Central Analytical Facilities

STELLENBOSCH UNIVERSITY

Stellenbosch University CT Scanner Facility: "after your scans"

A guideline on what to do with all your microCT data

Dear client, user, collaborator,

Congratulations on getting your CT scans done! The scanning process is shown in the video at this link: https://youtu.be/Yqui4OPVZu0

This document is meant to assist in getting you started with data analysis and reporting your X-ray tomography results. Please note that our facility is at heart a research facility and we are researchers, so we hope you will publish your work as much as possible and we are here to assist with that. You will note we do not distinguish between client, user or collaborator. This is because you are all of the above, and your work is important to us. We offer the best possible X-ray tomography facility, skills and expertise and this is made possible by people like you supporting us. This document outlines three important aspects:

(1) how to analyze 3D data and what are your options

(2) when to include us as co-authors in your paper and

(3) how to report your work in scientific publications, including possible references from similar work at our facility which you may cite

But before we start, please note that we do not keep your data in archive of any sort, your data is your responsibility, so please keep it safe and make a backup! We sell hard drives for this purpose.

CT Scanner Facility
CT Scanner Facility, PO Sauer Building, Bosman Road, Stellenbosch, 7600
Private Bag X1, Matieland, 7602, South Africa
Tel: +27 21 808 9389 anton2@sun.ac.za
www.sun.ac.za/caf
www.sun.ac.za/ctscanner

(1) How to analyze your 3D data and what are the options

X-ray microCT generates high quality 3D volumetric data of an object, ie. your volume data set comprises of typically up to 2000 x 2000 x 2000 volumetric pixels (voxels), each having a grey value in the range 0 - 65 535, depending on the material density and atomic composition. That means when a dense particle is inside your material, the associated voxels will be brighter (higher grey values) and surrounding material will be less bright. This data is typically analyzed in 3D data viewing and analysis software: in our facility we extensively use the market leading software for microCT data, Volume Graphics VGStudioMax 3.2. We also offer Avizo Fire and Simpleware for users familiar with these softwares. For analyzing 2D images, imageJ or Fiji is often used by researchers and this can also be applied to 3D data, but requires some effort. A simpler and more powerful solution for 2D images is MiPAR, also available at our facility. Custom image analysis procedures can also be written by users in matlab or python, for example. If you have an interest in making your own analysis, all you need to do is obtain the suitable format for your data set. We can generate any output type but our default output is a Volume Graphics format – VGI and VOL files, and when we have made analysis this is included in the VGL interface file and associated folder with project information. Please note the raw X-ray images with your scan are not part of the 3D data set, but included in your data (for the purposes of backup). For more information on your data, please see the youtube video here:

https://youtu.be/A0KZFeCOJHY

For more on the free 3D viewer (myVGL) and how to open your data, see here:

https://youtu.be/7xW5iHvl3sA

For now, you need to know that you have 3D image data and you need to analyze it. We offer analysis support, here below are some easy options

1. Make use of our analysis PCs, which can be booked via the online system in booking slots of 4 hrs. Month-bookings are available at a discounted price
2. Assisted analysis involves a trained analyst to directly assist you with routine analysis tasks, and sometimes assist in developing custom image analysis procedures. These bookings are also in 4 hr slots and can take the form of training when required, but is highly effective because it is done on your own data.
3. Provide us your requirements and data and we do all analysis for you, the cost depends on the complexity of the task. Typically accurate volume and dimensional measurements require 1 hr, porosity analysis 1 hr, making images and videos and data processing for easy viewing 1 hr. Routine analysis tasks are described in a later user guide, but the rule is – if its

possible (you have seen it in a publication), we can do it. If its not possible, its highly likely we can figure out how to do it

(2) When to include us as authors in your paper

We welcome the opportunity to take an active part in your research, as we are researchers ourselves. As researchers, we provide the best possible support to allow you make discoveries which would not have been possible without our inputs. When this is the case, we expect co-authorship, irrespective of the payments made. Ethically when a contribution is made by a staff member you are obliged to include them as an author in your work. This is not the case for routine work, such as basic generation of images. But, when an analysis involved custom analysis procedures, method development or insight by the person involved, this constitutes a scientific contribution and needs to be reported as such in the paper, by the person who did the work. We gladly assist in writing the paper and taking part in the work, which also simplifies the process for you. When you are unsure please discuss it with us directly.

