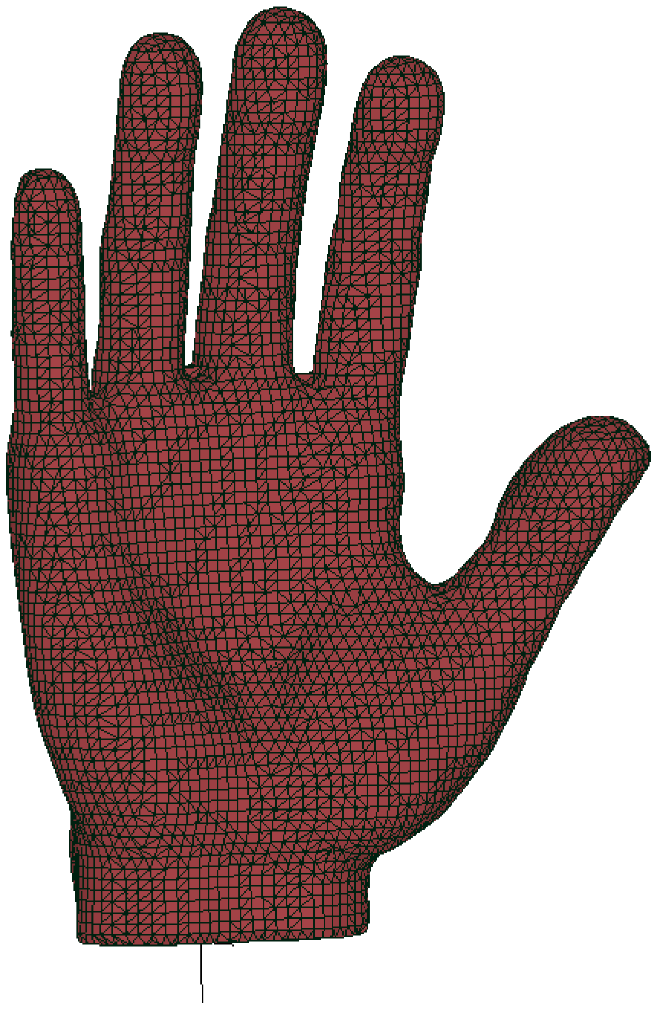
Hex-dominant Voxelization Meshing



By Samson Galvin

Abstract

Meshes composed of hexahedral elements are known to offer superior numerical performance compared to tetrahedral meshes, but their adoption is often limited by geometric constraints. This work presents a fully automated, hex-dominant voxelization-based meshing program capable of generating simulation-ready meshes from both CAD (STEP) and surface-based (STL/OBJ) geometry. Benchmark results demonstrate improved accuracy and convergence per element compared to tetrahedral meshing at comparable element counts.

Key Advantages:

- Supports both STEP and STL/OBJ file types
- Utilizes hex-dominant meshing
- Fully automatic meshing
    - User controlled mesh resolution
- Improved accuracy per element vs. tetrahedral meshes

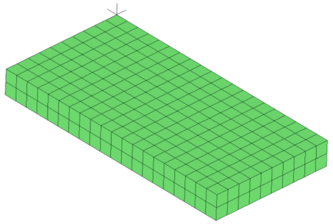
Study summary

I developed a fully automated hex-dominant voxelization based meshing tool that can mesh both STEP and STL/OBJ type files.

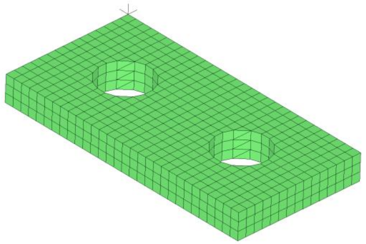
This presentation discusses results for meshing a range of geometries with increasing shape complexity.

Each shape was meshed with a coarse, medium, and fine mesh and compared against a tetrahedral mesh with a similar element count.

