X-ray CT simulation

Generate images for surface extraction and surface roughness characterisation

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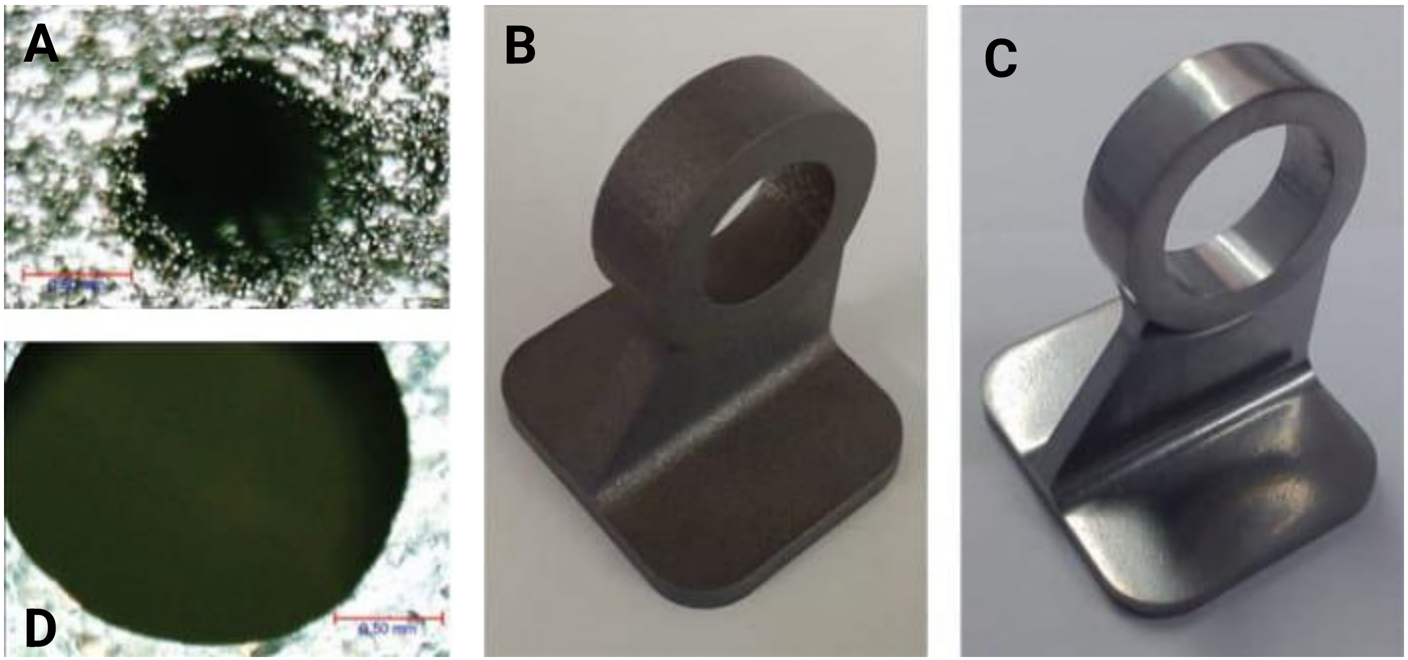
Additively Manufactured (AM) Parts in Industry

- The use of AM is on the rise in every sector (medical, automotive…)
- Offers versatility of creating:
  - bespoke designs
  - one-off prototypes
  - complex components that cannot be machined
- Without the correct finish, these components may fail at the early assessment stage
- The aerospace and defence industry has adopted AM. They must make sure the finish of these components fulfils the necessary requirements.

Additively Manufactured Parts in Industry



(James Bradbury, Lead Researcher, South West Metal Finishing (Exeter, UK).)

An example of AM part with different surface finish. (A),(B) AM part before treatment. (C),(D) Same part after surface treatment

Importance of surface roughness

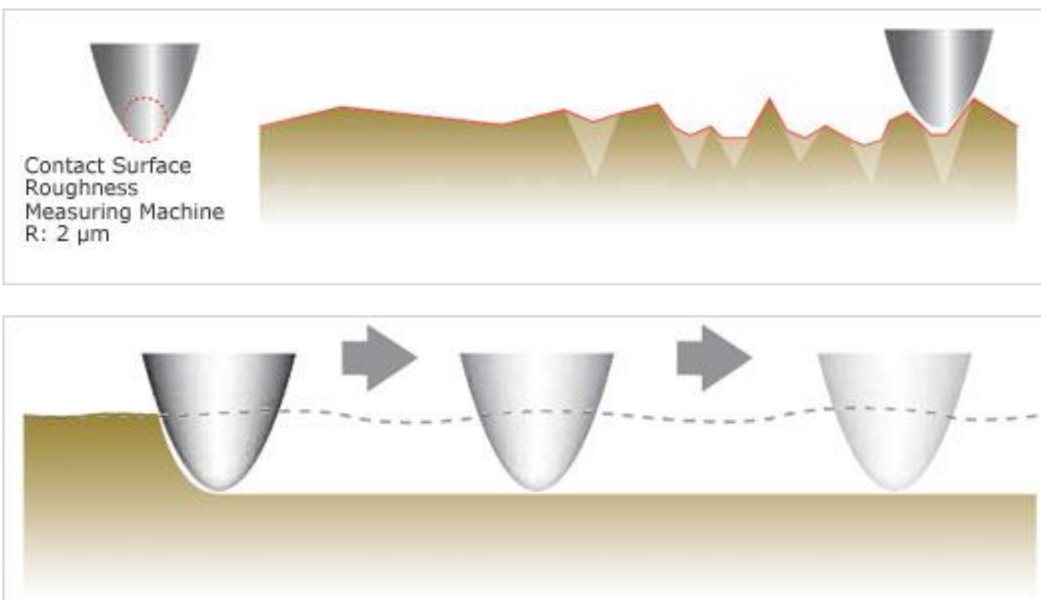
- The surface texture of these internal features needs to be controlled for a number of reasons:

  - rough surfaces are prone to initiate cracks
  - rough channel walls change fluid flow

- To control the surface texture of an AM surface, we need to measure the surface roughness!

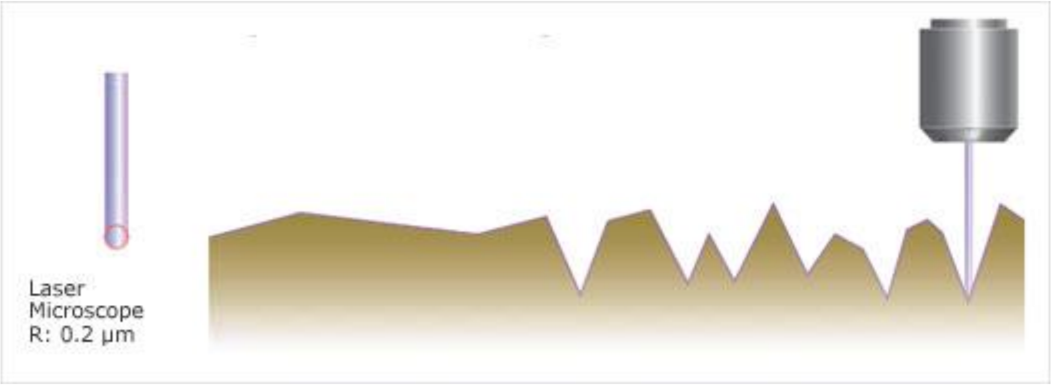
How to measure surface roughness (SR)?

- Contact measurement system : profilometer instrument
  - Resolution limited by the stylus diameter
  - Can scratch the surface of a soft specimen



How to measure surface roughness (SR)?

- Non Contact measurement system
  - Higher resolution
  - Small laser spot size
  - No impact on surface surface texture conditions



Surface roughness: S parameters (Amplitude)

Term	Definition	Use
Sa	The *Roughness average*	Sa is normally used to describe the roughness of machined surfaces. It is useful for detecting variations in overall surface height and for monitoring an existing manufacturing process. A change in Sa usually signifies a change in the process.
Sq	The root mean square (RMS) roughness	For finish of optical surfaces. Represents the standard deviation of the profile and is used in computations of skew and kurtosis. Sq cannot detect spacing differences or the presence of infrequent high peaks or deep valleys.
Ssk	Skewness measures the asymmetry of the profile about the mean plane. Negative skew indicates a predominance of valleys, while positive skew is seen on surfaces with peaks.	Ssk can illustrate porosity . Surfaces that are smooth but are covered with particulates have positive skewness, while a surface with deep scratches/ pits will exhibit negative skewness. If Ssk exceeds ±1.5, you should not use average roughness alone to characterize the surface. Skewness is very sensitive to outliers in the surface data.
Sku	*Kurtosis is a measure of the* "spikiness" of the surface, or the distribution of spikes above and below the mean line. • spiky surfaces, Sku > 3 • bumpy surfaces, Sku < 3 •perfectly random surfaces have kurtosis of 3.	Kurtosis is useful for evaluating machined surfaces and is sometimes specified for the control of stress fracture.

