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A Framework for 2D Mesh Generation from Computed Tomography of Rock Samples

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Abstract. Generating meshes is essential in fields like numerical simulations, computer graphics, and finite element analysis. CT scan technology is now widely used in different areas beyond medicine, including geosciences. The use of digital representations of rocks enables capturing different physical properties of real samples without altering the original rock samples. This study introduces a structured approach to digitally reconstruct rock samples from raw CT scan data and create 2D finite element meshes on Gmsh, incorporating both external libraries and self-developed algorithms. Tests are conducted on diverse rock types, including sandpack and carbonate. The level of mesh coarseness is regulated by specifying an area tolerance parameter between the original connected regions and its discretized representations. The resulting meshes are applied in finite element simulations using the NeoPZ environment.

Keywords: Mesh generation, computed tomography, digital rock, 2D mesh, finite element method.

1 Introduction

Porous media study is a crucial aspect in various fields, including geosciences, petroleum engineering, and material science. The analysis of porous media involves understanding the structure and properties of different materials with interconnected voids or pores. This knowledge is essential for applications such as reservoir characterization and fluid flow modeling. Micro CT (computed tomography) technology has emerged as a powerful tool for capturing the intricate details of porous media, enabling researchers to visualize and analyze the internal structure of materials at a microscopic level. Different studies have been conducted for characterisation of materials using micro computed tomography, including the research of Payton [1].

From the literature review, there have been conducted studies using commercial image reconstruction software and open source libraries such as CGAL and iso2mesh. These works developed by Fang and Boltcheva [2, 3] focused on 3D mesh generation from medical CT scan data. In the context of rock digital reconstruction, micro CT technology has been used in various studies. The use of digital rock models allows for the assessment of physical characteristics without altering the original material, which is particularly advantageous in geosciences and similar areas of study. For instance, Song [4] and Matsumura [5] have investigated the digital reconstruction of rock samples using micro CT scans, focusing on the analysis of 3D pore structures and morphologycal characterisation. The study proposed by Li [6] has been conducted for analysing a soil-rock mixture in 2D using the finite difference method. 2D mesh generation from a digital object representation is a crucial step in finite element simulations, as it allows for the representation of complex geometries and the analysis of boundaries or interfaces of the original domain.

The aim of this work is to develop a framework for generating 2D meshes from digital rocks, which can be used in finite element simulations. The framework will utilize tools from OpenCV library [7] and the Gmsh software [8] , which are widely used in the field of computational mechanics. The proposed method will be tested on different rock types, including sand pack, an homogeneous sandstone with little or no variation [9] in its mineralogy and carbonate samples.

2 Methodology

This study started with the rock samples data collection, three digital rocks were reconstructed using the raw data of each 2D slice. After it, an analysis of the connected regions is done, in order to estimate what particles could be considered as noise, because of its size in the domain. Then, a tolerance of size is considered, and a preprocessed stage takes please. Finally the 2D mesh is generated. A flow chart of this process could be seen in Figure 1.