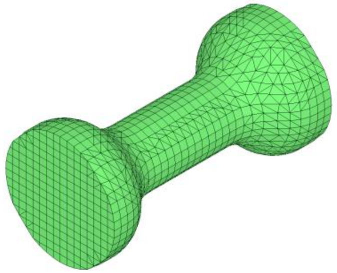
Both hex and tet meshes were evaluated under the same simulation setup, including identical boundary conditions and loads.



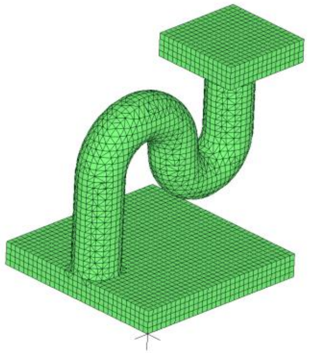
Simple Beam



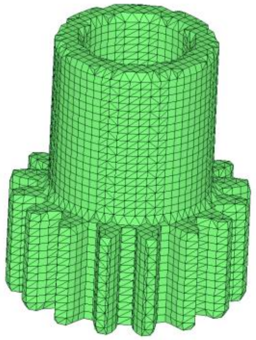
Beam with holes



Hourglass



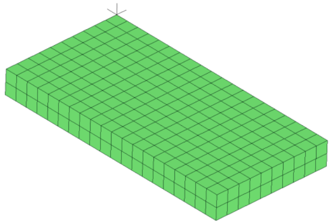
Diving board



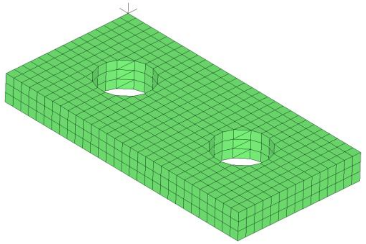
Gear

Study overview

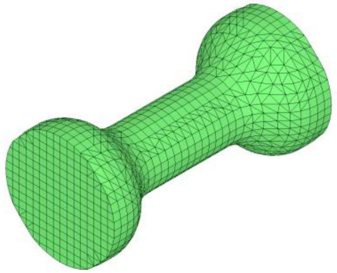
In this study, I evaluated the performance of my hex-dominant meshing tool across five geometries of increasing complexity. Each geometry was meshed using both my tool and established tetrahedral meshing workflows (Netgen/Gmsh). For each case, I generated coarse, medium, and fine meshes to observe convergence behavior as the element size decreased. To maintain a conservative comparison, I ensured that the hex-dominant meshes used element counts that were equal to or lower than those used in the tetrahedral meshes. All results were benchmarked against a very fine tetrahedral mesh, typically containing five to ten times more elements than the “fine” level. In any instance where the hex-dominant mesh converged more slowly than the tetrahedral mesh, I additionally generated a very refined hex-dominant mesh—again with approximately five to ten times more elements—to confirm that its solution approached the same reference value.