How to measure “internal” surface roughness

- The measurement and characterization of the complex functional AM surfaces is difficult due to their complicated shape or intricate internal geometries.
- The measurement of internal, inaccessible surfaces is a major challenge in the development of AM.
- Presently, AM researchers need to cut open samples to gain access to internal features in order to measure the surface roughness.
- XCT is the only valid non-destructive method

- **The surface determination method has a significant effect on dimensional information extracted from XCT volume data.**
- **→ SEGMENTATION method is the key!**
- **XCT image have often artefact and noise at the surface making it more complex to interpret**

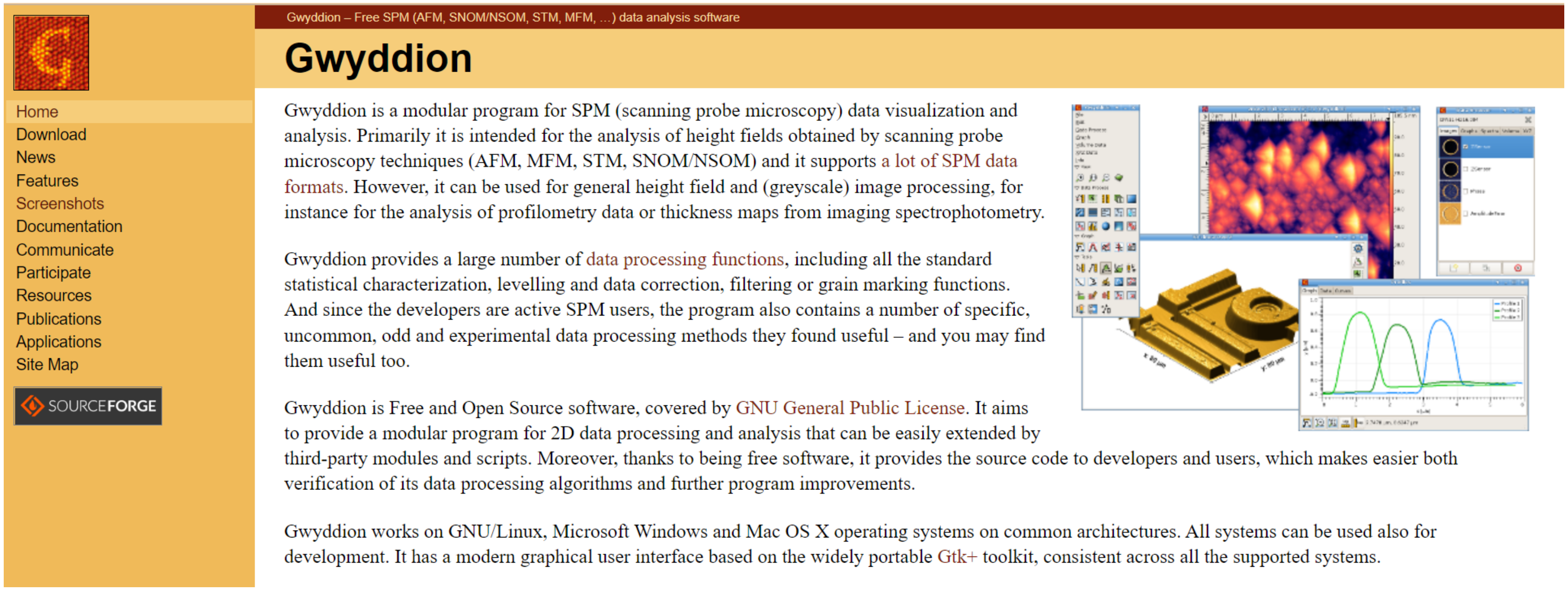

TARGET

Synthetic surface in XCT

- Synthetic data are of increasing importance and can be used for:
  - development of data processing methods
  - analysis of uncertainties
  - estimation of various measurement artefacts

- Create easy and quick data set for ML and DL
- Validation of employed segmentation technique and IPA workflow and to estimate their sensitivity and reliability.

Generating synthetic surfaces



Gwyddion – Free SPM (AFM, SNOM/NSOM, STM, MFM, ...) data analysis software

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SOURCEFORGE

Gwyddion

Gwyddion is a modular program for SPM (scanning probe microscopy) data visualization and analysis. Primarily it is intended for the analysis of height fields obtained by scanning probe microscopy techniques (AFM, MFM, STM, SNOM/NSOM) and it supports a lot of SPM data formats. However, it can be used for general height field and (greyscale) image processing, for instance for the analysis of profilometry data or thickness maps from imaging spectrophotometry.

Gwyddion provides a large number of data processing functions, including all the standard statistical characterization, levelling and data correction, filtering or grain marking functions. And since the developers are active SPM users, the program also contains a number of specific, uncommon, odd and experimental data processing methods they found useful – and you may find them useful too.

Gwyddion is Free and Open Source software, covered by GNU General Public License. It aims to provide a modular program for 2D data processing and analysis that can be easily extended by third-party modules and scripts. Moreover, thanks to being free software, it provides the source code to developers and users, which makes easier both verification of its data processing algorithms and further program improvements.

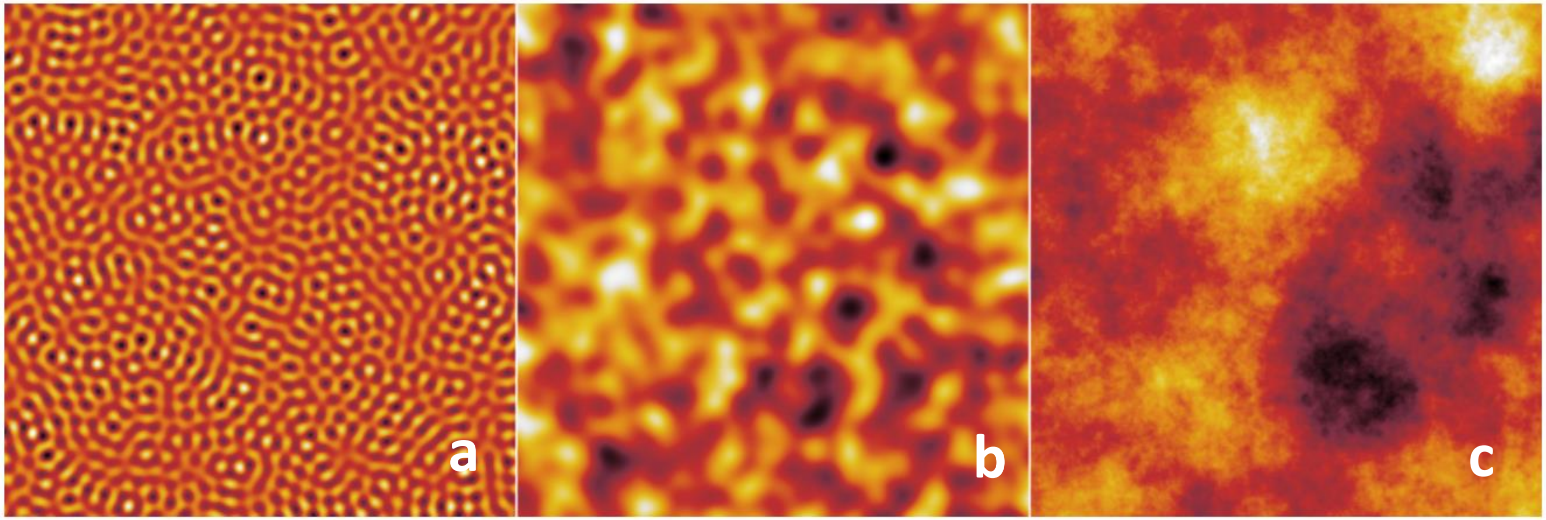
Gwyddion works on GNU/Linux, Microsoft Windows and Mac OS X operating systems on common architectures. All systems can be used also for development. It has a modern graphical user interface based on the widely portable Gtk+ toolkit, consistent across all the supported systems.

Gwyddion provides several generators of artificial surfaces that can be used for testing or simulations.

All the surface generators share a certain set of parameters, determining the dimensions and scales of the created surface and the random number generator controls.

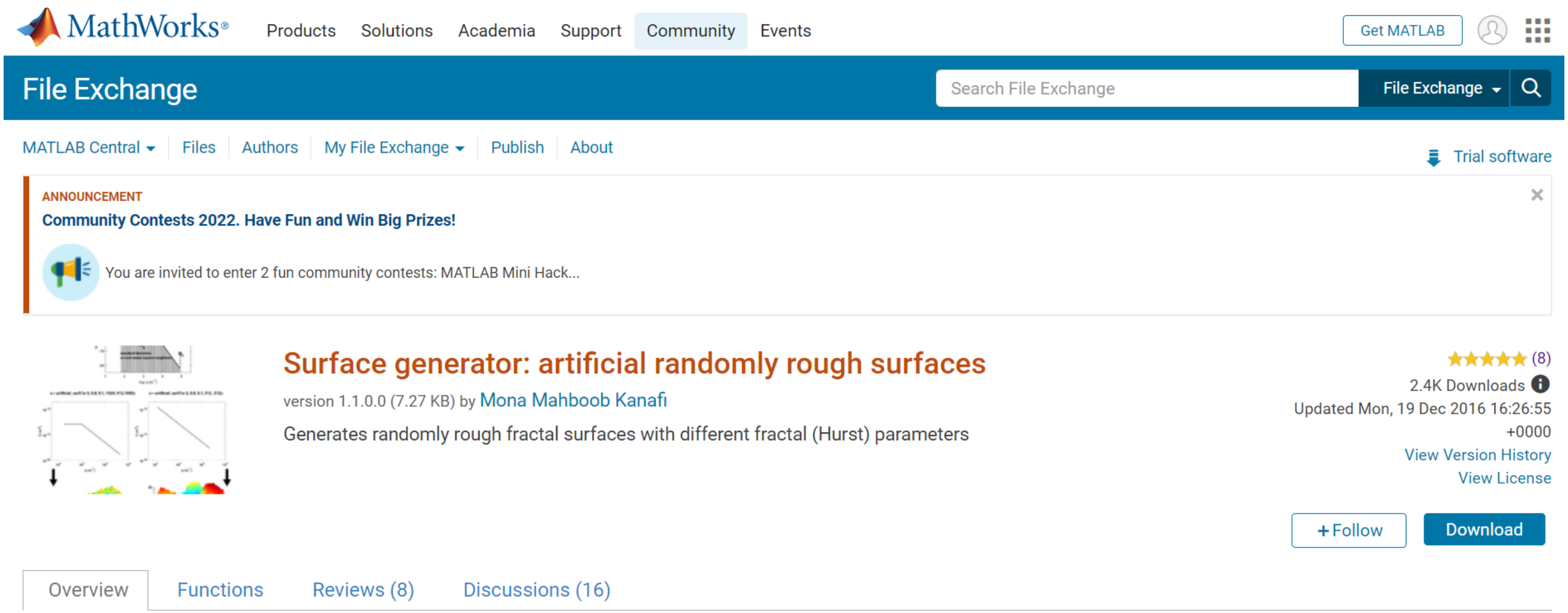
Generating synthetic surfaces

- ➢Artificial surfaces generated by spectral synthesis



- ➢ (a) Surface with narrow range of spatial frequencies
- ➢ (b) Gaussian random surface
- ➢ (c) Fractal surface

Generating synthetic surfaces



- This code generates artificial randomly rough isotropic surfaces.
- These surfaces could be useful for simulating surface roughness or topographies from nanometre features to large-scale topography of mountains, terrains or landscapes.

