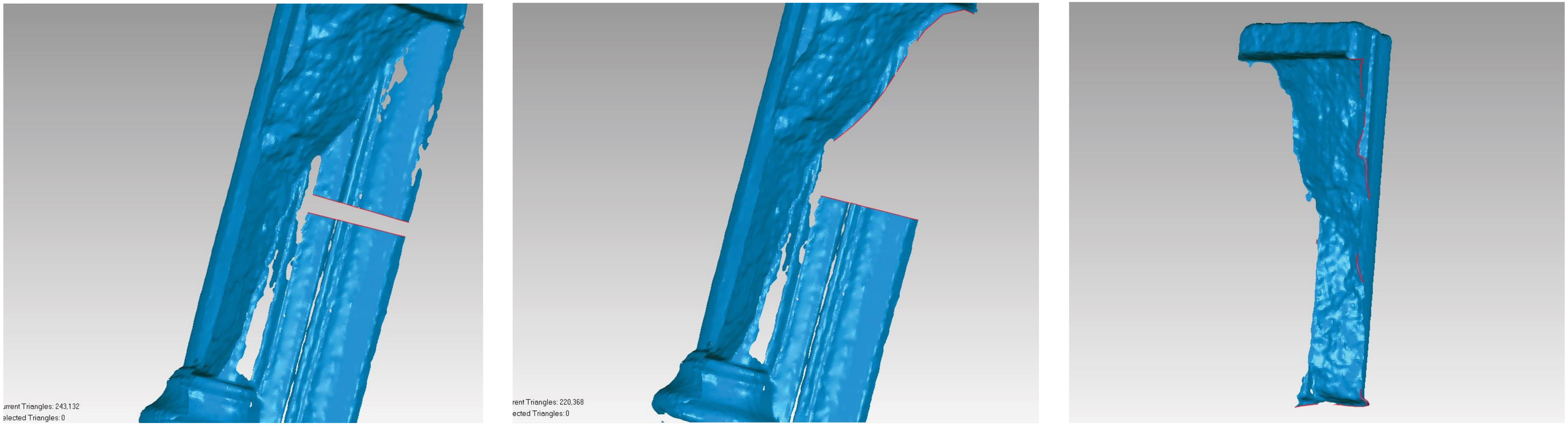


1. Mesh Doctor – Removal of non-manifold geometry



2. Selective removal of isolated geometry

Mesh Manipulation: Cleaning



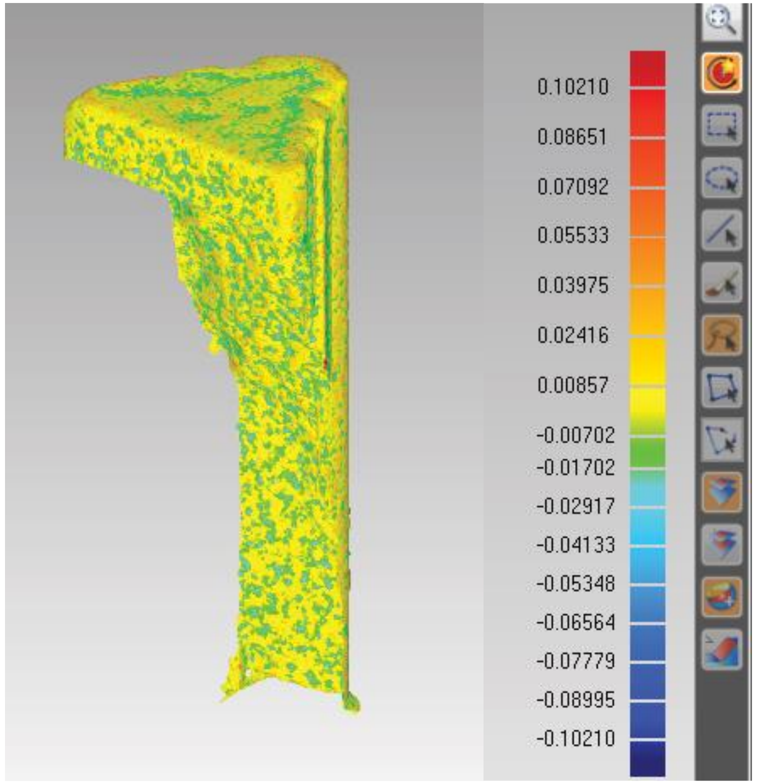
3. Manual slicing and removal of extra geometry

Mesh Manipulation: Cleaning

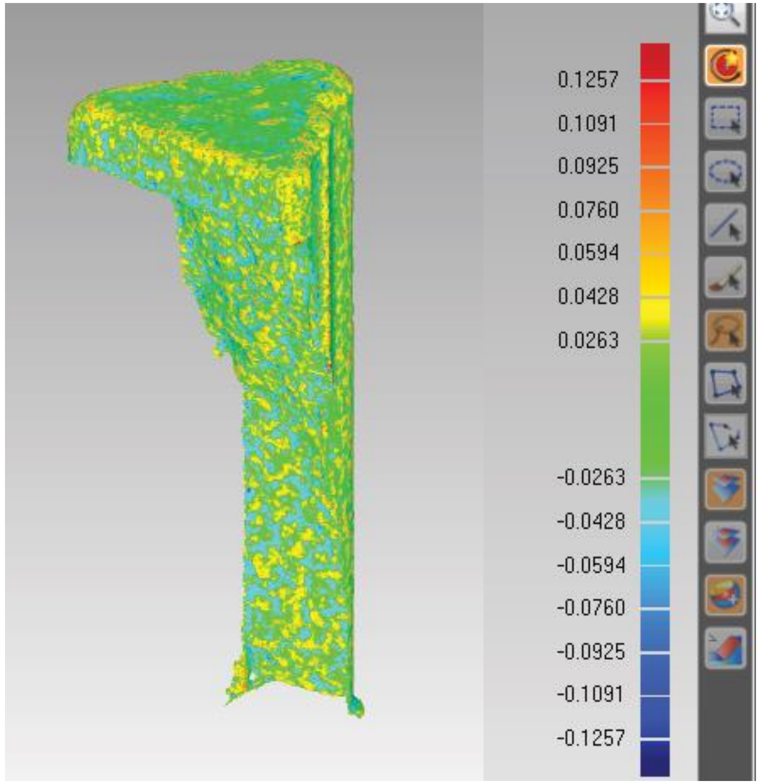
- Further **sculpting** needed along the edges of the geometry.

- Some very sharp edges were **softened** to prevent problems during the mold making process.

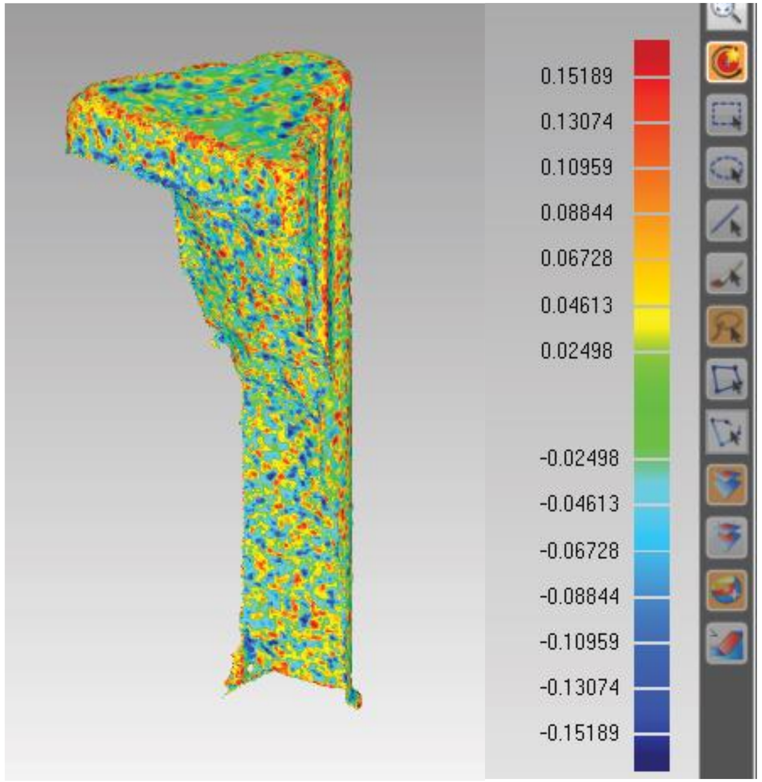
Mesh Manipulation: Cleaning



50% Triangles



25% Triangles



10% Triangles

- No decimation finally performed on mesh but that is dependent upon geometry.

Sculpting
with

Geomagic
Freeform®

and
finishing
with

Geomagic
Wrap®

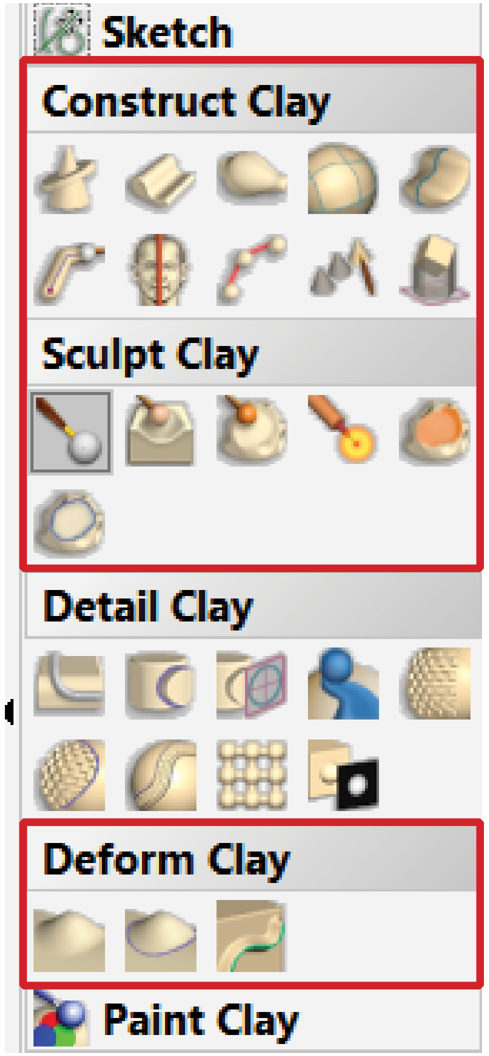
Mesh Manipulation: Sculpting

- **15 day trial** of Geomagic Freeform used for this exercise.

