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FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF TELECOMMUNICATION AND INFORMATION PROCESSING
RESEARCH GROUP OF IMAGE PROCESSING AND INTERPRETATION

AUTOMATIC MESH SIZE ESTIMATION IN DVC FOR IMAGES OF ISOTROPIC MATERIALS

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Zaira Manigrasso

- **PhD student in Computer Science Engineering @ Ghent University (Belgium)**
  - **Supervisors:** Prof. Wilfried Philips and Dr. Jan Aelterman

- **Department:** Telecommunication and Information Processing (TELIN)
- **Research group:** Image Processing and Interpretation (IPI)
- **Research topic:** My work aims to develop an accurate, robust and efficient Digital volume correlation technique able to cope with high-resolution displacement and image artifacts such as noise, motion artifacts or abrupt material changes (such as fractures).

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OUTLINE

- Introduction
- State of the art
- Proposed method
- Experimental setup and dataset
- Results
- Discussion and conclusion

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INTRODUCTION

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DIGITAL IMAGE/VOLUME CORRELATION

Magnitude and direction of the deformation are the same

In deformation estimation problem some parameters (as the mesh size) require experience to be set.

My work aims to automate the research of the optimal mesh size

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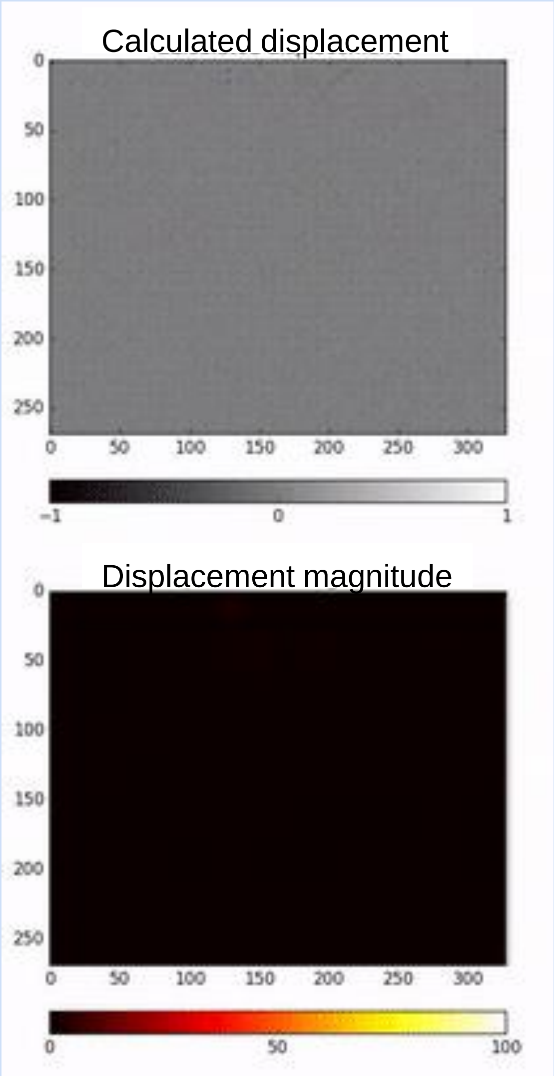
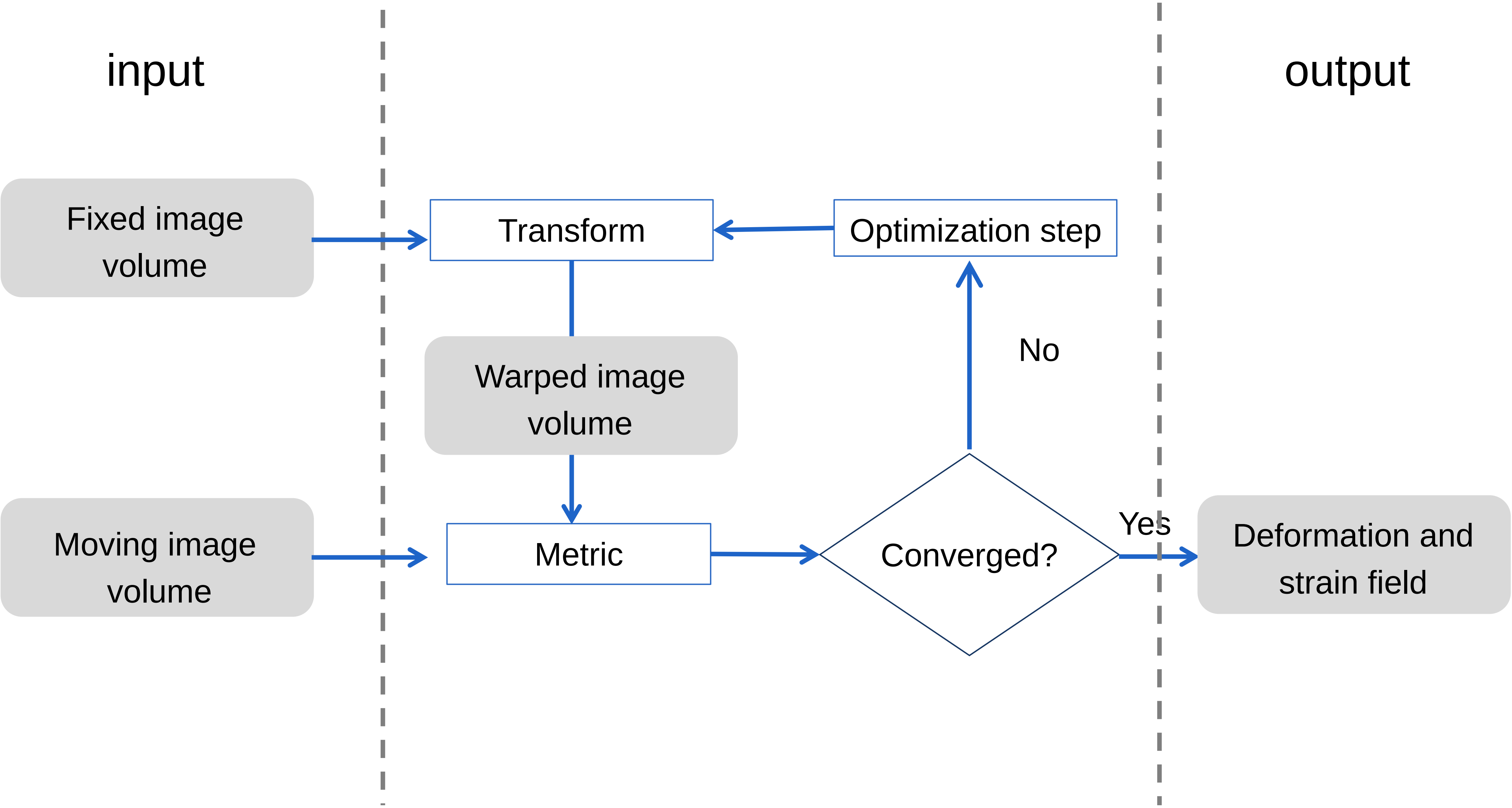
DIGITAL IMAGE/VOLUME CORRELATION

Digital volume/image correlation (DVC/DIC) is a technique for 3D/2D strain and deformation measurements





The transformation is based on B-spline.

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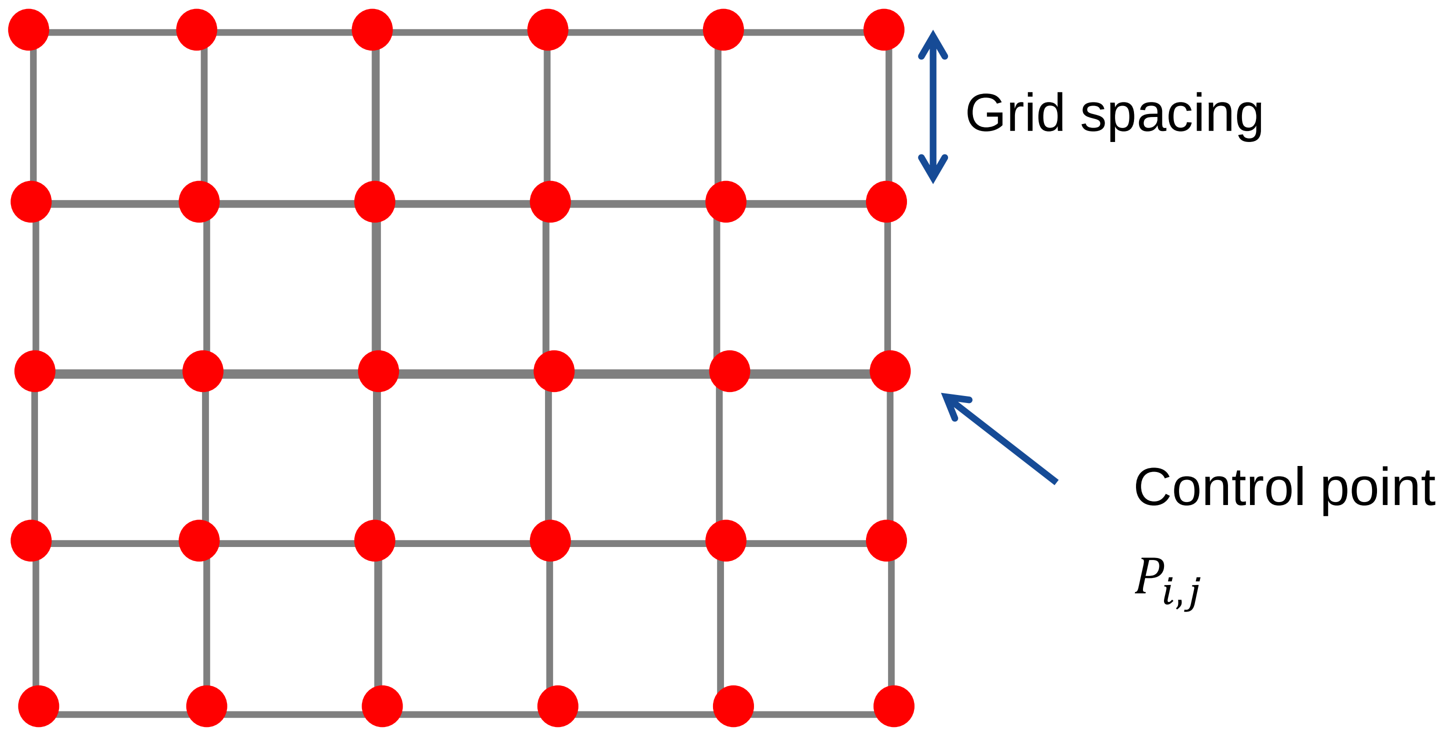
B-SPLINE TRANSFORMATION