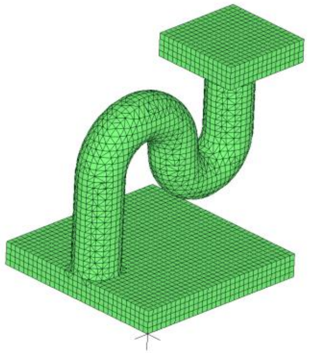
Simple Beam



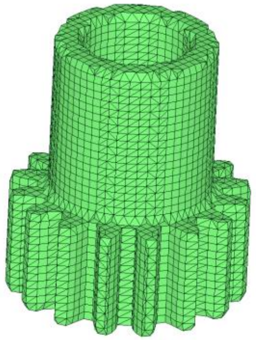
Beam with holes



Hourglass



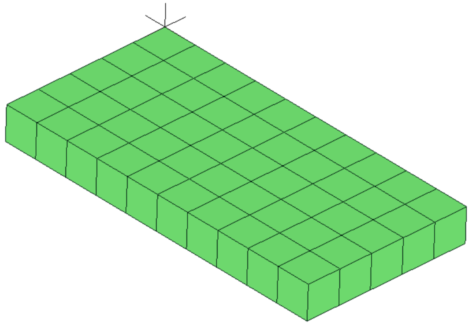
Diving board



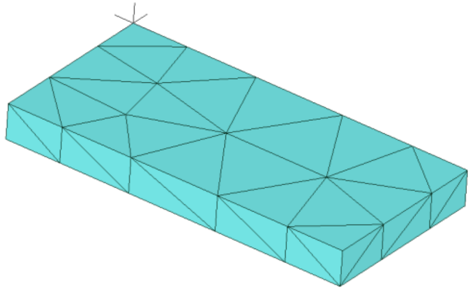
Gear

Simple beam

Coarse Mesh

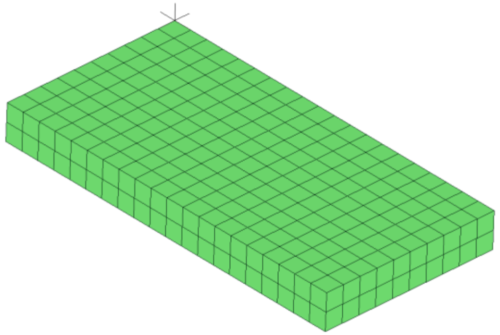


Hex-dominant: 50 elements
(100% hexes)

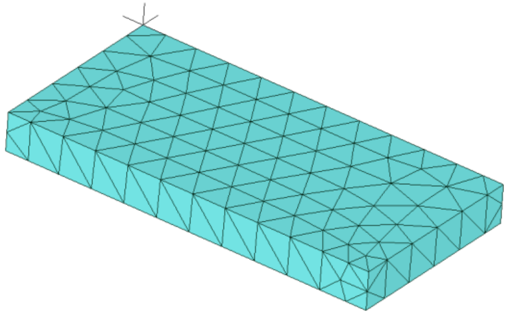


Tets: 68 elements

Medium Mesh

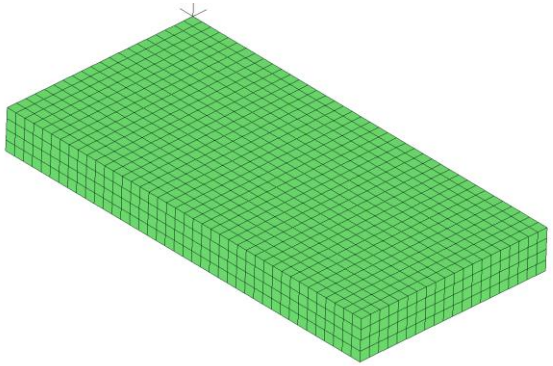


Hex-dominant: 400 elements
(100% hexes)

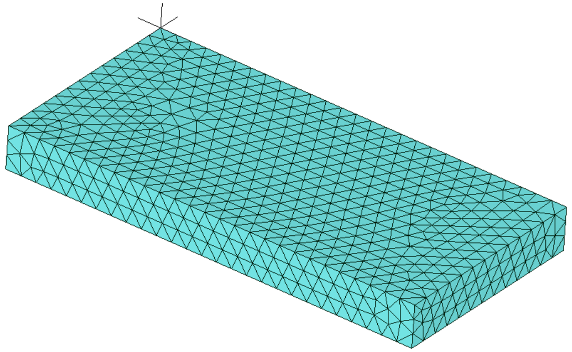


Tets: 434 elements

Fine Mesh



Hex-dominant: 3200 elements
(100% hexes)



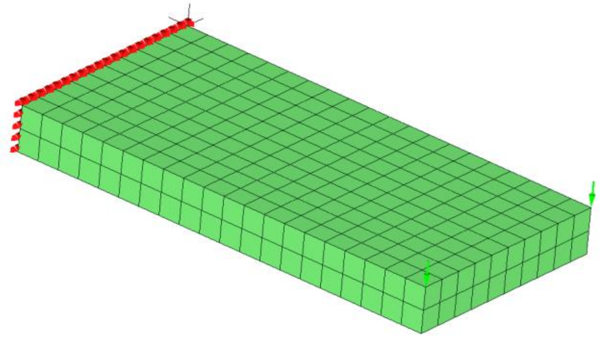
Tets: 3480 elements

Simple beam bending results

Mesh refinement	Error from hex-dominant mesh results	Error from tet mesh results	Comparison of tet to hex-dominant results
Coarse	5.58	8.00	1.43
Medium	2.74	4.8	1.75
Fine	0.4	1.66	4.15
Average			2.45

Hex-dominant mesh results converge 2.45x faster compared to tet meshes for this simulation.

