

# Advanced 3D analysis of X-ray computed tomography data

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## Aims

Micro-CT is becoming a well known tool for a wide range of research applications. Whether you are a biomedical or material researcher, geologist, physicist, chemist or pharmaceutical scientist, X-ray computed tomography must have crossed your path somewhere down the line.

This paper studies how 2D reconstructed slice images coming from micro-CT are converted into quantifiable 3D surface and volume models for porosity analysis, batch-measurement implementation, reverse engineering, 3D printing, FEA/CFD, centerline creation and more.

## Method

A range of analysis and engineering features are studied on four different objects/animals.

The first is an anaesthetized field mouse on which both 2D and 3D segmentations are performed. The 2D segmentation relates to multiple binarizations on a slice level while 3D segmentation means to differentiate, select and adapt 3D calculated geometries. For this model the aim is to obtain soft skin tissue, skeleton, lungs and heart as separate geometries. On the mouse skeleton scripted geometrical measurements are applied as a proof of concept for batch scanning and analysis of small animals.

The second model is a concrete core on which, after segmentation and 3D generation, porosity and composition analysis are performed. Parameters of interest include volume composition, interconnectivity of the pores, statistical overview of the diameters of the pores and aggregates.

A third case focuses on a polymeric foam. More specifically, starting from a 3D generated model, an optimized finite element mesh is prepared for structural analysis. The goal is to obtain macroscopic, homogenized material properties from the microscopic foam properties through simulation.

A fourth and final case is a broken fan component which is micro-CT scanned, 3D reconstructed, virtually repaired, 3D printed and reverse engineered.

All scans are performed using SkyScan hardware and **CTAn reconstruction software**. All 3D images, advanced measurements and engineering are performed using the Materialise Mimics Innovation Suite.

## Results

### Mouse model

Micro X-ray tomography scanning the field mouse results in reconstructed images of which one example is shown in figure 1. Using the 2D segmentation algorithms in Mimics the following structures are binarized into masks: bone, skin, heart and lungs. These binarizations are transformed into 3D surface mesh models. The 3D model accuracy is validated and although dependent on the scan quality can reach up to 1/5<sup>th</sup> of the voxel size for high quality data since Mimics takes into account the partial volume effect<sup>1</sup>. Figure 2 shows the 3D result for this particular example. Following this first step, an automatic centerline calculation is done on the 3D airways model.

Figure 3 shows the result of this centerline algorithm, including local measurements of diameters, tortuosity, area and others can be output at intervals along the centerline's length.

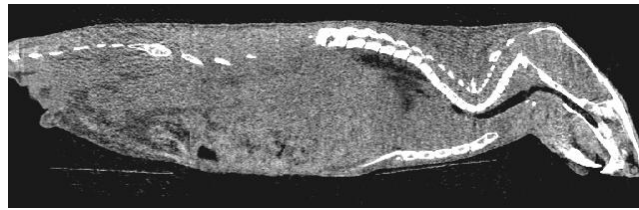


Figure 1: X-ray tomography reconstructed slice image of field mouse



Figure 2: 3D reconstruction of field mouse skin, skeleton, heart and airways

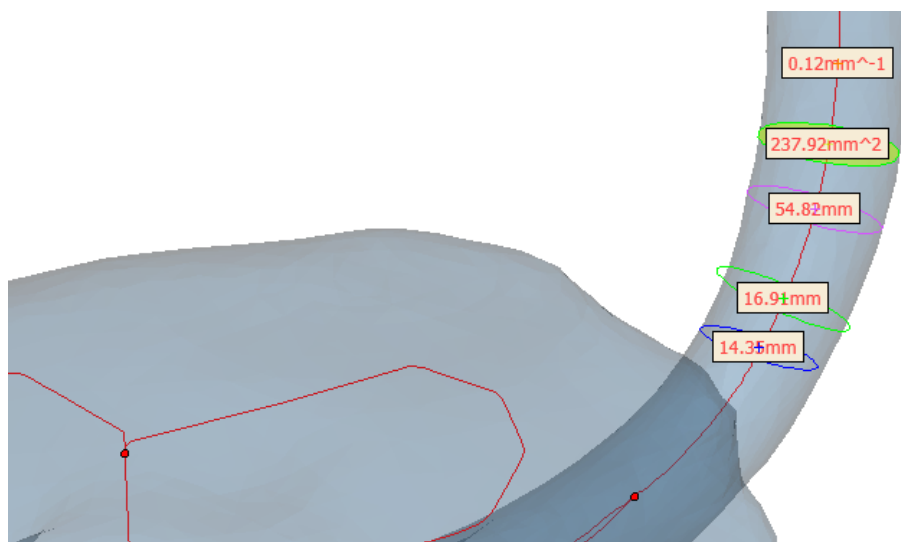


Figure 3: Centerline and – measurements example on part of the mouse trachea

Taking into account only the mouse skeleton a measurement script is written within Mimics that allows batch processing of mouse results for statistical reference. This method is based on selectable marker points which can be seen on figure 4.

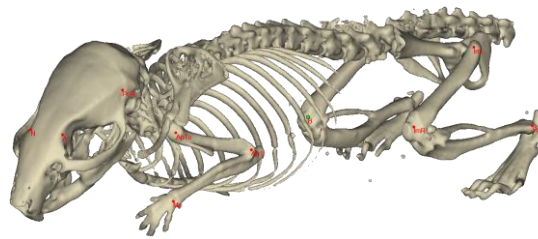


Figure 4: Mouse skeleton with selectable marker points for use with scriptable measurement routines

Concrete

Figure 5 shows the 3D reconstruction of the concrete core scan. Matrix, aggregates and air are shown as 3D models. A porosity and composition analysis is performed on the matrix of this 3D model. Results are given in table 1 as overall sample parameters but can also be exported into Excel per pore for statistical analysis.