The transformation is based on B-spline defined on a <u>uniform</u> grid of control points.

$$\boldsymbol{u}(x,y,z) = \sum_{i,j,w=0}^{n,m,l} \boldsymbol{P}_{i,j,w} N_{i,k}(x) N_{j,q}(y) N_{w,t}(z)$$

k, q, z : B - Spline order
n, m, l: the number of control points
$P - values$: form a set of parameters that fix the motion model (control points)
$N_{i,k}\ N_{i,q},\ N_{w,t}$: kth-degree B-Spline basis functions
$p = n + k + 1.$



- Element order
- Grid spacing/mesh size

- Accuracy in terms of spatial resolution
- Computational time

The choise of the grid size/order is usually user dependent

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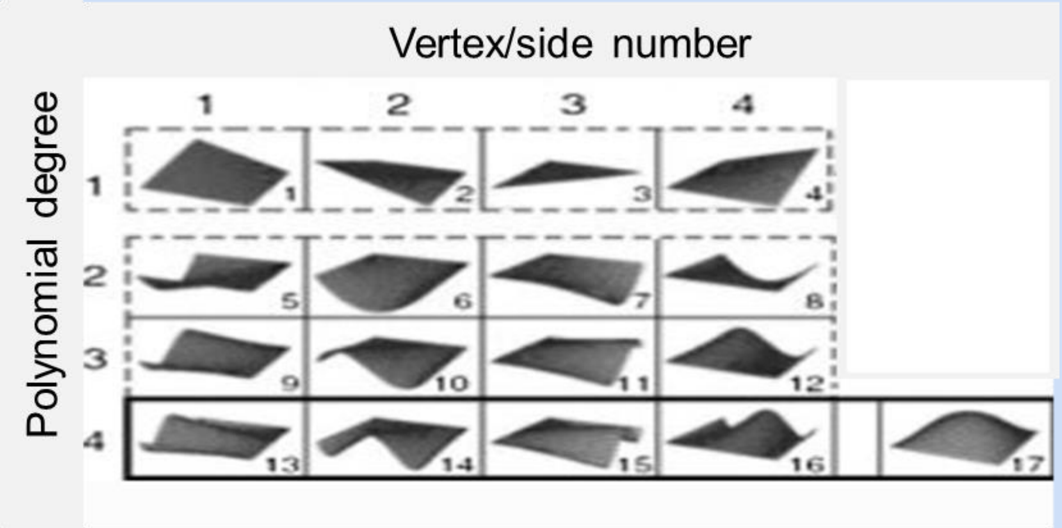
STATE OF THE ART

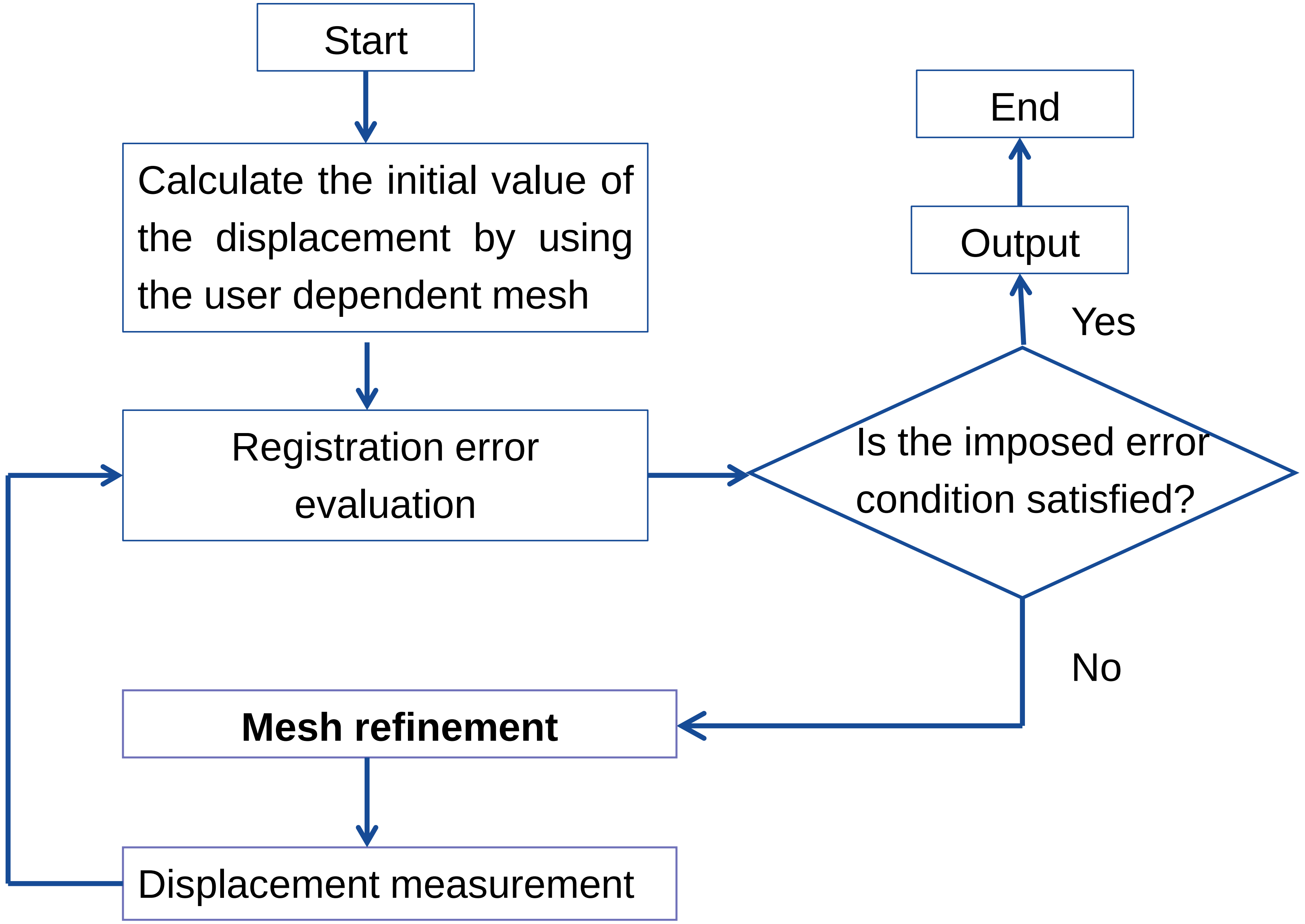
SELF-ADAPTING ALGORITHMS(1)

Self – adapting algorithms are based on the concept of **mesh refinement**.

- **P-refinement** : mesh elements can transform to higher orders → extra DOFs to faces/edges.



  - Indipendency of the result on the user's input
  - Improvement of the adaptivity of the mesh in order to obtain a better rapresentation of the deformation field