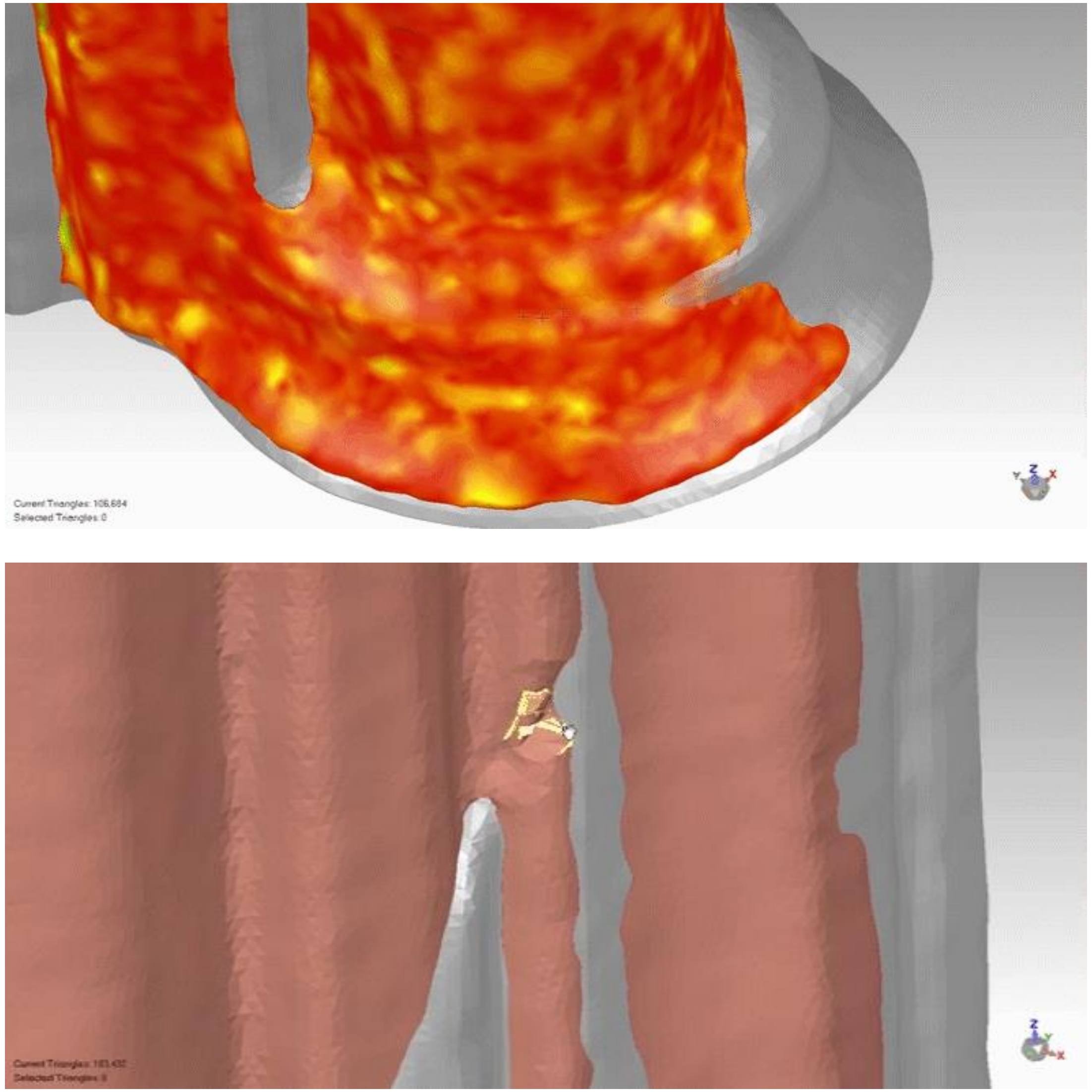
- Sculpting support requires conversion of **mesh** (vertices) to **clay** (voxels) and vice versa for export.