When you have no interest in our possible scientific contributions, please still feel free to use the facility and make bookings for self-analysis. Everyone is welcome and we understand that your work is important to you. It is mandatory that our facility paper is cited:

du Plessis, A., le Roux, S.G. and Guelpa, A., 2016. The CT Scanner Facility at Stellenbosch University: an open access X-ray computed tomography laboratory. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, *384*, pp.42-49.

https://www.sciencedirect.com/science/article/pii/S0168583X16303433

This also indirectly acknowledges the National Research Foundation and Stellenbosch University for financial support of our facility through the initial equipment purchases.

(3) How to report your work in scientific publications

In order to report your results in the scientific literature (and in your thesis/dissertation), you need to provide enough details for others to be able to reproduce the work. Below you will find a typical paragraph from work done at our facility. All these details can be found in the "*.PCA" file of each scan.

MicroCT scans were performed at the Stellenbosch CT Facility [1], using a General Electric V|TomeX L240 system. Optimized parameters were selected according to the guidelines set out in [2]. X-ray settings included 220 kV and 200 µA and copper beam filtration of 1.5 mm was used, with a voxel *size set to 80 µm. Image acquisition time was 500 ms per image and images were recorded in 2000 rotation steps during a full 360 degree rotation of the sample. At each step position, the first image was discarded and the subsequent 3 images averaged to provide high image quality. Detector shift was activated to minimize ring artefacts and automatic scan optimizer was activated to eliminate artefacts due to possible sample movement or X-ray spot drift. Reconstruction was performed in system-supplied Datos reconstruction software. Visualization and analysis was performed in Volume Graphics VGStudioMax 3.2.*

[1] du Plessis, A., le Roux, S.G. and Guelpa, A., 2016. The CT Scanner Facility at Stellenbosch University: an open access X-ray computed tomography laboratory. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 384, pp.42-49.

[2] Du Plessis, A., Broeckhoven, C., Guelpa, A. and Le Roux, S.G., 2017. Laboratory X-ray micro-computed tomography: a user guideline for biological samples. GigaScience, 6(6), pp.1-11.

Please do not cut and paste the above, as you need to report it in your own words. Sometimes less detail is required, other times more is required in terms of image processing steps. Sometimes it is easier to cite other similar work, especially when the analysis if performed in the same way. Below are some papers which can be cited for specific application types, but also check our website under "research" at this link for updated publications list:

http://blogs.sun.ac.za/ctscanner/research/

Or my google scholar profile here:

https://scholar.google.co.za/citations?hl=en&user=JlqadDkAAAAJ&view_op=list_works&sortby=pubdate

Below are some examples to get you started (last updated in 2017)

Many examples are shown in our facility paper:

du Plessis, A., le Roux, S.G. and Guelpa, A., 2016. The CT Scanner Facility at Stellenbosch University: an open access X-ray computed tomography laboratory. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 384, pp.42-49.

Porosity / defect analysis, wall thickness analysis and CAD variance analysis in metal parts

du Plessis, A. and Rossouw, P., 2015. X-ray computed tomography of a titanium aerospace investment casting. *Case Studies in Nondestructive Testing and Evaluation*, *3*, pp.21-26.

Porosity analysis in metal, before-after processing

du Plessis, A. and Rossouw, P., 2015. Investigation of porosity changes in cast Ti6Al4V rods after hot isostatic pressing. *Journal of Materials Engineering and Performance*, *24*(8), pp.3137-3141.

Porosity analysis of concrete

Du Plessis, A., Olawuyi, B.J., Boshoff, W.P. and Le Roux, S.G., 2016. Simple and fast porosity analysis of concrete using X-ray computed tomography. *Materials and Structures*, *49*(1-2), pp.553-562.

Analysis of additive manufactured / 3D printed parts

Du Plessis, A., Seifert, T., Booysen, G. and Els, J., 2014. Microfocus X-ray computed tomography (CT) analysis of laser sintered parts. *South African Journal of Industrial Engineering*, *25*(1), pp.39-49.

du Plessis, A., le Roux, S.G., Els, J., Booysen, G. and Blaine, D.C., 2015. Application of microCT to the non-destructive testing of an additive manufactured titanium component. *Case Studies in Nondestructive Testing and Evaluation*, *4*, pp.1-7.

du Plessis, A., le Roux, S.G. and Steyn, F., 2015. X-Ray Computed Tomography of Consumer-Grade 3D-Printed Parts. *3D Printing and Additive Manufacturing*, *2*(4), pp.190-195.

du Plessis, A., le Roux, S.G., Booysen, G. and Els, J., 2016. Directionality of cavities and porosity formation in powder-bed laser additive manufacturing of metal components investigated using X-ray tomography. *3D Printing and Additive Manufacturing*, *3*(1), pp.48-55.

du Plessis, A., le Roux, S.G., Booysen, G. and Els, J., 2016. Quality Control of a Laser Additive Manufactured Medical Implant by X-Ray Tomography. *3D Printing and Additive Manufacturing*, *3*(3), pp.175-182.

