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GRID GENERATION IN COMPLEX COMPUTATIONAL DOMAINS WITH THE USE OF SUBDIVISION TEMPLATES

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1. Introduction

3D Numerical analyses often require volume discretization through the generation of a grid which divides the computational domain into finite elements or finite volumes. In complex geometries, domain boundaries are also complex. When such domains are discretized, it is important that the grid fits the boundaries well; this is, however, difficult to achieve with strongly curved boundaries (edges). Figure 1 illustrates a few examples of computational domains.

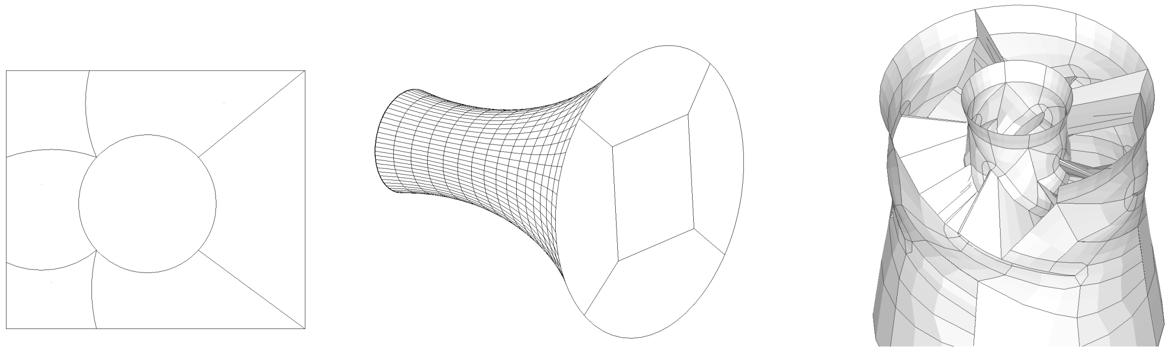


Figure 1. Examples of computational domains and subdivision

A subdivision template is a method of dividing an entire computational space (volume) into smaller, primitive subspaces. It is possible to control the node distribution and grid quality more precisely within smaller units. Subspaces can be of any topology (2D rectangle, 2D triangle, 3D tetrahedron, wedge, block, etc.), as long as an algorithm can be defined that enables grid generation in subspace topology. Three parts of the grid generation procedure were developed, as follows (Figure 2):
In the first step we define a sufficiently large volume, representing a computational domain. In order to maximize grid orthogonality, the entire computational volume is divided into primitive units, and the method of division is called "template". In conceptual design, templates can be used for a large number of shapes.
In the second step we transform entirely general shapes into a systematic description of the volume with mathematical B-splines by means of operators (coded functions). This descriptive concept enables a consistent variation of the shape and position of computational domain components.

The third step is grid optimization concerning orthogonality. The optimization is controlled by "control points" – vertices of primitive volumes, which "slide" along "carrier geometry". For this purpose we created interactive software with a user-friendly interface.

