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Generation of complex block materials for *3DEC* numerical modelling using Grasshopper

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1 INTRODUCTION

The first step of numerical modelling is usually the generation of a geometrical model, which can be sometimes difficult and time consuming. Discrete element codes as *3DEC* (Itasca 2013), require either the explicit definition of blocks, or sets of fractures to generate them. Among the different applications of these models, there is a growing use of grain-based models (GBM) to represent either rock micro-structure or the stochastic distribution of material structure, allowing inter-grain fracturing. These models make use of an assembly of complex polyhedrons (e.g. Voronoi tessellations) for which explicit manual definition of each block would not be feasible.

Currently, Itasca's *Griddle* (Itasca 2016) allows the automated generation of tetrahedral or hexahedral block assemblies for *3DEC*. However, in case more complex polyhedrons are required, they have to be explicitly generated or cut from previous blocks in *3DEC*. In particular, Voronoi 3D tessellations cannot be directly generated in *3DEC*, as it is possible with *UDEC* (Itasca 2019).

In this paper, a practical methodology for the generation and exportation to *3DEC* of 3D Voronoi grains, using Rhinoceros Grasshopper is presented. A similar process could be used to export other types of polyhedron-shaped geometries to *3DEC*, avoiding discretizing them into subsets of tetrahedral/hexahedral blocks, using Rhinoceros as a common graphical development tool with *Griddle*.

2 DESIGN AND ANALYSIS.

The process presented in this paper can be divided in four steps:

- Generation of the Voronoi 3D material geometry in Rhinoceros (using Grasshopper tools for Voronoi tessellation).
- Processing of the Rhinoceros geometry to obtain and organize node coordinates information.
- Generation of a ".3ddat" file with all required commands.
- Virtual testing of the sample.

Regarding the first step, Voronoi tessellations in 2D have been widely used and studied for brittle rock characterization (Lan et al. 2010, Fabjan et al. 2015, Mayer & Stead 2017), although their use for 3D modelling is more limited. One of the main problems encountered when Voronoi tessellations are needed in *3DEC*, compared to *UDEC*, is the lack of an embedded tool for generation of Voronoi tessellations. In the case of 3D, for the initial creation of the geometry it is required to use complex algorithms or external libraries (Ghazvinian et al. 2014, Ghazvinian et al. 2017, Li et al. 2017).

For this study, it was decided to test the potential use of one of Rhinoceros' plug-ins, Grasshopper, to create the initial block set. This tool allows simple parametric modelling of Rhinoceros geometries through the development of intuitive graphical algorithms. The main advantage of working with Grasshopper is the possibility to avoid complex programming for geometrical operations and work with the same environment already used by Itasca's *Griddle*.

2.1 *Generation of Voronoi 3D geometry*

The process begins defining the main geometrical characteristics of the model (height, diameter, initial block width and number of grains). These parameters can be passed through a simple code in Grasshopper to the Voronoi 3D generation tool. This part of the process produces a set of Rhinoceros solids (Fig. 1) representing a prismatic assembly of 3D Voronoi blocks, generated according to the specific set of the input parameters. However, these complex solids cannot be directly exported to *3DEC*.

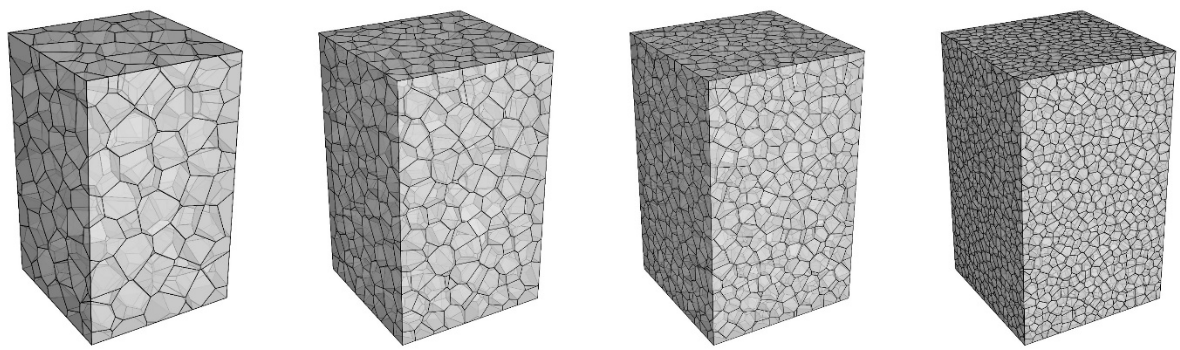

Figure 1. Initial blocks of solids in Rhinoceros generated with 500, 1000, 3000 and 10000 grains.