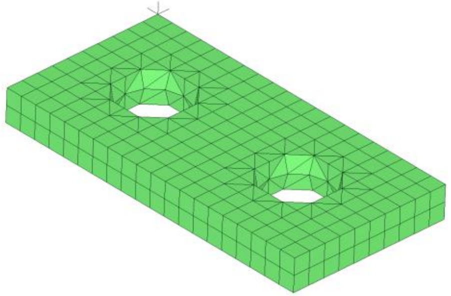
Simulation setup:
Beam bending. Fixed face (red dots) and force applied to two points (green arrows).



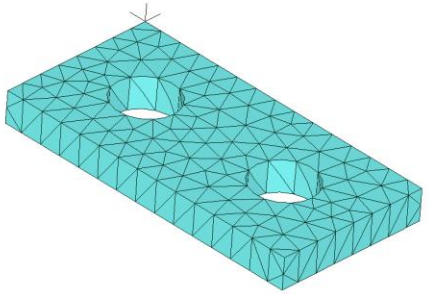
Note: Error is the displacement of the beam using the given mesh, compared to the displacement when using a very refined tet mesh.

Beam with holes

Coarse Mesh

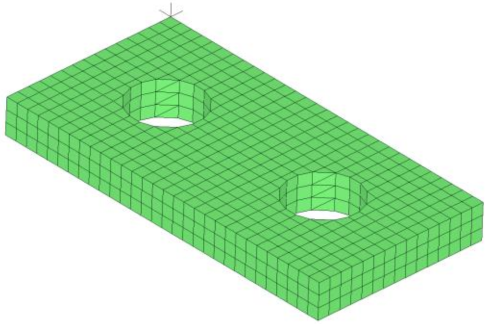


Hex-dominant: 640 elements
(78.5% hexes)

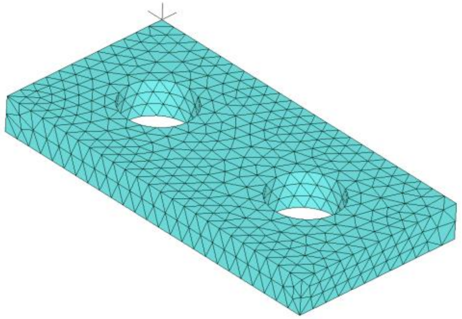


Tets: 691 elements

Medium Mesh



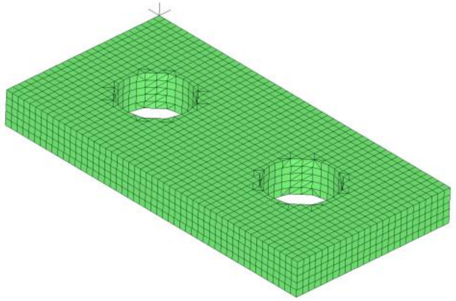
Hex-dominant: 1272 elements
(99% hexes)



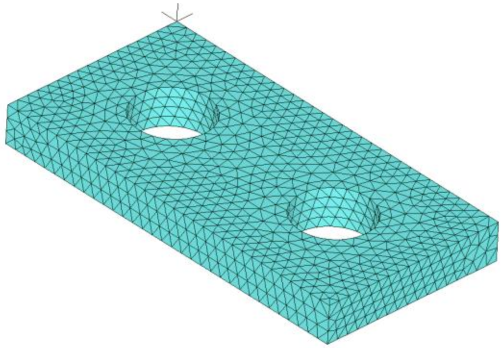
Tets: 2342 elements

*Tet meshing with netgen had corrupted elements when the element count was closer to 1272

Fine Mesh



Hex-dominant: 5976 elements
(98.1% hexes)



