Forensic Applications in 3D Imaging

The case for Foundational Validation

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We acknowledge and pay our respects to the Kaurna people,
the traditional custodians whose ancestral lands we gather on.

We acknowledge the deep feelings of attachment and relationship of the
Kaurna people to country and we respect and value their past, present
and ongoing connection to the land and cultural beliefs.

Biography

I'm an engineer and forensic scientist in Adelaide, South Australia who has been printing and designing models ever since my boss at GM Holden dropped a 3D Printer on my desk as part of a community outreach program with local schools.

I've played with dozens of printers ranging from hobby to commercial grade and designed numerous engineering models and parts for business, schools and consumers alike. I began scanning models in 2018 when I started writing courses in 3D printing and prototyping for the University of Adelaide.

In 2019 I was awarded my PhD in digital forensic science. Since then, I have been exploring interdisciplinary topics such as the applications of machine leaning, open-source intelligence and various mental models that can be applied to our domain of forensic science.

I've regularly appeared in the media on topics relating to 3D printed firearms and other applications of this technology for our profession.

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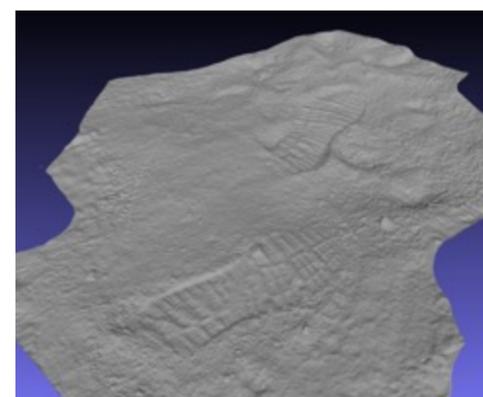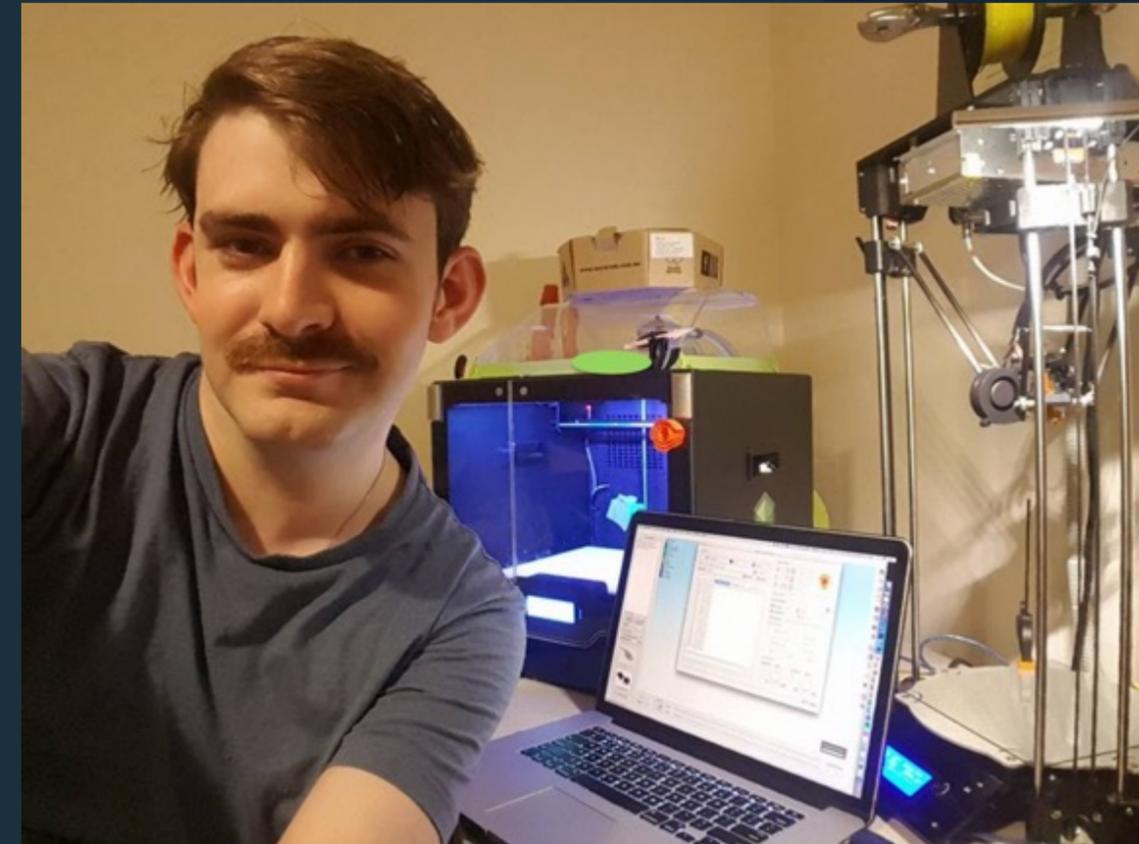
Today

- **Applications of 3D Imaging**

- **The Case for Foundational Validity**

- **A Pipeline Model for 3D Imaging**
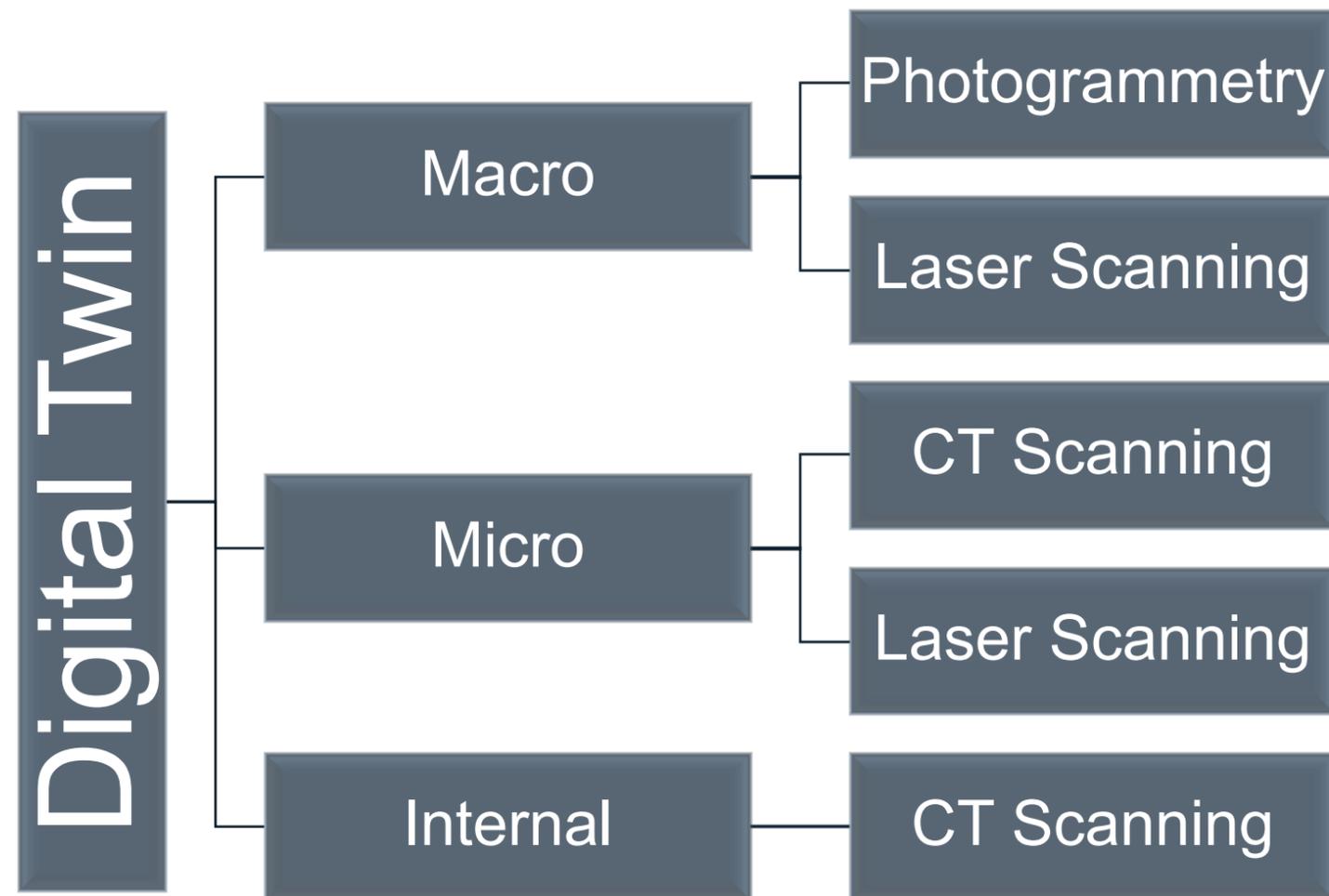
- **Assessing Error in the 3D Pipeline**

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Conception

Digital Twin

*"A **virtual representation** that serves as the real-time digital counterpart **of a physical object** or process."*

(Attributed to Michael Grieves, 2002 then University of Michigan)