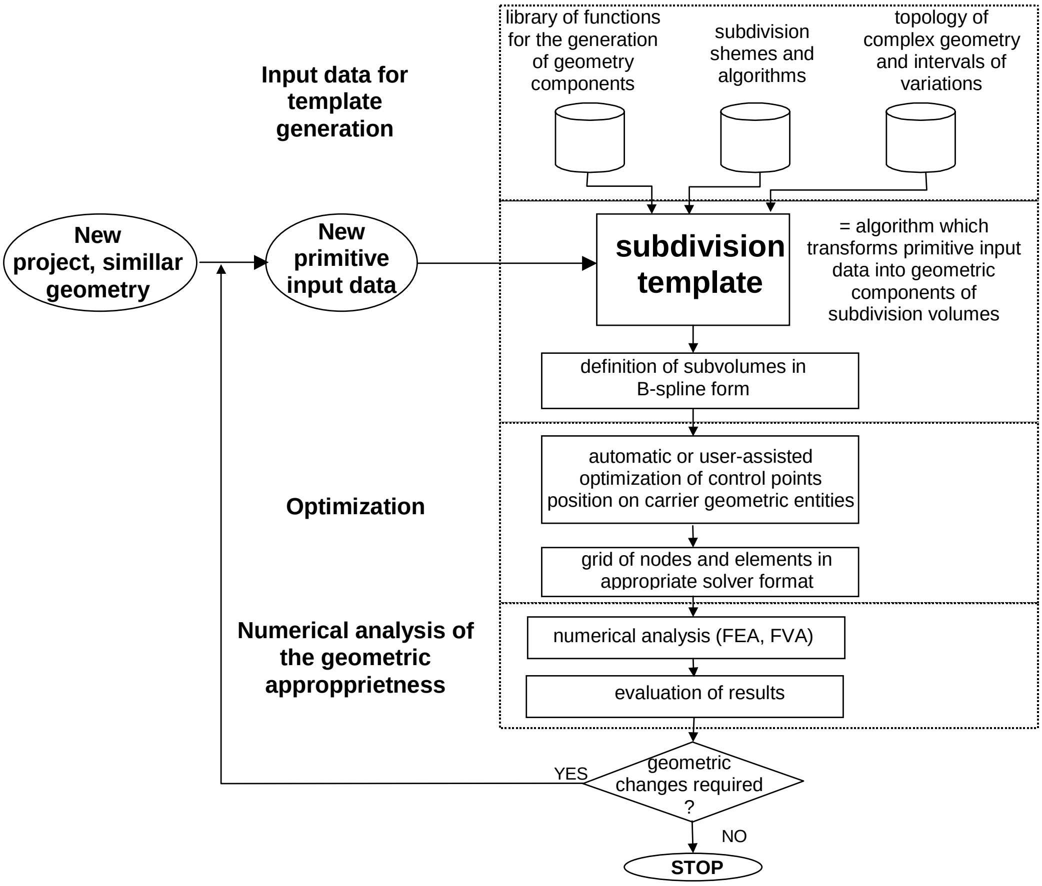


Figure 2. The concept of the use of subdivision template

2. Subspaces and constitutive elements

The components of subspaces are vertices, edges and surfaces (Figure 3). The most general mathematical description of edges and surfaces is obtained using B-splines or NURBS, which are widely established in CAD [Farin, Mortenson, Pegl, Park, Watt]. Subspaces are also defined by consistent associations between the components.

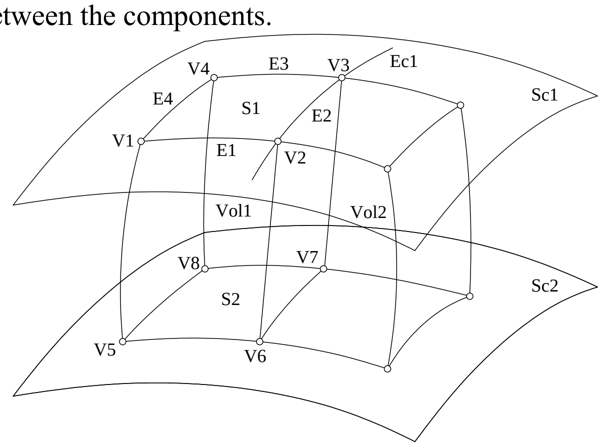


Figure 3. Subspace components: *V* – vertex, *E* – edge, *S* – surface, *Vol* – volume, *Ec* – carrier edge, *Sc* –carrier surface

In addition to geometry, templates also define the geometric constraints for subspace components. These constraints ensure the consistency of computational domain geometry upon anticipated changes of vertex, edge or surface position. Geometric constraints are defined as follows: “vertex V_i is positioned on surface S_j,” “edge E_i is defined as the connection between the two vertices V_i and V_j and lies on surface S_k,” “vertex V_i is periodic with vertex V_j,” “vertices $\{V_i\}$ rotate around the w-w axis, depending on the value of parameter fi,” etc. The desired changes of geometry are entered by changing the position of, for example, control points V_i. Changes can also be implemented implicitly, by defining a parameter φ on which positions of subspace building blocks are dependent.