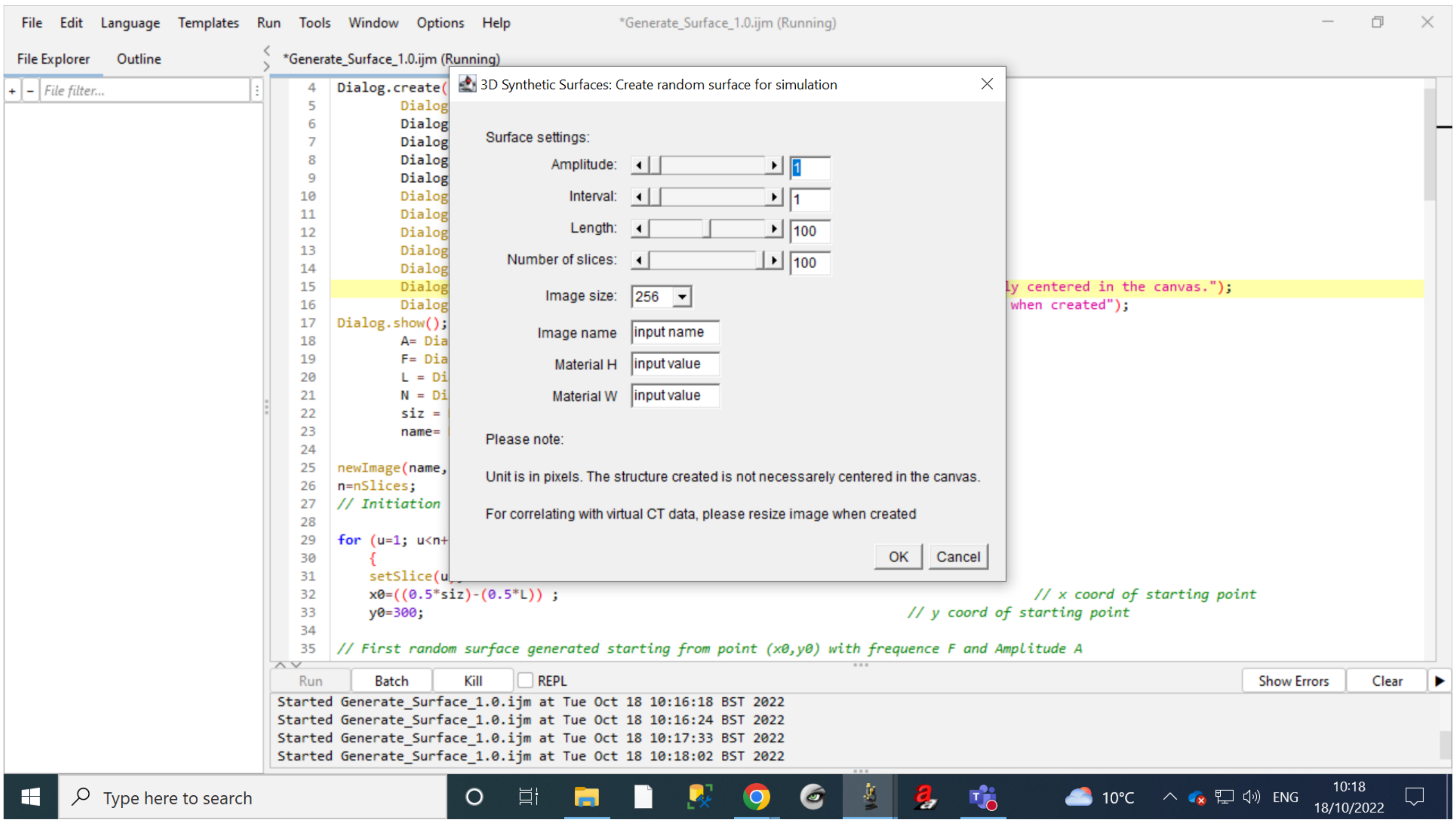
Generating synthetic surfaces

- Solutions presented can not generate 3D volumetric datasets
- Work only for flat surfaces
- Can not generate enclosed surfaces
- We propose new plugin (IJ based) to generate synthetic surface

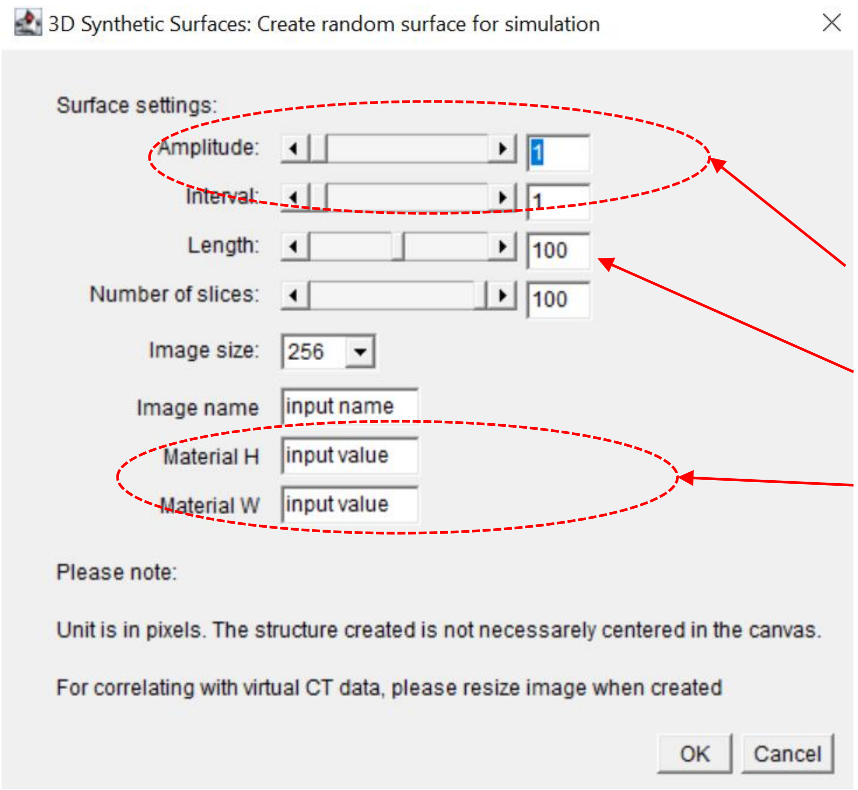
Generating synthetic “internal” surfaces

- Measuring surface roughness from XCT images is not straightforward. The proposed research work is composed of four parts:
  - Creation of binary synthetic images with a cuboid hollow shape presenting various surface roughness
  - Virtual XCT scanning of those synthetic images
  - Surface determination using ML learning approach and hysteresis thresholding
  - Comparison of their measured surface roughness to the ground truth synthetic images

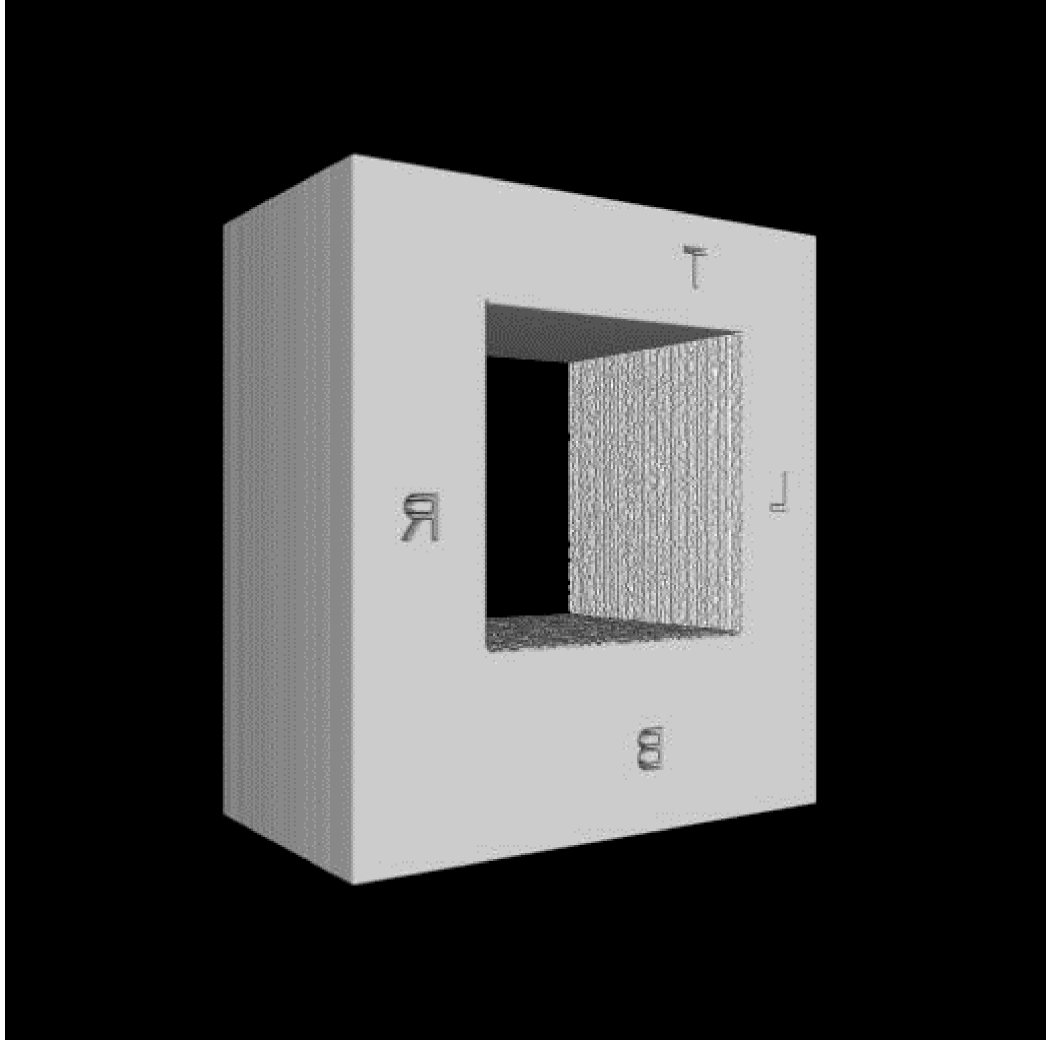
Generating synthetic “internal” surfaces