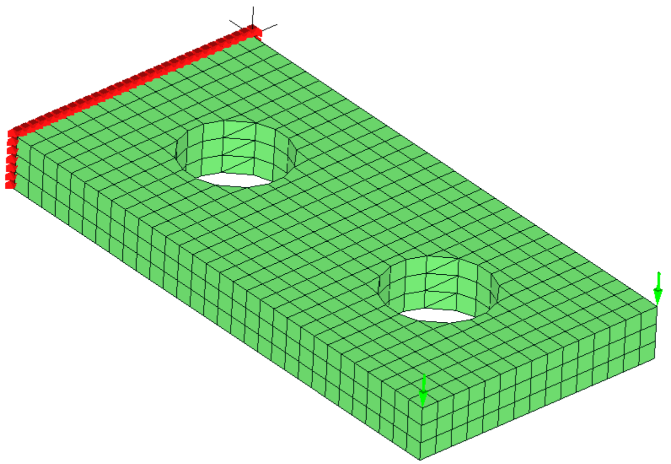
Tets: 7173 elements

Beam with holes bending results

Simulation setup:
Beam bending. Fixed face (red dots) and force applied to two points (green arrows).

Mesh refinement	Error from hex-dominant mesh results	Error from tet mesh results	Comparison of tet to hex-dominant results
Coarse	0.77	6.68	8.73
Medium	1.47	2.89	1.97
Fine	0.19	1.47	7.93
Average			6.21

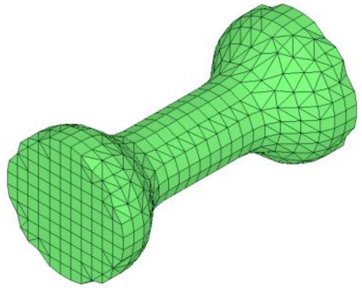
Hex-dominant mesh results converged 6.21x faster compared to tet meshes for this simulation.



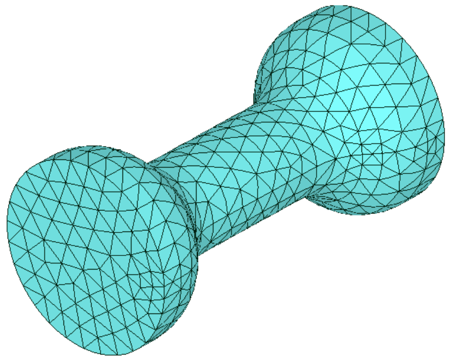
Note: Error is the displacement of the beam using the given mesh, compared to the displacement when using a very refined tet mesh.

Hourglass geometry

Coarse Mesh

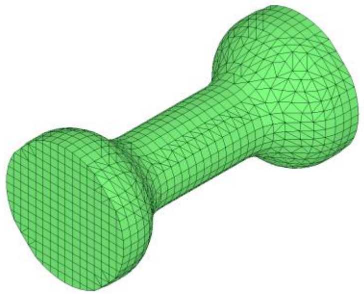


Hex-dominant: 2382 elements
(75.6% hexes)

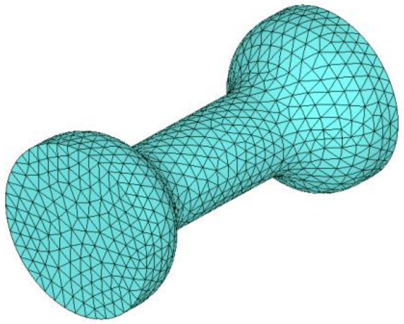


Tets: 2323 elements

Medium Mesh

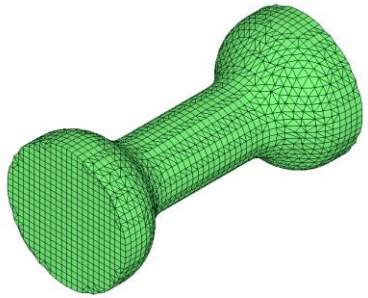


Hex-dominant: 6392 elements
(81.8% hexes)