- **Recommended:**
  Geomagic Haptic Devices

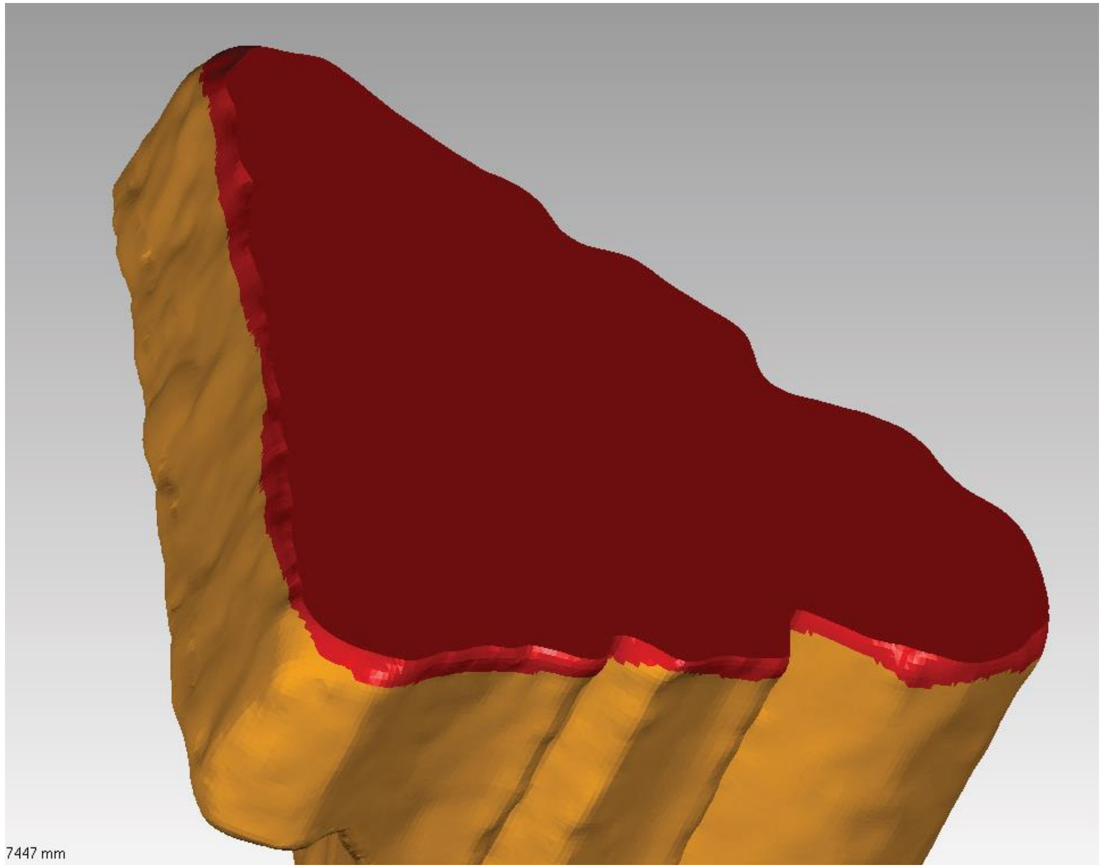
- **Used:**
  Intuos 4 Graphics Tablet

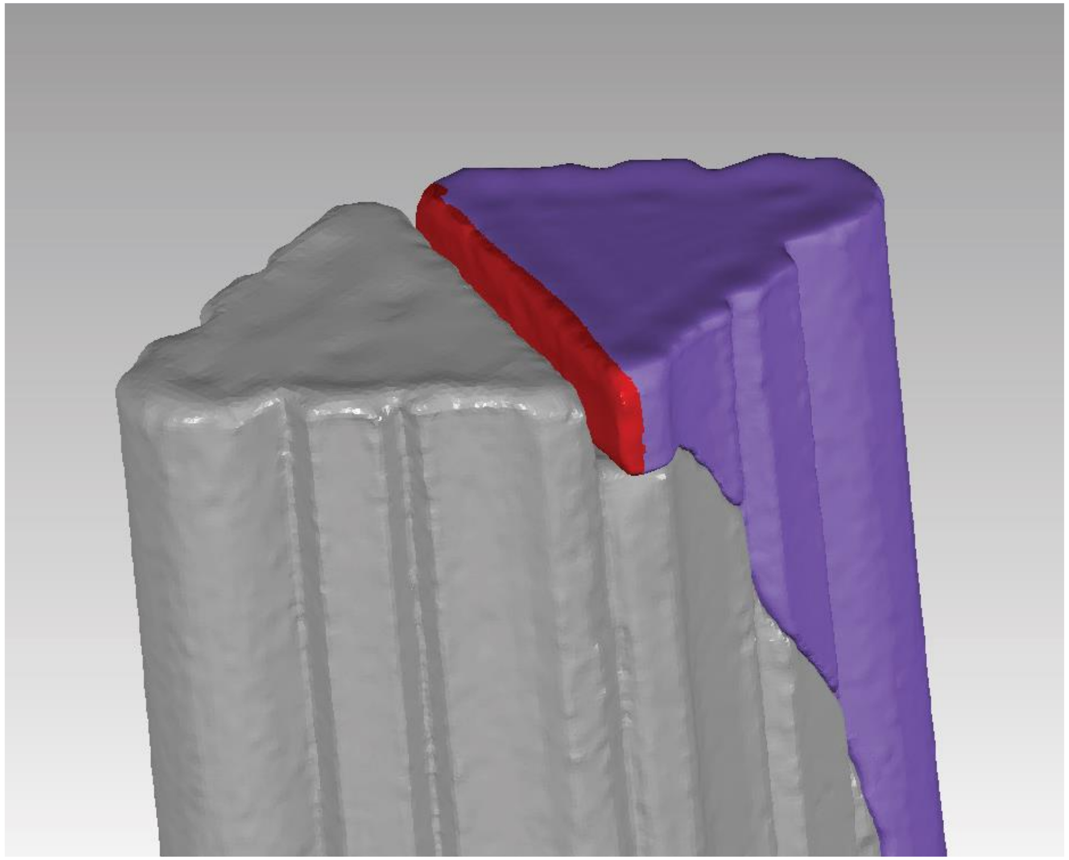


- Hot wax tool for cleaning edges

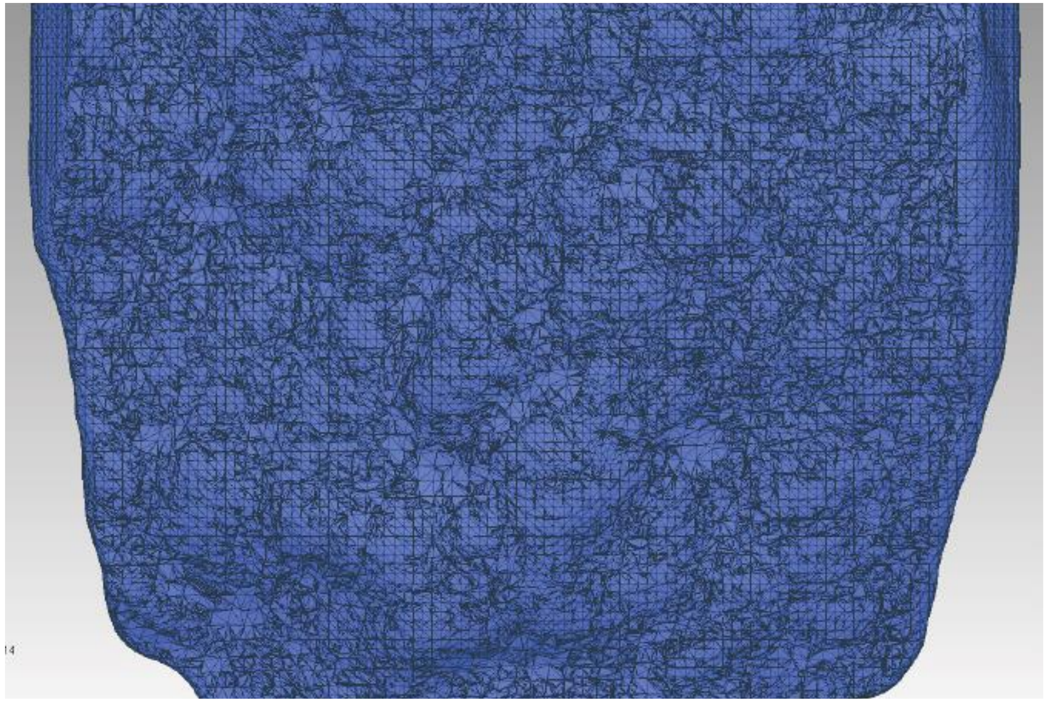


- Carve tool for cutting geometry





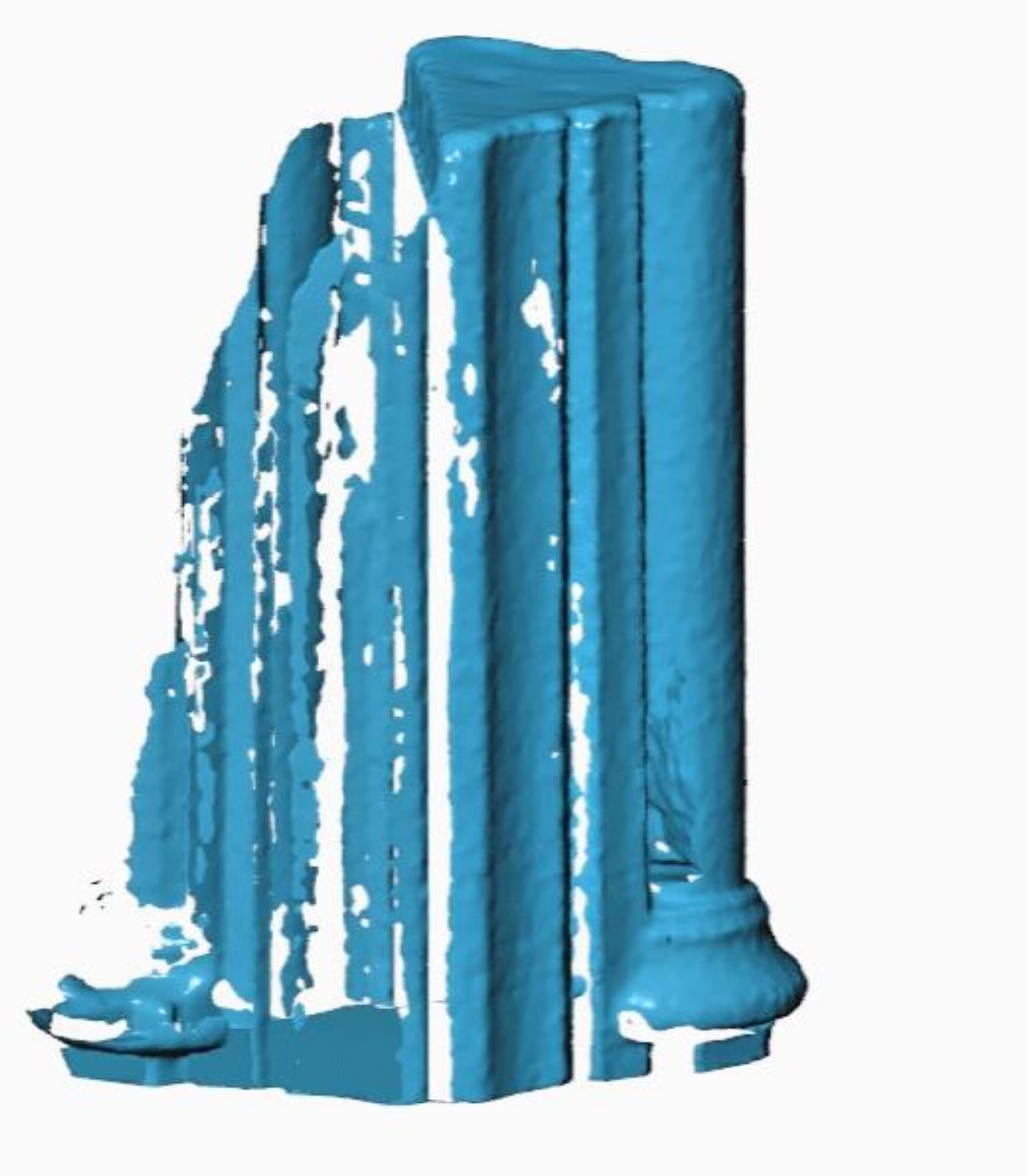
- Some anomalous geometry was flattened and smoothed out.



- Remeshing normalizes the triangles distribution.

- This should prevent problems during the manufacturing stage.

- Lower values of edge length retain detail.



Boolean Result

Finished Mesh

Restoration Alternatives

Generation of New Geometry

- Signifies original form
- Creates contrast between old and new
- Can be distracting, taking away from the experience of the site

Interpolation with Existing Geometry

- Signifies undamaged form except for day to day wear
- Contrast can be created with materials
- More cohesive experience of space

- Both approaches disseminate information and recreate experience.

Restoration Matrix

	Safety	**Durability**	**Costs**	**Historical Accuracy**
Reversibility	-	Binder should be resistant to acid/erosion.	Costs are not as important for this aspect as other construction activities.	If the used epoxy is reversible then the restoration can be reversed if better techniques are available for higher historical accuracy.
Compatibility	-	The **thermal expansion and contraction rates** of the new and old material should be the same to prevent cracking.	-	-
Original materials	The original stone would be heavier than any casted material therefore requiring stronger bonding.	Original stone would be more durable than casted material	Having a craftsman carve the missing pieces can incur more costs (especially with Dutchman method)	Using the original material would ensure partial historical accuracy.
Minimum intervention	**No steel binding rods** (only epoxy) could cause safety issues.	-	Costs can be reduced as the existing stone does not have to be altered.	The column would be more historically accurate as more of the original material would survive.
Traditional techniques	Steel rods can be used in addition to epoxy for a stronger bond.	-	Traditional techniques can be potentially more expensive than digital fabrication.	Carving by hand would be more historically accurate as a process but not necessarily the end result.
Maintenance	**-**	The elements should be regularly checked for failure of the binding material.	Maintenance costs can be derived from the funds saved via Digital Fabrication.	-
Digital Fabrication	Generating complementary fracture surfaces can increase **surface adhesion**.	The same stone, Belgian Blue Limestone can be **CNC milled directly** for higher durability.	Costs can be lower than hiring a traditional craftsman if the **workflow is streamlined**.	It is possible to create an **exact replica** of an existing ornament, something that is not achievable if a new one is carved by hand.

Manufacturing

Manufacturing: Preferential Workflows

1. Direct Multi-axis Milling of Stone

2. Silicone Molding

3. 3D Printing Concrete

Manufacturing: Preferential Workflows

1. Direct Multi-axis Milling of Stone

2. Silicone Molding

3. 3D Printing Concrete

Chosen Workflow:

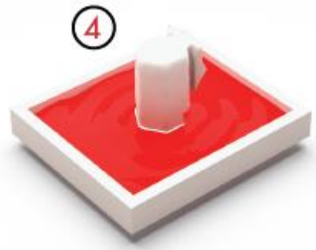
- Accessibility of technique
- Ability to vary material or color
- The mold can be reused to create a variety of prototypes
- Cement (colloquially called liquid stone) can emulate stone

Manufacturing: Investment Casting

Representation of fractured stone column

Surface replication of fracture morphology (LIDAR)

Digital modeling of fragment



Manufacturing using SLA Printing (alternatively FDM)

Polymer 'pattern' is dipped in Silica slurry or alternatively stuccoed

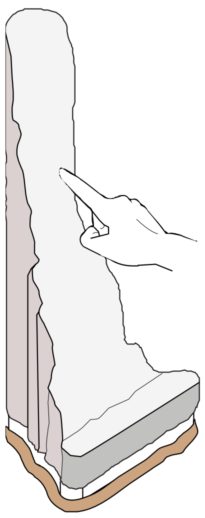
The ceramic 'investment' needs to be dried for 1-2 days before use.

The oven is first heated to around 200°C (for Nylon 6) to remove the polymer 'pattern' and then at 900°C for sintering.

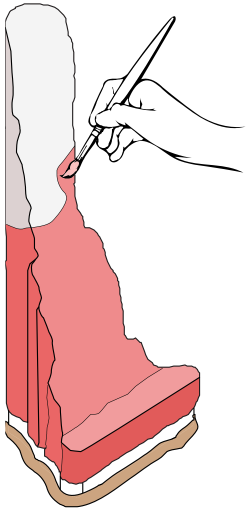
The ceramic mold is then used to cast the cement addition.

1. Preferential if geometry requires **closed mold** | 2. Required **specialized oven** | 3. **Master** for mold is **wasted**

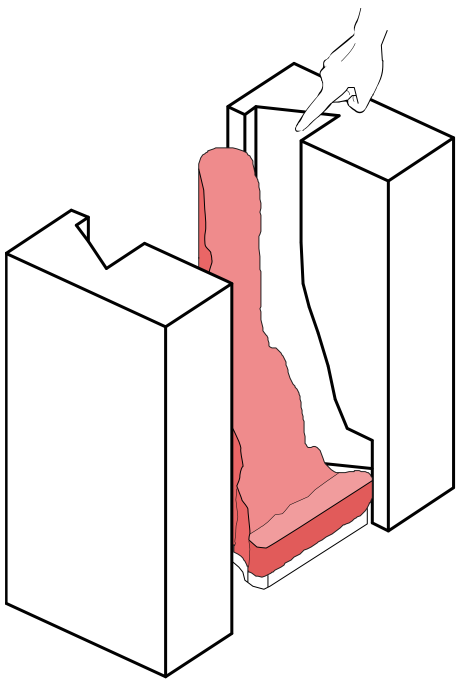
Manufacturing: Silicone Molding (Chosen Workflow)



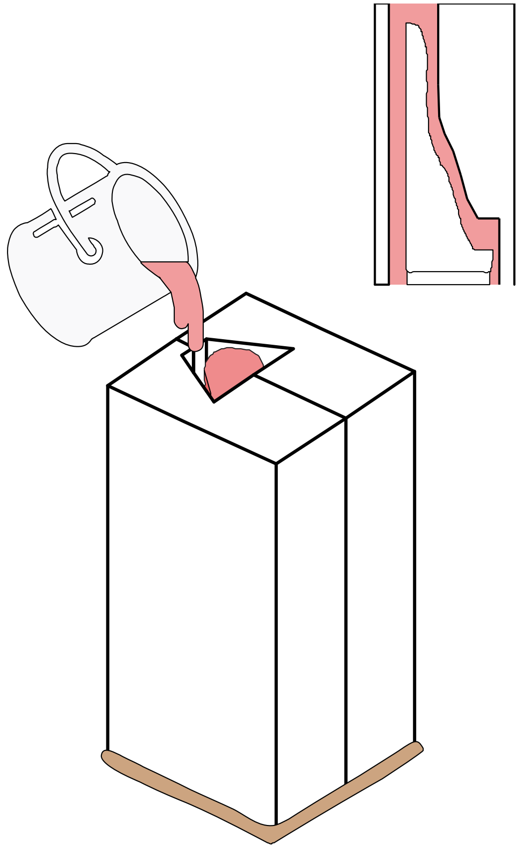
1. A **release agent** is applied to the polymer pattern surface, and the pattern is held fast to the surface using wet clay.



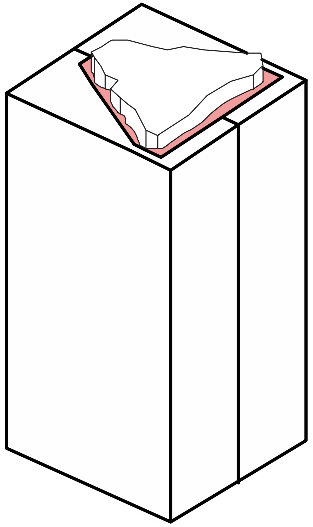
2. Three layers of mold making silicone are applied after intermittent intervals of 20 minutes.