Elisa Negri (2017). "A review of the roles of Digital Twin in CPS-based production systems". *Procedia Manufacturing*. **11**: 939–948.
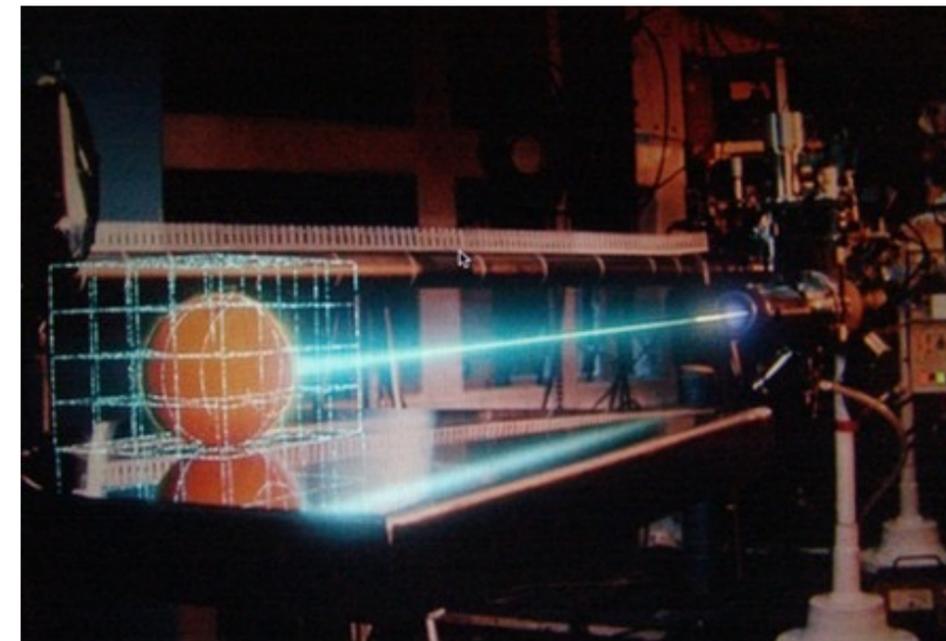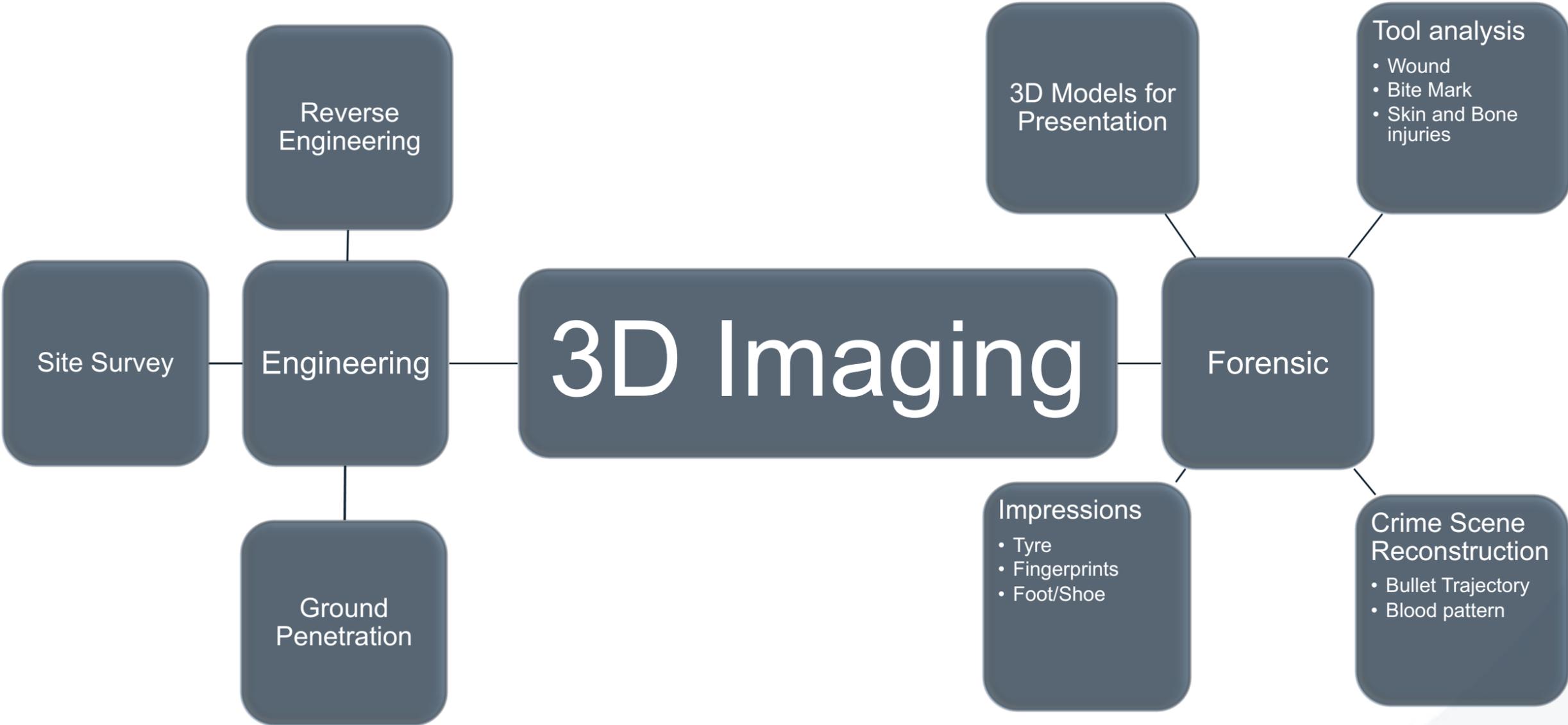
```
Digital Twin
├── Macro
│   ├── Photogrammetry
│   └── Laser Scanning
├── Micro
│   ├── CT Scanning
│   └── Laser Scanning
└── Internal
    └── CT Scanning
```


Image Credit:
Tron. (1982). Lisberger, S. Walt Disney Productions

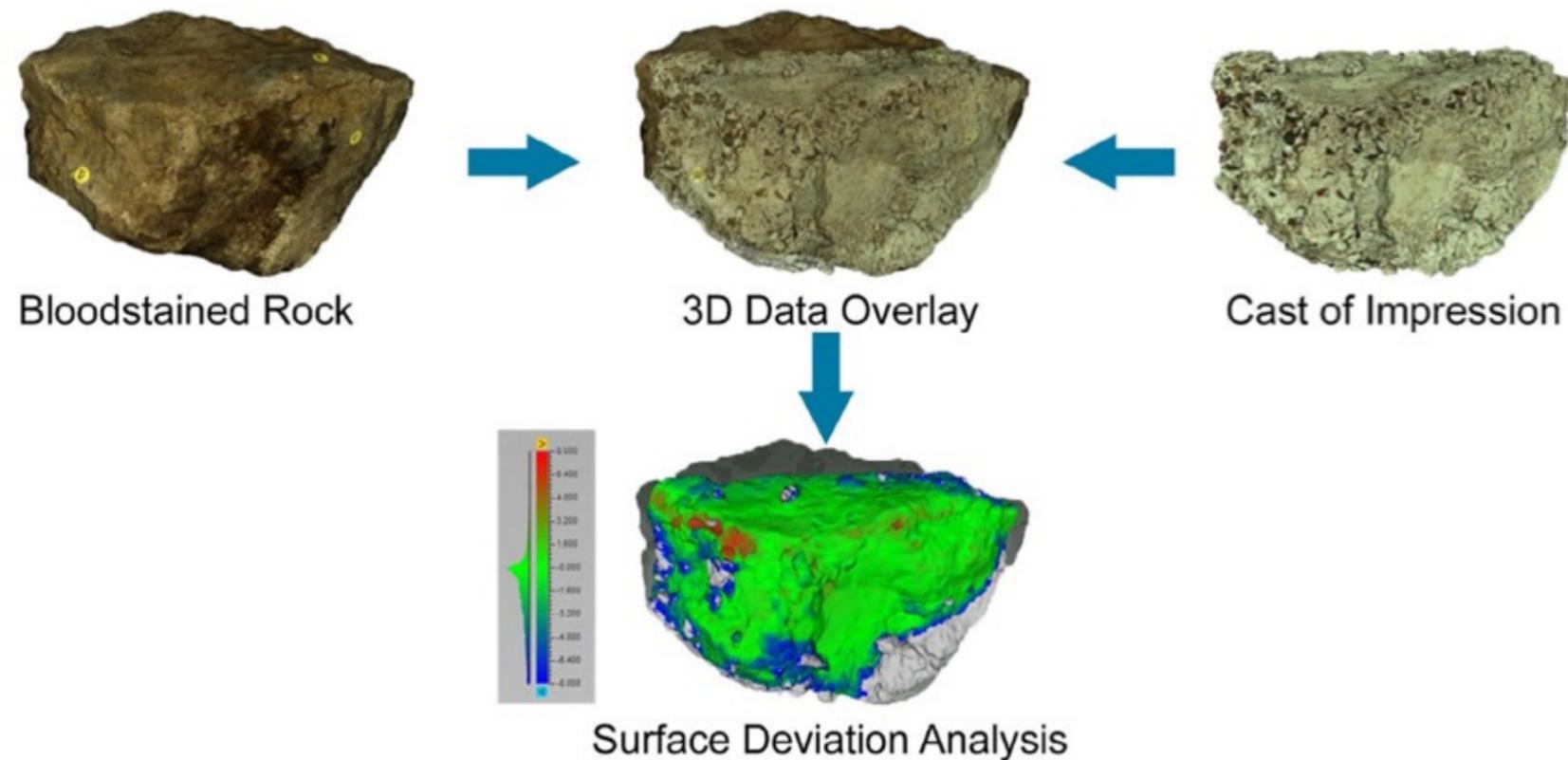THE UNIVERSITY of ADELAIDE

Application Space

Crime Scene Reconstruction: Lindt Café Siege

- Tripod mounted 360° scans supplemented by exhibit scans

- Review trajectories and likely positions using field of view analysis, CCTV, and audio analysis.

- 3D fly throughs created of the scene.

- Conclusions drawn regarding EA and the unintentional killing of Katrina Dawson.
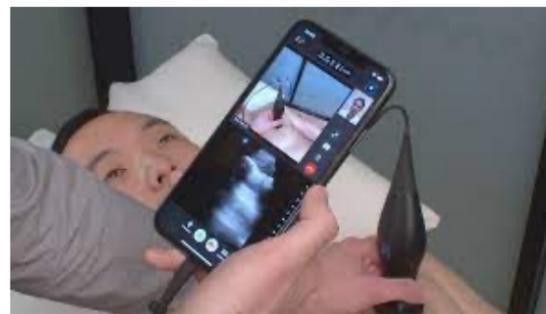
THE UNIVERSITY of ADELAIDE
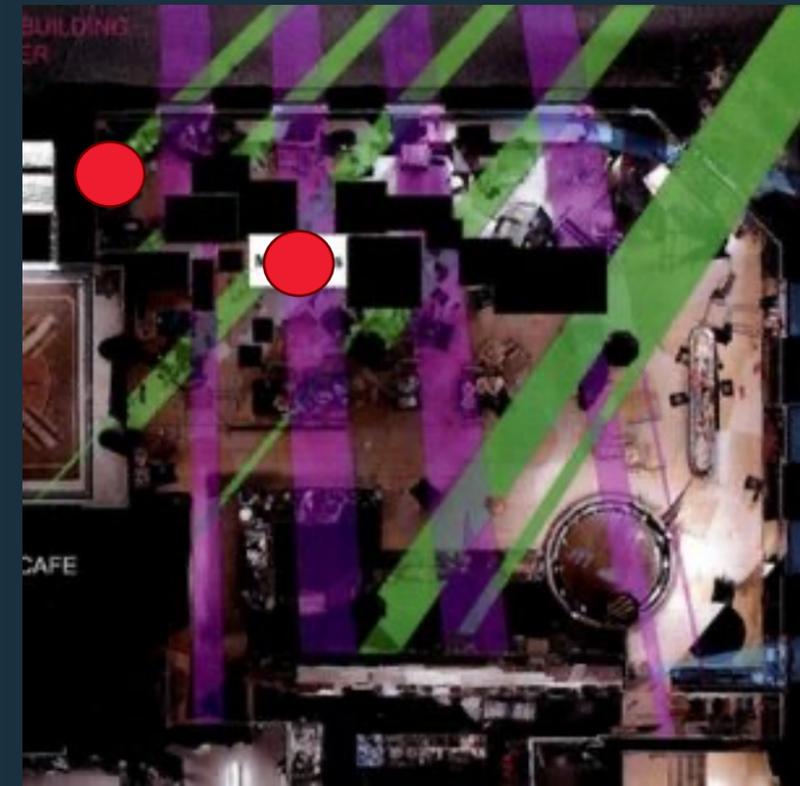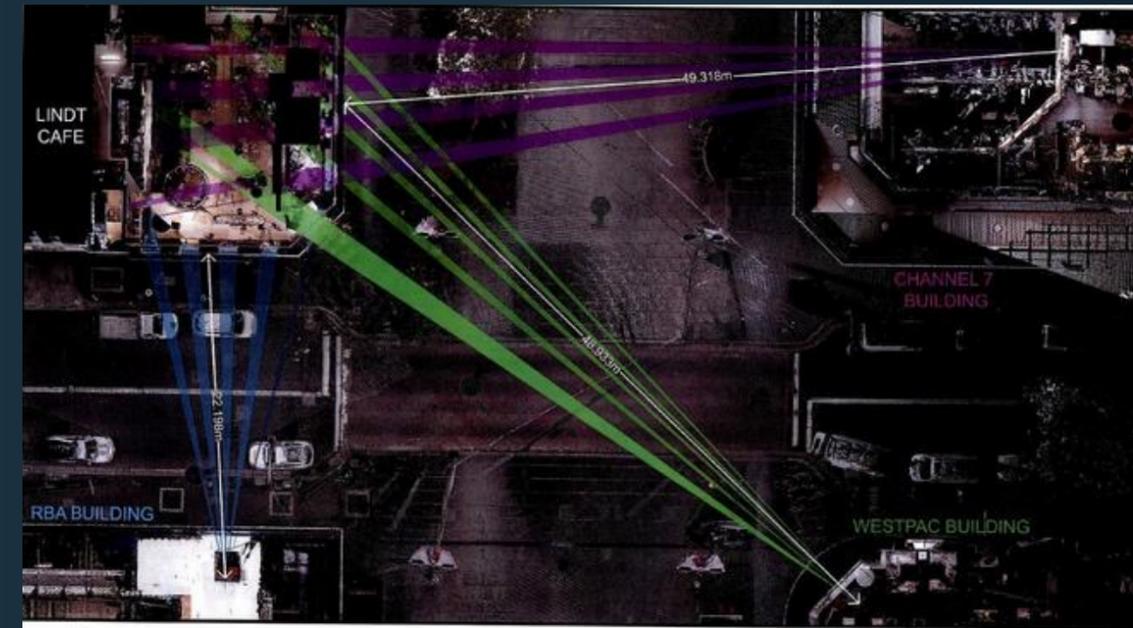
Tool and Impression Analysis: Homicide