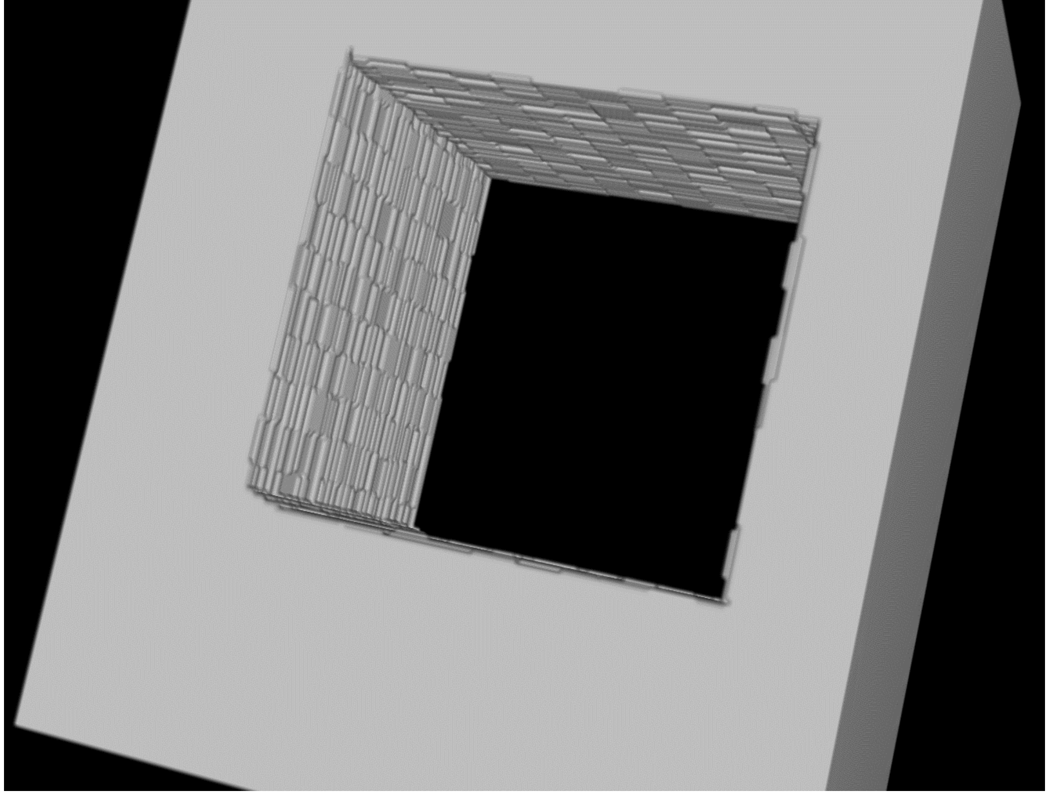
Generating synthetic “internal” surfaces



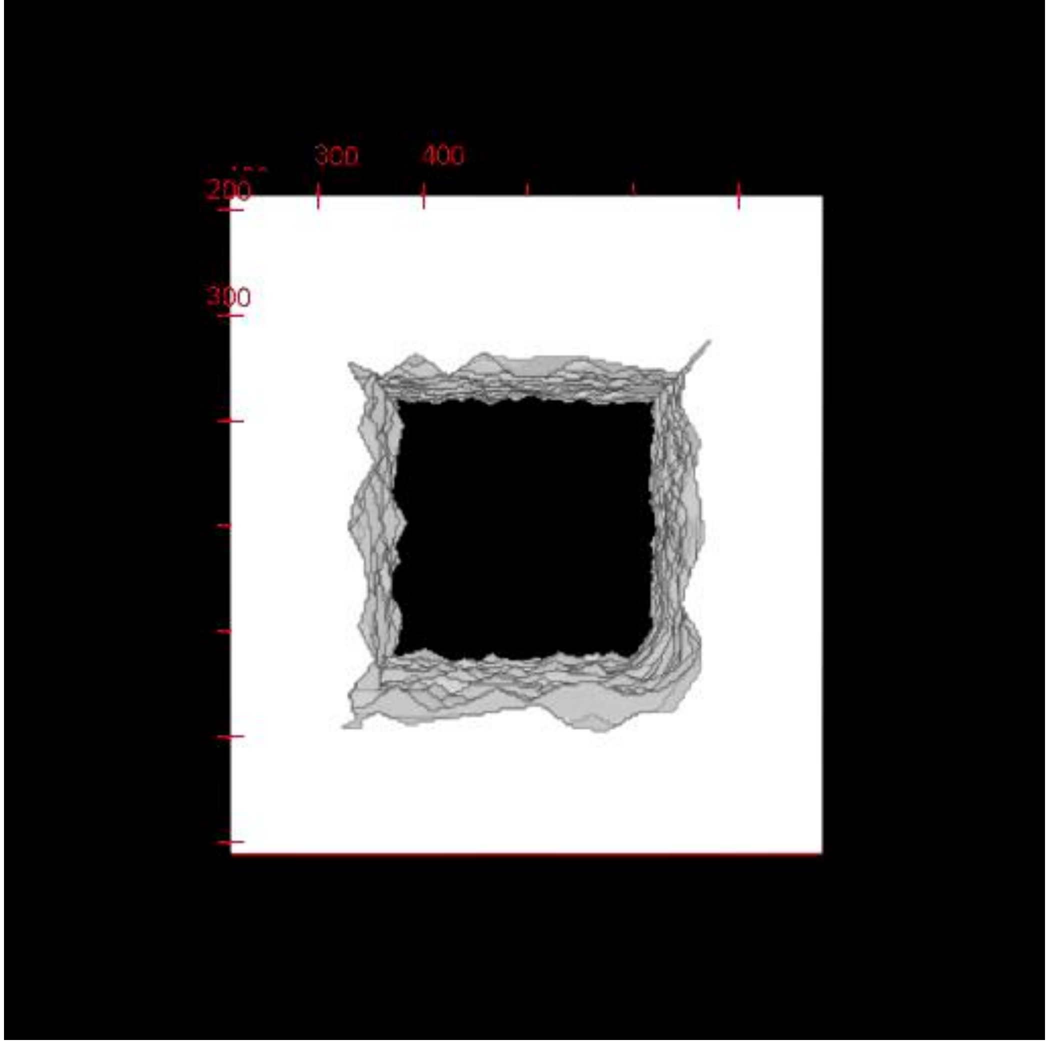
- **Hollow cuboid shape**
- **Inner structure has four faces**
- **Variable SR of those faces**
- **Can change sample size**
- **Can change surrounding material thickness**



SAMPLE	AMPLITUDE	INTERVAL	HOLE SIZE	IMAGE SIZE
1	1	1	100*100*100	512x512x100



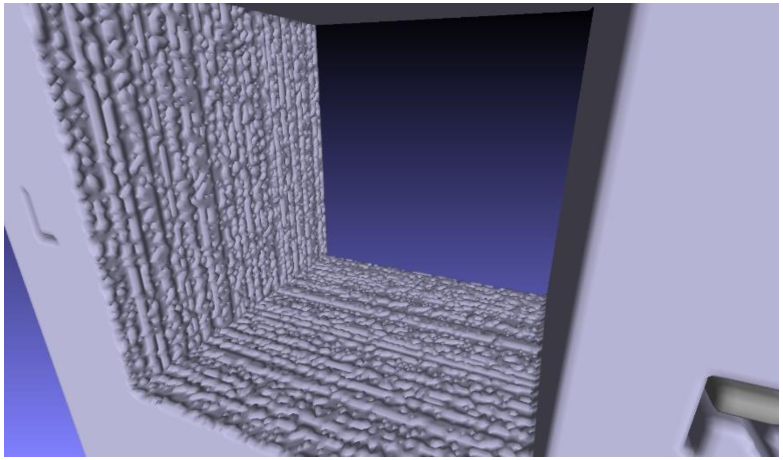
SAMPLE	AMPLITUDE	INTERVAL	HOLE SIZE	IMAGE SIZE
20	2	10	100*100*100	512x512x100