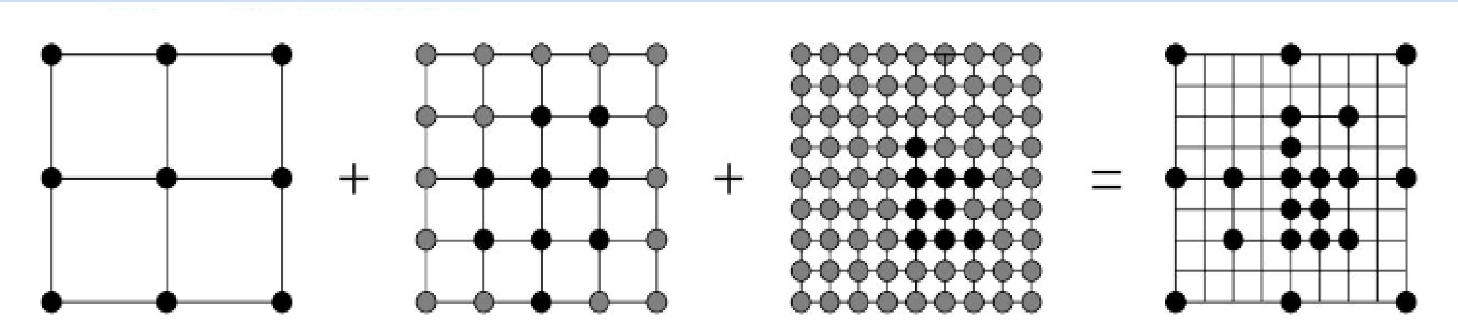


L. Wittevrongel et al., « A Self Adaptive Global Digital Image Correlation Algorithm»,Experimental mechanics, 2014.

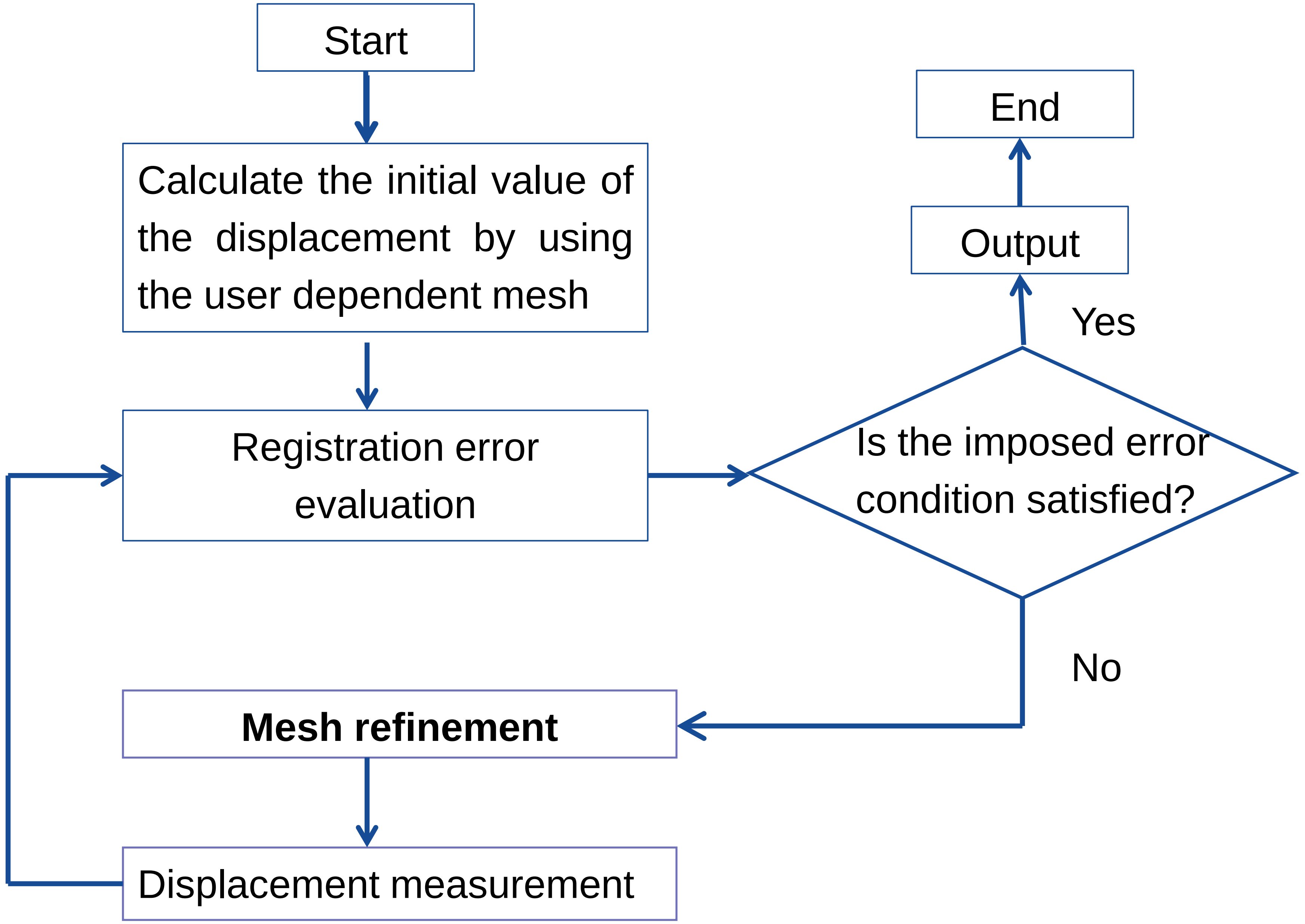
SELF-ADAPTING ALGORITHMS(2)

Self – adapting algorithms are based on the concept of **mesh refinement**.

- **H-refinement** : mesh elements can change in size



- Indipendency of the result on the user's input
- Improved performacies in image registration
- Reduction in run-time



J.A.Schnabel, «A Generic Framework for Non-rigid Registration Based on Non-uniform Multi-level Free-Form Deformations», MICCAI, 2001

PROPOSED METHOD

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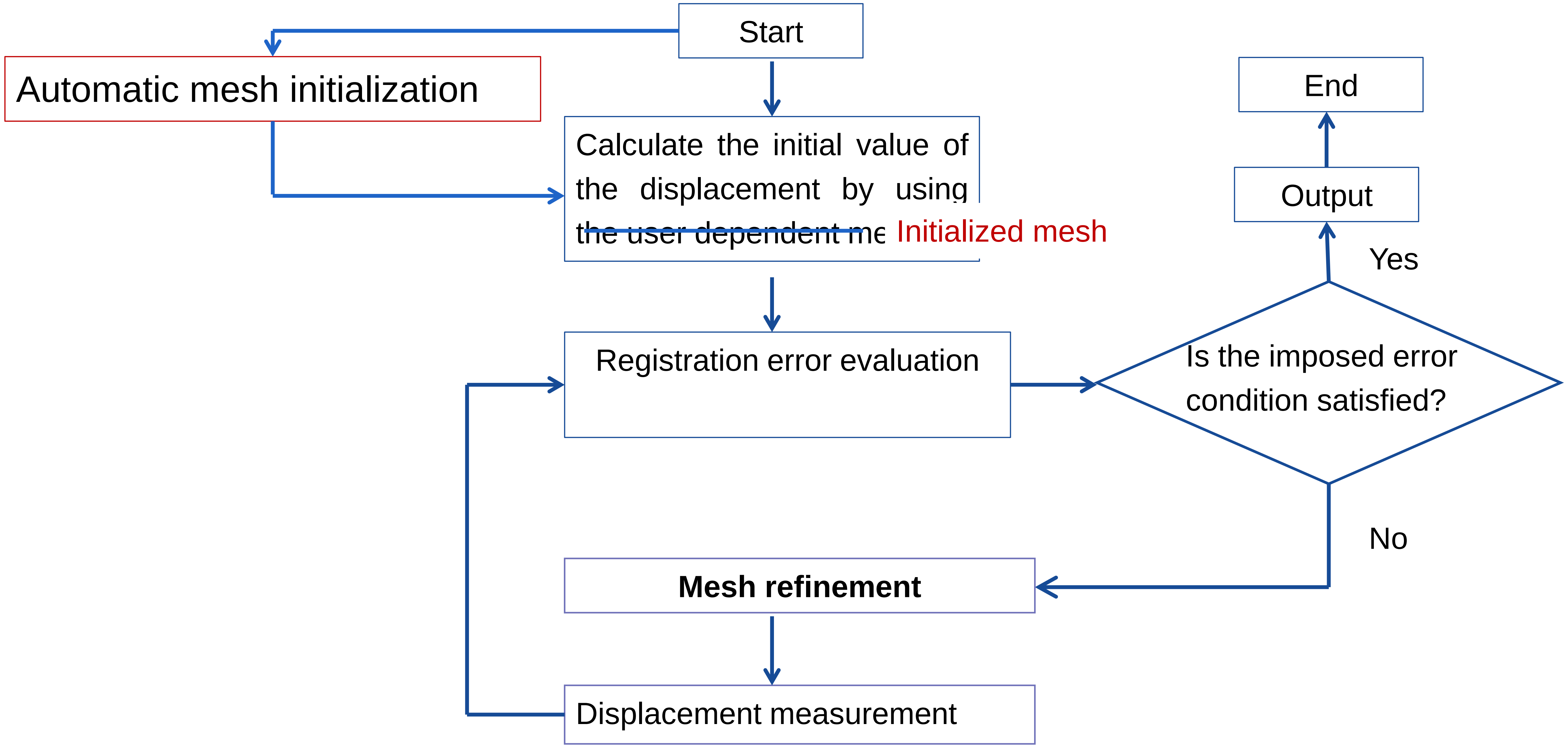
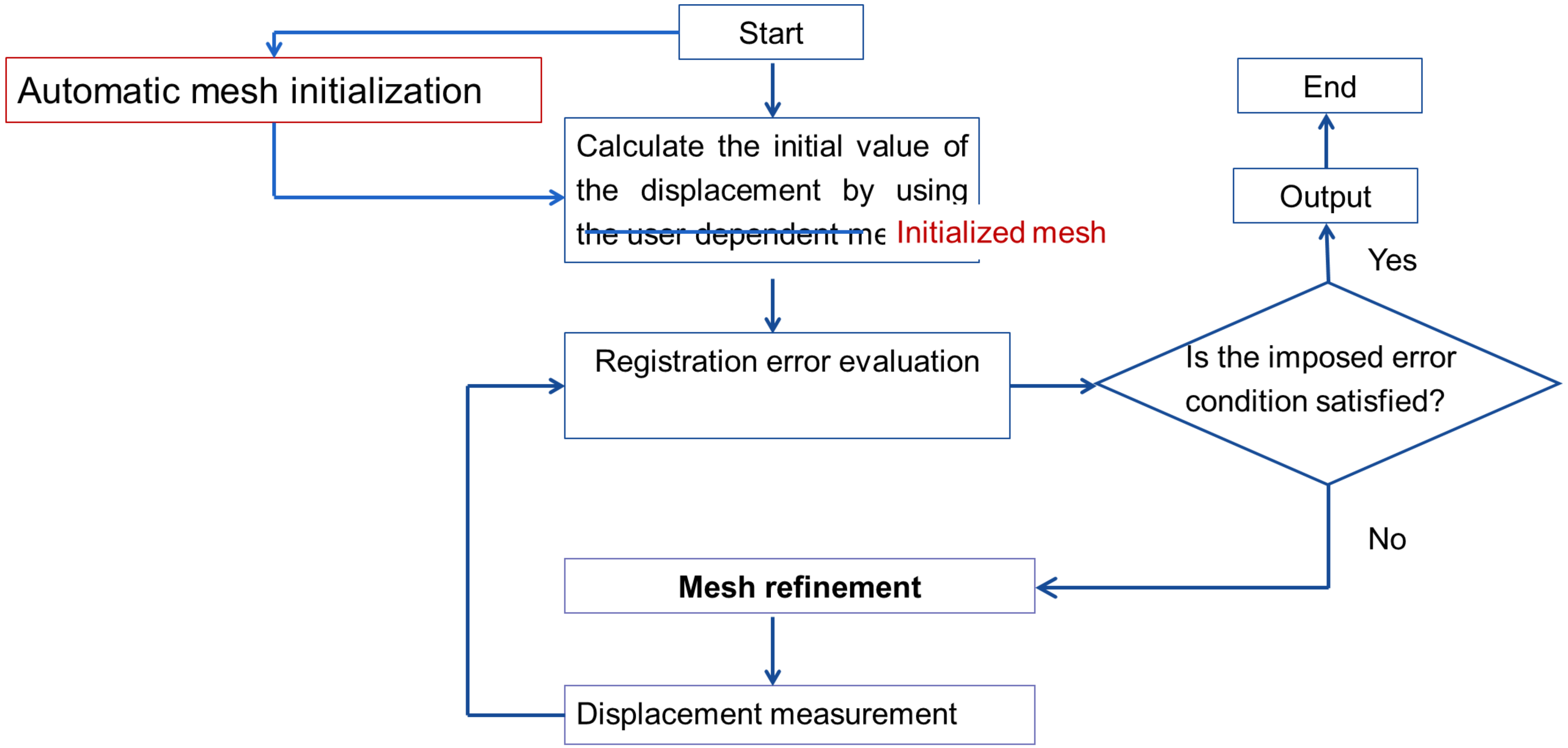
PROPOSED METHOD



An appropriate mesh initialization brings accurate registration results whitout going through mesh size refinement process

PROPOSED METHOD: MESH INITIALIZATION



Hypothesis: <u>for images of isotropic materials</u> the optimal mesh size is a function of the image content.