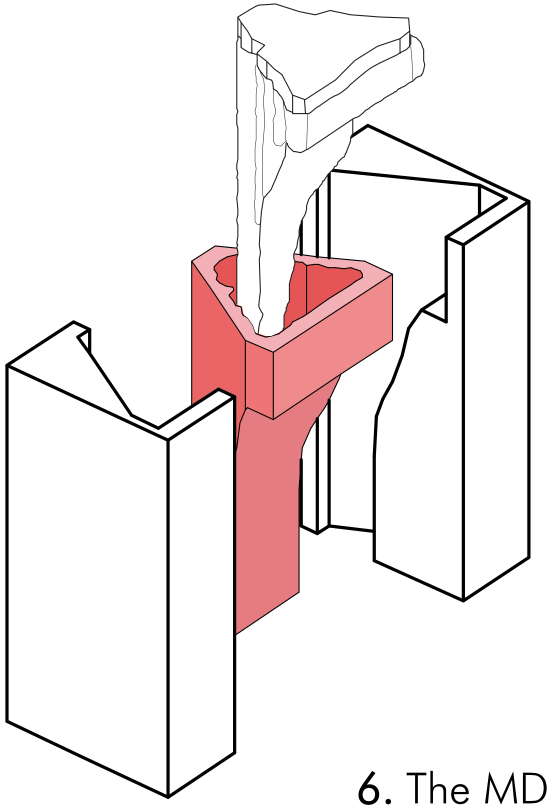
3. A split milled MDF mold is used to enclose the silicone covered pattern. A release agent is applied to the MDF before closing.



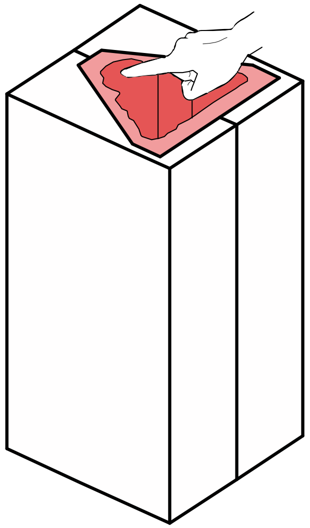
4. Silicone is poured into the newly created cavity, till it reaches at least **2 cm** above the end of the 3D printed pattern.



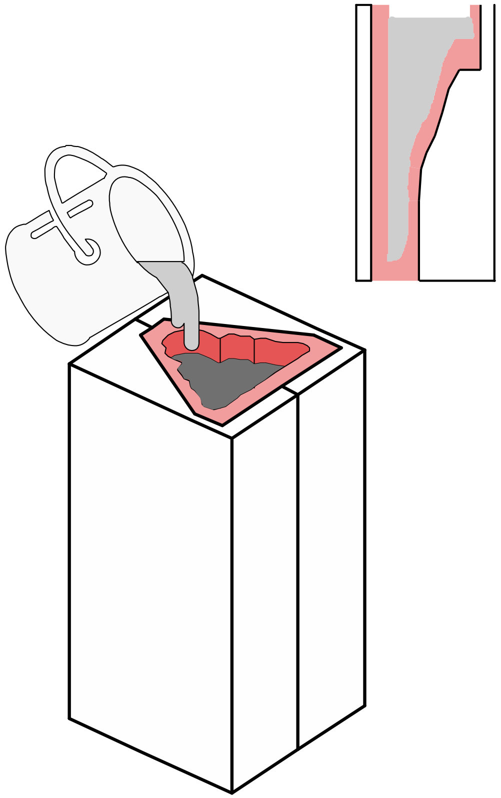
5. The silicone is left to cure for 24 hours and the mold is flipped.



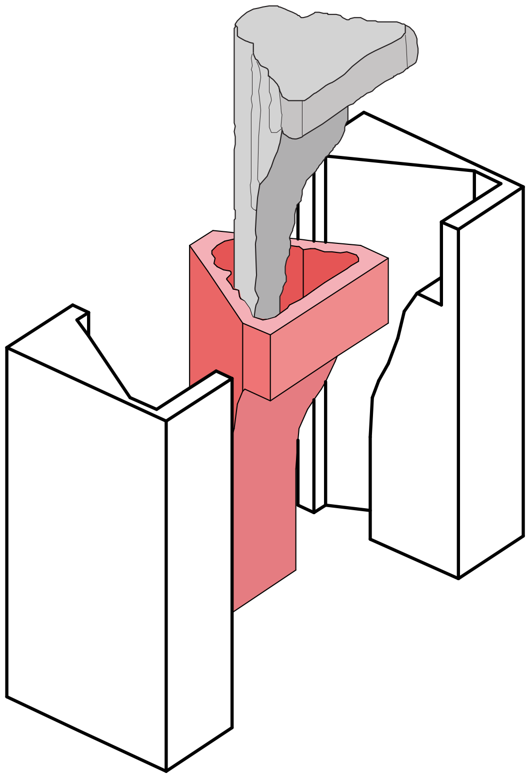
6. The MDF mold is released and the polymer pattern is manually extracted from the silicone shell.



7. The mold is clamped again and a release agent is applied to the inner surface of the silicone shell.



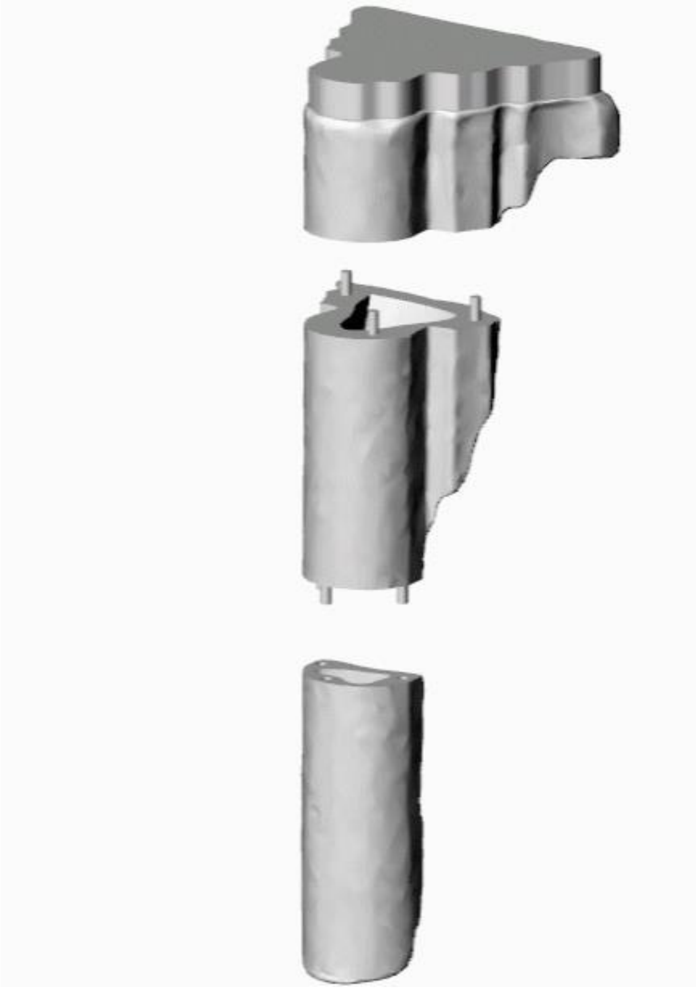
8. A cement mixture is poured into the **silicone shell** (with gentle shaking to avoid bubbles) until it reaches the marked top surface.



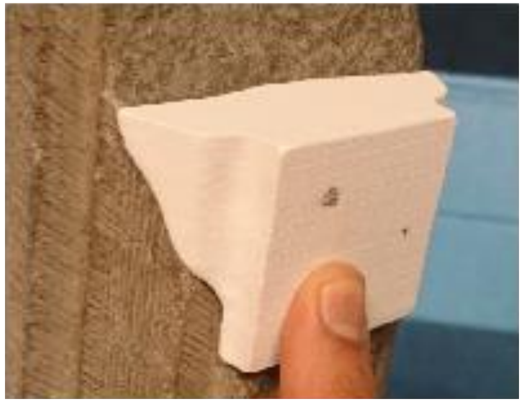
9. The cured cement positive is removed from the mold after 2-3 days.

Prototyping

Prototyping: Surface tests and sectional printing



3-Part print for Form 1+ 3D Printer
(Build Volume: 125×125×165 mm)