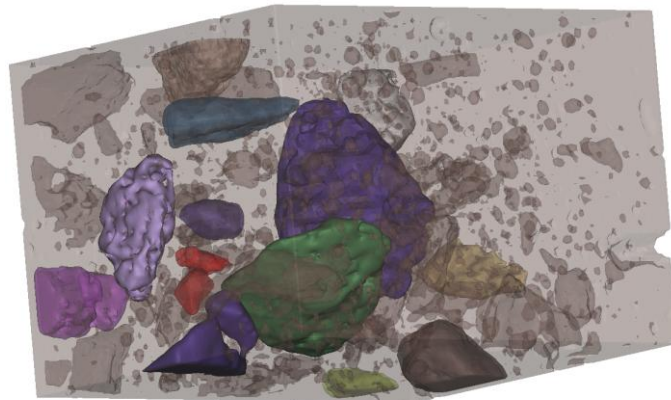


Figure 5: 3D reconstruction of a portion of a concrete core

Porosity (%)	Average pore diameter (mm)	Specific surface area $\text{mm}^{-1}$	Pore interconnectivity (%)
7.73	0.8649	0.0121	8.4%

Table 1: Porosity analysis results

Foam

For the foam specimen figure 6 shows the 3D reconstructed result. In order to establish homogenized material properties from simulation the 3D model is remeshed to a high quality tetrahedron volume mesh with a maximum element skewness of 25. Figure 7 shows a visualization of Von Mises stress for a vertical compression test on this sample using NX Nastran.

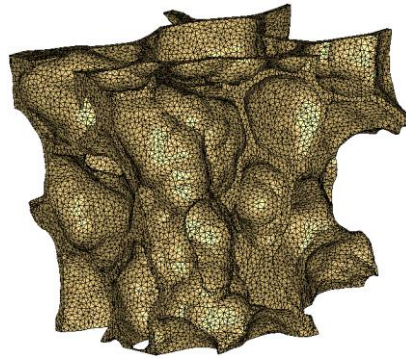


Figure 6: 3D reconstruction of a portion of the polymeric foam, the foam has been remeshed and is exported as a native Nastran tetrahedron volume mesh

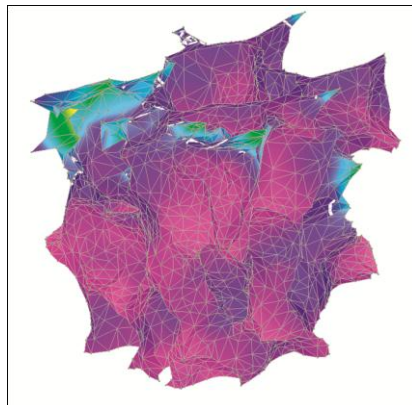


Figure 7: Von Mises stress for vertical compression on foam model

### Fan

For the broken fan component the 3D reconstructed result is shown in figure 8. The fan was virtually repaired using the Mimics Innovation Suite. The repaired component was then 3D printed using layered manufacturing techniques at Materialise. This is shown in figure 9, as is a reverse engineering proof of concept result on this particular component.

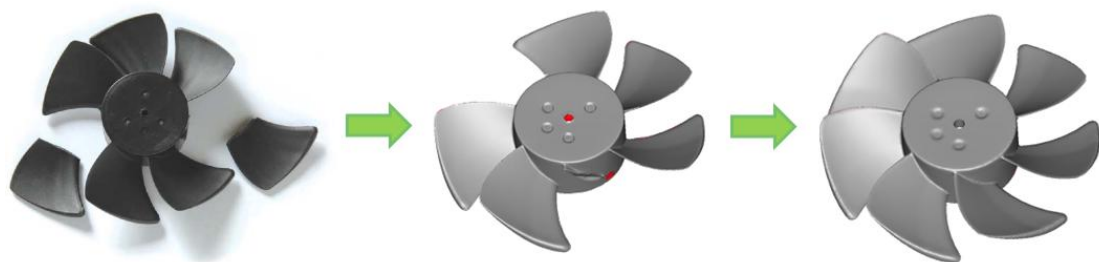


Figure 8: Picture (left), 3D model from micro-CT scan (middle) and repaired virtual model (right) of a broken fan component

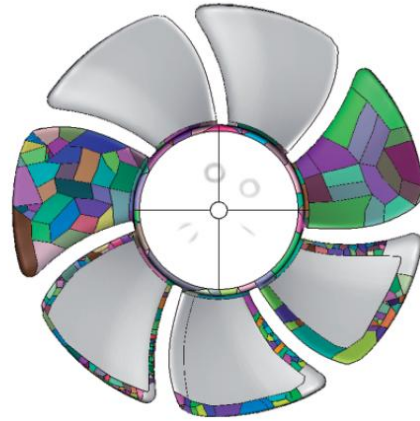


Figure 9: 3D printed, repaired fan component coming out of sinter powder bed (left) and reverse engineered IGES representation of the component (right)

### **Conclusion**

This paper showed that the Mimics Innovation Suite is capable of performing a wide range of 3D advanced analyses starting from 2D reconstructed micro-CT data. Both for life sciences and material research it allows creation of quantifiable 3D surface and volume models for porosity analysis, batch-measurement implementation, reverse engineering, 3D printing, FEA/CFD, centerline creation and more.

### **References:**

1. Gelaude F., Van der Sloten J. & Lauwers B., Accuracy assessment of CT-based outer surface femur meshes, *Computer Aided Surgery*, 13(4), p188-199, 2008