The <u>characteristic size</u> of the most frequently occurring material structure is a good predictor of the optimal mesh size.

PROPOSED METHOD: MESH INITIALIZATION

Step I:

Connected component labeling*

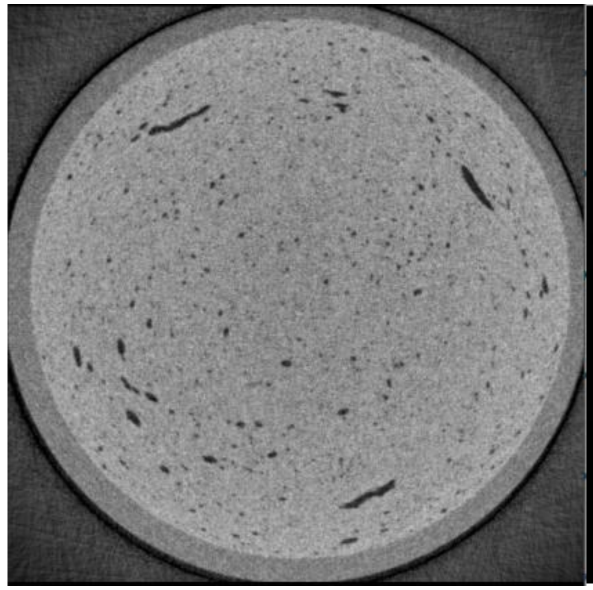
Step II:

Study of the characteristic object size distribution

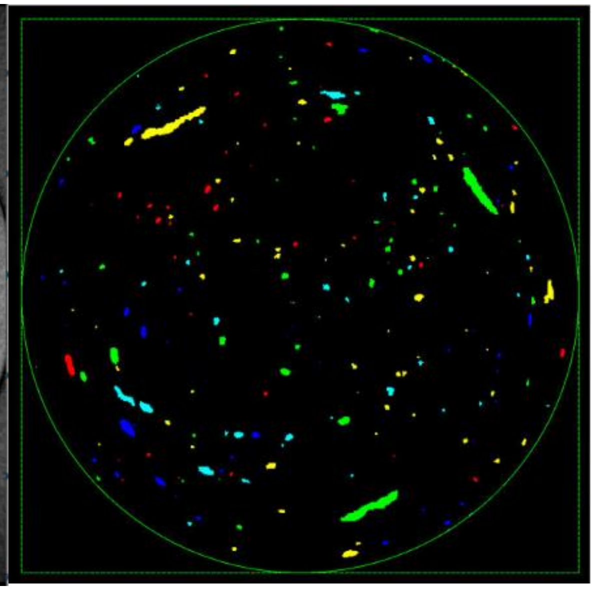
Step III:

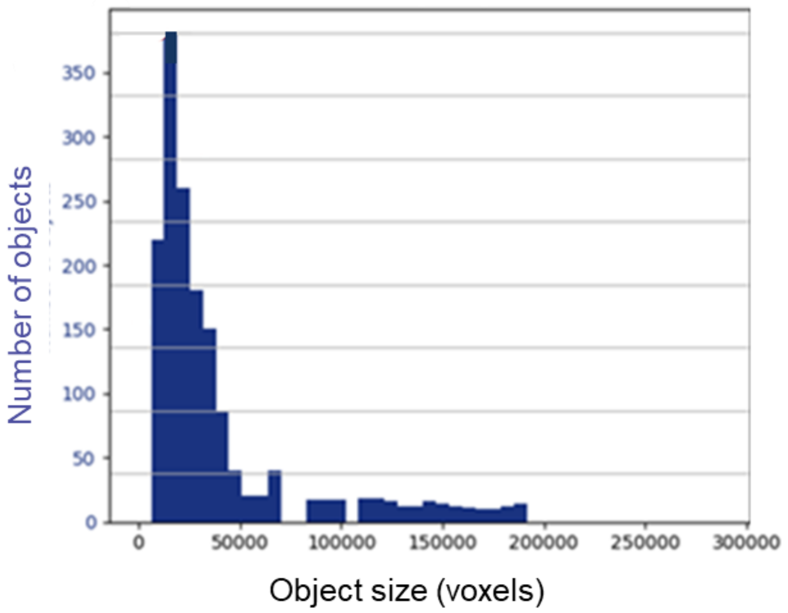
Grid size setting

Central slice of µCT image volume



Labeled image





* Q. Hu et al., «Fast connected-component labelling in three-dimensional bunary images based on iterative recursion», Computer Vision and Image Understanding, 2005.

EXPERIMENTAL SETUP AND DATASET

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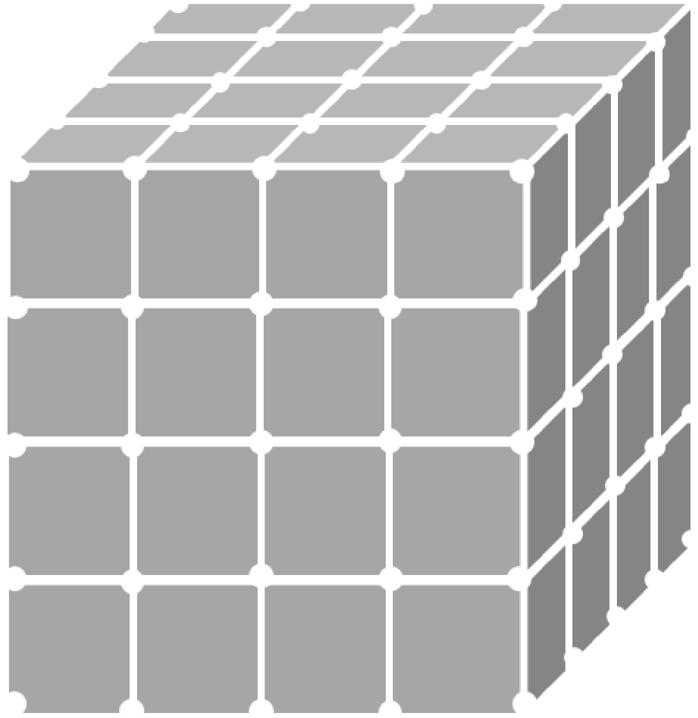
EXPERIMENTAL SETUP: MESH SETTINGS

The expriment was designed for a dual pourpose:

- Investigating the impact of different mesh size in the registration result
- The characteristic size of the most occurring material stucture is predictive for the optimal mesh size



Mesh cubic element size	
2^3-2^4-2^5-2^6	same size of the most occurring object size in the image

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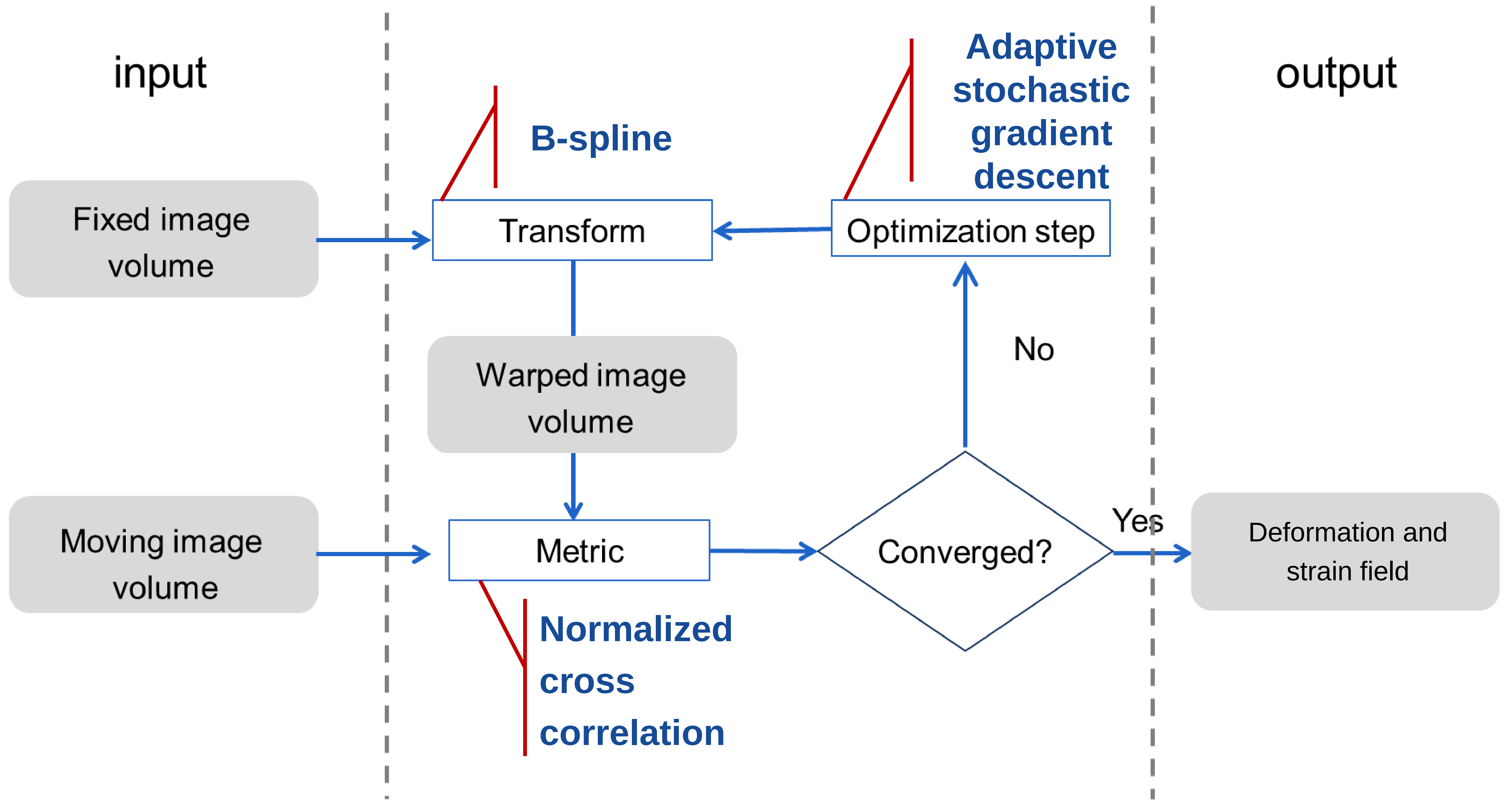
EXPERIMENTAL SETUP: DVC SETTINGS