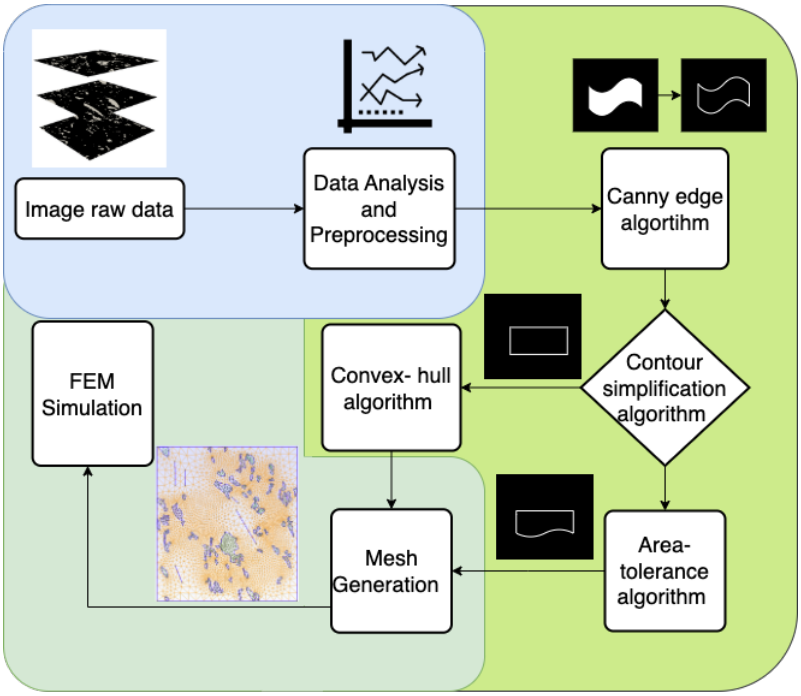


Figure 1. Flowchart of process to generate 2D meshes from digital rocks

The input data consists of 2D slices from CT scans, the methodology begins with raw binary tomographic images. Edge detection was performed using the Canny algorithm [10]. An example of how this algorithm works is shown in Figure 2. This algorithm highlighted the intensity gradients to define the edges, which are then used to create contours. To create the contours, the algorithm of Suzuki and Abe [11] was used through the OpenCV library. The contours are then simplified using a custom-developed algorithm based on an area tolerance criterion, which reduces the number of points in the contour while preserving its overall shape. Figure 2 shows an example of the usage of the contours result to create the mesh representing every pixel as a point for the mesh. The area tolerance criterion is defined as the maximum allowable difference in area between the original and the simplified contours. The simplification process iteratively removes points from the contour until the area difference exceeds the specified tolerance. The pseudocode of this algorithm is presented in Algorithm 1. Finally, the simplified contours are used to generate 2D meshes using Gmsh, which is a widely used open-source mesh generation software. The resulting meshes are then used in finite element simulations using the NeoPZ environment [12].

Figure 3 shows an example of the contour simplification process. The example of pentagonal geometry contour is shown on the left, while the simplified contour is shown on the right. The area tolerance criterion is applied to reduce the number of points in the contour while preserving its overall shape. This process is essential for generating accurate and efficient 2D meshes from the digital rock samples. After the contour simplification process, the simplified contours are used to generate 2D meshes using Gmsh. The Delaunay triangulation is an algorithmic process that constructs a triangulated mesh from a discrete point set, ensuring that the circumcircle (or circumsphere) of each element contains no other input points. The method is widely used for surface reconstruction, interpolation, and numerical modeling due to its favorable element quality. Figure 4 illustrates a comparison between a valid Delaunay triangulation (left) and an invalid example (right). In the valid case, the circumcircle of each triangle is free of any other points from the dataset. In contrast, the invalid case shows a circumcircle that contains another point, resulting in an overlap between the two circles.

Algorithm 1 Contour Simplification Algorithm

Procedure CONTOURSIMPLIFICATION($contoursList$)
Input: contoursList (list of contours)
Output: simplified contoursList
Centroid and Area Calculation
for each contour $i \in contoursList$ **do**
  Calculate centroid coordinates (cx, cy) and area $(area)$ using OpenCV's moments
  Estimate equivalent diameter $(eq_diameter)$
end for
Point Reduction
for each contour j in contoursList **do**
  Set initial area (area1)
  Set index (idx) $\leftarrow 1$
  Set check counter (check) $\leftarrow 0$
  while check $<$ length of contoursList[j] **and** idx < 100 **do**
    Create temporary contour (Ltemp) by removing next point
    Calculate area2 of Ltemp
    if $-errorLim \leq area1 - area2 \leq errorLim$ **then**
      Update contoursList[j] with Ltemp
    else
      Increment idx
    end if
    if np.array_equal(contoursList[j], Ltemp) **then**
      Increment check
    else
      Reset check $\leftarrow 0$
    end if
  end while
end for
End Procedure