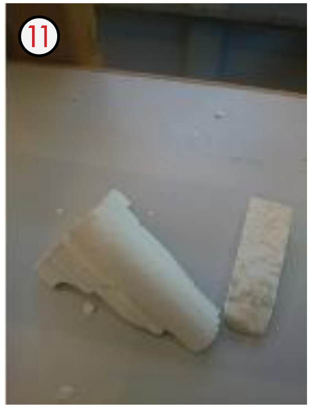


VisiJet PXL Gypsum Print Section Test

SLA Printing (Form 1+) failed prints

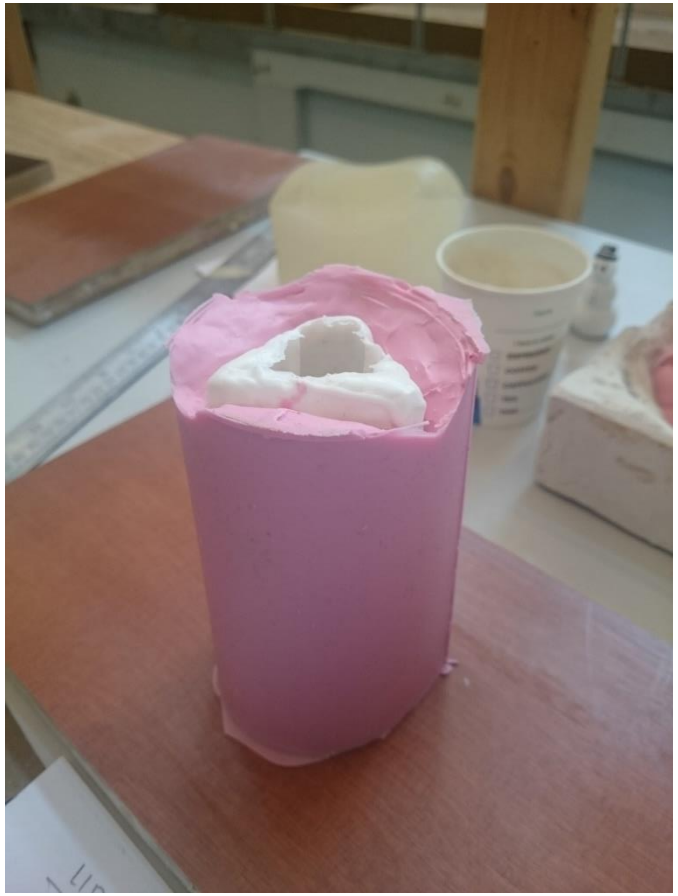
Mold and Material Testing

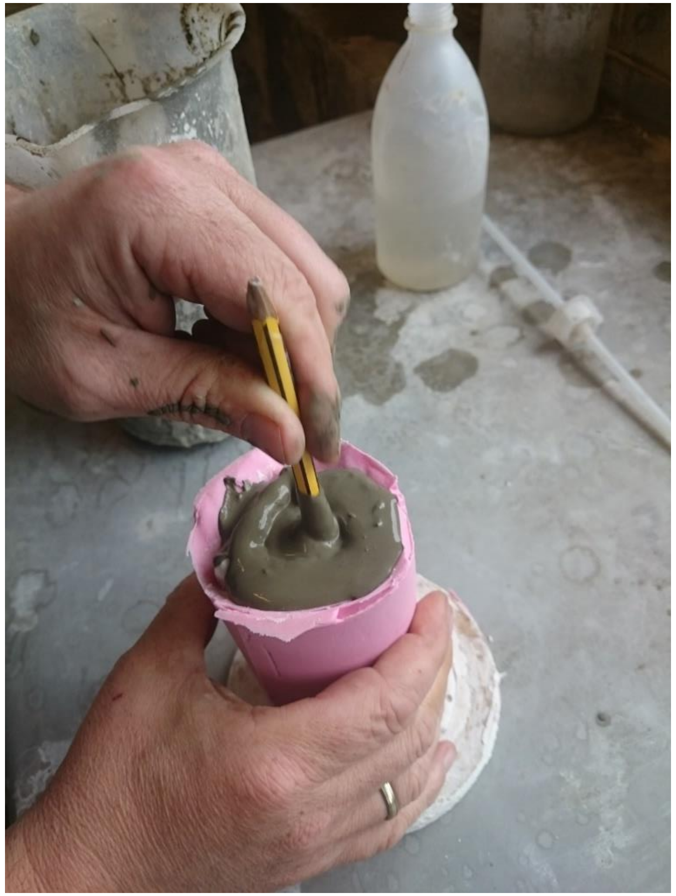
The pattern was covered with a release agent and brushed with three layers of silicone, which was then reinforced with a split gypsum shell.



The stiffness of the gypsum would break all casted material upon removal.

Mold and Material Testing II





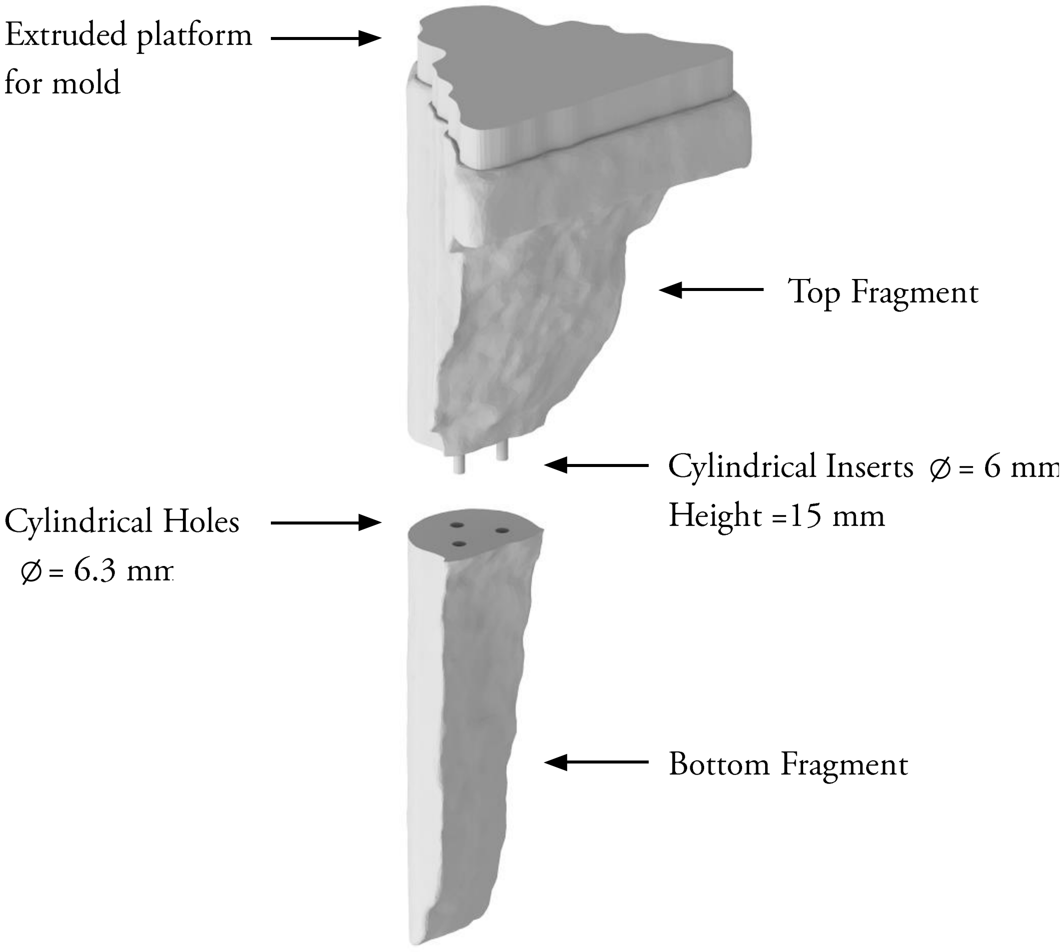
i.tech Ultracem 52.5 premixed cement was used for testing the casting.



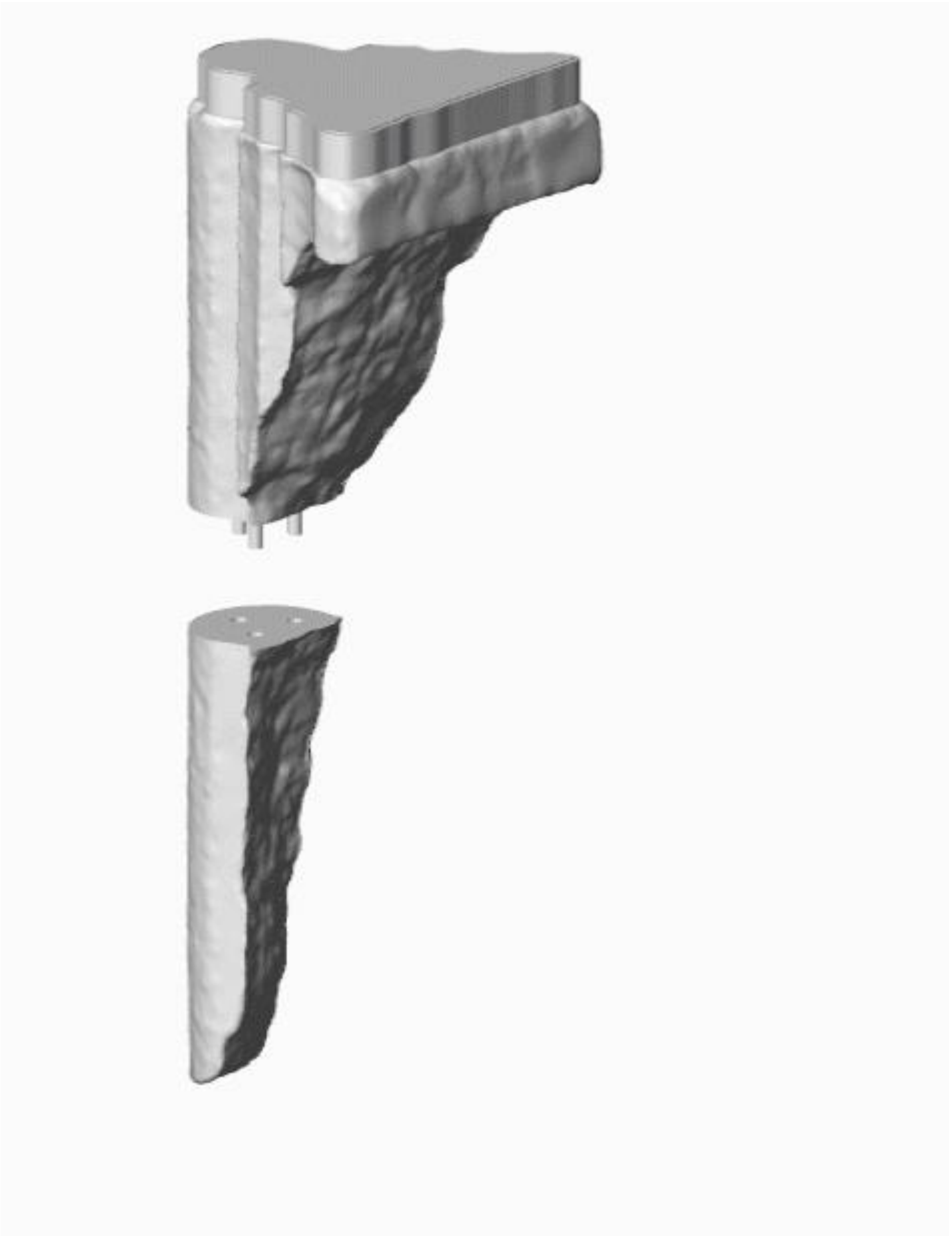
Bubbles would cause regular breakage.

3D Print | Ultracem with lightening pigment and glass fibers | Just Ultracem

3D Printed Reference Pattern



Two part model for Ultimaker 2+ Extended Printer
(Build Volume: 125×125×165 mm)