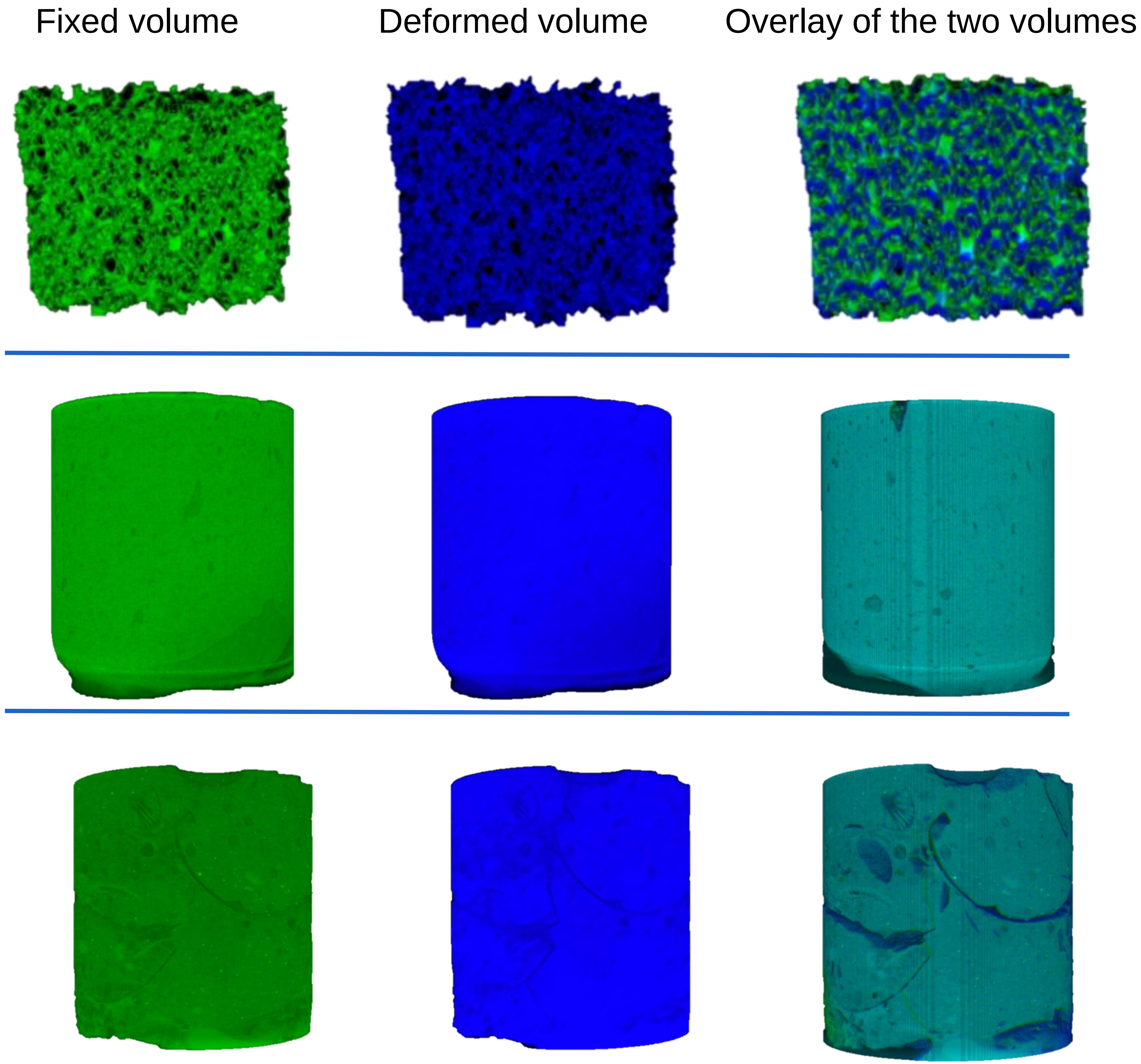


EXPERIMENTAL DATASET (1)

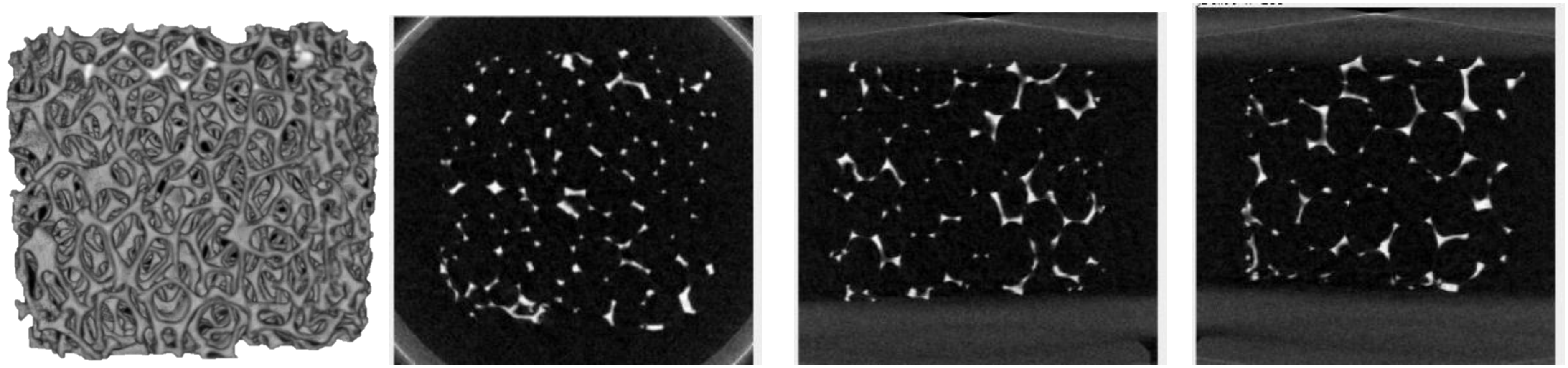
6 different datasets:

- 3 are from different materials and they exhibit different dynamics:
  - Compression of aluminum foam;
  - Leavening of the bread dough;
  - Expansion of the stone (Lede type) caused by water absorption.

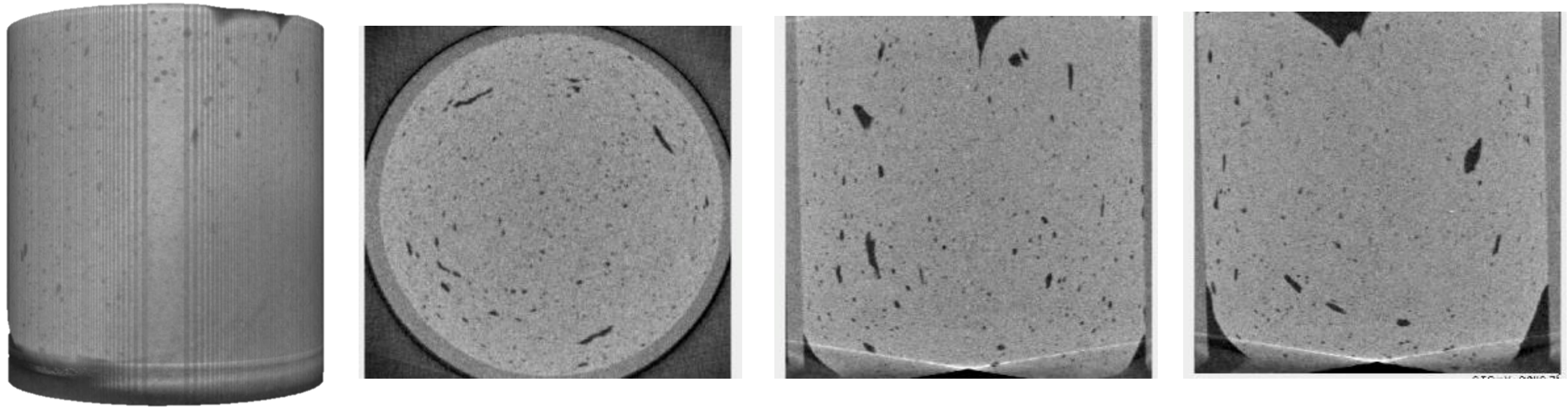
- 3 additional datasets have been created artificially, decreasing the resolution of the previous dataset by a factor of 2 in the 3 dimensions (half resolution).



xy slice | yz slice | xz slice

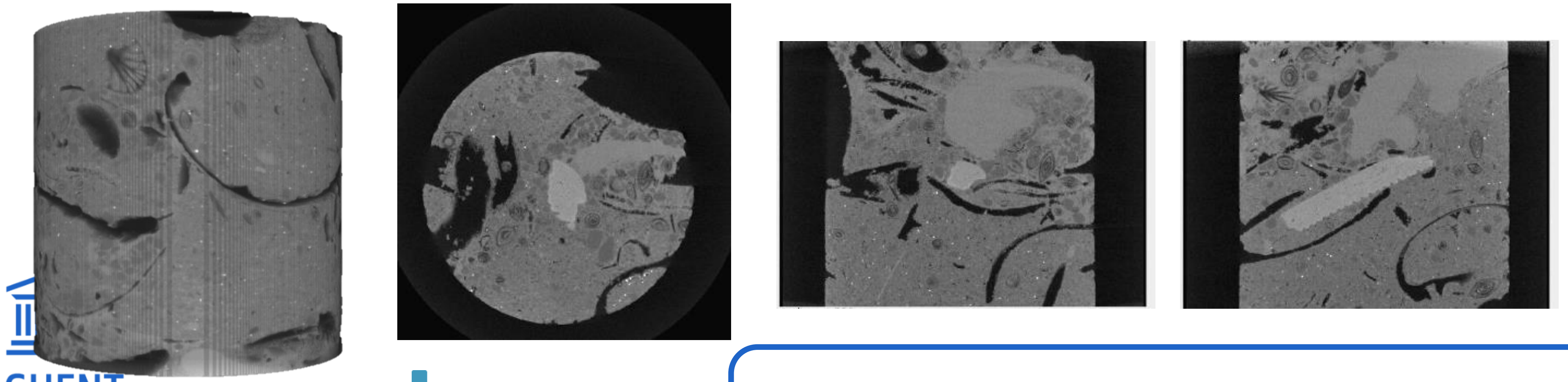


Acquisition time	14 min
No. gantry rotation	60
No. projections per rotation	700
Total compression per rotation	+133µm
Total compression	+8mm
Voxel size	0.02mm
Volume dimension	512x512x512