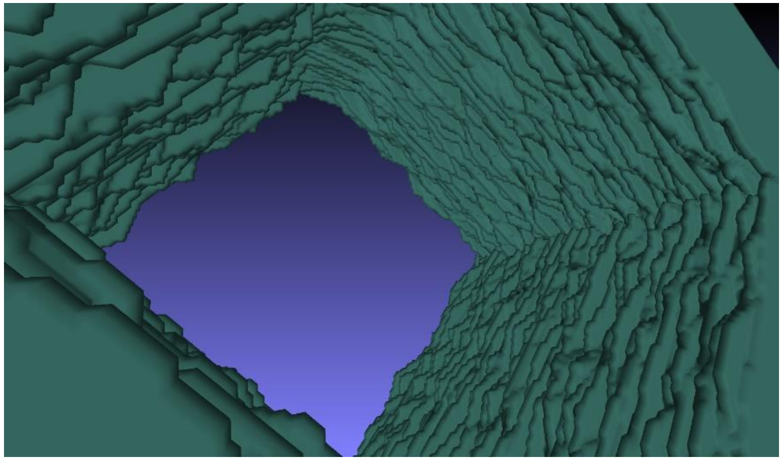


SAMPLE	AMPLITUDE	INTERVAL	HOLE SIZE	IMAGE SIZE
100	10	10	100*100*100	512x512x100

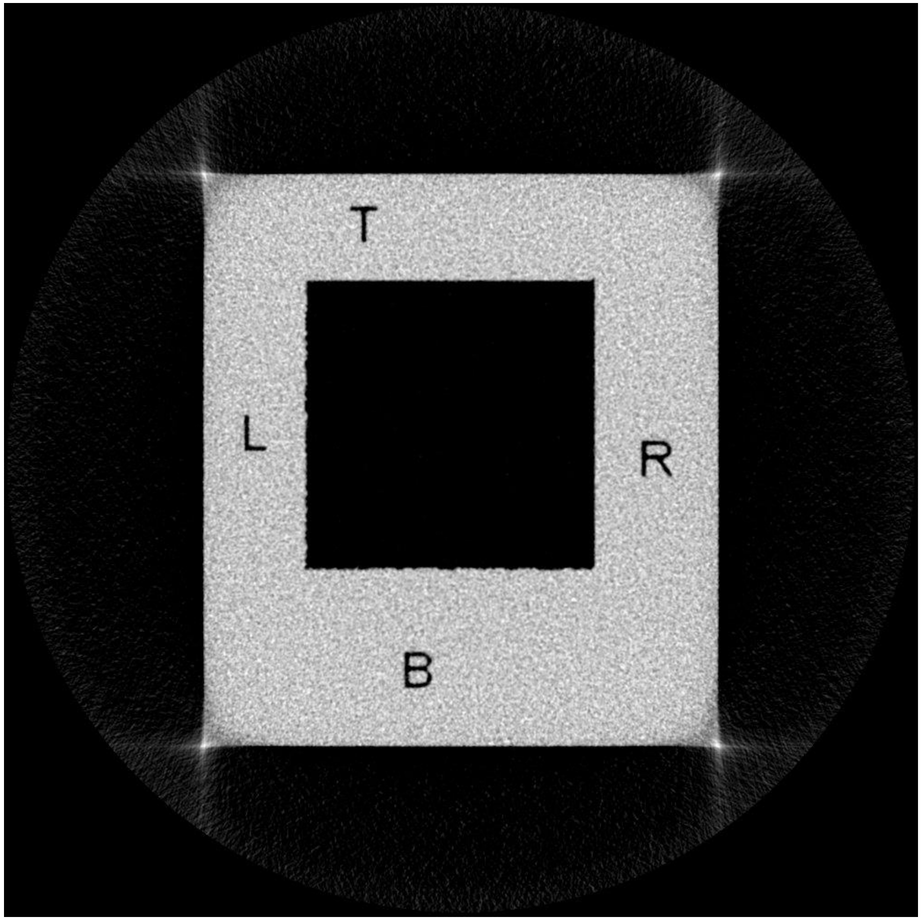
Virtual X-ray CT scanning

- Converting synthetic data to meshes (below)
- Simulator used : aRTist 2.10
- Aluminium was the chosen material
- Settings: 150kV, voxel size 0.032mm , 3200 projections, no filter

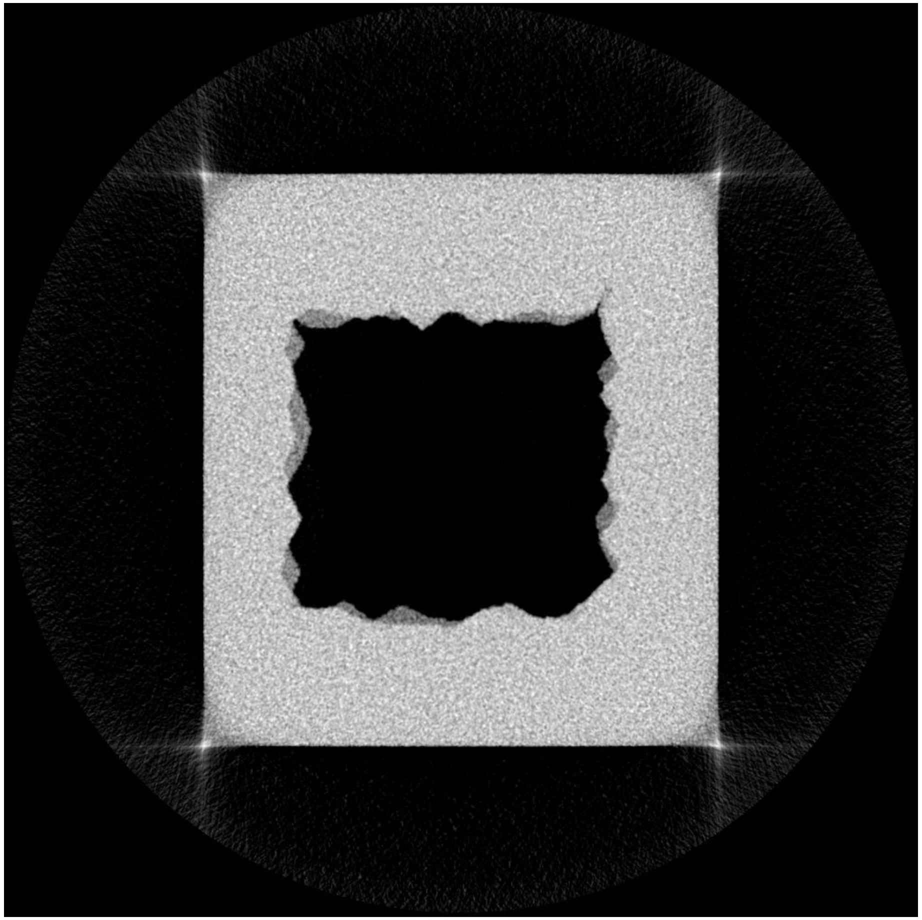




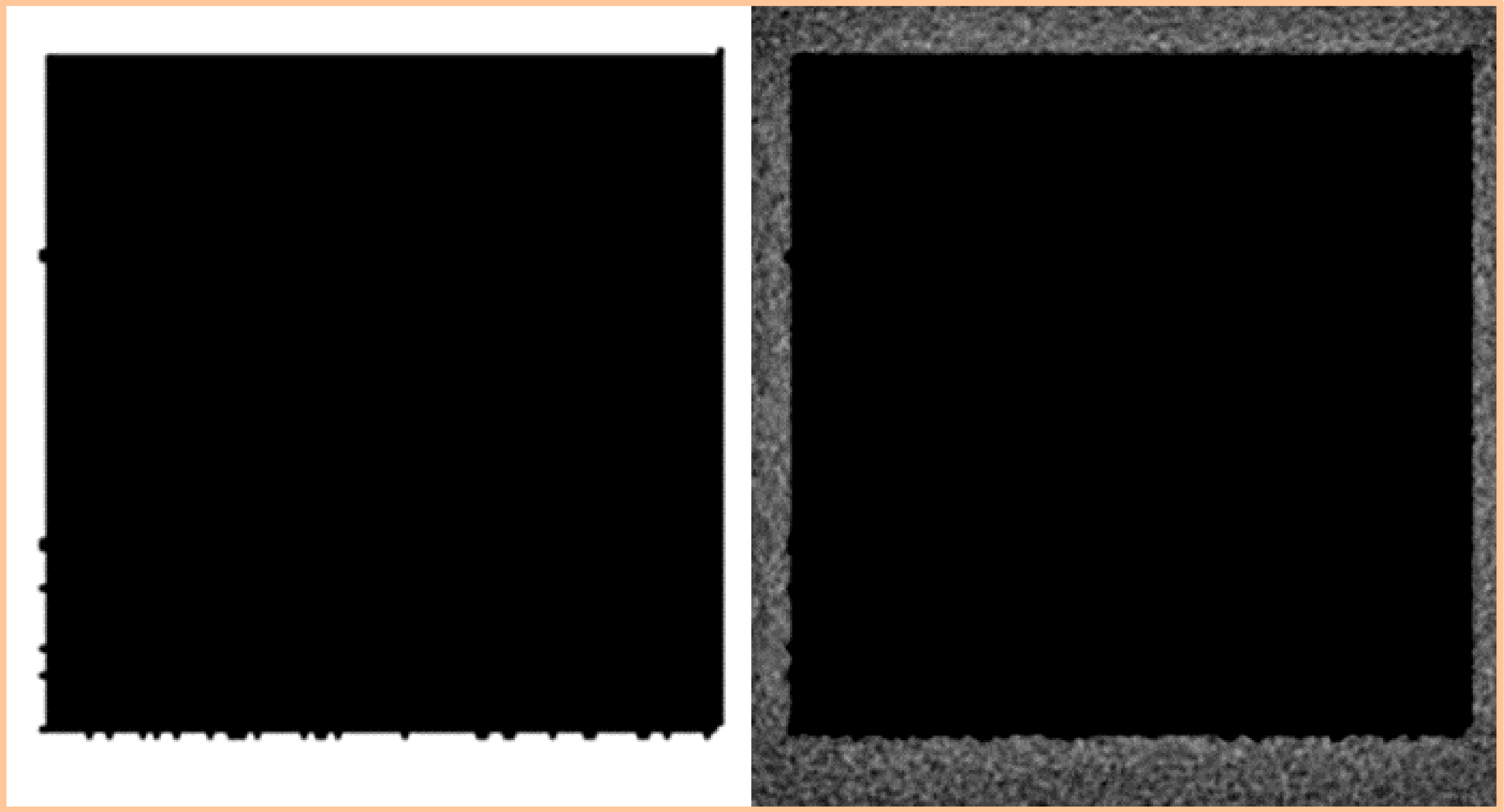
Example of simulated XCT surface : sample1