2.2 *Obtaining of block, face, and vertices data*

For this second part, a more complex algorithm with Grasshopper was developed to extract and process geometrical data from Rhinoceros solids for its later exportation to *3DEC*.

This code first extracts and classifies (in a tree structure) all the geometrical elements defining the model, hierarchically structured as: blocks-faces-vertices-coordinates. This will provide most required information to generate polyhedrons in *3DEC*. However, polyhedron generation in *3DEC* also requires the sequential clockwise orientation of vertices forming every block face, as seen from outside of the block. Grasshopper Voronoi 3D generator and most Rhinoceros solids already have their face vertices ordered sequentially, although the second condition is not guaranteed. Thus, using vector algebra tools in Grasshopper, a general check on the whole set of elements is performed and those faces whose vertices are ordered counterclock-wise are flipped. Next, all data (point coordinates and element hierarchical relations) are formatted into structured text, as shown by Figure 2.

The main advantage of this part of the process is not just specifically allowing the exportation of Voronoi 3D tessellations to *3DEC* but showing the potential application of visual algorithms as well for the use of other block assemblies generated with Rhinoceros or Grasshopper.

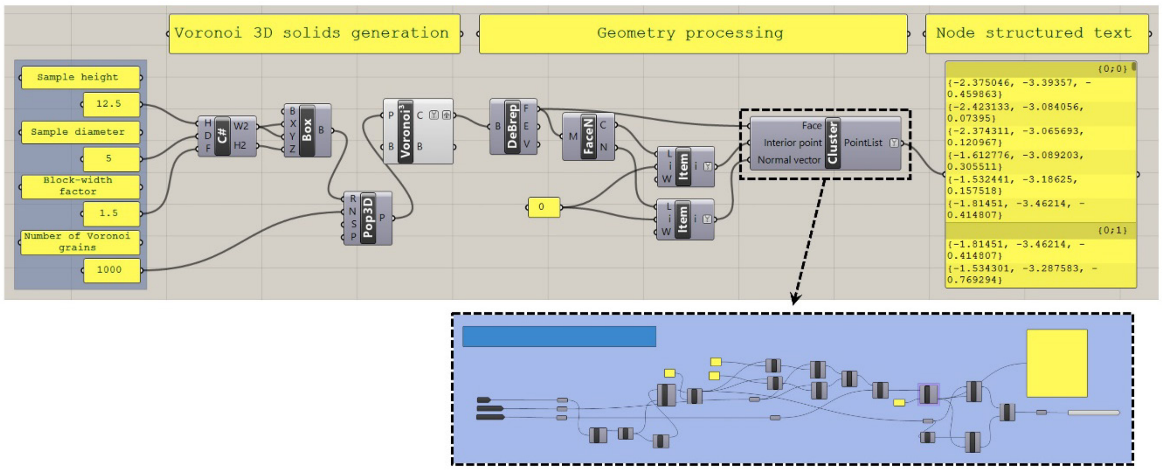

Figure 2. Grasshopper visual code used for Voronoi 3D geometry generation and processing.

2.3 *Generation of 3DEC data file*

Previously generated text is then reformatted to include all required *3DEC* commands and written into a ".3ddat" file which can be directly called from *3DEC* for the explicit generation of all elements. To accomplish this, simple parsing and text formatting operations can be used. In this case, C# programming language was used for simplicity, although formatting may also be carried out with *FISH* scripting or even in Grasshopper as well. Additional commands are automatically added to the final file, to directly cut the sample's final cylindrical geometry, based in the initial parameters.

2.4 *Virtual testing*

Virtual testing was then carried out in *3DEC* under the hypothesis of rigid grains to save processing time. Loading was performed by applying constant velocity intervals to loading plates at the ends of the samples and measurement of stresses was carried out at the contact between plates and sample. Axial and lateral strain were measured as well and volumetric deformation calculated from them.