Acquisition time	30 min
No. gantry rotation	75
No. projections per rotation	800
Voxel size	0.02mm
Volume dimension	640x640x640

Acquired by Environmental Micro-CT scanner (EMCT) @ Ghent University Centre of X-ray Tomography (UGCT)



Acquisition time	48 min
Voxel size	0.02mm
Volume dimension	1014x1014x752

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Acquired by Tescan CoreTOM

RESULTS

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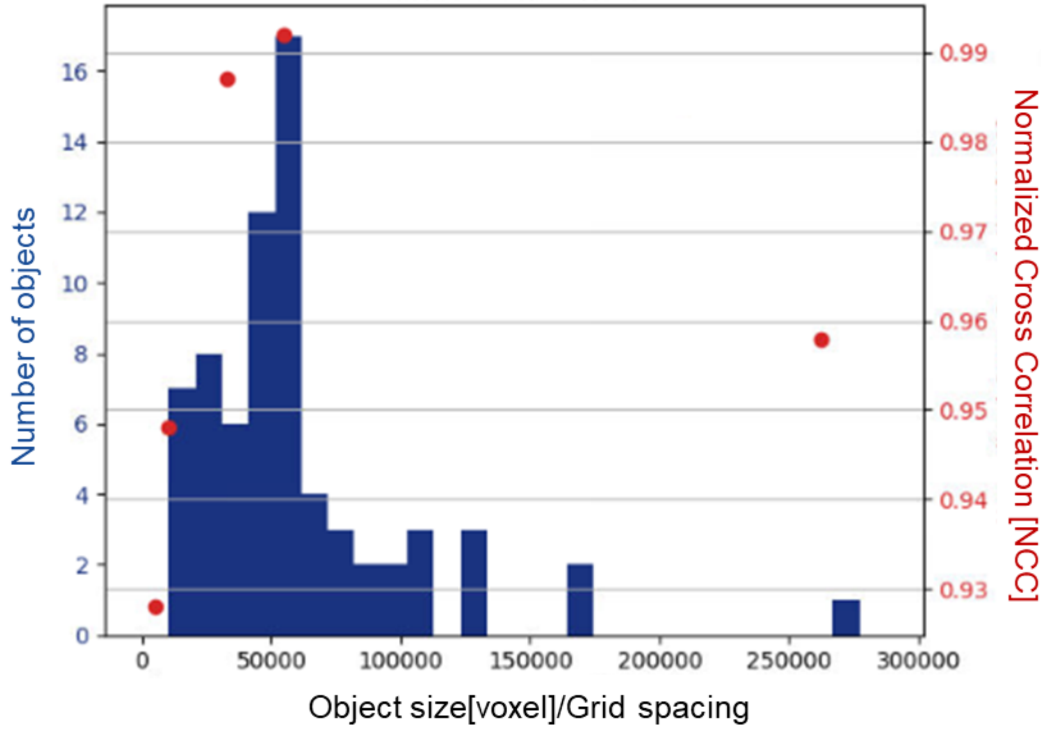
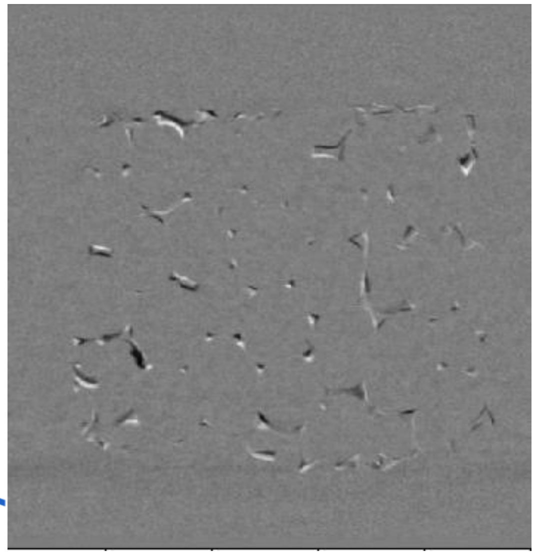
RESULTS ALUMINUM FOAM (512X512X512)

Z-Y slice of the difference between transformed and reference images at different mesh size.

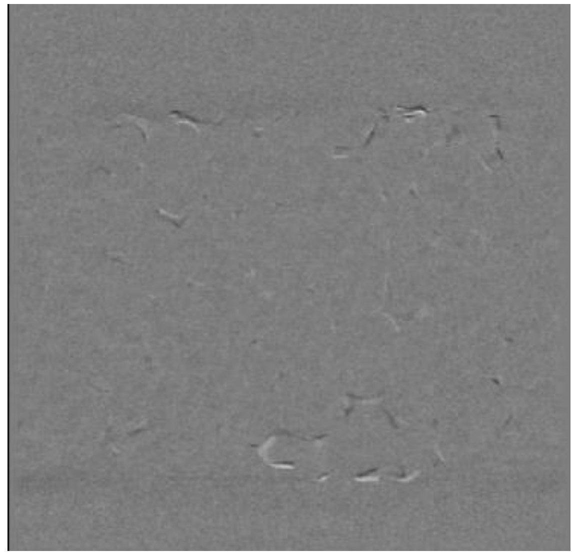


$32^3 - 40^3$: 42.85% of the objects belongs to this interval

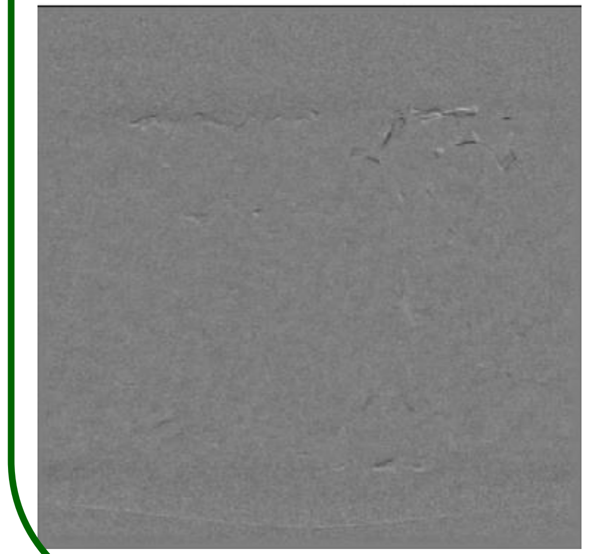
Mesh size: 8x8x8 (512 voxels)
NCC: 0.926



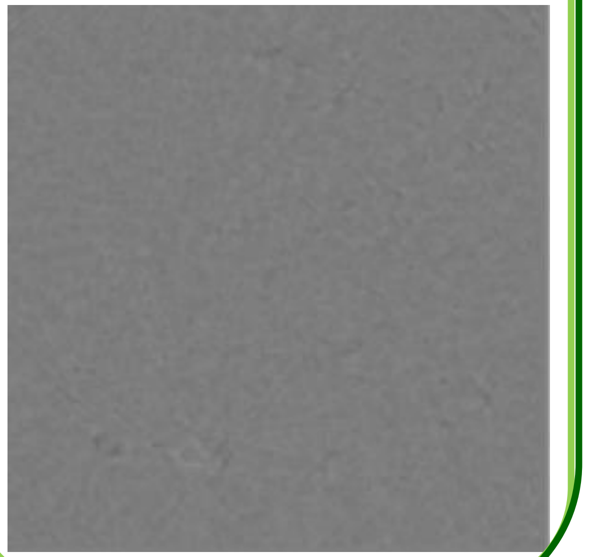
Mesh size: 16x16x16 (4096 voxels)
NCC: 0.948



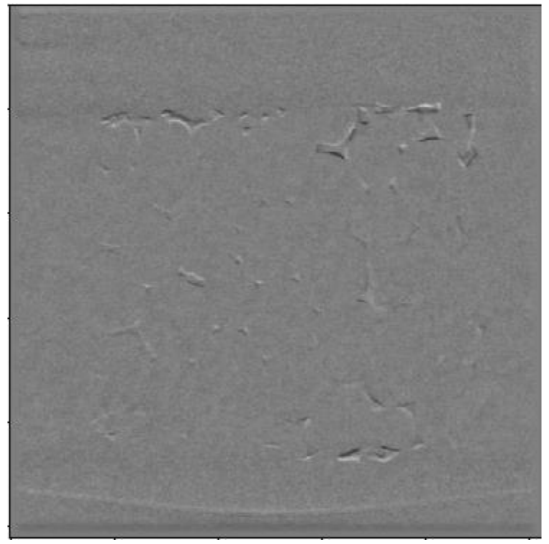
Mesh size: 32x32x32 (32768 voxels)
NCC: 0.987