Moletsane, M.G., Krakhmalev, P., Kazantseva, N., Du Plessis, A., Yadroitsava, I. and Yadroitsev, I., 2016. Tensile properties and microstructure of direct metal laser-sintered TI6AL4V (ELI) Alloy. *South African Journal of Industrial Engineering*, *27*(3), pp.110-121.

Yadroitsev, I., Krakhmalev, P., Yadroitsava, I. and Du Plessis, A., 2017. Qualification of Ti6Al4V ELI Alloy Produced by Laser Powder Bed Fusion for Biomedical Applications. *JOM*, pp.1-6.

Simulations of microCT data

du Plessis, A., Yadroitsava, I., le Roux, S.G., Yadroitsev, I., Fieres, J., Reinhart, C. and Rossouw, P., 2017. Prediction of mechanical performance of Ti6Al4V cast alloy based on microCT-based load simulation. *Journal of Alloys and Compounds*.

Analysis of geological materials

Rozendaal, A., Le Roux, S.G., du Plessis, A. and Philander, C., 2017. Grade and product quality control by microCT scanning of the world class Namakwa Sands Ti-Zr placer deposit West Coast, South Africa: An orientation study. *Minerals Engineering*.

Rozendaal, A., Le Roux, S.G. and du Plessis, A., 2017. Application of microCT scanning in the recovery of endo-skarn associated scheelite from the Riviera Deposit, South Africa. *Minerals Engineering*.

Le Roux, S.G., Du Plessis, A. and Rozendaal, A., 2015. The quantitative analysis of tungsten ore using X-ray microCT: Case study. *Computers & Geosciences*, *85*, pp.75-80.

Miller, J.A., Faber, C., Rowe, C.D., Macey, P.H. and du Plessis, A., 2013. Eastward transport of the Monapo Klippe, Mozambique determined from field kinematics and computed tomography and implications for late tectonics in central Gondwana. *Precambrian Research*, *237*, pp.101-115.

Clarke, C.E., Majodina, T.O., du Plessis, A. and Andreoli, M.A.G., 2016. The use of X-ray tomography in defining the spatial distribution of barite in the fluvially derived palaeosols of Vaalputs, Northern Cape Province, South Africa. *Geoderma*, *267*, pp.48-57.

Biological sciences

Broeckhoven, C. and du Plessis, A., 2017. Has snake fang evolution lost its bite? New insights from a structural mechanics viewpoint. *Biology Letters*, *13*(8), p.20170293.

Broeckhoven, C., du Plessis, A. and Hui, C., 2017. Functional trade-off between strength and thermal capacity of dermal armor: insights from girdled lizards. *Journal of the Mechanical Behavior of Biomedical Materials*.

Du Plessis, A., Broeckhoven, C., Guelpa, A. and Le Roux, S.G., 2017. Laboratory X-ray micro-computed tomography: a user guideline for biological samples. *GigaScience*, *6*(6), pp.1-11.

Broeckhoven, C., Plessis, A., Roux, S.G., Mouton, P.L.F.N. and Hui, C., 2017. Beauty is more than skin deep: a non-invasive protocol for in vivo anatomical study using micro-CT. *Methods in Ecology and Evolution*, *8*(3), pp.358-369.

Matthews, T. and du Plessis, A., 2016. Using X-ray computed tomography analysis tools to compare the skeletal element morphology of fossil and modern frog (Anura) species. *Palaeontologia Electronica*, *19*(1), pp.1-46.

Landschoff, J., Plessis, A. and Griffiths, C.L., 2015. A dataset describing brooding in three species of South African brittle stars, comprising seven high-resolution, micro X-ray computed tomography scans. *GigaScience*, *4*(1), p.52.

Landschoff, J., Du Plessis, A. and Griffiths, C.L., 2015. 3-dimensional microCT reconstructions of brooding brittle stars. *GigaSci Database*.