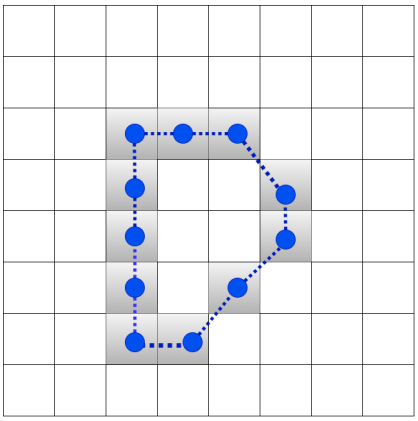


Figure 2. Contour simplification example

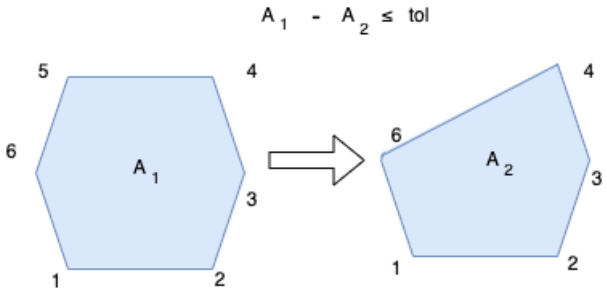


Figure 3. Contour simplification example

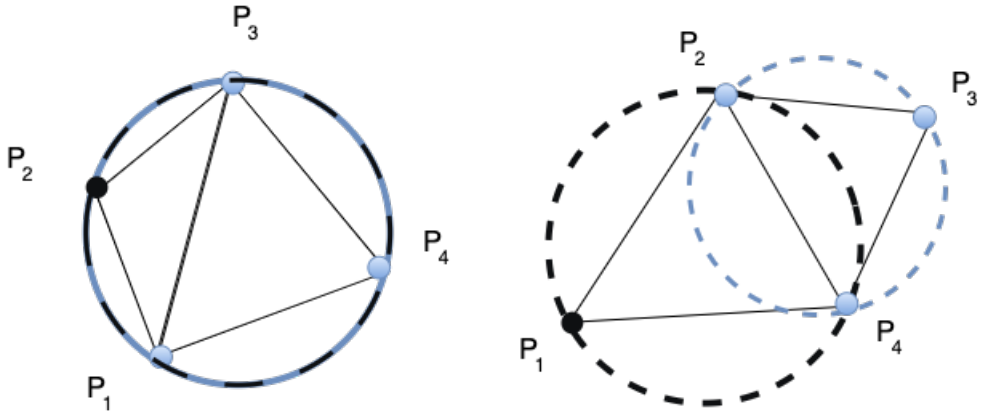


Figure 4. Contour simplification example

3 Results

Table 1 shows more information about the three rock sample data. For the first case, Cepetro sample rock is part of a dataset provided by the School of Mechanical engineering of the Universidade Estadual de Campinas, the second rock is part of a dataset provided by the School of Petroleum Engineering of the Univesity of New South Wales [13] and the third rock is part of a dataset provided by the King's College London [14]. Figure 5 shows the meshes obtained from the CT scans of the three rock samples.

The generated mesh does not yet include all minor internal heterogeneities. These will be evaluated in subsequent work through permeability-based correlations prior to their inclusion in numerical simulations. While

Table 1. Informative chart of rock samples

Sample Data (voxels)	Cepetro Sample	UNSW Sample [13]	KCL Sample [14]
Lenght(voxels)	616	600	500
Width (voxels)	676	600	500
Total images (slices)	600	600	500
Voxel size(Micrometers)	41.58	5.2	8.7

the current mesh captures the main internal structures, it is acknowledged that unresolved microstructures may still impact the results. Their influence will be indirectly assessed via permeability analysis. As a limitation of the current stage, smaller inclusions are not yet represented; they will be addressed through complementary studies focused on hydraulic property correlations.