Mesh size: 37x37x37 (50653 voxels)
NCC: 0.992



Mesh size: 64x64x64 (262144 voxels)
NCC: 0.992



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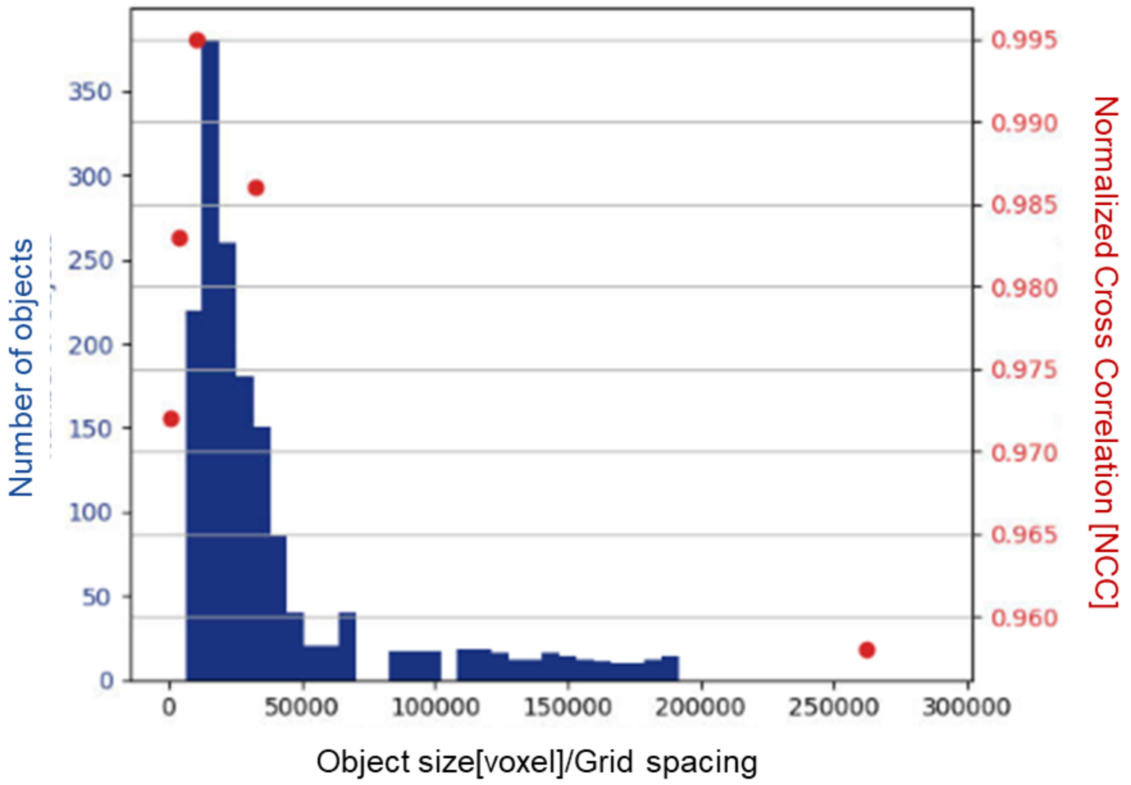
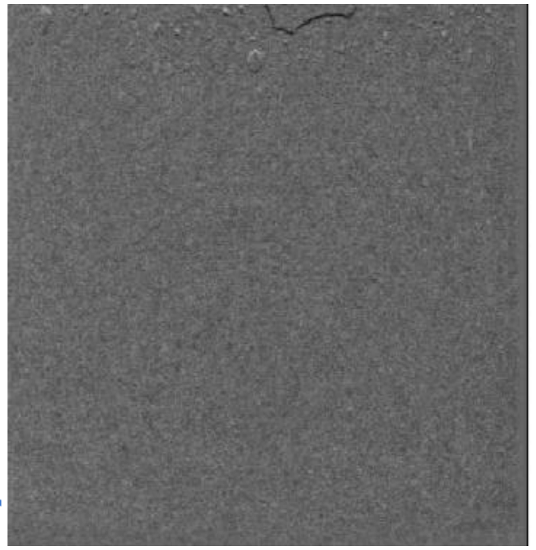
RESULTS LEAVENING DOUGH

Z-Y slice of the difference between transformed and reference images at different mesh size.

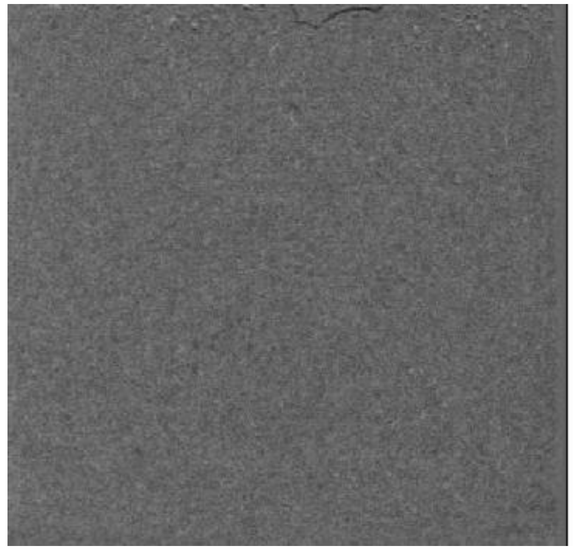


$15^3 - 30^3$: 73.33% of the objects belongs to this interval

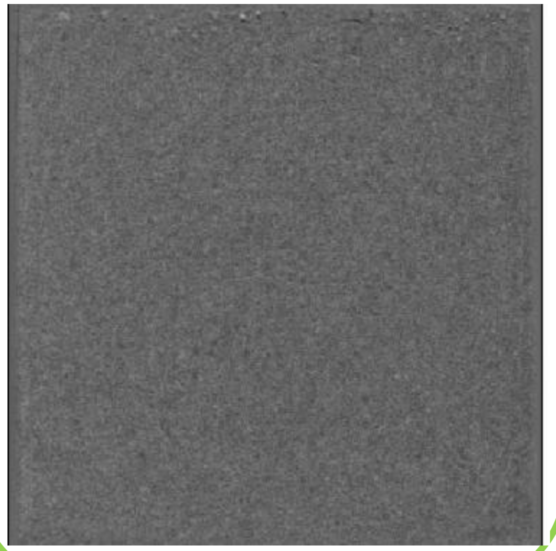
Mesh size: 8x8x8 (512 voxels)
NCC: 0.972



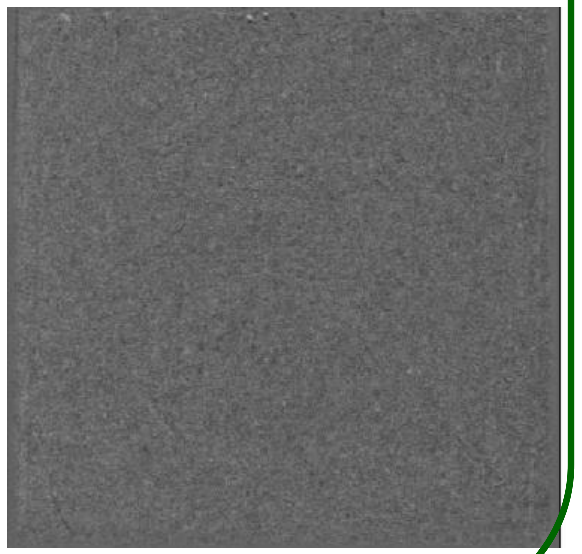
Mesh size: 16x16x16 (4096 voxels)
NCC: 0.983



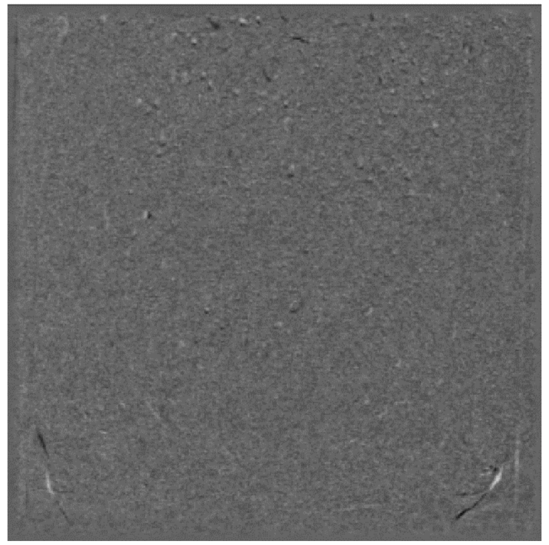
Mesh size: 22x22x22 (10648 voxels)
NCC: 0.995



Mesh size: 32x32x32 (32768 voxels)
NCC: 0.985



Mesh size: 64x64x64 (262144 voxels)
NCC: 0.965



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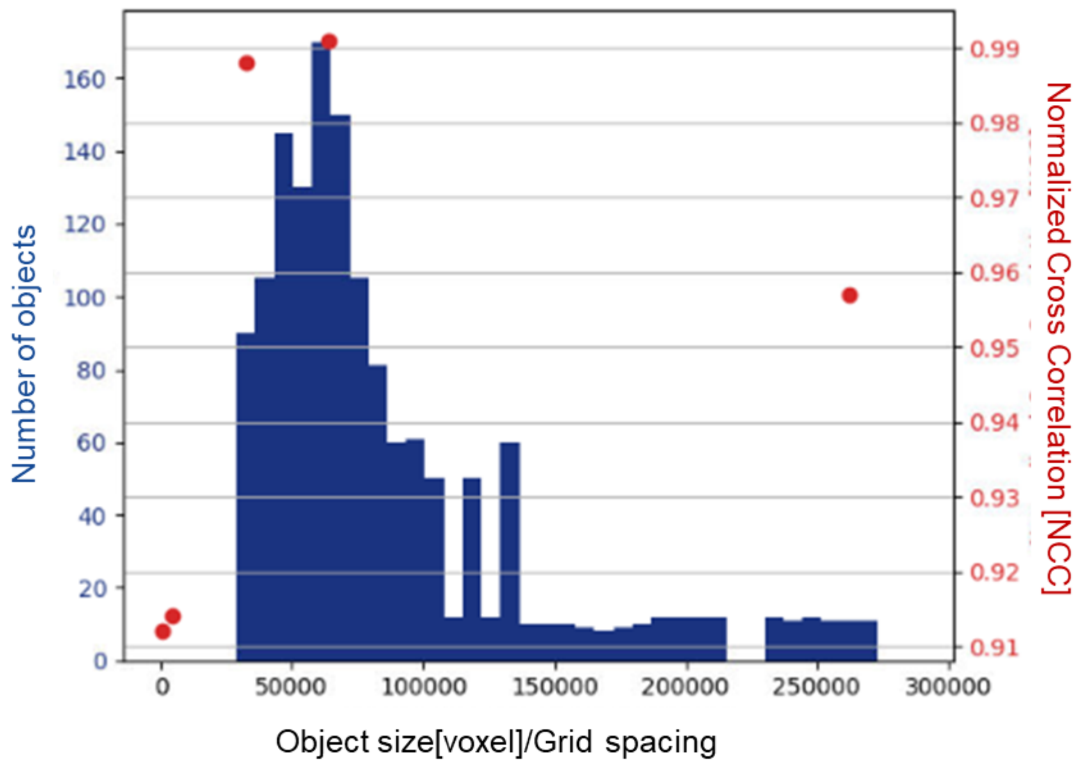
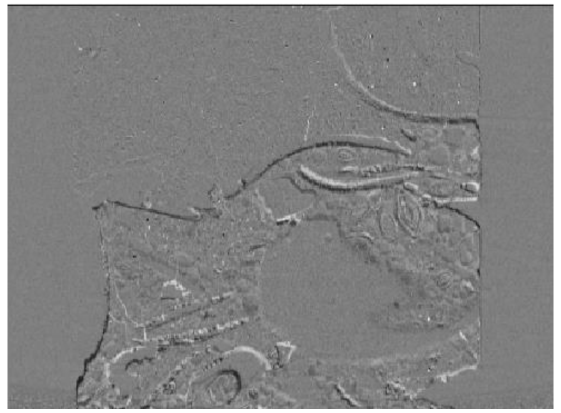
RESULTS LEDE STONE