Food and agrisciences

Schoeman, L., Williams, P., du Plessis, A. and Manley, M., 2016. X-ray micro-computed tomography (μCT) for non-destructive characterisation of food microstructure. *Trends in Food Science & Technology*, *47*, pp.10-24.

Ham, H., Du Plessis, A. and Le Roux, S.G., 2017. Microcomputer tomography (microCT) as a tool in Pinus tree breeding: pilot studies. *New Zealand Journal of Forestry Science*, *47*(1), p.2.

Schoeman, L., du Plessis, A. and Manley, M., 2016. Non-destructive characterisation and quantification of the effect of conventional oven and forced convection continuous tumble (FCCT) roasting on the three-dimensional microstructure of whole wheat kernels using X-ray micro-computed tomography (μCT). *Journal of Food Engineering*, *187*, pp.1-13.

Schoeman, L., du Plessis, A., Verboven, P., Nicolaï, B.M., Cantre, D. and Manley, M., 2017. Effect of oven and forced convection continuous tumble (FCCT) roasting on the microstructure and dry milling properties of white maize. Innovative Food Science & Emerging Technologies.

Lindgren, O., Seifert, T. and Du Plessis, A., 2016. Moisture content measurements in wood using dual-energy CT scanning–a feasibility study. *Wood Material Science & Engineering*, *11*(5), pp.312-317.

Guelpa, A., du Plessis, A. and Manley, M., 2016. A high-throughput X-ray micro-computed tomography (μCT) approach for measuring single kernel maize (Zea mays L.) volumes and densities. *Journal of Cereal Science*, *69*, pp.321-328.

Vaziri, M., Plessis, A.D., Sandberg, D. and Berg, S., 2015. Nano X-ray tomography analysis of the cell-wall density of welded beech joints. *Wood Material Science & Engineering*, *10*(4), pp.368-372.

Guelpa, A., du Plessis, A., Kidd, M. and Manley, M., 2015. Non-destructive estimation of maize (Zea mays L.) kernel hardness by means of an X-ray micro-computed tomography (μCT) density calibration. *Food and Bioprocess Technology*, *8*(7), pp.1419-1429.

Meincken, M. and Du Plessis, A., 2013. Visualising and quantifying thermal degradation of wood by computed tomography. *European Journal of Wood and Wood Products*, *71*(3), pp.387-389.

Fossils / heritage

Grine, F.E., Marean, C.W., Faith, J.T., Black, W., Mongle, C.S., Trinkaus, E., le Roux, S.G. and du Plessis, A., 2017. Further human fossils from the Middle Stone Age deposits of Die Kelders Cave 1, Western Cape Province, South Africa. *Journal of Human Evolution*, *109*, pp.70-78.

Matthews, T. and du Plessis, A., 2016. Using X-ray computed tomography analysis tools to compare the skeletal element morphology of fossil and modern frog (Anura) species. *Palaeontologia Electronica*, *19*(1), pp.1-46.

Ikram, S., Slabbert, R., Cornelius, I., du Plessis, A., Swanepoel, L.C. and Weber, H., 2015. Fatal force-feeding or Gluttonous Gagging? The death of Kestrel SACHM 2575. *Journal of Archaeological Science*, *63*, pp.72-77.

Du Plessis, A., Slabbert, R., Swanepoel, L.C., Els, J., Booysen, G.J., Ikram, S. and Cornelius, I., 2015. Three-dimensional model of an ancient Egyptian falcon mummy skeleton. *Rapid Prototyping Journal*, *21*(4), pp.368-372.

du Plessis, A., Steyn, J., Roberts, D.E., Botha, L.R. and Berger, L.R., 2013. A proof of concept demonstration of the automated laser removal of rock from a fossil using 3D X-ray tomography data. *Journal of Archaeological Science*, *40*(12), pp.4607-4611.

Cornelius, I., Swanepoel, L.C., Du Plessis, A. and Slabbert, R., 2012. Looking inside votive creatures: Computed tomography (CT) scanning of ancient Egyptian mummified animals in Iziko Museums of South Africa: A preliminary report. *Akroterion*, *57*(1), pp.129-148.

Energy materials

Burheim, O.S., Crymble, G.A., Bock, R., Hussain, N., Pasupathi, S., du Plessis, A., le Roux, S., Seland, F., Su, H. and Pollet, B.G., 2015. Thermal conductivity in the three layered regions of micro porous layer coated porous transport layers for the PEM fuel cell. *International Journal of Hydrogen Energy*, *40*(46), pp.16775-16785.

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