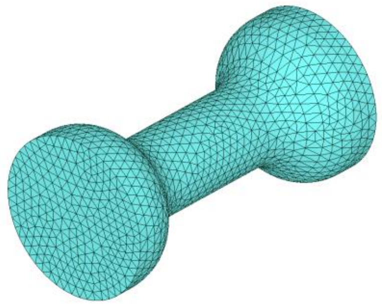


Tets: 8345 elements

Fine Mesh



Hex-dominant: 14968 elements
(85.7% hexes)



Tets: 19857 elements

*Tet meshing with netgen had corrupted elements when the element count was closer to 14968

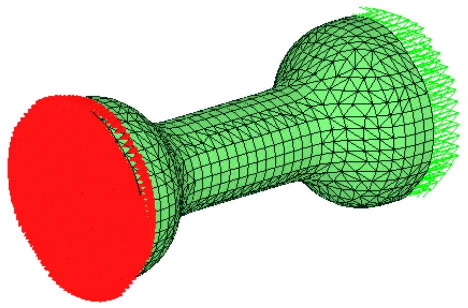
Hourglass in tension results

Mesh refinement	Error from hex-dominant mesh results	Error from tet mesh results	Comparison of tet to hex-dominant results.
Coarse	2.89	1.79	0.62
Medium	2.52	0.93	0.37
Fine	1.5	0.19	0.13
Average			0.37

Hex-dominant mesh results converged 2.69x slower compared to tet meshes for this simulation

The hex-dominant mesh is converging to a value that is 0.1% greater than the "very refined" tet mesh.

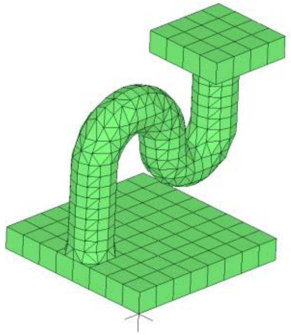
Simulation setup:
Tensile test. Fixed face (red dots) and force applied to opposite face (green arrows).



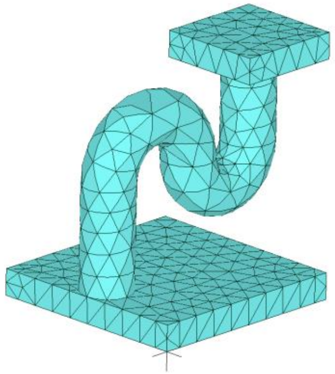
Note: Error is the displacement using the given mesh, compared to the displacement when using a very refined tet mesh.

Diving board geometry

Coarse Mesh

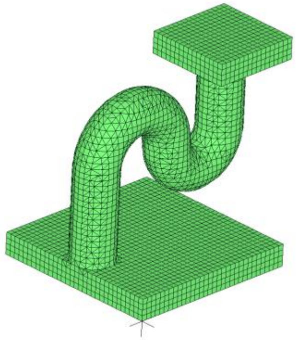


Hex-dominant: 1500 elements (83.2% hexes)

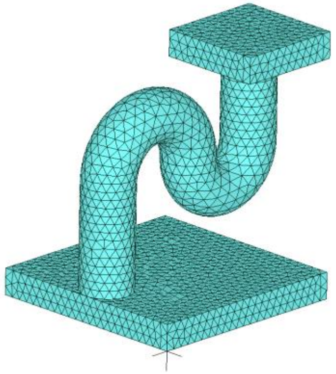


Tets: 1650 elements

Medium Mesh

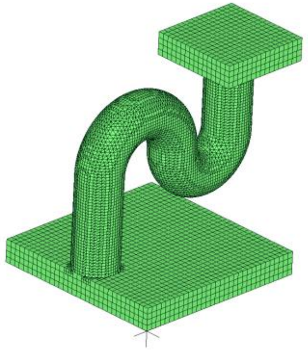


Hex-dominant: 13080 elements (88.2% hexes)