Z-Y slice of the difference between transformed and reference images at different mesh size.

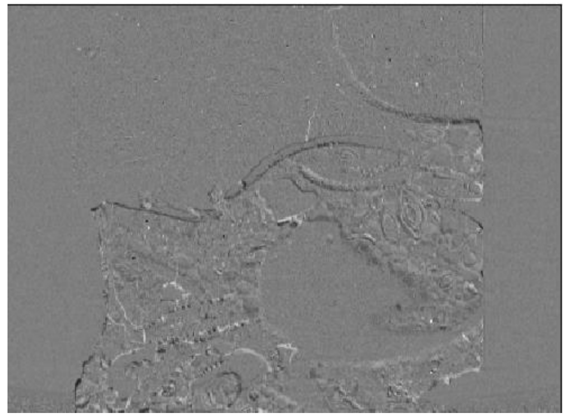


$24^3 - 48^3$: 75.43% of the objects belongs to this interval

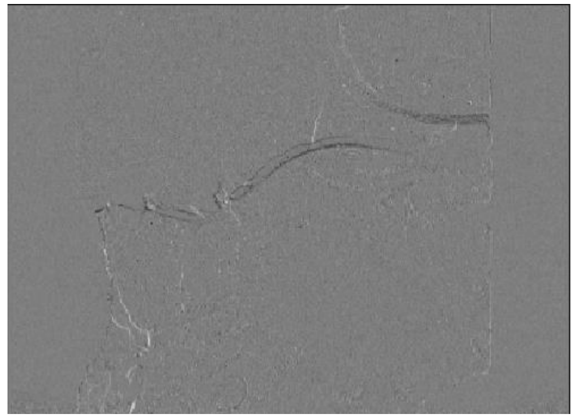
Mesh size: 8x8x8 (512 voxels)
NCC: 0.912



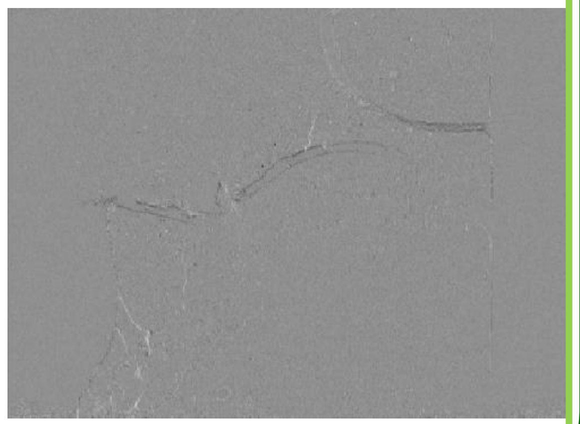
Mesh size: 16x16x16 (4096 voxels)
NCC: 0.915



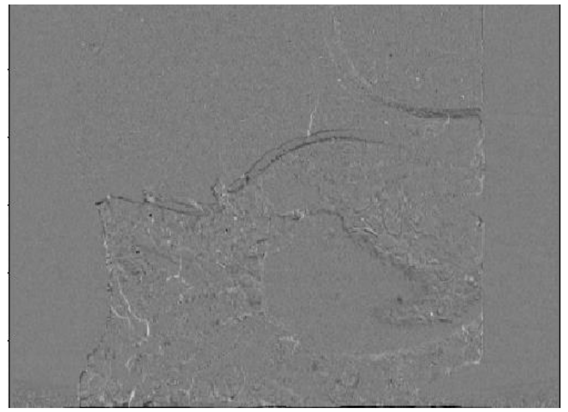
Mesh size: 32x32x32 (32768 voxels)
NCC: 0.989



Mesh size: 40x40x40 (64000 voxels)
NCC: 0.991



Mesh size: 64x64x64 (262144 voxels)
NCC: 0.954



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RESULTS @ HALF OF THE RESOLUTION

Aluminum foam	512x512x512	256x256x256
Best mesh size	37x37x37	18x18x18
NCC	0.992	0.993

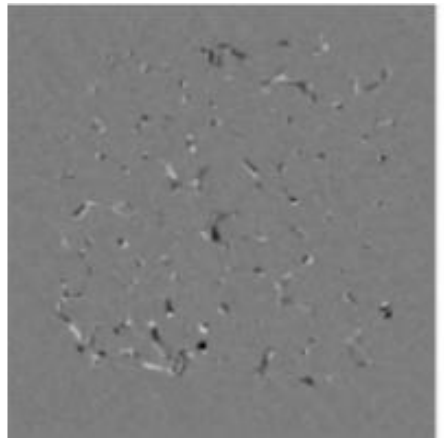
Leavening bread dough	640x640x640	320x320x320
Best mesh size	22x22x22	11x11x11
NCC	0.995	0.996

Lede stone	1014x1014x752	256x256x256
Best mesh size	40x40x40	20x20x20
NCC	0.991	0.991

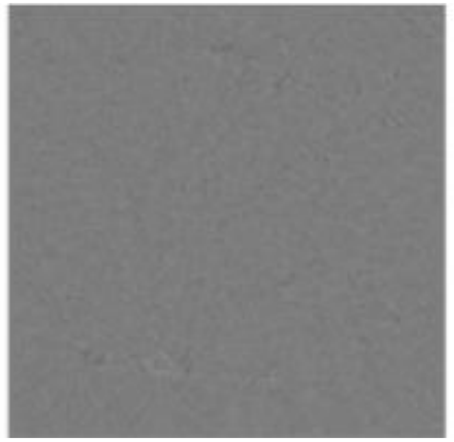
Worst performing mesh size

Best performing mesh size

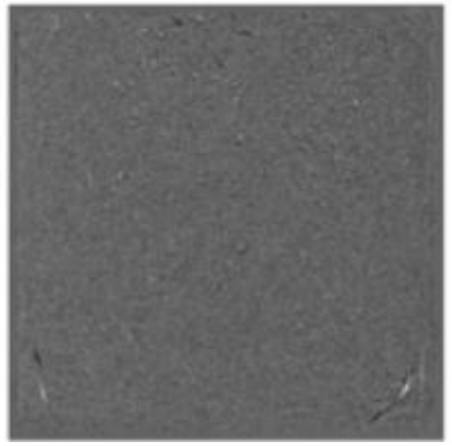
Mesh size:64x64x64



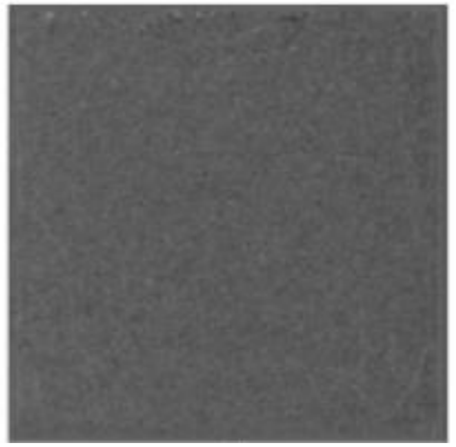
Mesh size:18x18x18



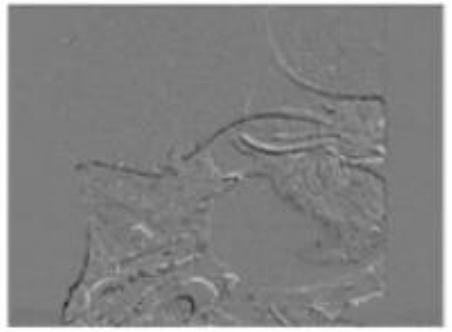
Mesh size:64x64x64



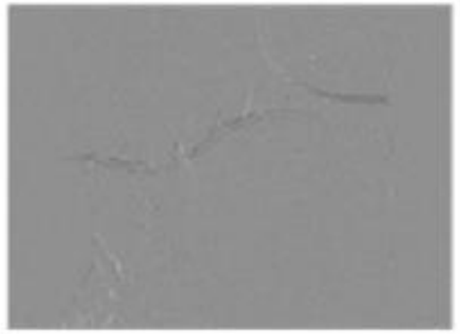
Mesh size:11x11x11



Mesh size:64x64x64



Mesh size:20x20x20



The best performing mesh size for the three dataset has been obtained using our method.

The values of the mesh size that perform bad are still reasonable, but they are not suitable for these dataset.

DISCUSSION AND CONCLUSION

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DISCUSSION & CONSLUSION

Our experiments clearly show:

- The result of the DVC is strongly depentent on the mesh size.
- The characteristic size of the most occurring material stucture is predictive for the optimal mesh size

PROS:

- The algorithm is able to provide a value to correctly initialize the mesh size, in this way it is possible to avoid the error introduced by the user.

Thanks for your attention!

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