Bloodstained Rock → 3D Data Overlay ← Cast of Impression

Surface Deviation Analysis

- Rock used to bludgeon victim to death.

- Weight of exhibit caused issues with examination

- Matching to impression

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Synthesis

Ubiquitous scanning on demand?

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Previous work

- 2019 Honours projects at the University of Adelaide funded by the Australia and New Zealand Policing Advisory Agency National Institute of Forensic Science.

  - Tang, J. 2019. Forensic Applications of 3D Scanning. Honours. University of Adelaide. Adelaide South Australia.

  - Walsh, G. 2019. Forensic Applications of 3D Scanning. Honours. University of Adelaide. Adelaide South Australia.

Could we create low cost a ubiquitous scanner?

What does forensic science and Star Trek: Picard have in common?
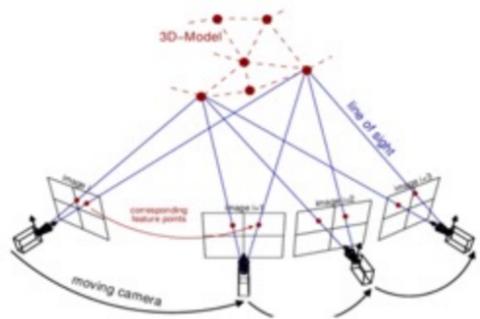

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Our aims

- **Compare a selection of 3D imaging technologies**
  - o Photogrammetry
  - o Laser Scanning
  - o Dot Projection
- **View in the context of two key application spaces**
 - o Blood Pattern Analysis
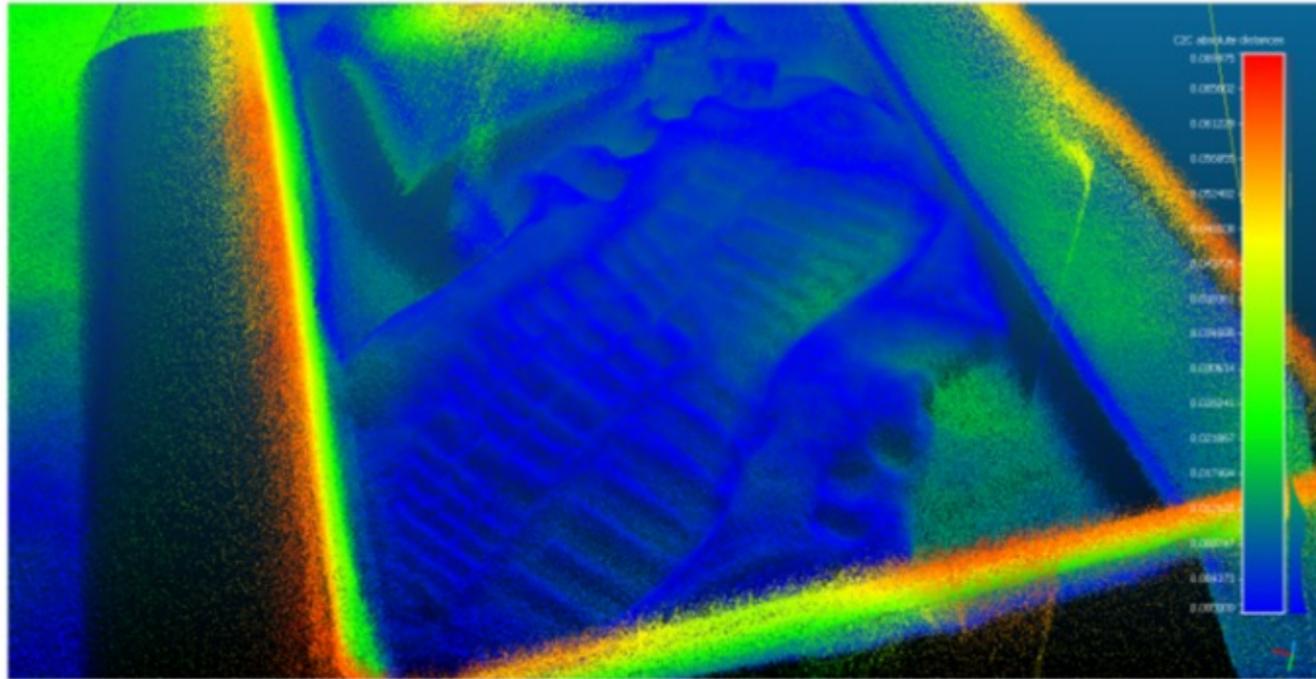 - o Shoe impressions

Experiment

J	Superfine Self-raising Flour (Waitrose)	39g	
	Sodium Chloride (Sigma)	1g	Mix to a homogeneous constituency and store at room temperature
	Glycerol (Supercook)	1ml	
	Strawberry Sugar Syrup (Lyles)	1ml	
	Scarlet Food Colouring (Supercook)	1ml	
	Sterile Distilled Water	183ml	

Goldilocks Principle

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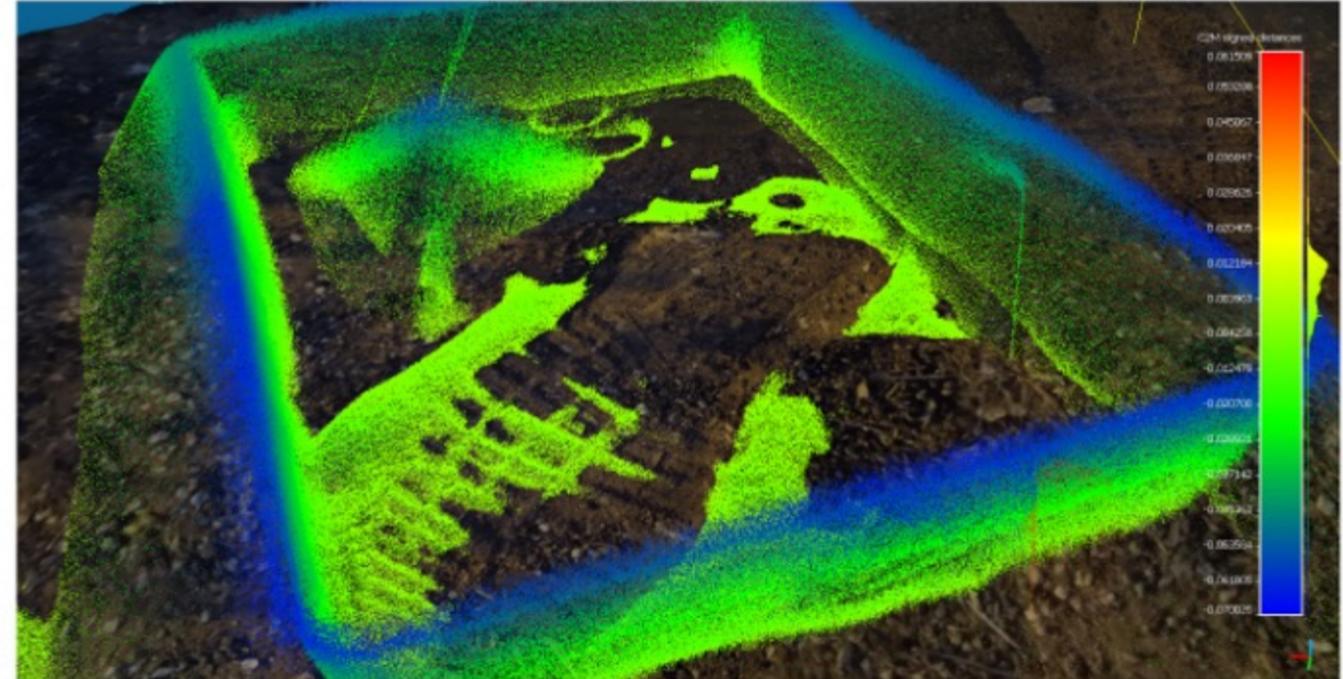
Blood Pattern Analysis
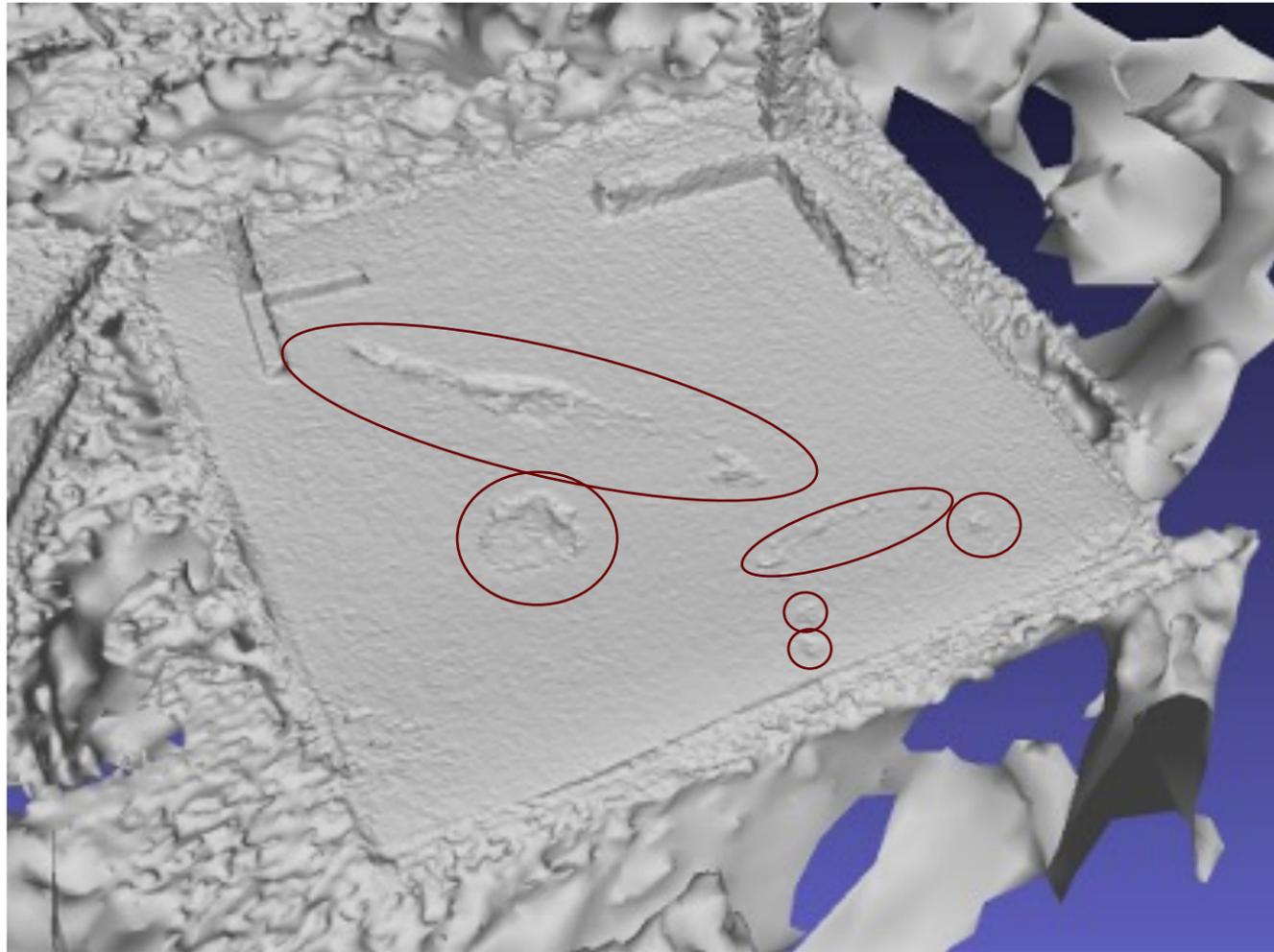
Footwear: Surface Deviation Analysis