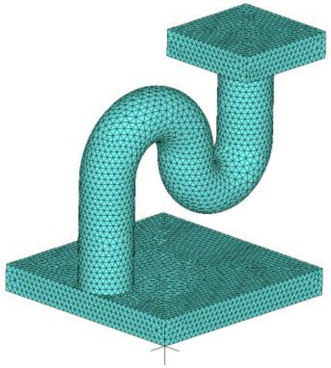


Tets: 15756 elements

Fine Mesh



Hex-dominant: 34184 elements (95.1% hexes)



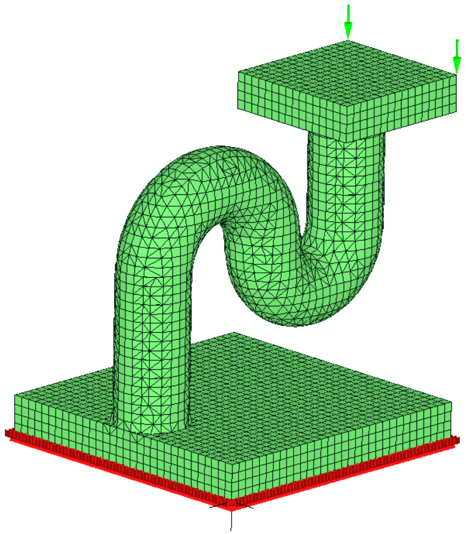
Tets: 39243 elements

Hourglass in tension results

Mesh refinement	Error from hex-dominant mesh results	Error from tet mesh results	Comparison of tet to hex-dominant results
Coarse	11.54	22.48	1.95
Medium	2.66	0.07	0.03
Fine	1.65	0.02	0.01
Average			0.66

Hex-dominant mesh results converged 1.5x slower compared to tet meshes for this simulation.

Simulation setup:
Bending. Fixed face (red dots) and force applied to two points (green arrows).

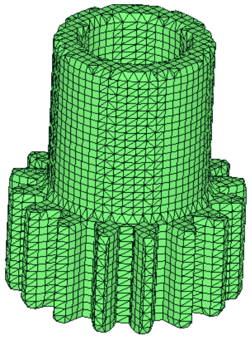


The hex-dominant mesh is converging to a value that is 0.8% greater than the "very refined" tet mesh.

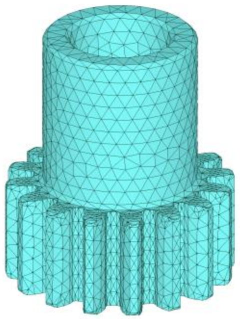
Note: Error is the displacement using the given mesh, compared to the displacement when using a very refined tet mesh.

Gear geometry

Coarse Mesh

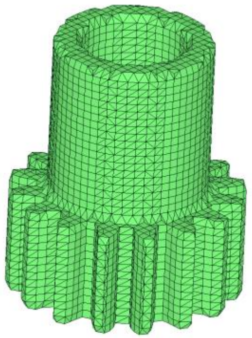


Hex-dominant: 15194 elements (85.7% hexes)

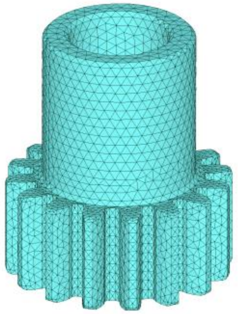


Tets: 15123 elements

Medium Mesh

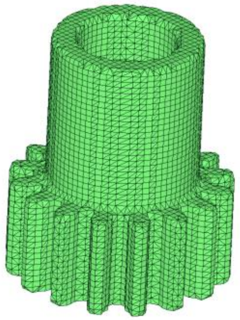


Hex-dominant: 28229 elements (88.3% hexes)

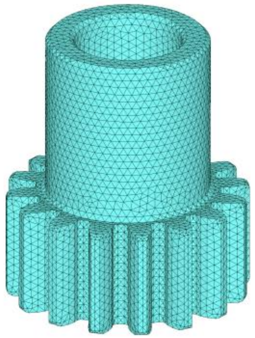


Tets: 30796 elements

Fine Mesh



Hex-dominant: 58416 elements (91.6% hexes)