3 RESULTS AND DISCUSSION

The previously explained methodology has been applied for the generation and testing of cylindrical laboratory-size rock samples, used for research work in brittle behavior (Tonkins et al., 2019). As well, ongoing work focuses on scale effects and the influence of fracture networks in strength, according to a Synthetic Rock Mass approach (Ivars et al. 2011), using a grain-based model. Figure 3 shows a sample created from a 3000 grains block intended to reproduce a material of 100 MPa resistance and 30 GPa of Young modulus, and the results obtained after Uniaxial Compressive Strength (UCS) testing, where it can be observed the fracture mechanism, after peak-resistance is reached.

Regarding the resultant grain block mesh, the authors have not found problems with point coordinate precision, apart from the possible need to configurate the allowed minimum edge tolerances for sample cutting in *3DEC*, and the need to remove a thin material layer in both plate-sample contacts to ensure proper contact behavior during loading.

Results show that correct modelling of brittle failure against UCS testing could be carried out using the Voronoi 3D mesh imported from Grasshopper, reproducing the failure mechanism, resistance, brittleness, and deformability of a sedimentary rock.

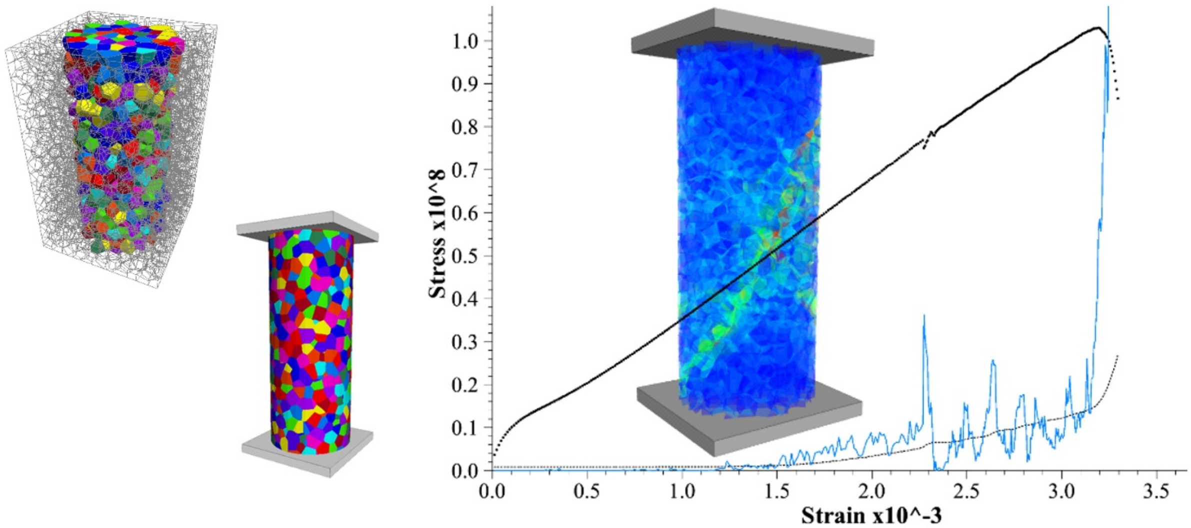

Figure 3. Example of *3DEC* sample cut from imported blocks (left) and results (right) obtained for UCS (stress-strain curve as black dotted line, fracture count per strain unit as blue curve, total number of cracks as thin black line and contact strain as blue-green-red scale within the sample).

4 CONCLUSIONS

A friendly and practical methodology to provide 3D Voronoi tessellations for *3DEC* has been developed using Rhinoceros' Grasshopper, showing the applicability of this tool to the generation of complex polyhedron-shaped blocks for *3DEC* numerical modelling.

Grain assemblies are useful for numerical modelling of brittle failure or rock microstructure. Geometries generated through the process presented in this paper are adequate for the numerical modelling and further research could focus on the use of Grasshopper for the generation of other grain distributions, including size grain variations or heterogeneous materials.

Finally, Grasshopper has the advantage of being a free tool for Rhinoceros, commonly used for graphic design in mining and civil engineering as host of Itasca's meshing plug-in *Griddle*.

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