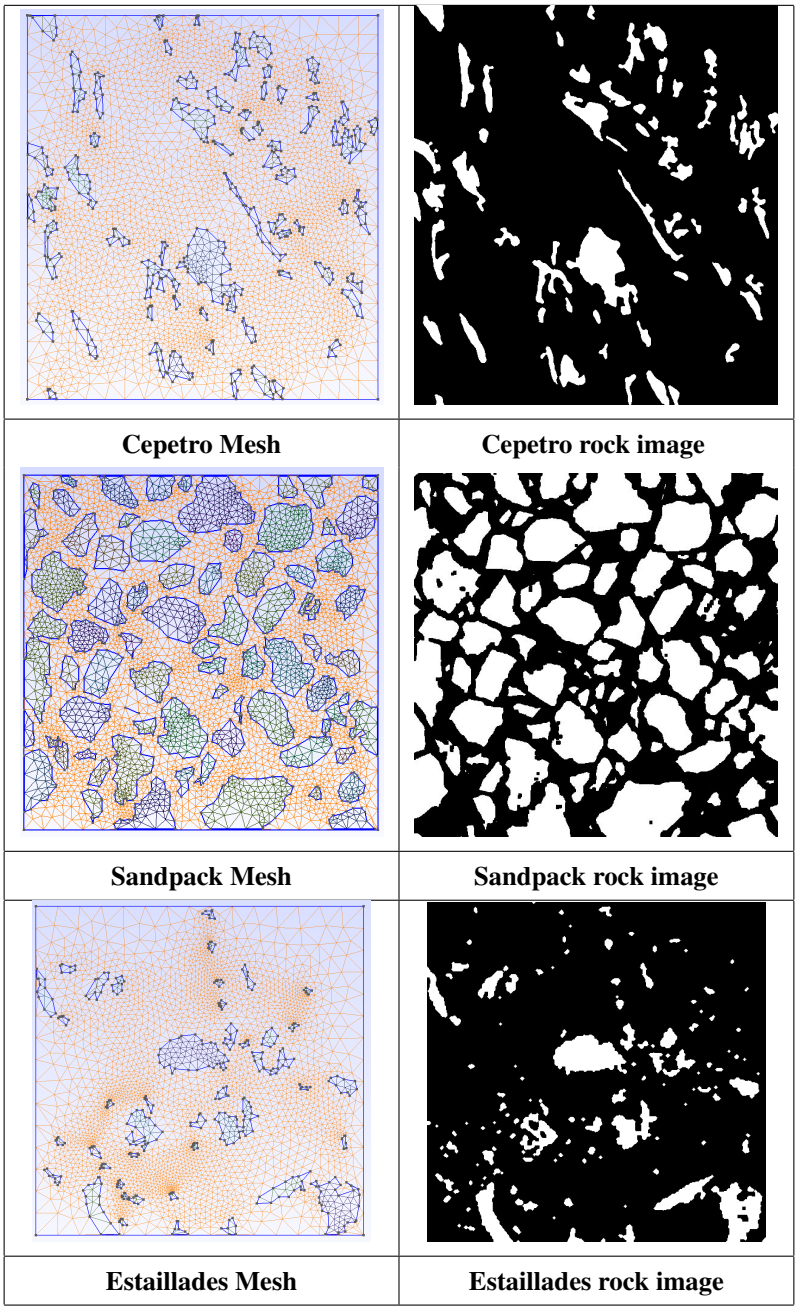
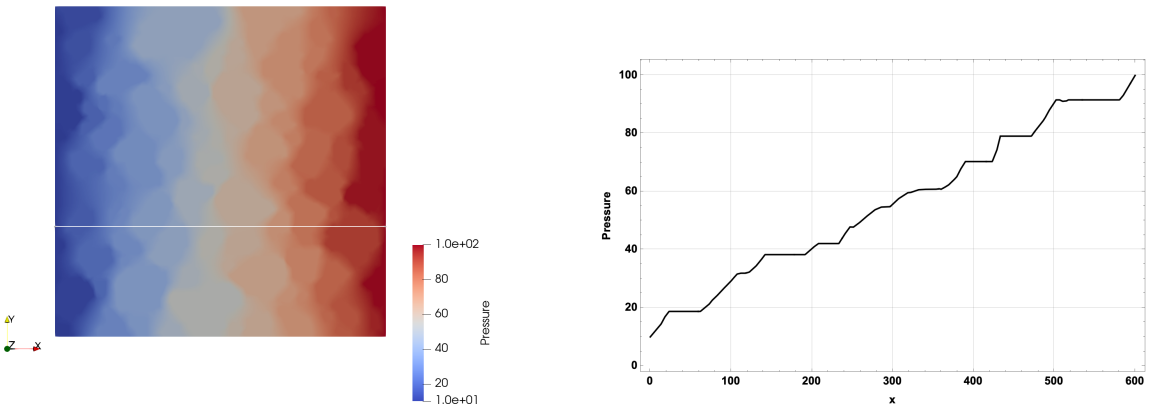


Figure 5. Mesh obtained from Estaillades CT Scan

A verification simulation of Darcy Flow for the Sandpack case was conducted. The results of the simulation are shown in Figure 6, which shows the pressure distribution in the Sandpack sample. The results show that the pressure distribution is consistent with the expected behavior of Darcy Flows, since a high permeaility of order of 10^{12} m^2 was set up for the vugs subdomains, while a low permeability of order of 10^{-1} m^2 was set up for the matrix subdomain.



(a) Pressure distribution in the Sandpack sample.

(b) Pressure distribution along the x-axis.

Figure 6. Simulation verification of Darcy Flow for the Sandpack case.

4 Conclusions

A practical workflow for generating finite element meshes from CT datasets of rock samples is proposed, integrating established methods with custom algorithms. Applied to microtomography images of different rock types, it successfully produced meshes for both 2D and 3D applications.

The datasets have resolutions in the range of 500–600 voxels along each axis, corresponding to volumetric sizes between 125 and 216 million voxels. These dimensions impose high computational demands, particularly during reconstruction, segmentation, and meshing. The presence of small, fragmented, and irregularly shaped regions adds another layer of difficulty, as such structures can compromise mesh quality or drastically increase the element count. To address this, a preprocessing pipeline was implemented to clean the data, remove irrelevant fragments, and simplify geometries, while preserving key structural information.

The meshes generated at this stage capture the principal internal features of the rock samples but exclude smaller inclusions and fine-scale heterogeneities. These unresolved microstructures, though not yet represented, may influence numerical results. Their effect will be assessed indirectly in future studies via permeability-based correlations, prior to their integration into updated mesh versions. This stepwise refinement reflects a deliberate balance between computational efficiency and structural detail, allowing for manageable processing of large datasets while maintaining flexibility for future improvements in resolution and completeness.

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