Photogrammetry to Laser scan point cloud comparison. Value in absolute distance.

(Scale: blue = 0 red =0.07 m)

0 difference across the impression

Laser Scan point cloud to Generated Mesh comparison

(Scale: blue = -0.07 red =0.06 m)

- 4mm is difference across the print

Results

- Photogrammetry is an acceptable low-cost method of 3D imaging for most applications

- There are issues with precision loss when converting from point cloud to mesh.

- Blood and other specular applications resist scanning

- Precision of survey equipment may not be sufficient to create digital twin of blood pattern evidence – no gain over simple images bar digital workflow improvements.
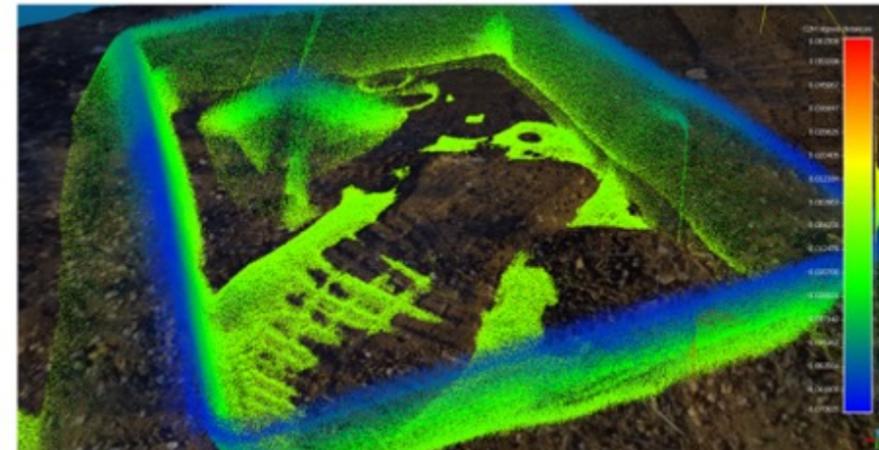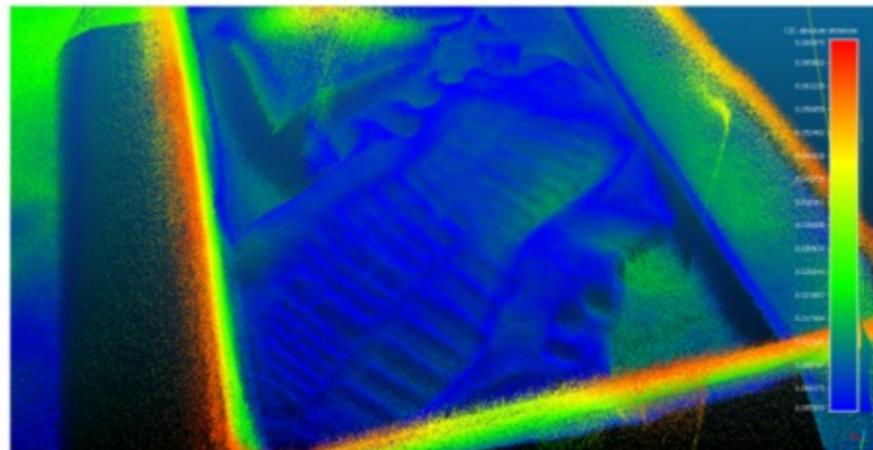
- Use the right tool for the job.

Limitations

Foundational Validity?

Bloodstained Rock → 3D Data Overlay ← Cast of Impression

Surface Deviation Analysis
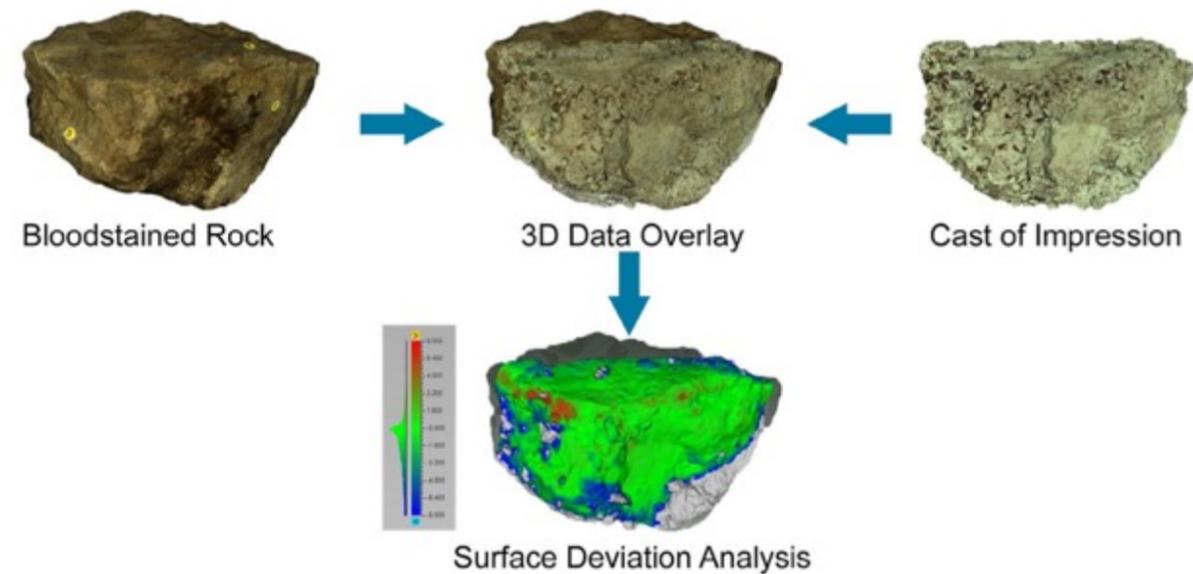
- Where are the losses in the system?
- How do we quantify them?
- Are these errors acceptable?
- Do we understand them?
- What are the standard processes?

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Foundational Validity

"The interpretation of forensic evidence is not always based on scientific studies to determine its validity."

- National Research Council of The National Academies
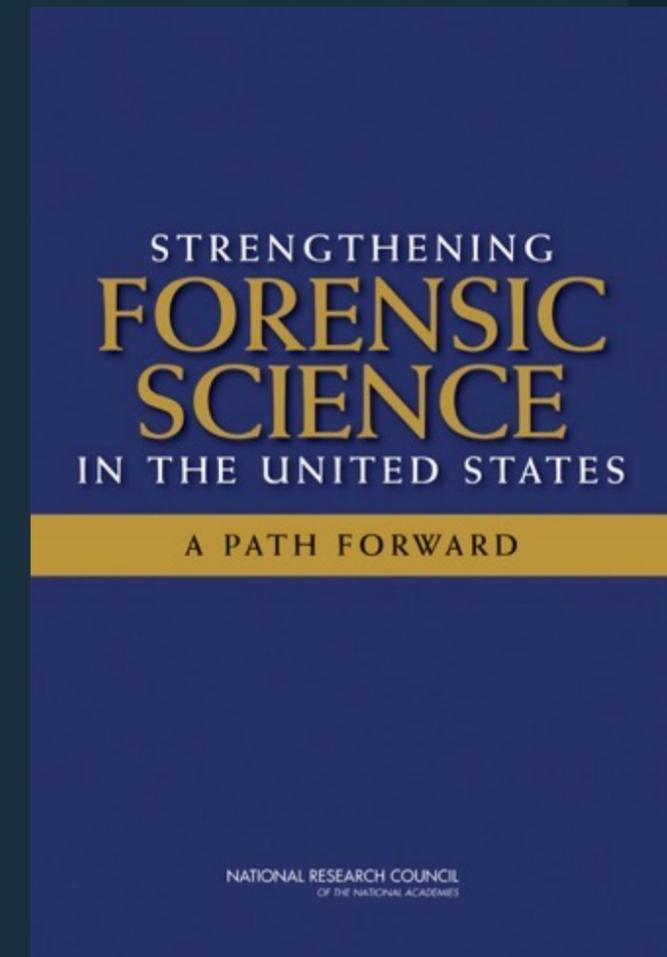
Foundational Validity

- Expanded upon the findings of NAS in critical areas:

    - Footwear, Firearms, DNA, Bite Marks, Fingerprints, Hair Analysis.

