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An automatic partitioning method for multi-disciplinary non-orthogonal building spatial design and optimisation

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Abstract

Design support systems should be able to handle a variety of Building Spatial Designs (BSDs), while at the same time considering multiple disciplines, to support the preliminary multi-disciplinary building design process. For this purpose, this paper presents a Triangulation Partitioning method (TP) to obtain a triangular prism conformal geometry for a wide variety of BSDs, however, limited to vertical walls and horizontal floors. It is shown that this method offers a generalized geometric basis for the definition of discipline specific models.

Keywords: Automatic partitioning, Conformal geometry, Non-orthogonal building spatial design, Multidisciplinary optimisation and simulation, Design support systems

1 Introduction

The built environment consumes about 40 to 60 % of all energy and material resources [1,2], and serious reductions of this depletion must be reached [3]. In addition, the preliminary design process of buildings is highly interdisciplinary, and shows complex relationships between the disciplines. This may lead to sub-optimal decisions, whereas these will determine to a large extent the final performance of the building, different from decisions later in the design process [4]. Therefore, the preliminary design process should be understood, improved, and supported by appropriate design support systems.

Design support systems should be able to handle the variety of Building Spatial Designs (BSDs) as currently seen in practice, while at the same time should consider multiple disciplines. However, discipline related building representations often differ (e.g. [5-8]), which may result in discrepancies between the models. Therefore, here a general base geometry is proposed (for example using cuboids) to describe the BSD to be used for several disciplines [9-10]: cuboid surfaces can then be amended by discipline specific representations.

Alongside the general base geometry, a conformal geometry representation can be developed. In such a conformal geometry representation, for all entities: the vertices of an entity are, if intersecting another entity, only allowed to coincide with this other entity's vertices, see figure 1 ("Conformal geometry") for an example. Such a conformal geometry of the BSD has multiple use-cases with respect to discipline-specific model definitions, figure 1 and [11]. For instance, developing a finite element mesh, where the partitioned geometry allows for proper meshing of the partitions and, in case of conformal partitions, node coinciding meshing. This process is defined as the multi-block method [12] and is generally applied to partition a single complex body [13-16]. And although some of these methods can handle multiple bodies [17-19], like the spaces in figure 1 of the BSD, none of these methods are able to make a conformal geometry for the wide variety of BSDs in practice. Therefore, here it is researched how to obtain a conformal geometry for a wide range of base geometries, however, limited to vertical walls and horizontal floors.