Tets: 64321 elements

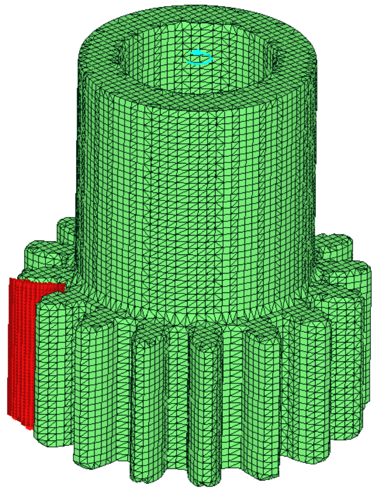
*The netgen meshing tool cannot create mesh for this geometry for under 90000 elements, gmsh was used instead.

Gear with torque applied results

Mesh refinement	Error from hex-dominant mesh results	Error from tet mesh results	Comparison of tet to hex-dominant results
Coarse	5.22	3.58	0.69
Medium	3.03	2.00	0.66
Fine	1.9	1.61	0.85
Average			0.73

Hex-dominant mesh results converged 1.36x faster compared to tet meshes for this simulation.

Simulation setup:
Torque applied to shaft (Blue circle arrow). Fixed tooth (red dots).



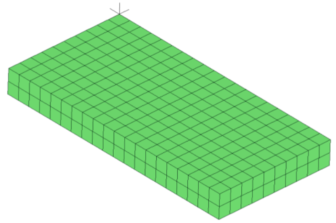
Note: Error is the displacement using the given mesh, compared to the displacement when using a very refined tet mesh.

Conclusion

Across the five geometries tested, the hex-dominant approach demonstrated faster convergence in three out of five cases. Its performance is geometry-dependent; however, several strengths are consistent. The voxelization-based workflow handles fillets and intricate features effectively and avoids the corrupt or invalid elements that Netgen produced in several scenarios. The method is also robust in terms of input formats, supporting both CAD-based STEP files and surface-based STL/OBJ files.

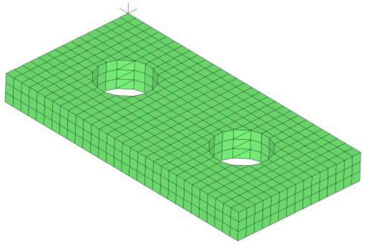
Collectively, these results indicate that the hex-dominant tool provides accuracy that is generally comparable to tetrahedral meshing, with performance that varies by geometry. While convergence may be slower for certain shapes, the method offers meaningful strengths in geometric robustness and input flexibility, particularly for complex or filleted geometries.

2.45x faster conversion. Converges to same result as tet mesh



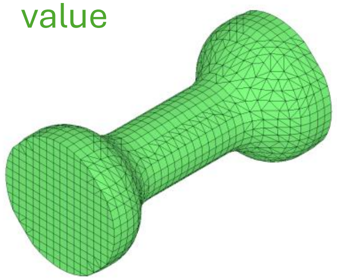
Simple Beam

6.21x faster conversion. Converges to same result as tet mesh



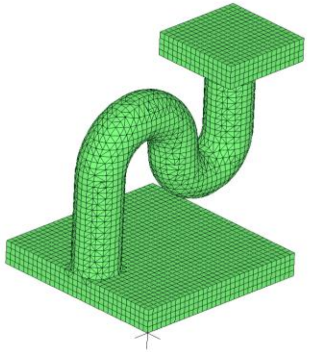
Beam with holes

2.69x slower conversion. 0.1% difference in expected converged value



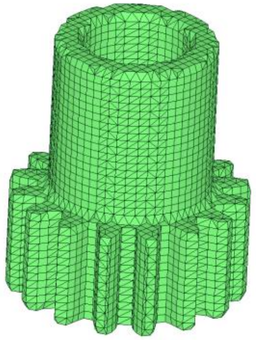
Hourglass

1.5x slower conversion. 0.8% difference in expected converged value



Diving board

1.36x faster conversion. Converges to same result as tet mesh



Gear