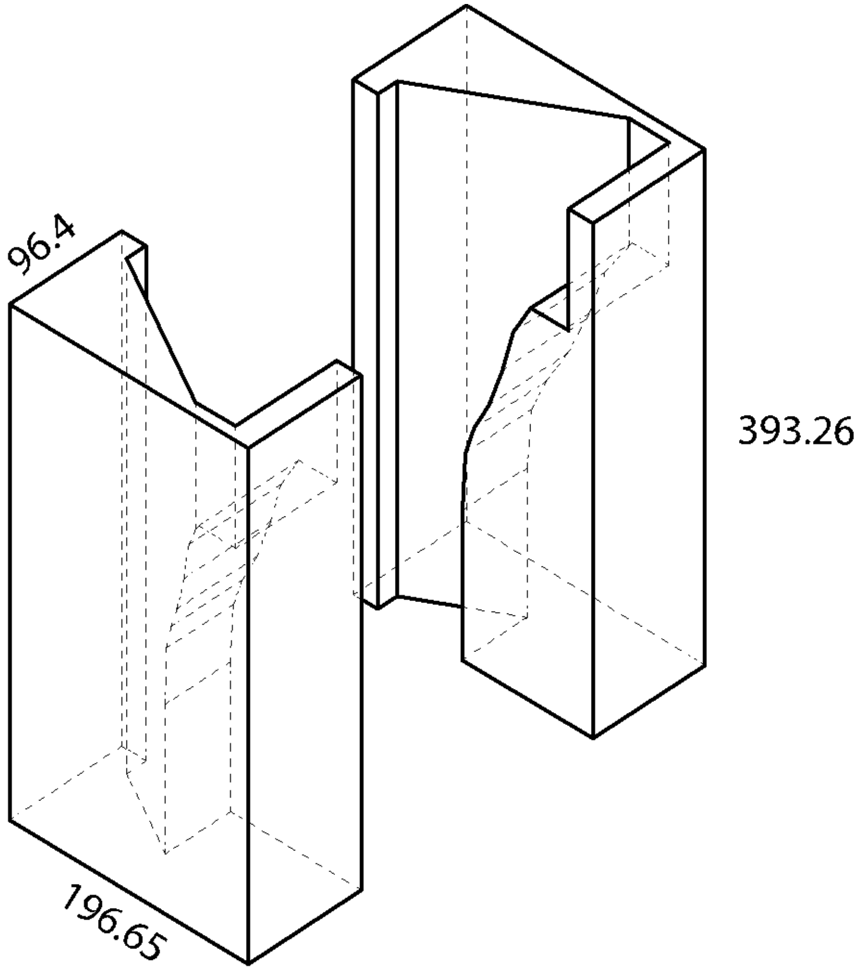


Reference Pattern Results

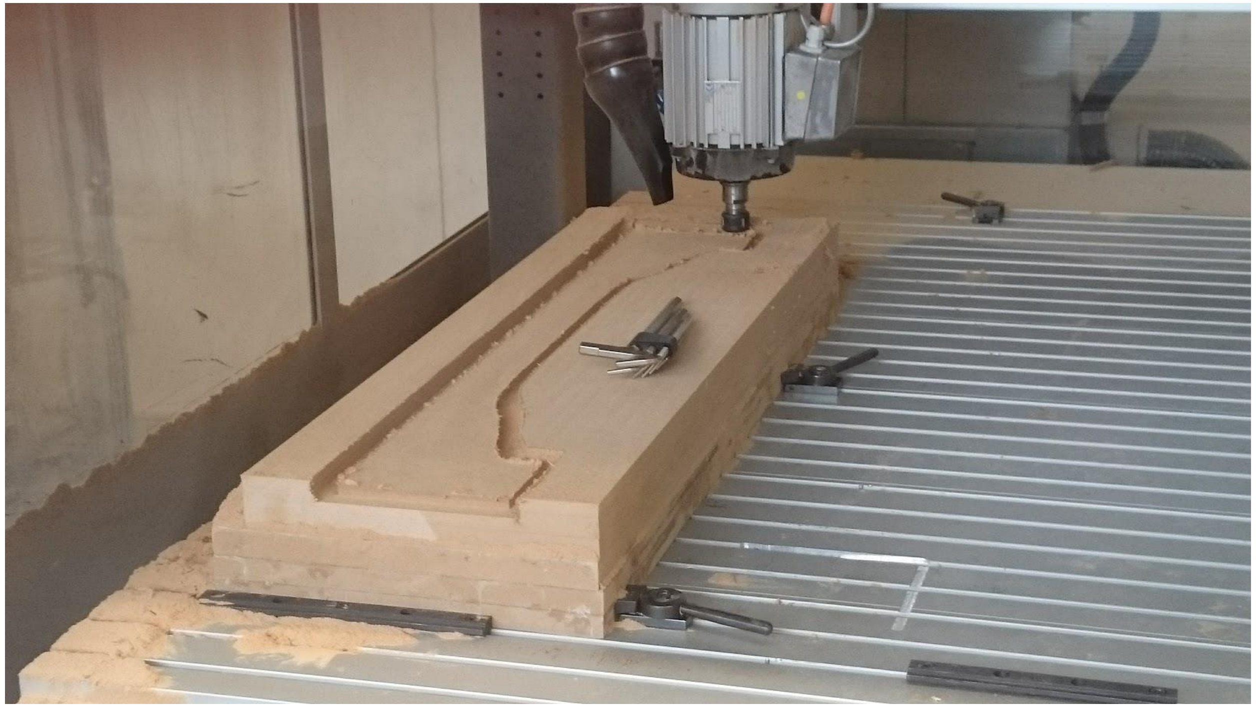
The 3D print adhered to the fracture surface without any adhesives.

White glue for temporary part adhesion.

Reinforcing MDF Mold



MDF Mold Reinforcement
(All Dimensions in mm)



Mold Max 30 Silicone

Part A is mixed with **Part B** to initiate curing process.

Two kinds of Part B were used:

Mold Max 30 (for pouring)

Mold Max Stroke (for brushing)

Application of release agent (Vaseline)

Brushing of Silicone

Progress after 1 Layer

Progress after 2 Layers

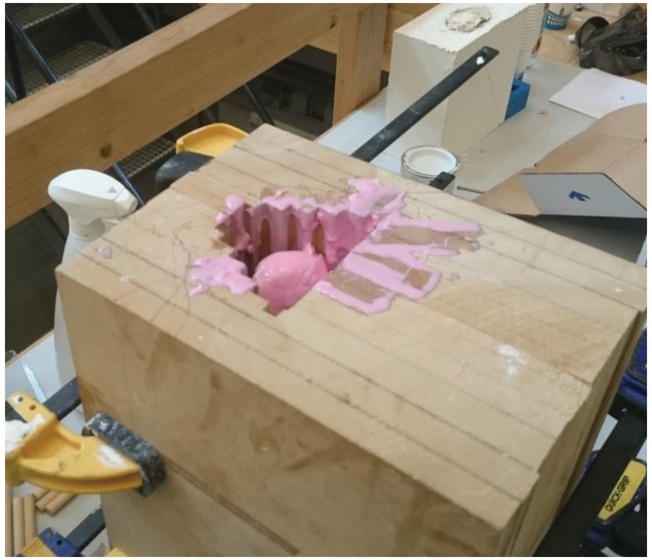
Third layer is textured to increase adhesion

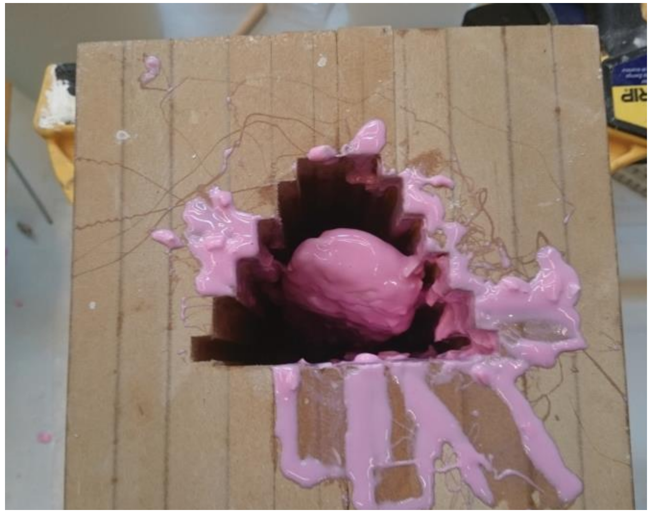
Overflow cut off

Held down with clay and release agent applied (clay only)

Release agent applied to the MDF mold reinforcement

Pattern was aligned with the reinforcement





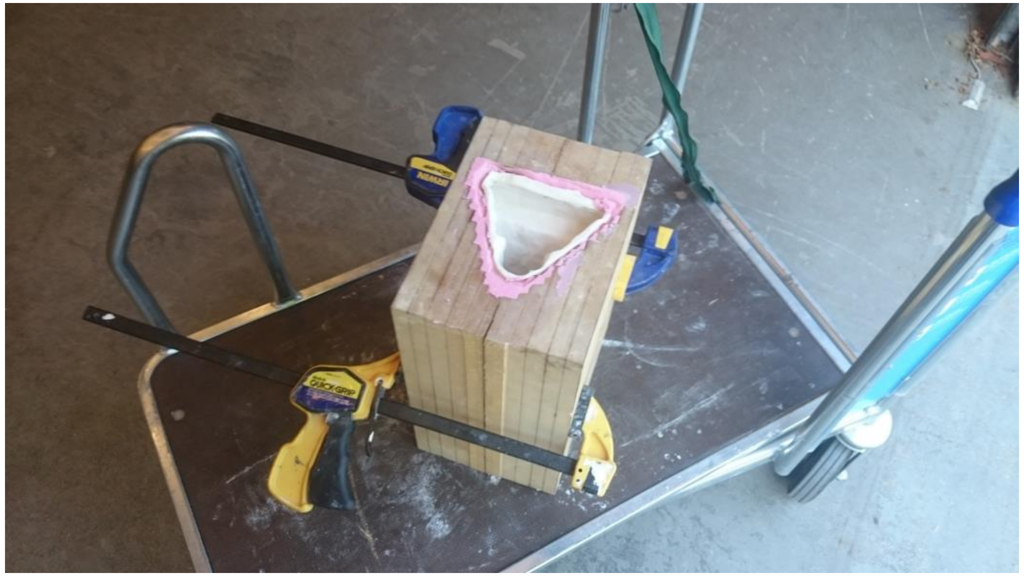
Silicone was poured with 2 cm margin

Left to cure for 24 hours

The silicone was released from the reinforcement

The mold was cleaned and inspected

Release agent applied to inside



Clamps were reapplied


The setup was placed on a vibrating table and the casting material (cement or cement and aggregate) poured


The cast was released (small incision was needed) and finished with medium grit sandpaper

First cast (no aggregate and 10 g white pigment)

Second cast (with aggregate and 20 g white pigment)

First cast

Second cast

Cost comparison (estimate)

	Lower Estimate	Upper Estimate
Traditional Method (Labor Costs)	25€ x 8 (hours) x 3 (days) = 600€	40€ x 8 (hours) x 3 (days) = 960€
Material Costs	100€	200€
Production Costs	Negligible	Negligible
Total Est. Costs	**700 - 1160€**	
Digital Fabrication (Labor Costs)	15€ x 8 (hours) x 3 (days) = 360€	25 x 8 (hours) x 3 (days) = 600€
Material Costs	20€ (PLA) + 102€ (Silicone) + 20€ (MDF) + 30€ (Cement and Misc)	100€ (PLA-SLA) + 102€ (Silicone) + 20€ (MDF) + 30€ (Cement and Misc)
Production Costs	Negligible (in-house)	60€ (3D Printing) + 20€ (Milling)
Total Est. Costs	**532 - 932€**	

Binding and Reversibility

1. Thermally reversible epoxy (90°C) could be used but has limited availability.

2. Using steel or titanium binding rods would increase level of intervention and defeat the purpose of the restoration.

3. Traditional mortar might work since the element is supported at the bottom.

Further Exploration

- Multiple prototypes with varying materials
- Restoration with Glass
- Casting suspended particles in binder

Candidate 2: Boerderij de Hamwoning

Renaissance Mannerism
Rotterdamseweg 155, Delft
Date: ~1608 CE

Angel Relief (Damaged) ▶

Angel Relief (Intact) ▶

Extrapolation using the symmetricity of the test candidate relief

Extrapolation using existing geometry from undamaged relief

Other factors:

Depending upon extent of rot, the procedure can change from scanning the geometry of the fracture to creating a new surface for connection.