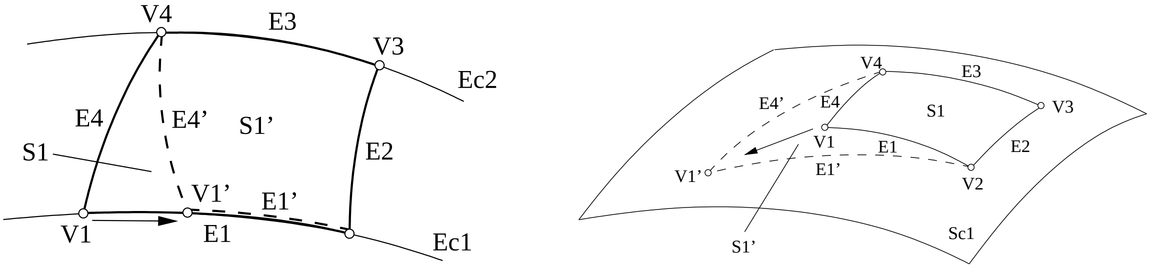


Figure 4. The concept of “control point” and “carrier” surface or edge

3. Generation of components on the basis of a subdivision template

In order to describe the widest possible interval of geometries, subdivision templates must be sufficiently general. The method of determining subspaces must be sufficiently robust for it to enable the widest possible range of dimensional changes of typified geometry. The method of presenting input data is also predefined. A suitable presentation method for complex geometries can be the one which uses a set of ordered points, which present cross-sections of the computational domain. Such data can be extracted from CAD packages, for example, but may also be the result of a synthetic generator or measurement data.

The method of transforming input data into subspace geometry is implemented in a preprocessor. A preprocessor consists of a set of functions which are capable of transforming the anticipated input (sets of points, dimensions, parameters) into the well-known B-spline structure. The series of preprocessor function calls can be stored in, for example, a macro datafile.

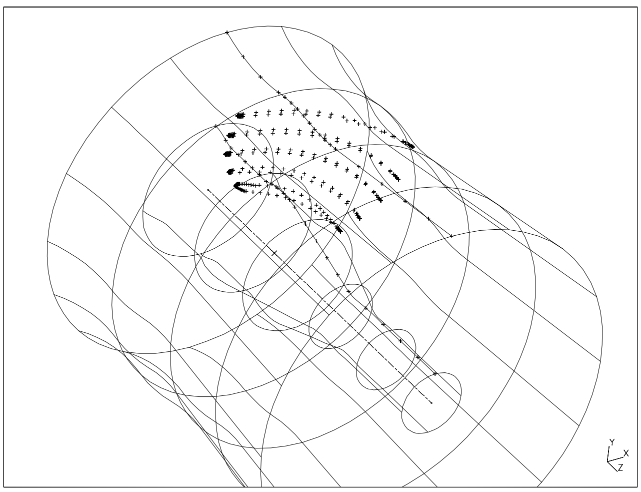


Figure 5. Example of input data (three groups of points)

Complex geometries can be described as a series of points showing a characteristic boundary or volume shape. For the case of a 3D computational domain around a runner blade (guide vane) in an axial water turbine, characteristic shapes are, for example, the contour of the hub and shroud surface and the blade cross-sections (Figure 5). A preprocessor transforms a set of points into appropriate edges and surfaces, then composes them into subspaces, which define the computational volume in its entirety.

Figure 6 presents an example of computational domain and subspace components which are generated by a preprocessor from primitive input data (a series of points). Various templates can be produced for any given computational domain. The guideline observed in the production of a template is appropriateness of division for the widest possible interval of anticipated geometric changes. The example of a computational domain shown in Figures 6a and 6b is used to anticipate the geometric changes of water turbine blade shape, shroud contour and hub. Another type of change is rotation of the blade around the chosen axis.