Example of simulated XCT surface : sample100

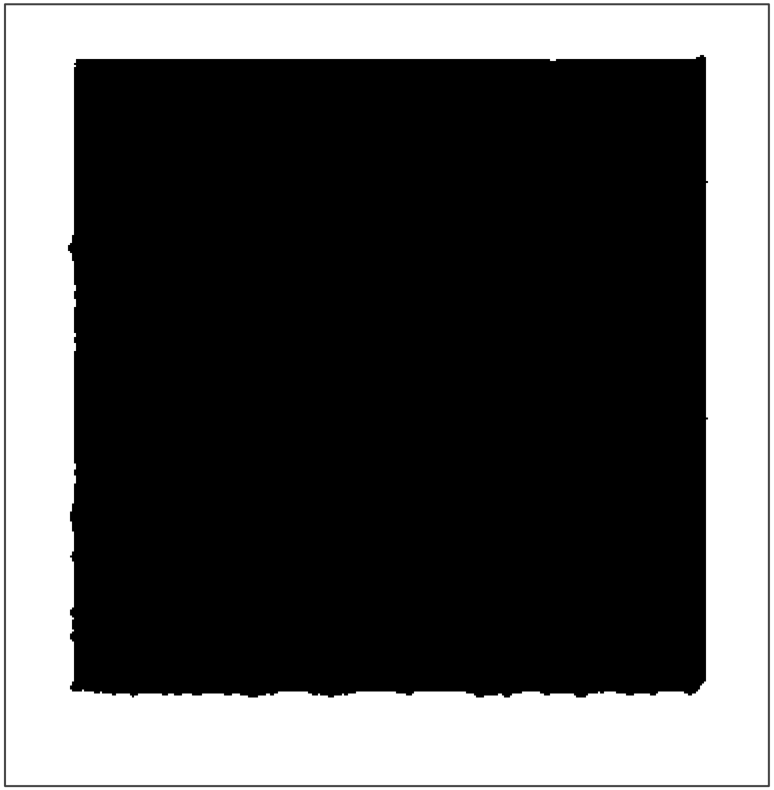


Virtual XCT correlated with synthetic image – sample1



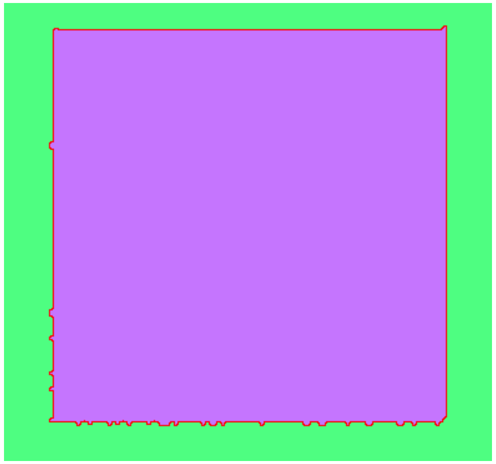
Determination of the surface: *virtual CT data*

- Hysteresis thresholding

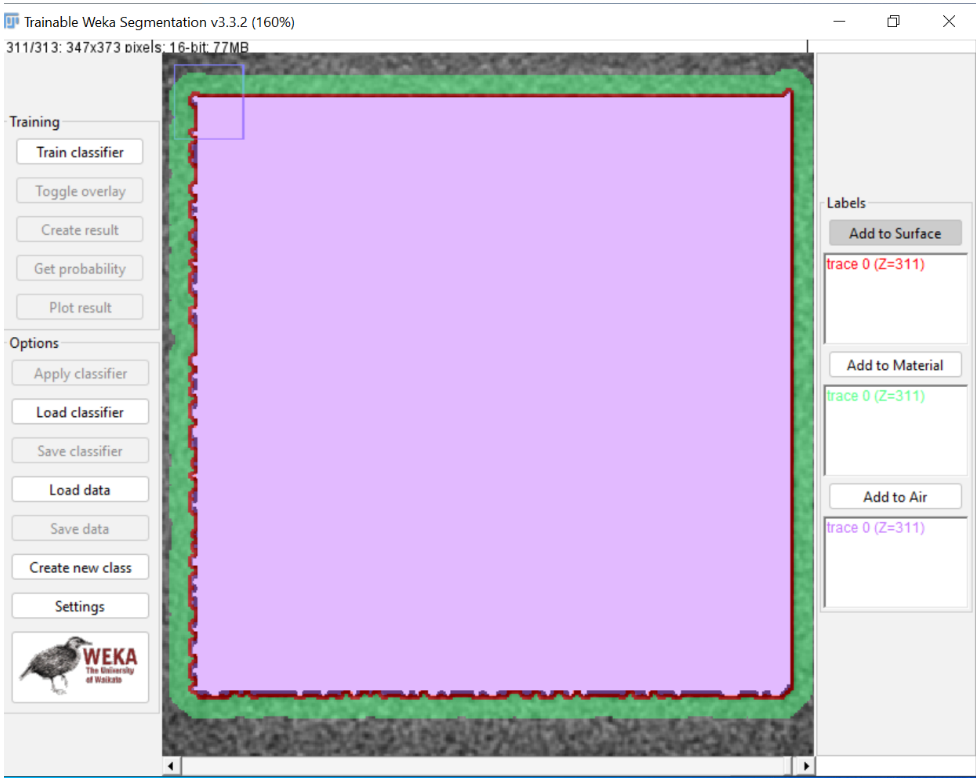


Determination of the surface: *virtual CT data*

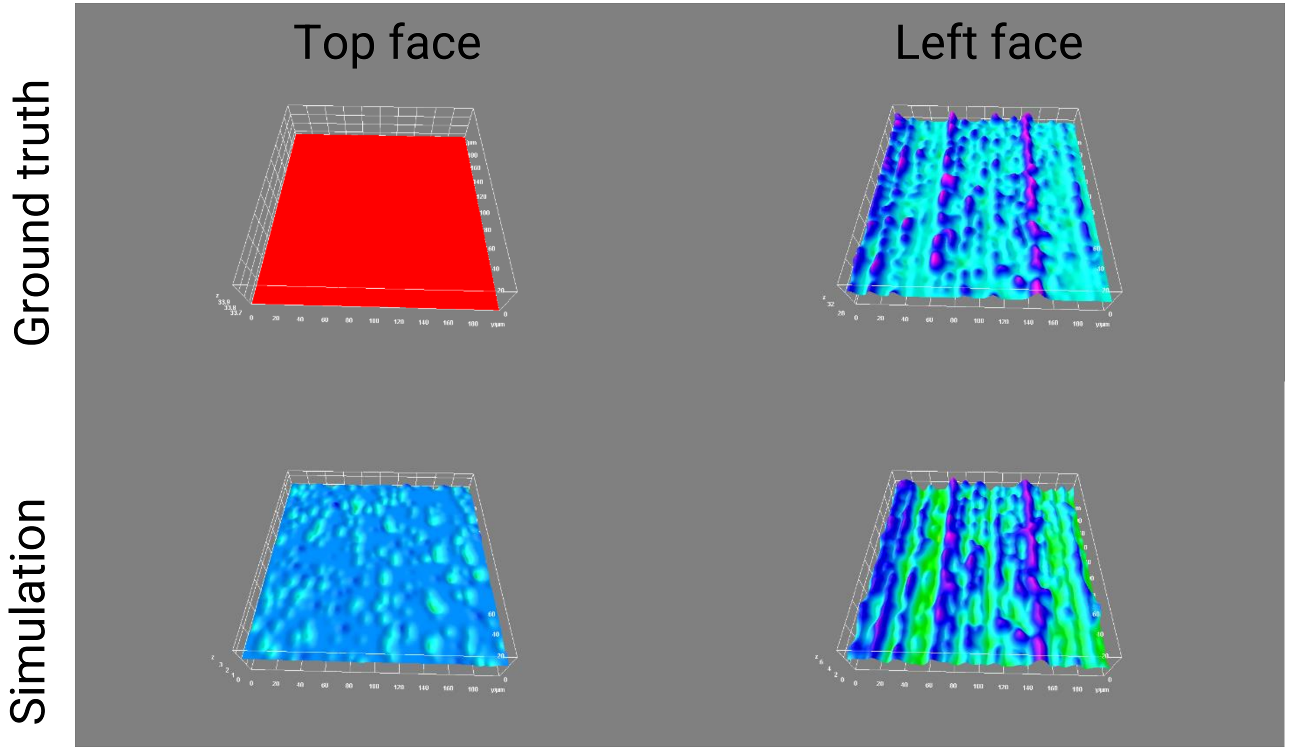
- ML approach
- Define three regions
- Use ground truth image to label
- Classifier