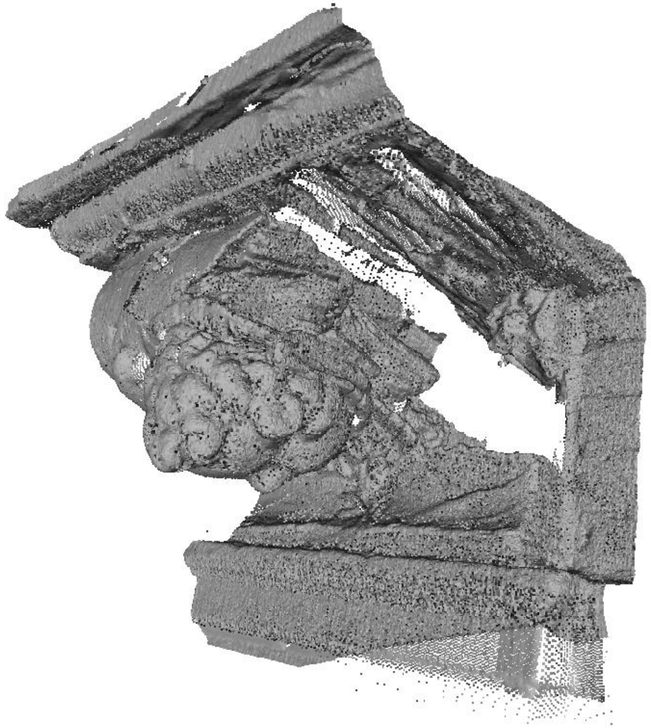
Since the paint cannot be removed before scanning, it shall be included in the scanned geometry.

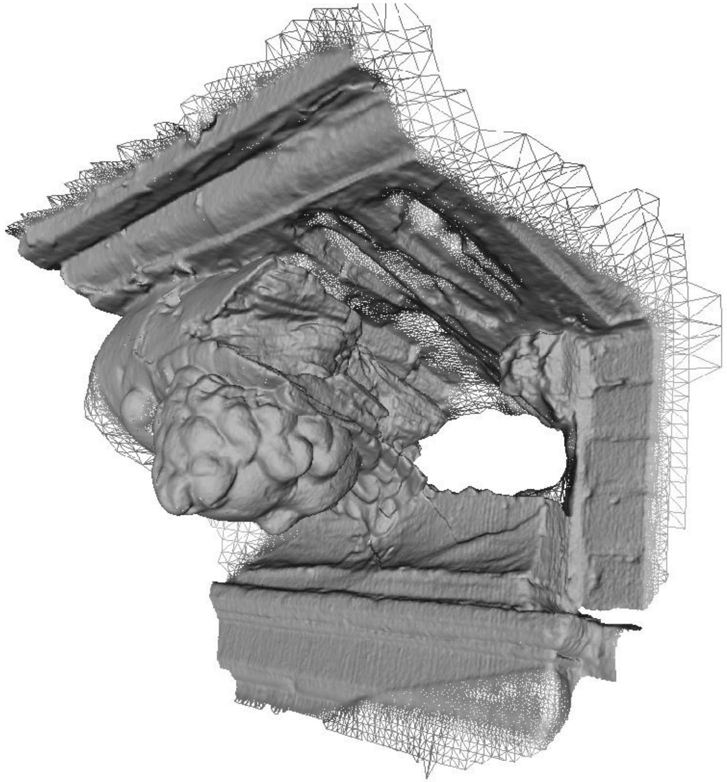

SP 2
SP 1
1608
ANNO
'Kamersteiger'
rented from Boels
1.85 m
SP 4
3.663 m
SP 5
Reference Spheres

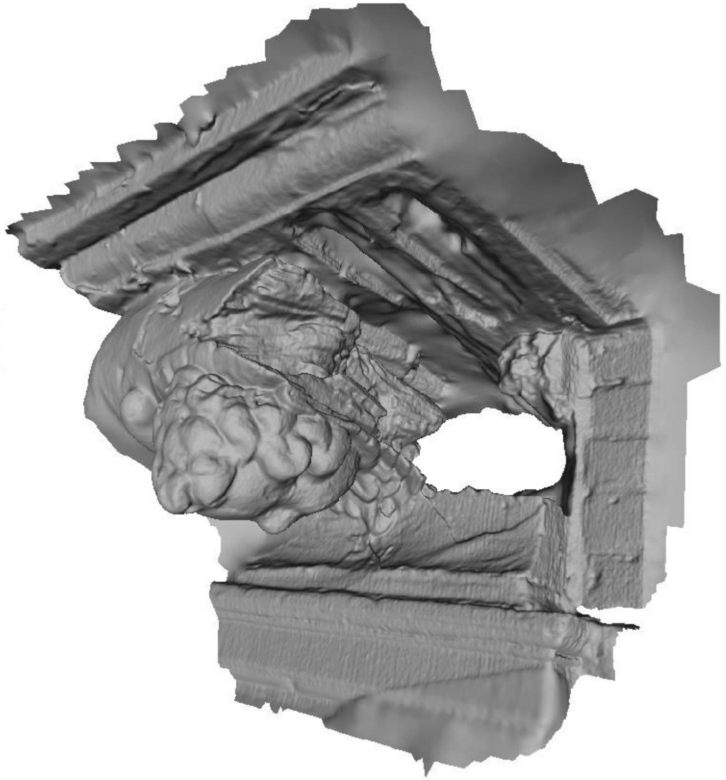

ANNO


ANNO

Damaged Angel Relief
(Target)



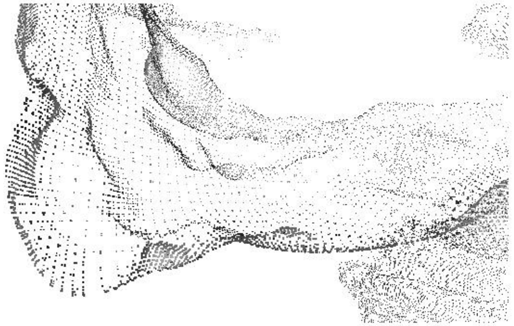


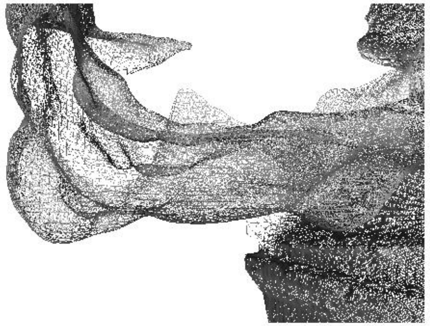


Imported Point Cloud

Triangulation using Poisson
Surface Reconstruction

Draft Mesh





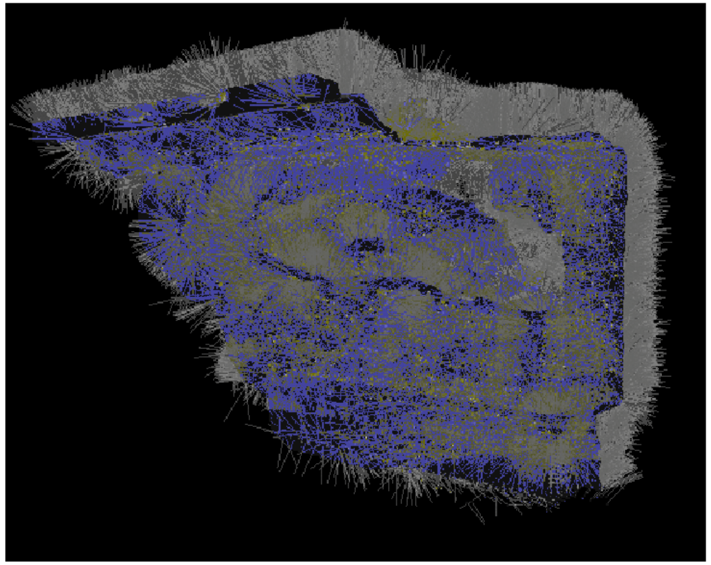
Meshlab Important Parameters

Generating Normals

Compute normals for point sets

Compute the normals of the vertices of a mesh without exploiting the triangle connectivity, useful for dataset with no faces

Neighbour num	10
Smooth Iteration	0
☐ Flip normals w.r.t. viewpoint	
Viewpoint Pos.	0 / 0 / -1000 — Get — View Dir



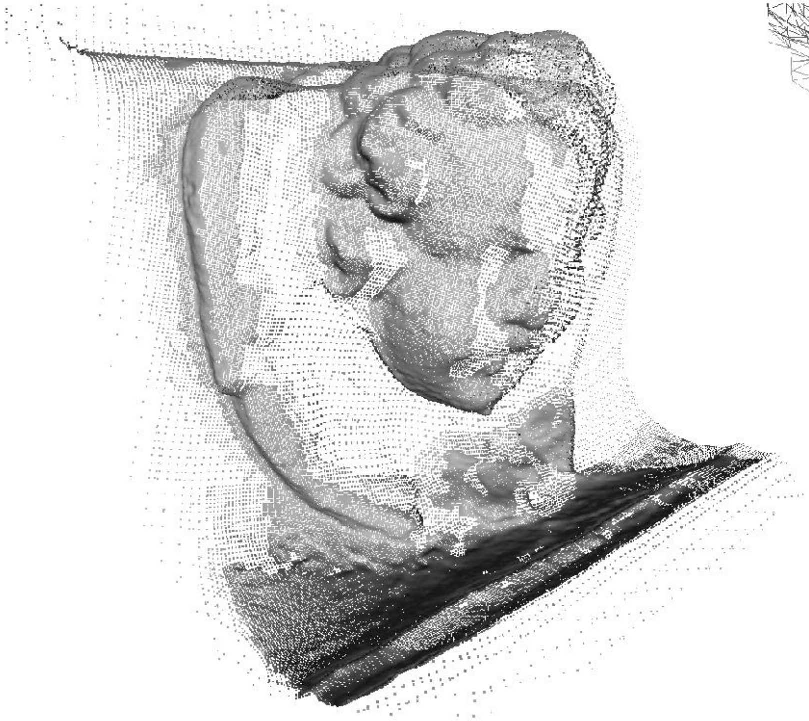
Generating Mesh

Use the points and normal to build a surface using the Poisson Surface reconstruction approach.

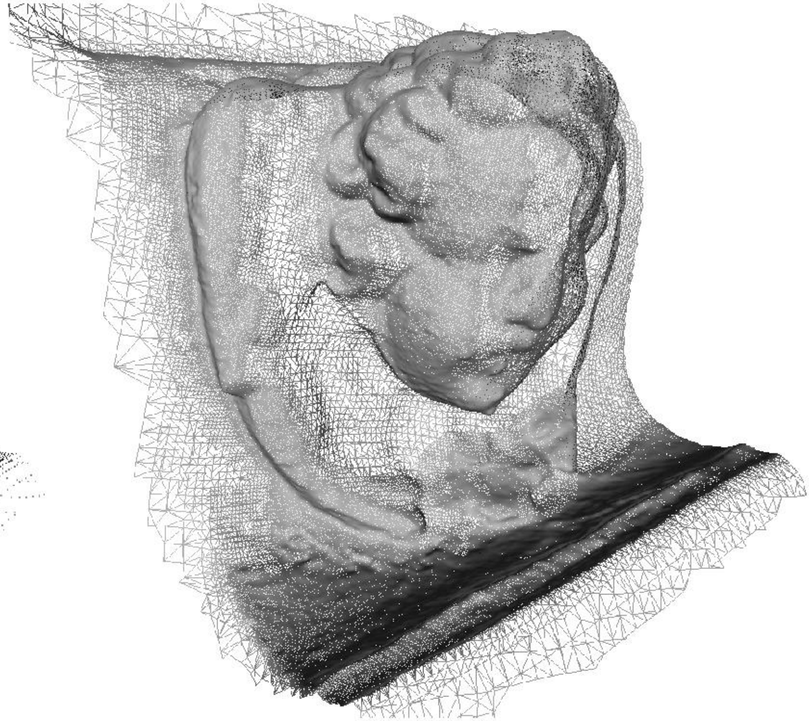
Octree Depth	12	Set the depth of the Octree used for extracting the final surface. Suggested range 5..10. Higher numbers mean higher precision in the reconstruction but also higher processing times. Be patient.
Solver Divide	7	This integer argument specifies the depth at which a block Gauss-Seidel solver is used to solve the Laplacian equation. Using this parameter helps reduce the memory overhead at the cost of a small increase in reconstruction time. In practice, the authors have found that for reconstructions of depth 9 or higher a subdivide depth of 7 or 8 can reduce the memory usage. The default value is 8.
Samples per Node	1	This floating point value specifies the minimum number of sample points that should fall within an octree node as the octree construction is adapted to sampling density. For noise-free samples, small values in the range [1.0 - 5.0] can be used. For more noisy samples, larger values in the range [15.0 - 20.0] may be needed to provide a smoother, noise-reduced, reconstruction. The default value is 1.0.
Surface offsetting	1	This floating point value specifies a correction value for the isosurface threshold that is chosen. Values 1 external offsetting.Good values are in the range 0.5 .. 2. The default value is 1.0 (no offsetting).