- No studies can answer if a cast came from a particular piece of footwear

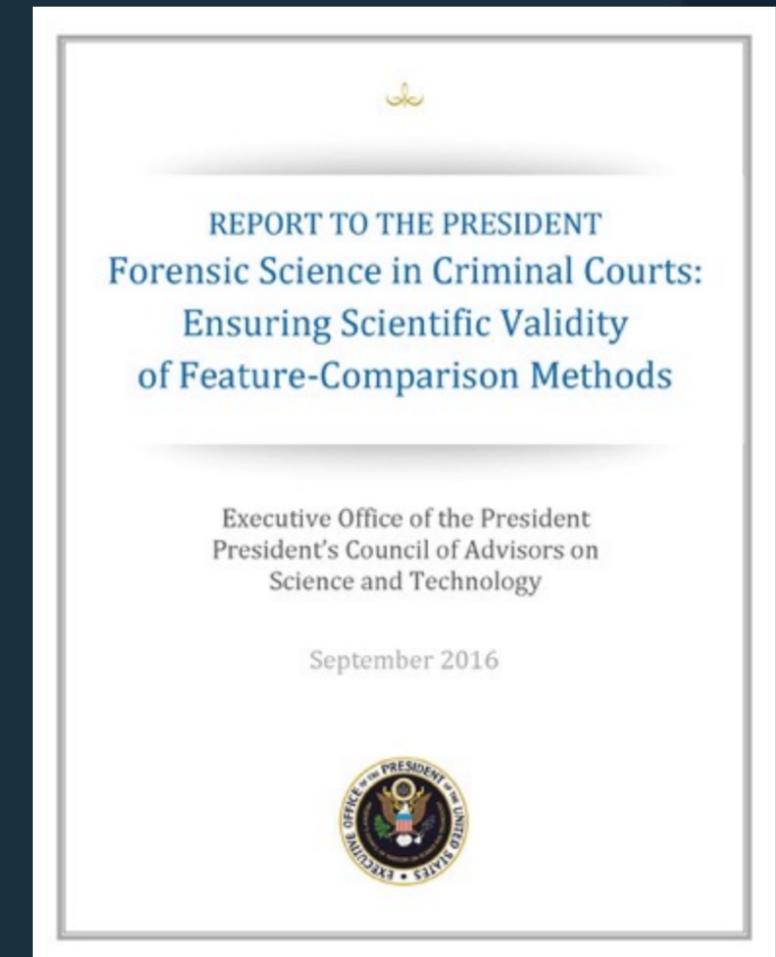- Ie. we cannot say if a particular impression came from a specific shoe based on identified marks

REPORT TO THE PRESIDENT
Forensic Science in Criminal Courts:
Ensuring Scientific Validity
of Feature-Comparison Methods

Executive Office of the President
President's Council of Advisors on
Science and Technology

September 2016

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Foundational Validity

- Rejected the findings of PCAST and not the only ones who have done so.

- Rejection based several critical points.

- The method of validation used in PCAST is not the **only** possible method of validation.

- Forensic Science does not meet the definition of measurement.

Foundational Validity

Forensic Science Definition

Forensic science is a case-based (or multi case-based) research-oriented endeavour using the principles of science to study and understand traces – the remnants of past activities (such as an individual's presence and actions) – through their detection, recognition, examination and interpretation to understand anomalous events of public interest (e.g., crimes, litigations, security incidents).

1.   Activity and presence produce traces that are fundamental vectors of information

2.   Scene investigation is a scientific and diagnostic endeavour requiring scientific expertise

3.   Forensic science is case-based and reliant on scientific knowledge, investigative methodology and logical reasoning

4.   Forensic science is an assessment of findings in context due to time asymmetry.

5.   **Forensic science deals with a continuum of uncertainties.**

6.   Forensic science has multi-dimensional purposes and contributions

7.   Forensic Science findings acquire meaning in context

https://iafs2023.com.au/cms/wp-content/uploads/IAFS-2023-Sydney-Declaration-18-May-2021.pdf

Sydney Declaration
18 May 2021
iafs 2023

| 2009 | | | 2016 | | | 2020 | 2021 | | 2023 |

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Addressing this issue for 3D imaging

- **Introducing a new concept for visualising the 3D imaging process using a systems engineering method of decomposition and reduction.**

- Basic steps taking evidence from scene to court room

- Consideration for additive/subtractive manufacturing technology

- Identification of likely sources of error

- Clustering of steps into easily identified stages or sub-systems.

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**Traditional
Process**
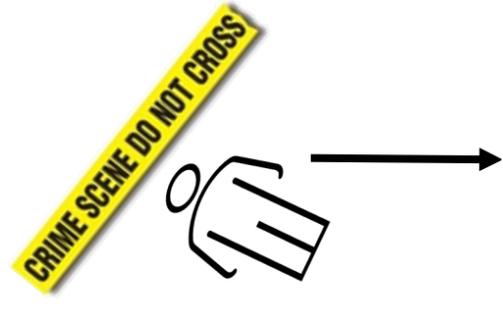
Crime Scene

*Source of Bias
(A)*

*Expert report and
object for Jury*

Court Room

Expert Witness

*Source of Bias
(G)*

*Source of Bias
(F)*

Traditional Process

Crime Scene

Source of Bias (A)

Long term Data Storage

Expert report and object for Jury

Court Room

Expert Witness

Source of Bias (G)

Source of Bias (F)

For notation simplicity all errors are assumed to be read as Root Mean Squared except where obviously not meant to be.

Traditional Process

Crime Scene

Source of Bias
(A)

Long term Data Storage

Expert report and object for Jury

Court Room

Expert Witness

Source of Bias
(G)

Source of Bias
(F)

TOTAL ERROR = A+F+G
= Presentation Error

Traditional Process

Crime Scene

Model Acquisition

Source of Error (A)

Raw data output

Clean Raw data

Source of Error (B)

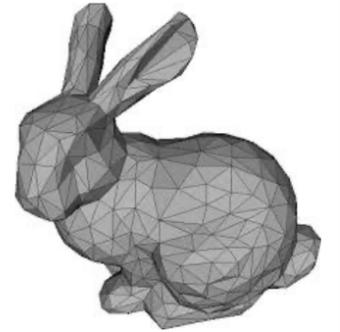Cleaned output

Three-Dimensional Process

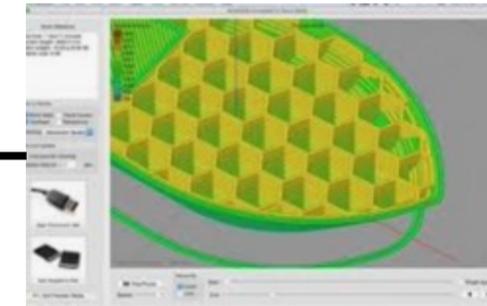Point to surface meshing

Source of Error (C)

Mesh Solid

Slice mesh solid into GCODE instructions for printing

Source of Error (D)

GCODE

Print scanned data into solid

Source of Error (E)

Printed Object

Expert Witness

Source of Bias (F)

Expert report and object for Jury

Long term Data Storage

Court Room

Source of Bias (G)
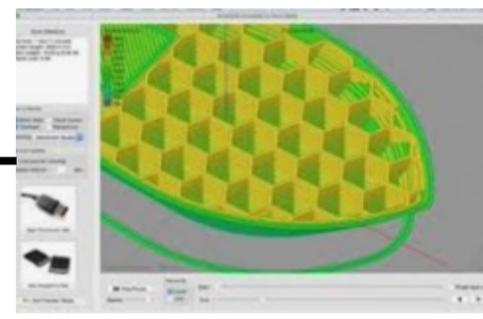
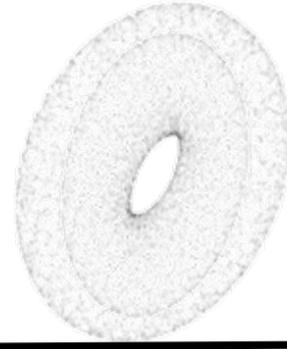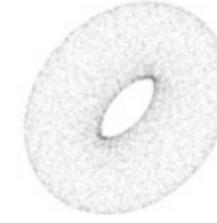**Traditional Process**

Crime Scene

Model Acquisition

Source of Error (A)

Raw data output
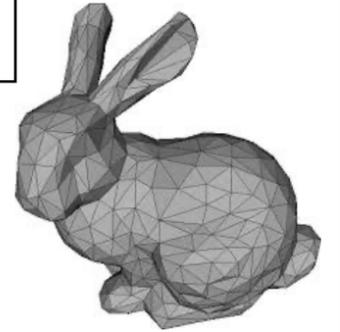
Clean Raw data

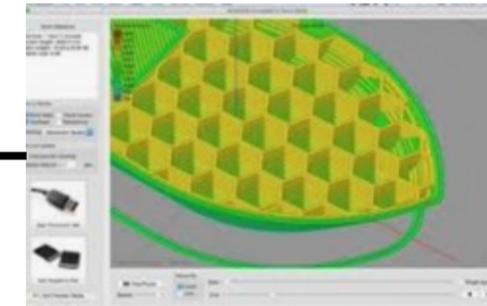Source of Error (B)

Cleaned output
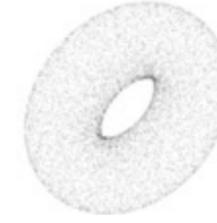
Point to surface meshing

Source of Error (C)

Mesh Solid

Slice mesh solid into GCODE instructions for printing

Source of Error (D)

GCODE

Print scanned data into solid

Source of Error (E)

Printed Object

Expert Witness

Source of Bias (F)

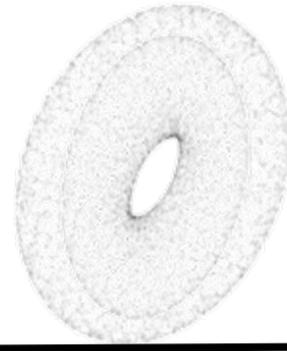Expert report and object for Jury

Court Room

Source of Bias (G)

Traditional Process

Crime Scene

Model Acquisition

Raw data output

Clean Raw data

Cleaned output

Point to surface meshing

Source of Error (A)

Source of Error (B)

Source of Error (C)

TOTAL ERROR = (A+B+C+D+E) + Presentation Error = Process Error + Presentation Error

Mesh Solid

Expert report and object for Jury

Printed Object

Print scanned data into solid

Slice mesh solid into GCODE instructions for printing

Court Room

Expert Witness

GCODE

Source of Bias (G)

Source of Bias (F)

Source of Error (E)

Source of Error (D)

Collection

Model Acquisition

Raw data output

Crime Scene

Source of Error
(A)

Creation

Clean Raw data

Cleaned output

Point to surface meshing

Source of Error
(B)

Source of Error
(C)

Mesh Solid

Presentation

Expert report and object for Jury

Printed Object

Court Room

Expert Witness

Print scanned data into solid

Slice mesh solid into GCODE instructions for printing

GCODE

Source of Bias
(G)

Source of Bias
(F)

Source of Error
(E)

Source of Error
(D)

Manufacture

Collection

Model Acquisition

Raw data output

Crime Scene

Source of Error (A)

Collection Error = A

Creation

Clean Raw data

Cleaned output
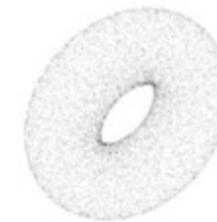
Point to surface meshing

Source of Error (B)