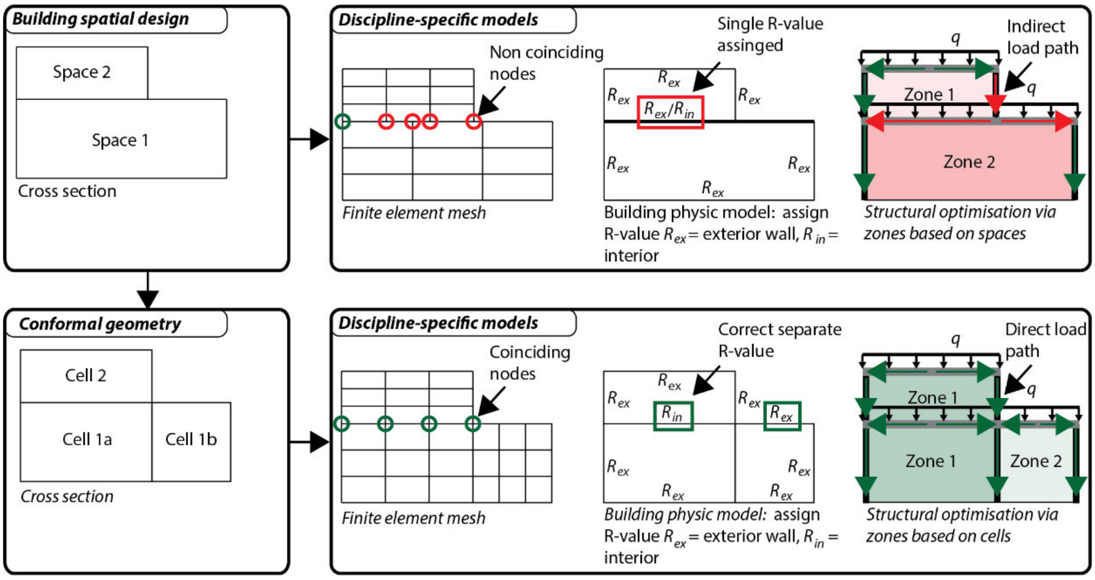

Figure 1: Generation of discipline-specific models from a building spatial design or from a conformal geometry [11].

2 Methods

To obtain a conformal geometry from a BSD, three partitioning methods have been investigated [20], for which the so-called Triangulation Partitioning method (TP) was selected as the most promising. The TP method will be presented first, and thereafter a meshing strategy for triangular flat shell elements is introduced. Finally, it will be shown that the partitioning method together with the meshing strategy will enable the domain specific analysis of BSDs with vertical walls and horizontal floors.

The TP method results in a conformal geometry as a collection of triangular prisms. As triangular prisms are the simplest possible geometrical entities with vertical walls, this implies that all polyhedron BSD base geometries with horizontal floors and vertical walls can be described. The conformal geometry is obtained as follows, see figure 2: (1) displace each quad-hexahedron along the z-axis so that its lowest values in the z-direction are at the z=0 plane. (2) Define all the points and constraint lines to perform a 2D constrained Delaunay triangulation in the z=0 plane. The points consist of all corner points on the ground plan (i.e. on the z=0 plane) and all intersections between the lines of the base geometries on the z=0 plane. The constraint lines are all lines along the border of the geometry. (3) Perform the constrained Delaunay triangulation. This is performed here with the 'FADE_2D' library [21]. The result is a collection of triangles. (4) Project along the z-axis back all triangles to fill the full original base geometry by generating a triangular prism between the z-values of all elevations for each triangle within the BSD generated in the constrained Delaunay solution.

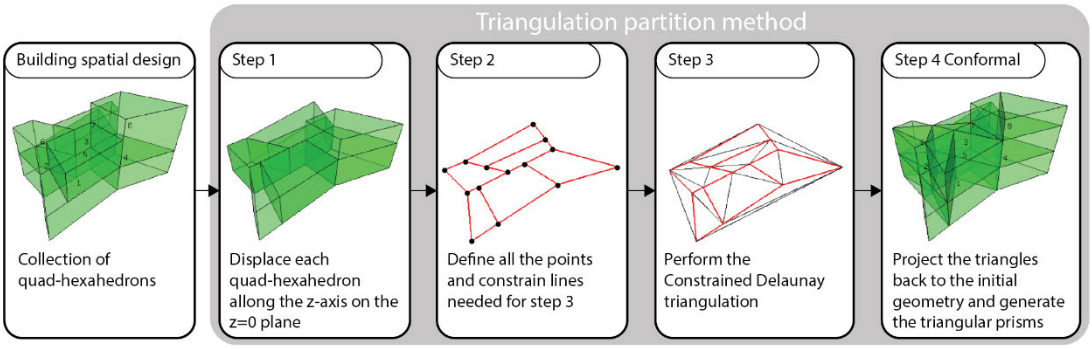

Figure 2: The triangulation partitioning method step by step.

The meshing strategy for a triangular flat shell structural component, using four-node quadrilateral flat shell elements, is self-explanatory, as shown in figure 3. By combining this strategy with the existing meshing approach for quadrilaterals [19], the triangular prism geometry can be meshed.

3 Results

The TP method results in a conformal geometry, as is demonstrated by the example of a complex BSD that consists solely out of a quad-hexahedron defined base geometry, see figure 4 on the left. From this conformal geometry, a structural model is defined by amending all base geometry surfaces of the BSD by flat shell structural components (shear walls or floors), and subsequently meshed with the above strategy. Note that all finite element nodes along shared lines coincide and so are merged, due to the conformal geometry, see also figure 1. This process is performed fully automatic, among others with the help of structural grammars and meshing procedures [19].