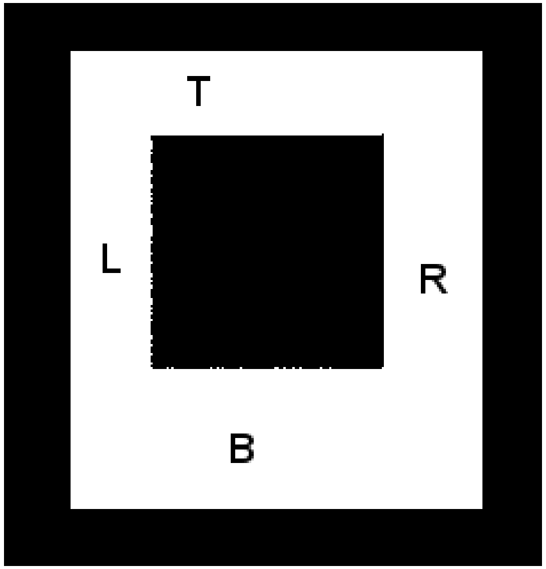


Classified image with the surface in red



3D surface plot of “Top” face Vs “Left” - sample1



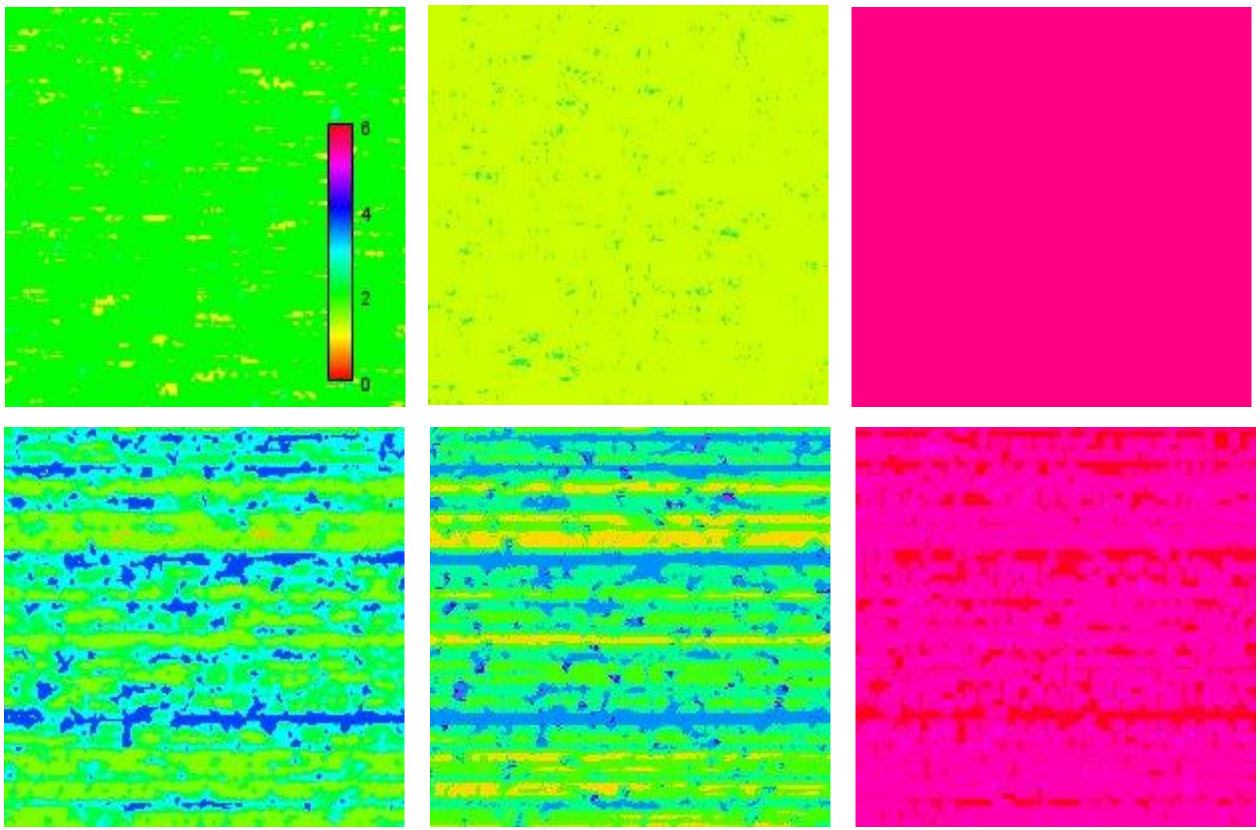


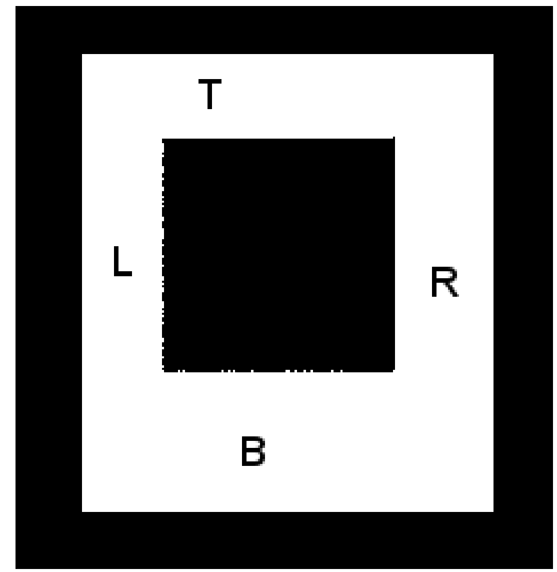
Synthetic image: different surfaces of sample1