Source of Error (C)

Creation Error = B +C

Mesh Solid

Presentation Error = G + F

Expert report and object for Jury

Court Room

Expert Witness

Source of Bias (G)

Source of Bias (F)

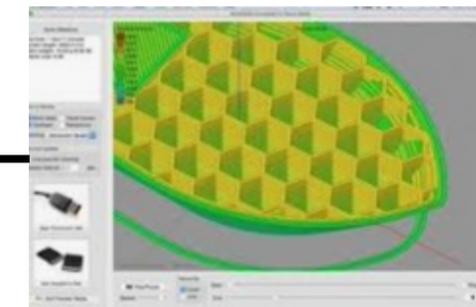**Manufacture Error = D + E**

Printed Object

Print scanned data into solid

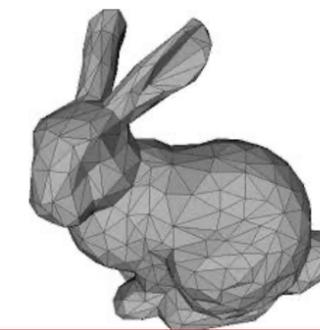Slice mesh solid into GCODE instructions for printing

GCODE

Source of Error (E)

Source of Error (D)

Manufacture

Collection

Crime Scene

Model Acquisition
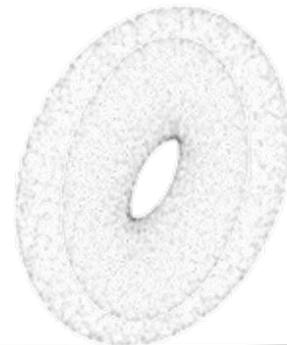
Raw data output

Source of Error (A)

Creation

Clean Raw data

Cleaned output
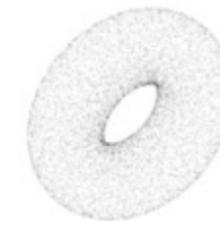
Point to surface meshing

Source of Error (B)

Source of Error (C)

TOTAL ERROR = Collection Error + Creation Error + Manufacture Error + Presentation Error

Expert report and object for Jury

Court Room

Expert Witness

Source of Bias (G)
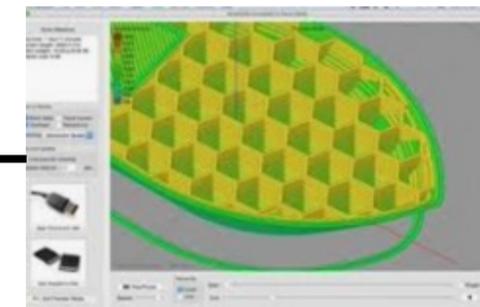
Source of Bias (F)
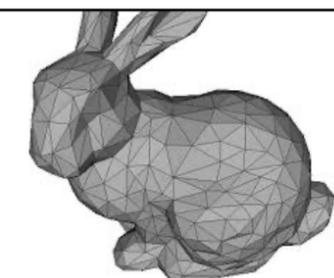
Printed Object

Print scanned data into solid

Source of Error (E)

GCODE
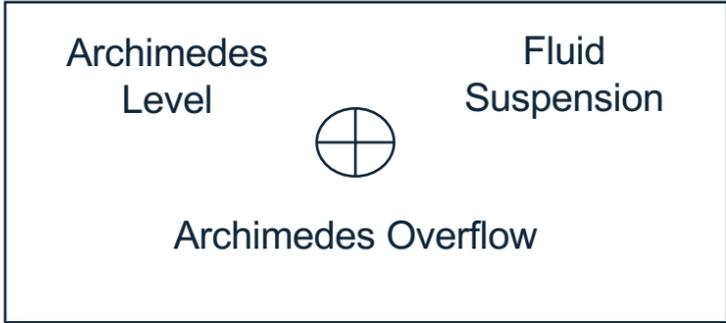
Slice mesh solid into GCODE instructions for printing

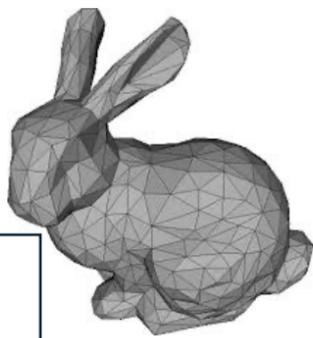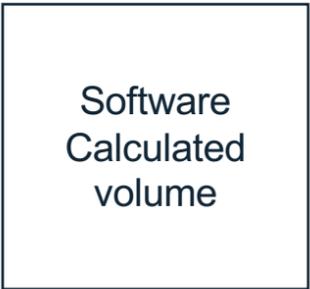*Source of Error (D)*

Manufacture

Generic Method

Precisely machined Volume

Archimedes Level $\oplus$ Fluid Suspension

Archimedes Overflow

V_m

Bland-Altman Analysis

V_s

Software Calculated volume

Model Acquisition

Raw data output

Clean Raw data

Cleaned output

Point to surface meshing
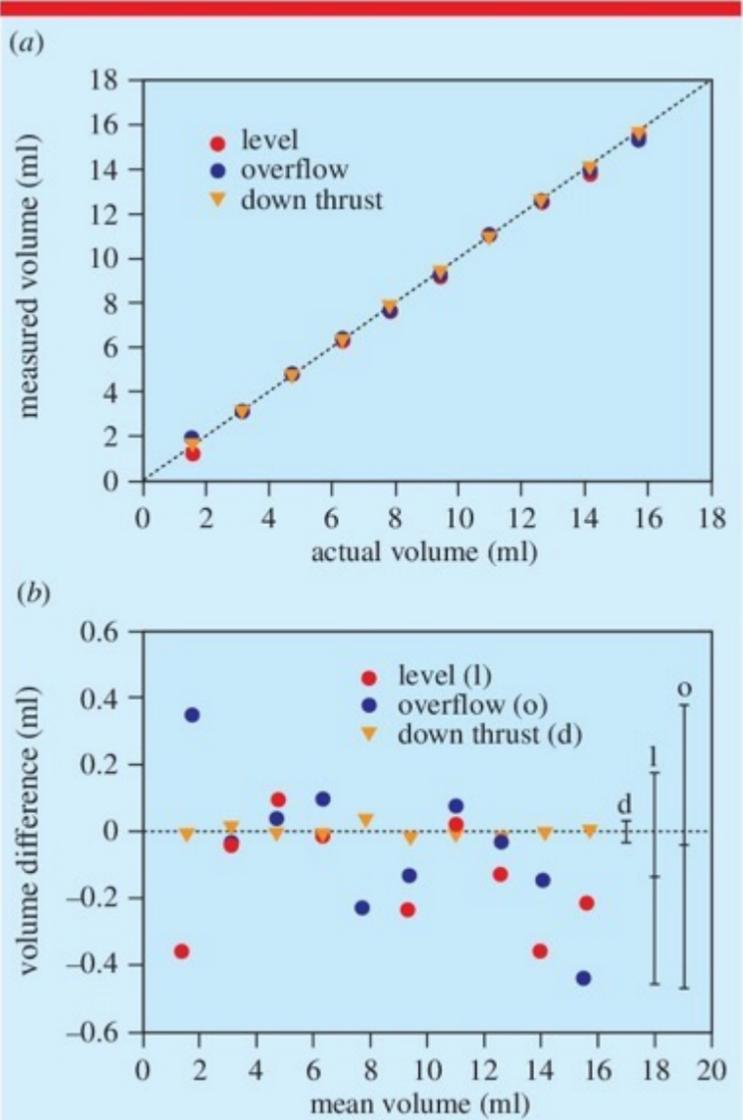
Mesh Solid

Hughes, S.W., 2005. Archimedes revisited: a faster, better, cheaper method of accurately measuring the volume of small objects. *Physics education*, *40*(5), p.468.

Extension: Build Error
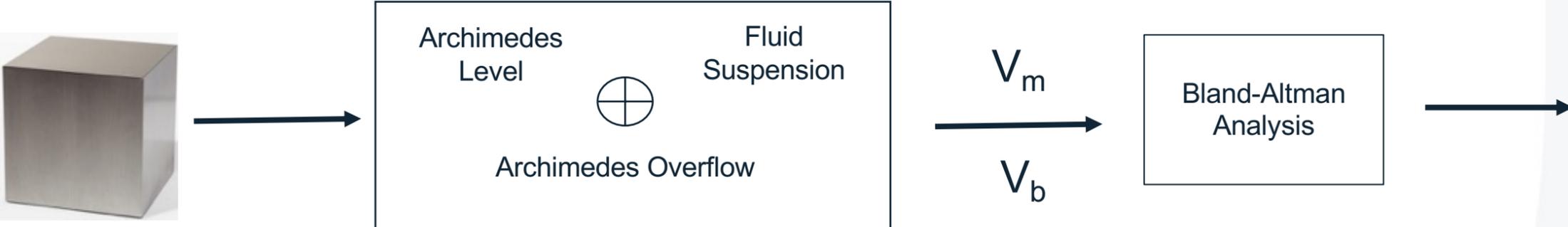
Archimedes Level $\oplus$ Fluid Suspension

Archimedes Overflow
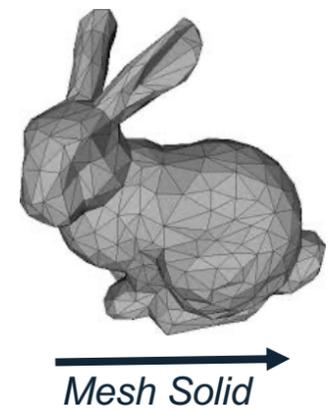
V_m

V_b

Bland-Altman Analysis

Printed Object

Slice mesh solid into GCODE instructions for printing

Print scanned data into solid

Mesh Solid

GCODE

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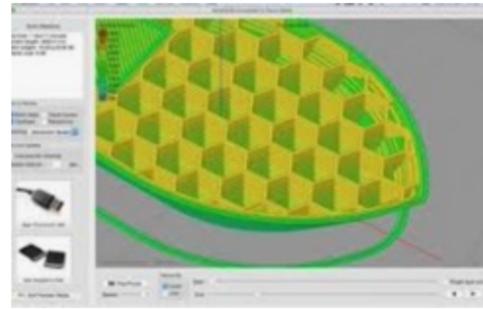
Example

We use an iPhone 12 Pro Max and an iPad Pro to scan common items. Both have LIDAR sensors. Both are cable of 3D imaging. Both are capable of photogrammetry. We use Scandy Pro to capture a model on the phone and output a data file.

What does forensic science and Star Trek: Picard have in common?