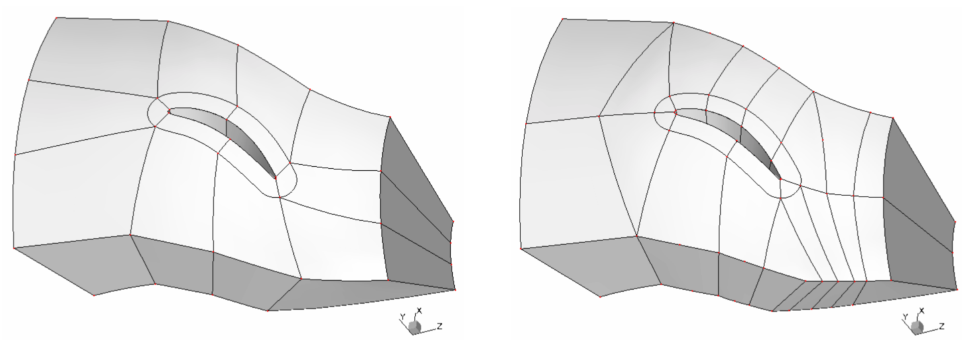
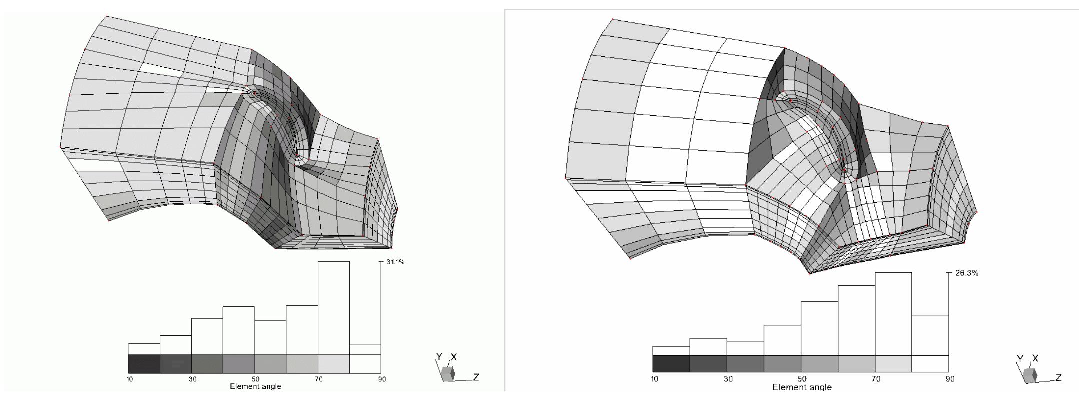


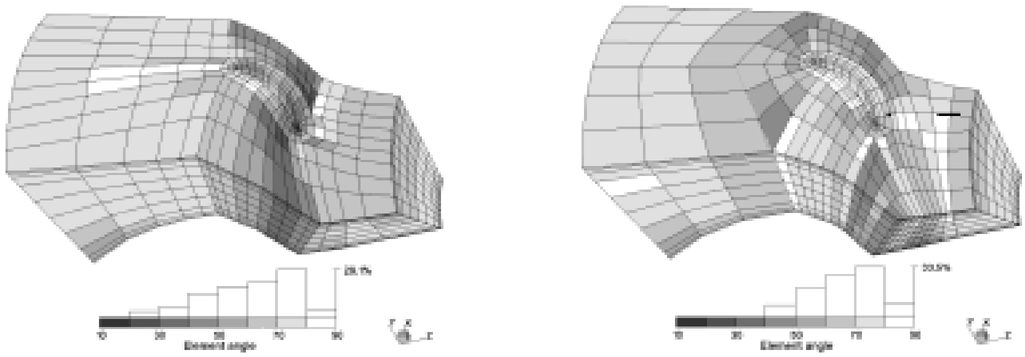
Figure 6. Subspaces of the computational domain around the distributor blade in an axial water turbine