2D surface plot: compare segmentation techniques - sample1

Hysteresis thresholding | ML learning (Weka) | Synthetic data

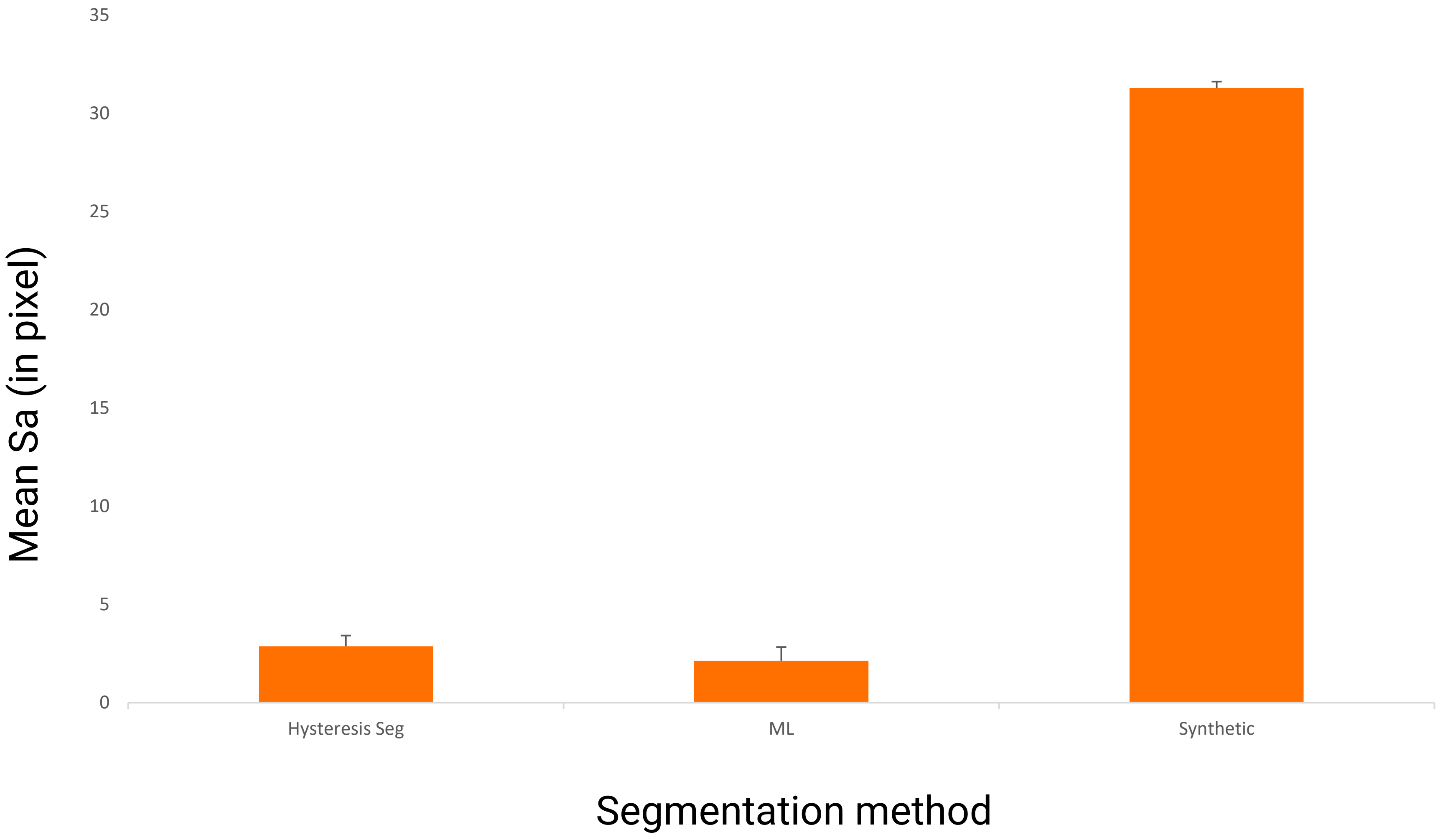
Top face / Left face



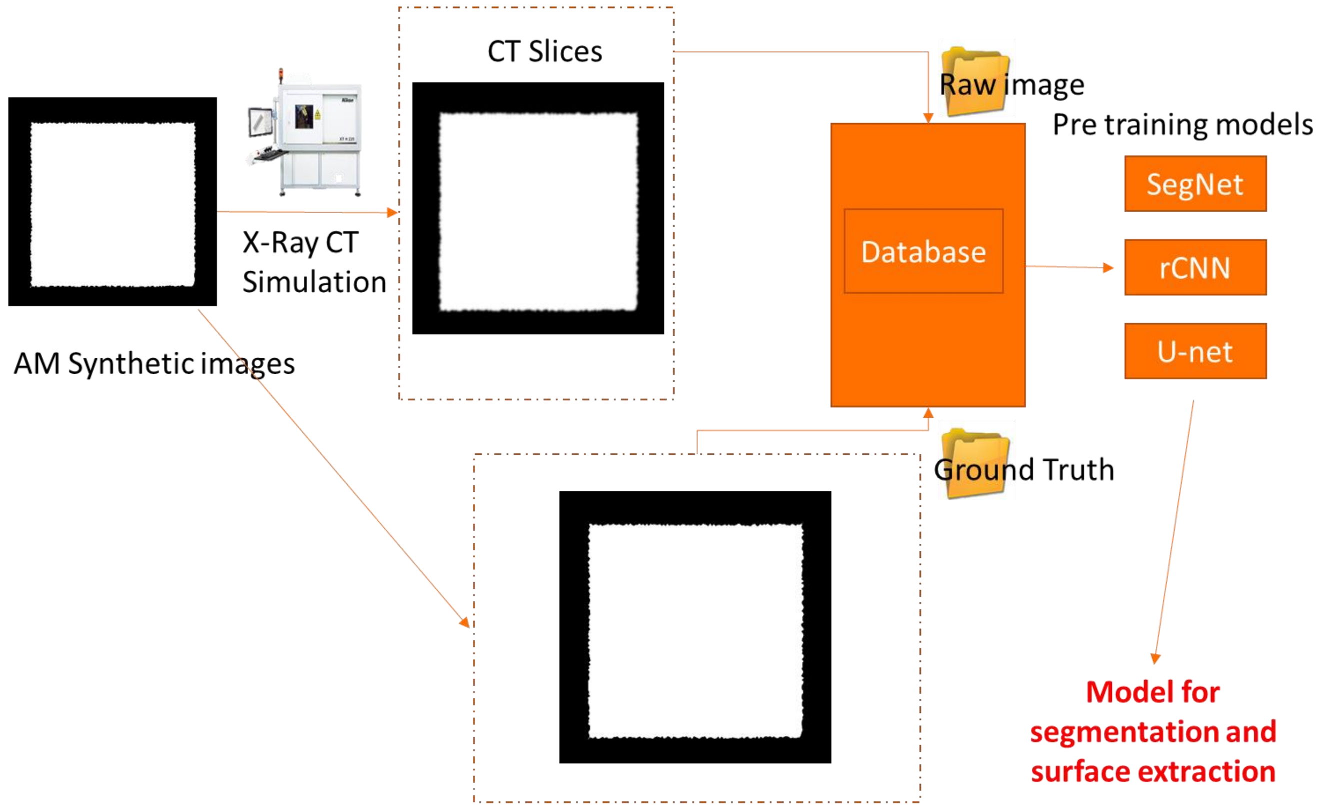


Synthetic image: different surfaces of sample1

Surface roughness parameter: Sa – sample1



Next steps: Deep Learning



- Needs more data
- Different type of data (#XCT parameters, #materials)

Next steps: validation

- We proposed a method to analyse surface roughness and evaluate the segmentation technique
- We correlated SR of artificial data and its virtual CT
- We propose to:
  - Use synthetic data to fabricate real part
  - Compare real vs virtual XCT
  - The fabricated part can be dismounted to measure SR using non contact method
  - A quantitative and qualitative comparison between the optical and XCT surface roughness measurements could be made

Conclusion

- Simulation provides quick and cost effective X-ray CT images.
  - Samples of various composition can be virtually scanned: ceramic, aluminium…
  - Various XCT settings with various resulting SR
  - Multiple reconstructions methods can be used
- Synthetic images
  - Large number of samples with different SR
  - Ground truth data
- Combined with synthetic images to create DL model for segmenting and extracting surface

Introduction to the NXCT

An EPSRC National Research Facility

NXCT Mission

- To provide access to X-ray CT to UK researchers
- To provide support for experimental design, data acquisition and data analysis
- Help turn data into understanding with computing and software access with support
- Provide access to a 'library' of rigs for *in situ* experiments
- Promote use of X-ray CT where it can make a positive impact

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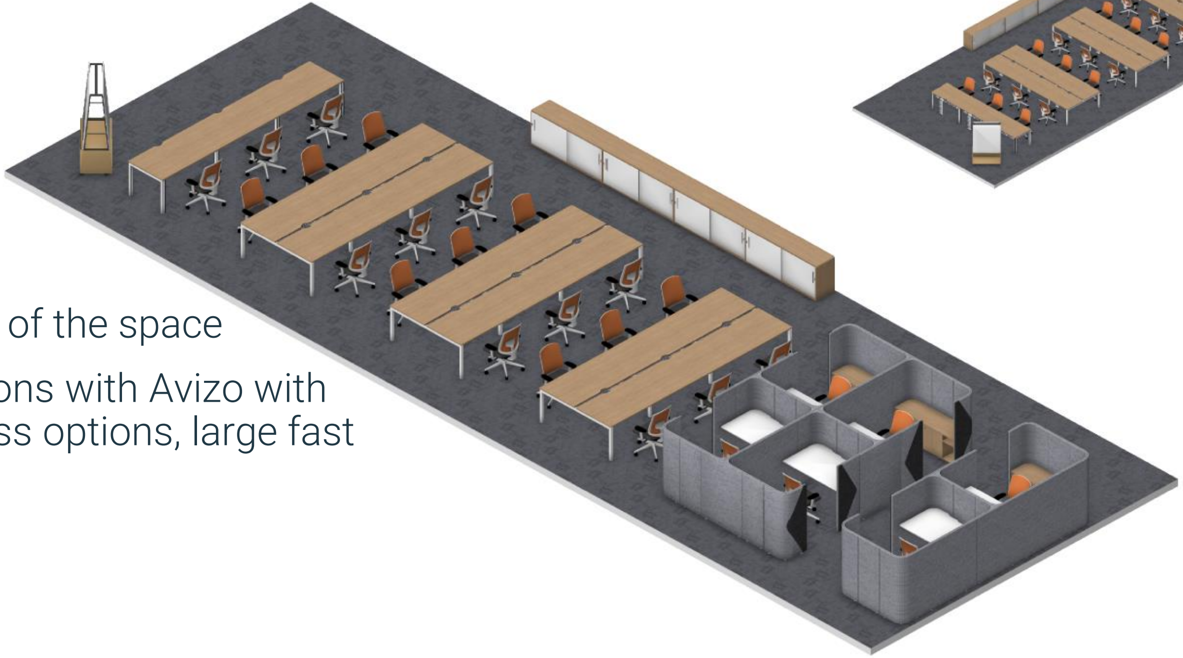
NXCT: Please get in touch!

Apply now for free access to our scanners!

- The NXCT has facilities at Manchester, Southampton, UCL and Warwick
- We have over 20 X-ray CT scanners available to use as well as many rigs which are available to access
- We have a free at point of access scheme for up to 3 days access for research including SME’s (different application form)
- Make an enquiry: https://nxct.ac.uk/contact/
- Make an application: https://www.surveymonkey.co.uk/r/Q89969J

NXCT Digital Imaging Lab @ Royce



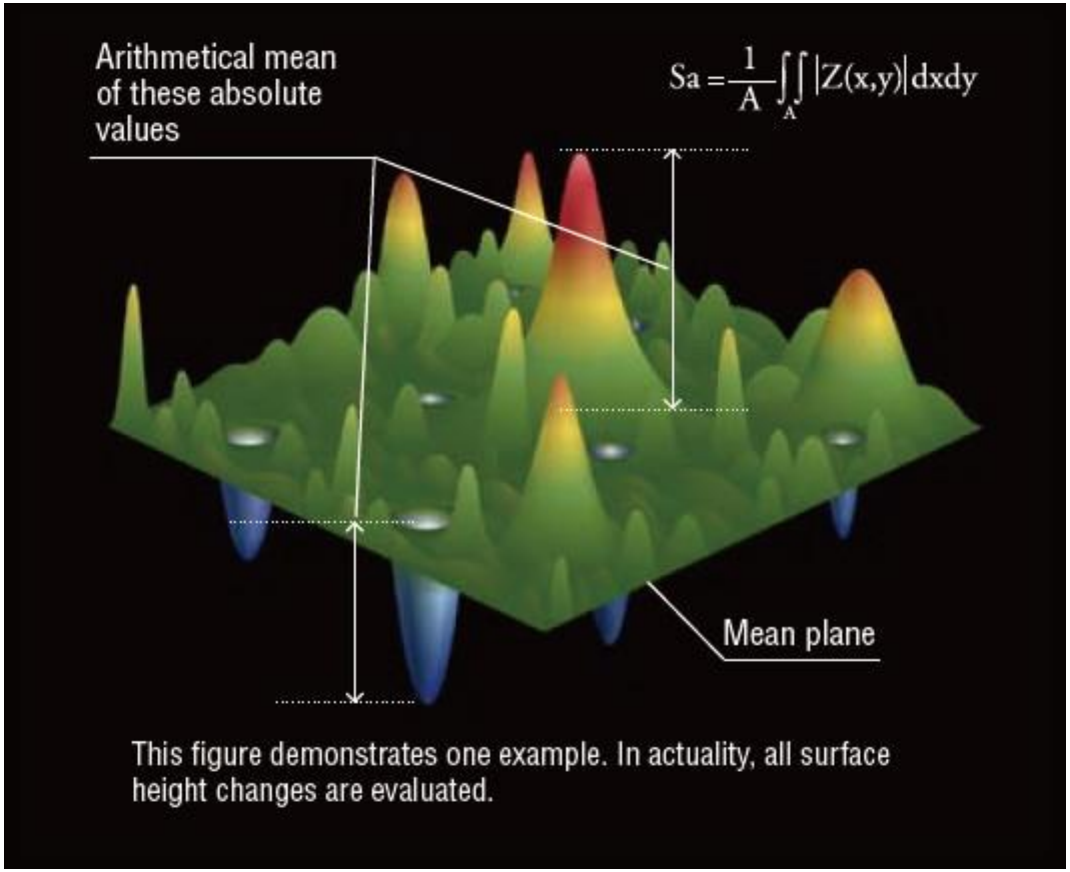
- 3D rendering of the space
- 20 workstations with Avizo with remote access options, large fast storage

Communications

- Please connect with us on social media!
  - LinkedIn (@National X-ray Computed Tomography)
  - Twitter (@nxrayct)
  - YouTube (NXCT)
- Latest news stories, new capabilities, introductions to staff etc.!

Determination of the surface: *synthetic data*

- The synthetic data are considered as the ground truth data
- Data already segmented
- Two approaches are used to segment the surface from the virtual CT scan images
  - Hysteresis segmentation
  - ML using Weka plugin


Arithmetical mean of these absolute values
$Sa = \frac{1}{A}\iint_A |Z(x,y)|dxdy$
Mean plane
This figure demonstrates one example. In actuality, all surface height changes are evaluated.