Optimum Values with 8 GB RAM

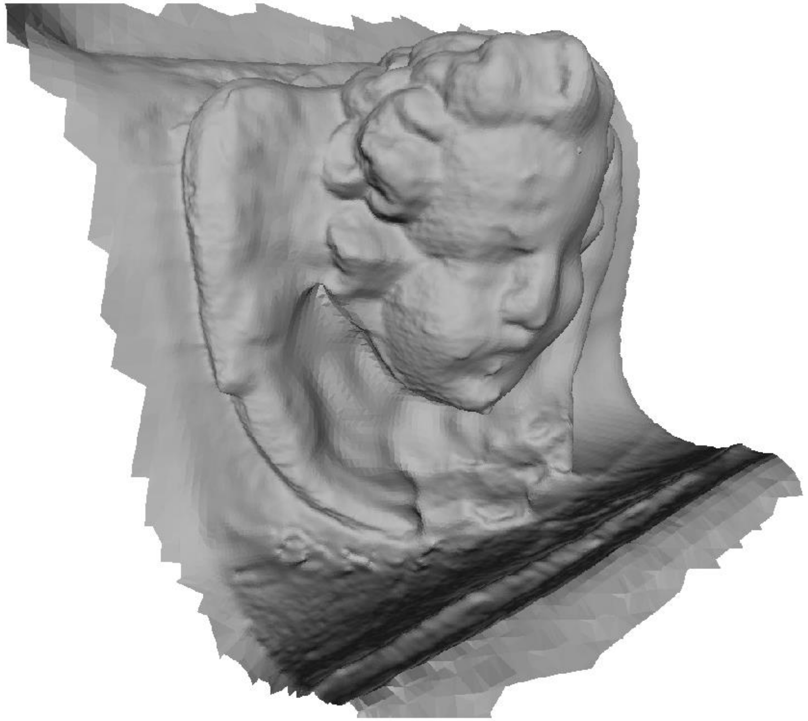
Intact Angel Relief
(Reference)



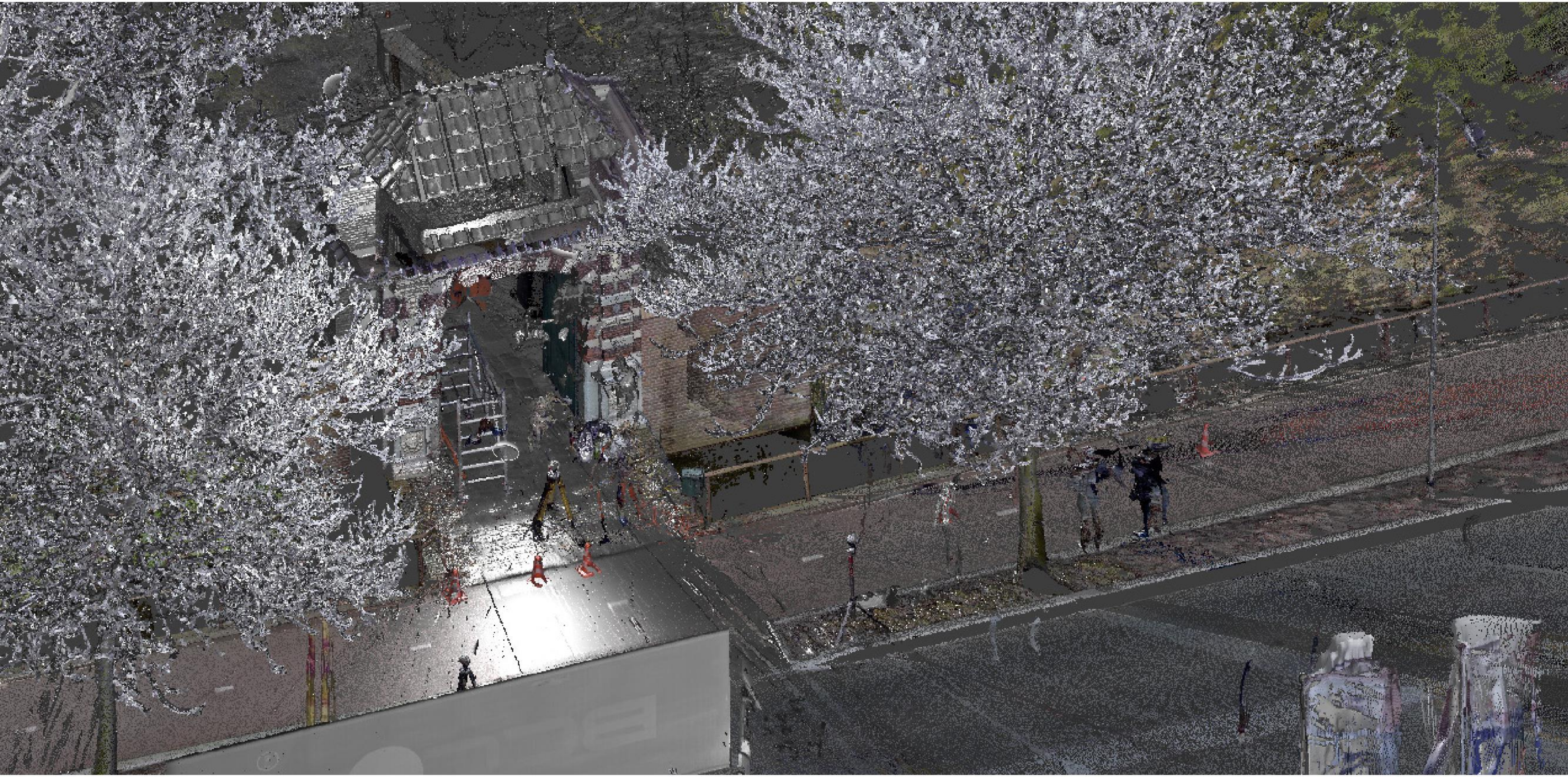
Imported Point Cloud

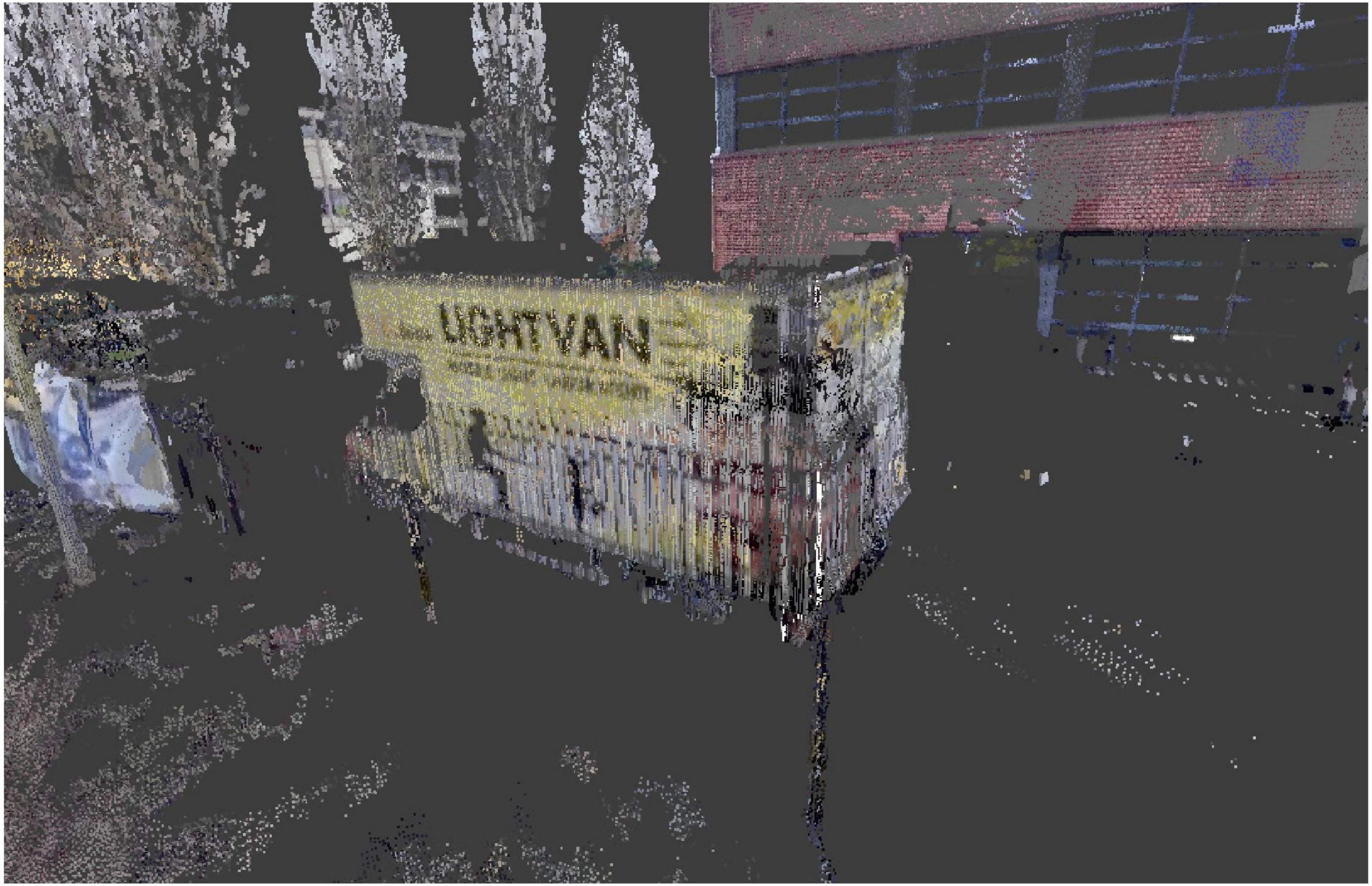


Triangulation using Poisson
Surface Reconstruction



Draft Mesh




LIGHTVAN

Conclusions

1. Cost comparisons are not conclusive since the bulk of the costs consists of labor, however digital fabrication can diminish geographical constraints giving access to a larger labor pool.

2. The use of molding techniques can provide more opportunities for hybridization.

3. Digital Fabrication and Scanning Technologies have to be used in conjunction to be used for the purposes of patching.

4. The selection of the right software packages plays an important role in the effective manipulation of digital geometry (dependent upon the type of geometry).

5. The use of Digital Fabrication provides more opportunities for reversibility and therefore promotes lower levels of intervention for restoration.

Questions?