Developing / Developed World

Recall our context of low cost tool

Collection

Model Acquisition

Raw data output

Crime Scene

Source of Error (A)

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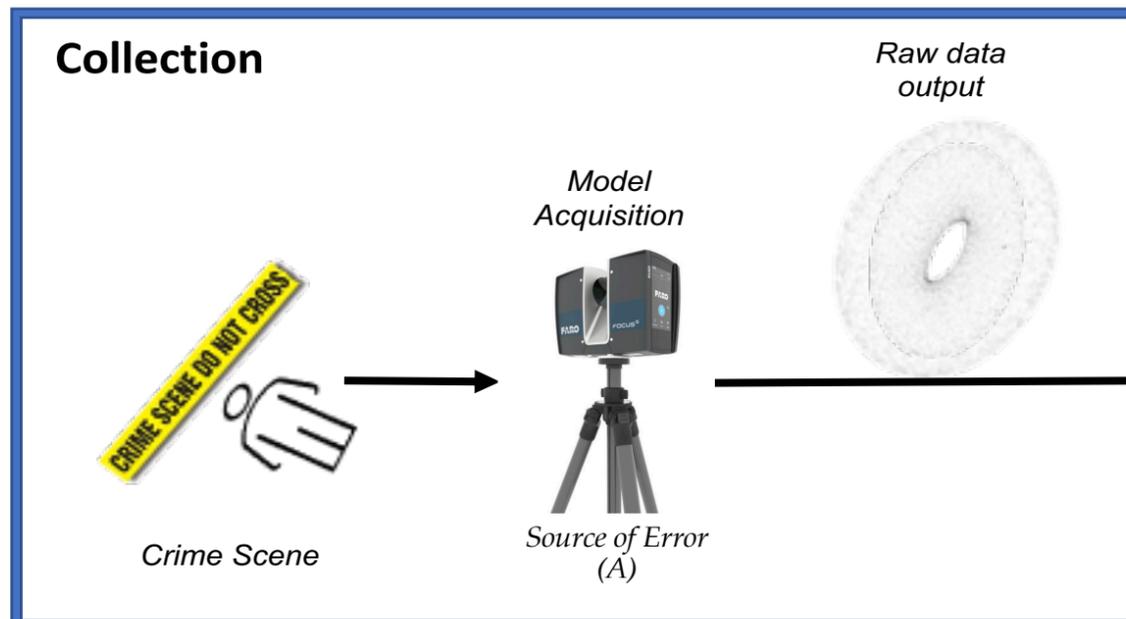
Example
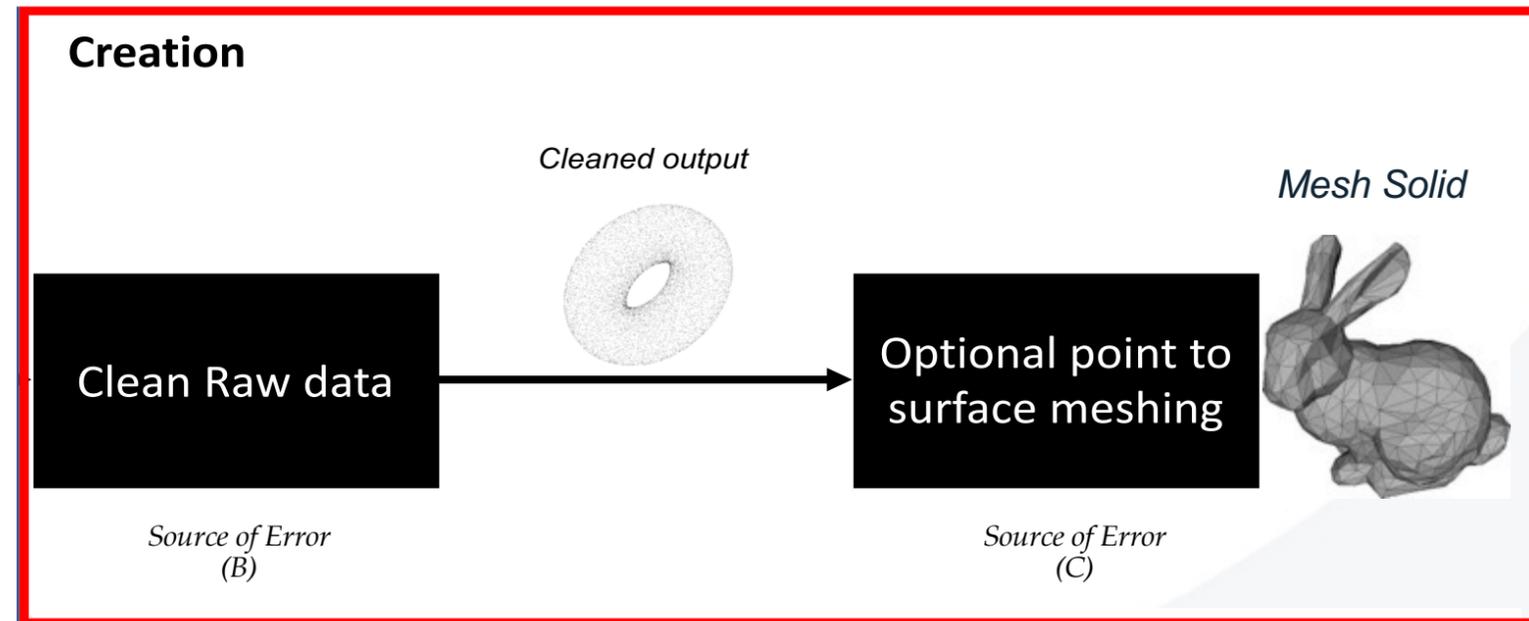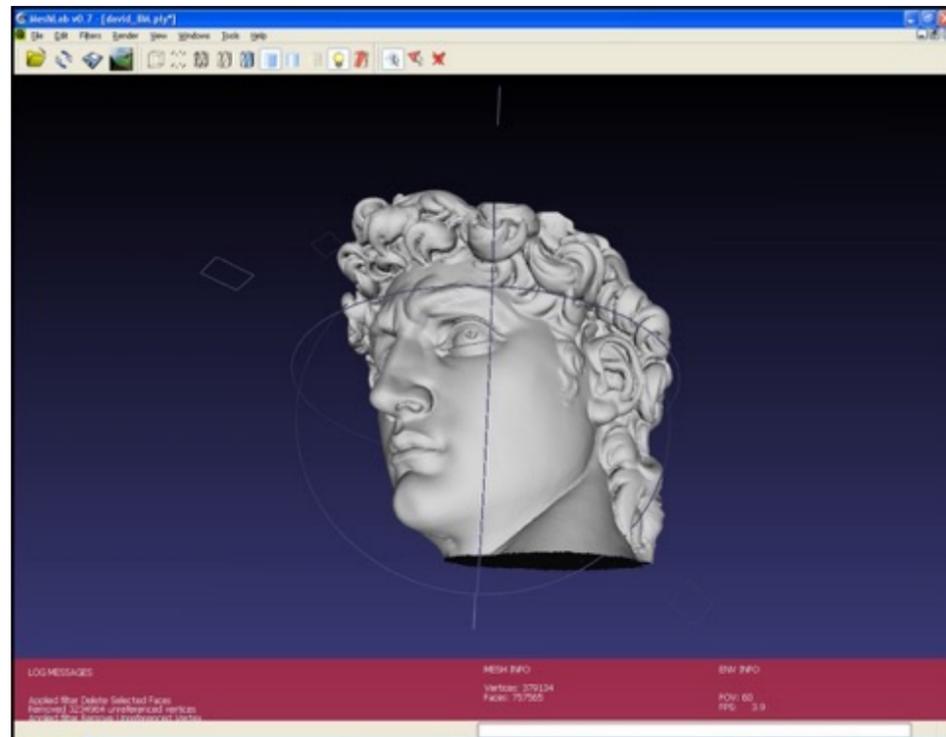
The file from Scandy Pro is exported as a mesh solid and loaded into MeshLab. Quality assurance steps are taken to ensure the model is closed watertight mesh.

The volume of the solid is then calculated in software V_s.

The final calculated volume of the mesh solid contains all the errors of this pipe.

Creation

Cleaned output

Mesh Solid

Clean Raw data → Optional point to surface meshing

Source of Error
(B)

Source of Error
(C)