4. Intervals of template use

In order to demonstrate the suitability (quality) of a template for dividing a certain computational domain, the criterion of comparison is selected. Since our goal is the quality of the generated computational grid, the degree of warpage of the generated elements will be established, the elements will be ranked into classes and their numbers observed. We might use any 3D interpolation sheme to generate grid inside subspaces [Thompson, Yu], but let us use simple tri-linear one, that works well with moderately curved boundaries. Let us first observe element grids in the computational domain around the blade, which were generated using two different templates (Figure 6). For both templates, the input data used for the generation of subspace components are the same series of points, the number of blades, the desired number of elements and the control ratios (width of the O-grid, etc.). It turns out that the second template (Figure 6b) enables the generation of a relatively high-quality grid over a wide range of blade rotation, while the first one (Figure 6a) generates grids of higher quality at small blade rotation ranges. Figure 7 shows, how subdivision volumes can be reshaped in an optimization process [Zhou] to achieve higher quality of the generated grid.



a) **b)**



c) d)

Figure 7. Difference in grid quality in the use of two different templates for the same geometric domain:a) grid using template 1 before optimization, b) grid using template 2 before ptimization, c) grid using template 1 after optimization, d) grid using template 2 after optimization

The multi-purpose nature of a template generally depends on the robustness of the division of the computational domain into blocks. In a simmilar way, templates for other turbine parts, like inlets and draft tubes can be defined.

5. Industrial application

To demonstrate the usefullness of subdivision templates concept, we have applied it to an industrial application. The computational geometry in this case was an entire water turbine passage, consisting of four distinctive parts: inlet, conical distributor consisting of 24 guide vanes, axial turbine runner with 4 blades and straight draft tube with circular cross-section at the entrance and quadratic one at the exit. The turbine power is being regulated with adjusting both guide vanes and runner blades simultaneously to achieve the highest possible efficiency. To evaluate the operation of turbine in a large number of operating regimes, we have automatically generated a number of numerical grids describing geometric varying of blade angles (Figure 7). The flow solver we used was capable of taking time-dependent geometric movements into account so we were able to calculate the behaviour of turbine during severe transients (emergency shut down, for example).

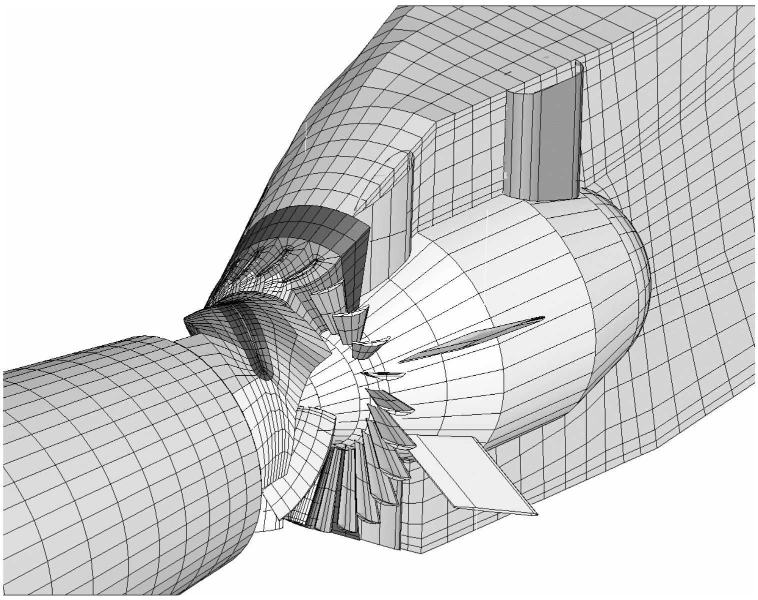


Figure 8. An industrial example: using subdivision templates on complete water passage computational domain

6. Conclusion

We have introduced the subdivision template concept, which can be implemented to guide the quality numerical grid generation process in complex domains. It consists of three steps: we first define a computatinal domain consisting of volume and its boundaries. The entire computational volume is then divided into primitive units, and the method of division is called a "template". In conceptual design, templates can be used for a large number of shapes. The second step involves transformation of general shapes into a systematic description of the volume with mathematical B-splines with a set of coded functions. The variation of shapes is enabled in "carrier edge/surface" and "control points"concept. The optimization is controlled by "control points' movements" with respect to orthogonality of topological constituting elements. The third step is numerical grid generation. The concept has been demonstrated on the example of water turbine computational domain.

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