THE UNIVERSITY of ADELAIDE
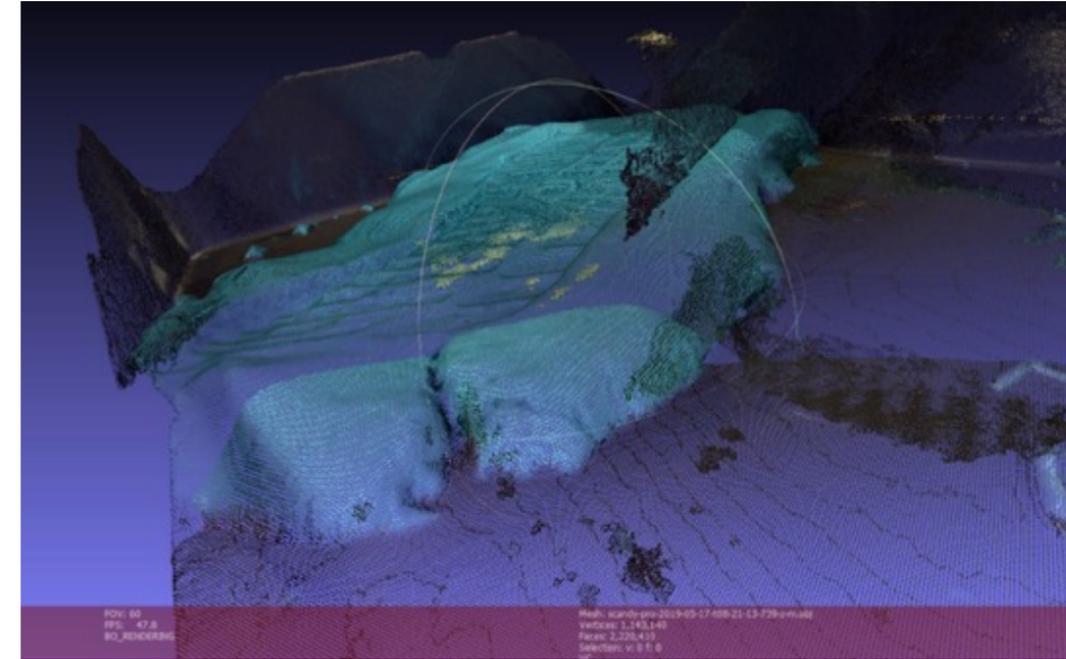
Exact volume will be calculated using the Volume displacement method. Objects will be submerged in a volume of liquid to measure displacement.
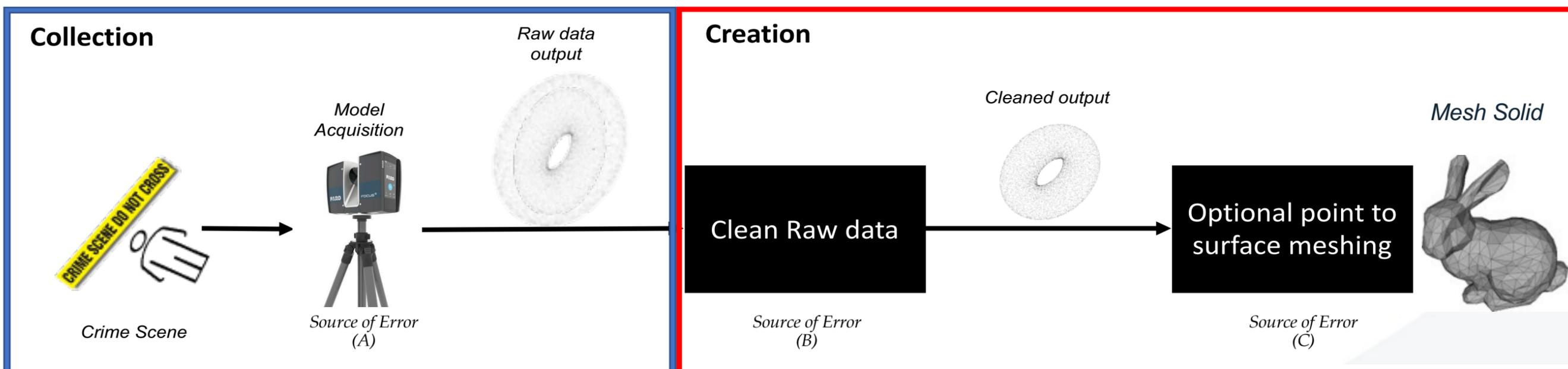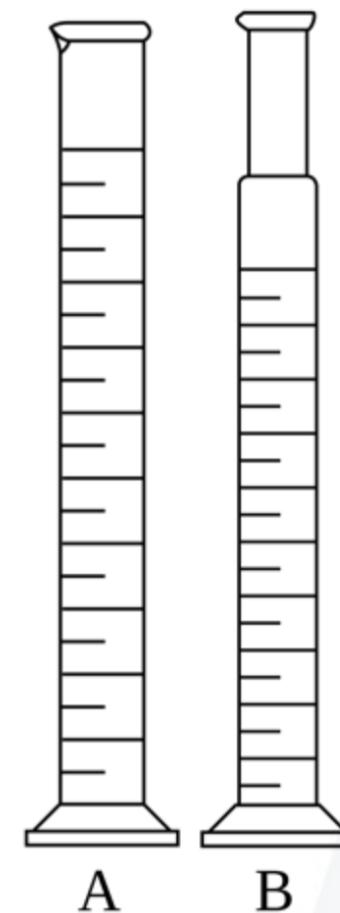
$V_m =$
starting volume of water – finish volume of water.
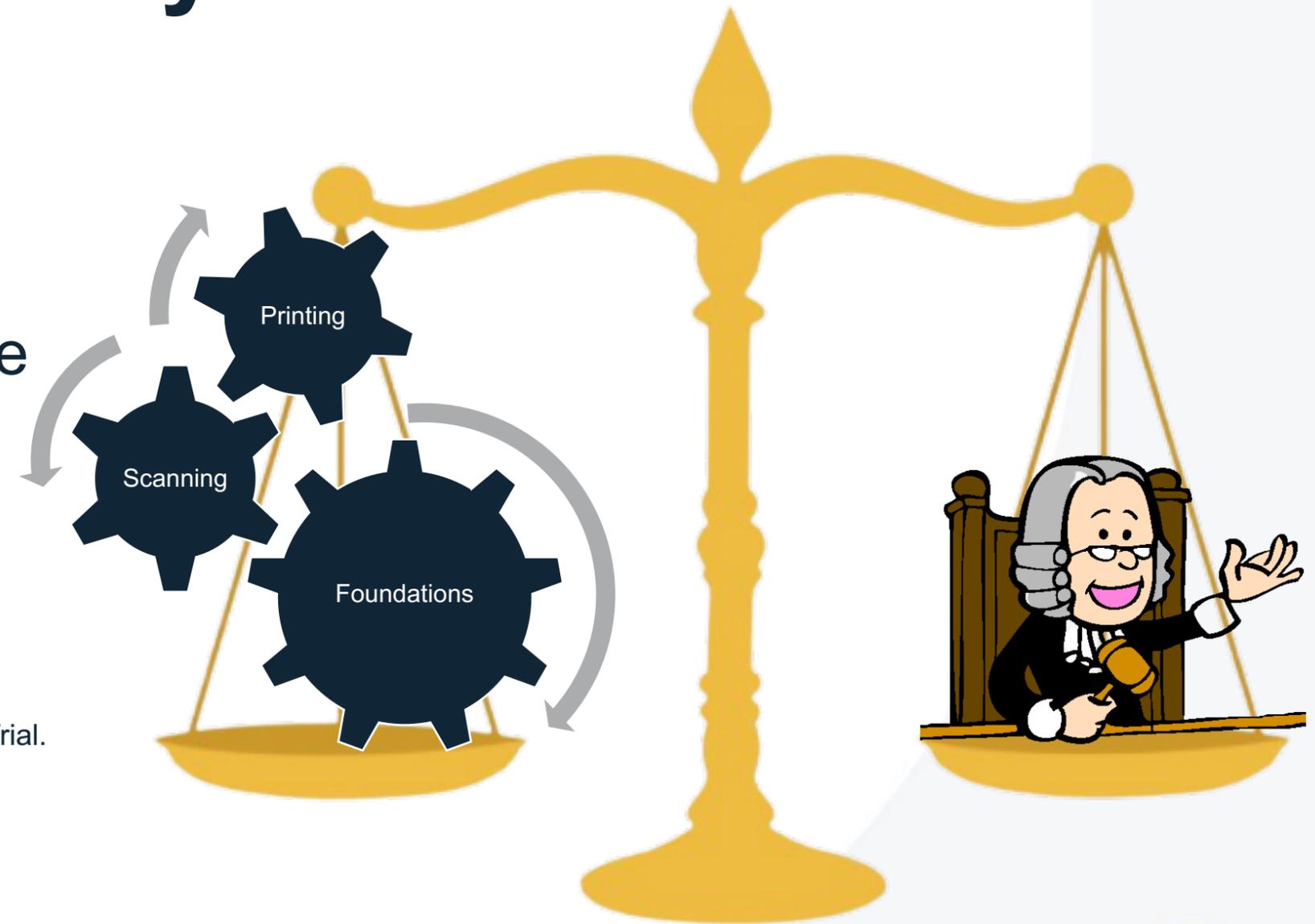
This value is then compared with the scanned volume from each application capable of measuring volume/ outputting an STL solid.

Collection

Raw data output

Model Acquisition

Crime Scene

Source of Error
(A)

Creation

Cleaned output

Clean Raw data

Optional point to surface meshing

Mesh Solid

Source of Error
(B)

Source of Error
(C)

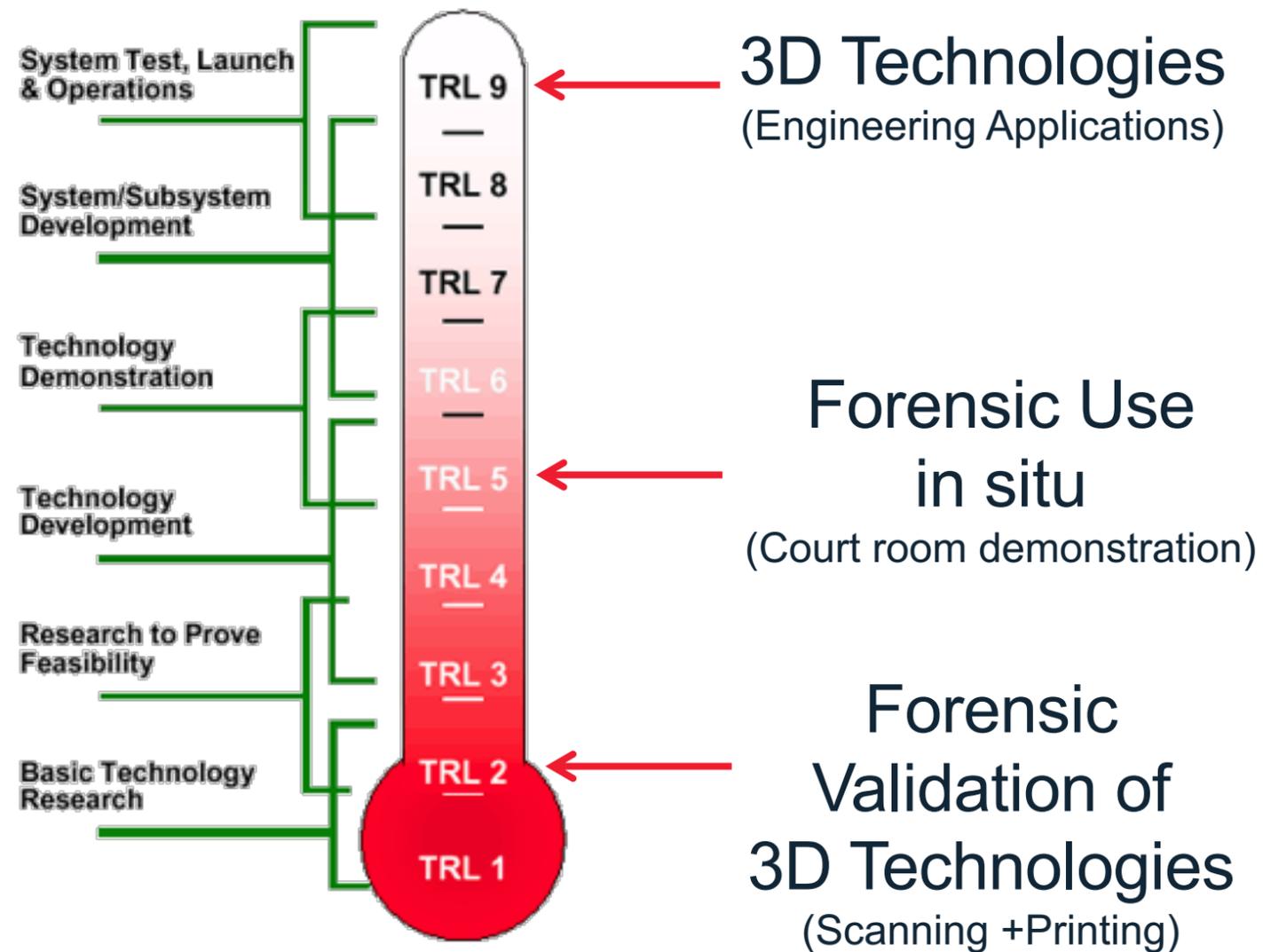THE UNIVERSITY of ADELAIDE

A word on Regional Validity

- **Assumption:** Without foundational validity the pioneering results from this technology may risk continual challenge in being admitted.

- UK vs US vs AU perspectives on the Judge as the gate keeper.

  - Weinberg, M. 2020. Juries, Judges, and Junk Science – Expert Evidence on Trial. AAS/AAL Symposium.

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So where are we?

System Test, Launch & Operations — TRL 9
TRL 8
System/Subsystem Development — TRL 7
Technology Demonstration — TRL 6
Technology Development — TRL 5
TRL 4
Research to Prove Feasibility — TRL 3
Basic Technology Research — TRL 2
TRL 1

3D Technologies
(Engineering Applications)

Forensic Use in situ
(Court room demonstration)

Forensic Validation of 3D Technologies
(Scanning +Printing)

What does forensic science and Star Trek: Picard have in common?

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**Levels are indicative only. Full analysis is needed.

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