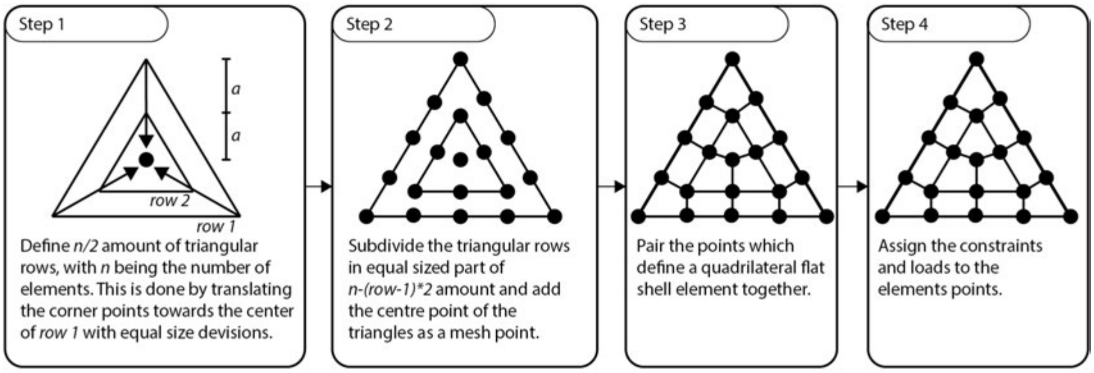

Figure 3: Meshing strategy for a triangular flat shell using quadrilateral flat shell elements.

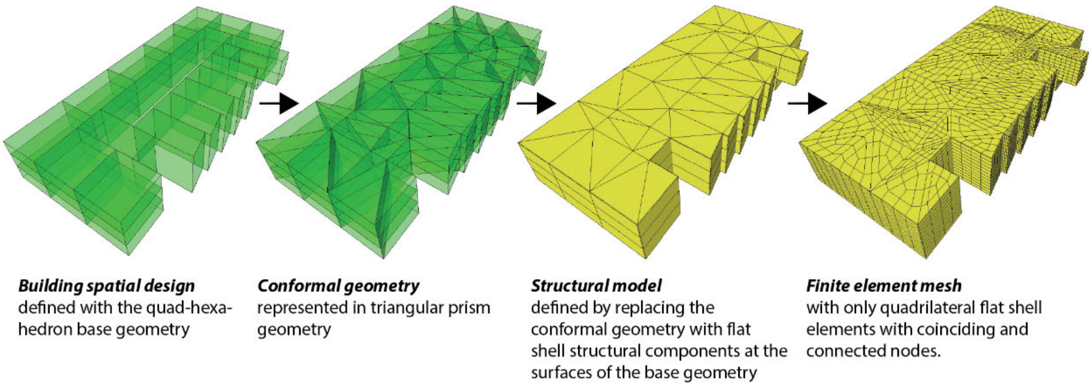

Figure 4: A BSD to a conformal geometry, to a structural model and finite element mesh: a fully automated procedure.

A convergence study has been carried out, comparing the quality of the original finite element mesh (based on a conformal geometry made by an alternative method [19], only applicable to rectangular designs) with the mesh obtained via the TP method and above meshing strategy, see figure 5. Both meshes use the same quadrilateral flat shell elements, and the same loads and constraints are applied [19]. Table 1 shows that a mesh size equal to 2 is too course for the original strategy, mesh size 4 is fine, and using finer meshes (above 4) does not show further convergence. As such, it can be concluded that relatively large elements already provide a converged solution (for this specific model). Also, the triangular prism-based geometry, although having distorted elements, provides accurate solutions. This is advantageous, as the triangular prism-based geometry results from non-rectangular geometries, which can handle the variety of Building Spatial Designs (BSDs) as seen in practice.

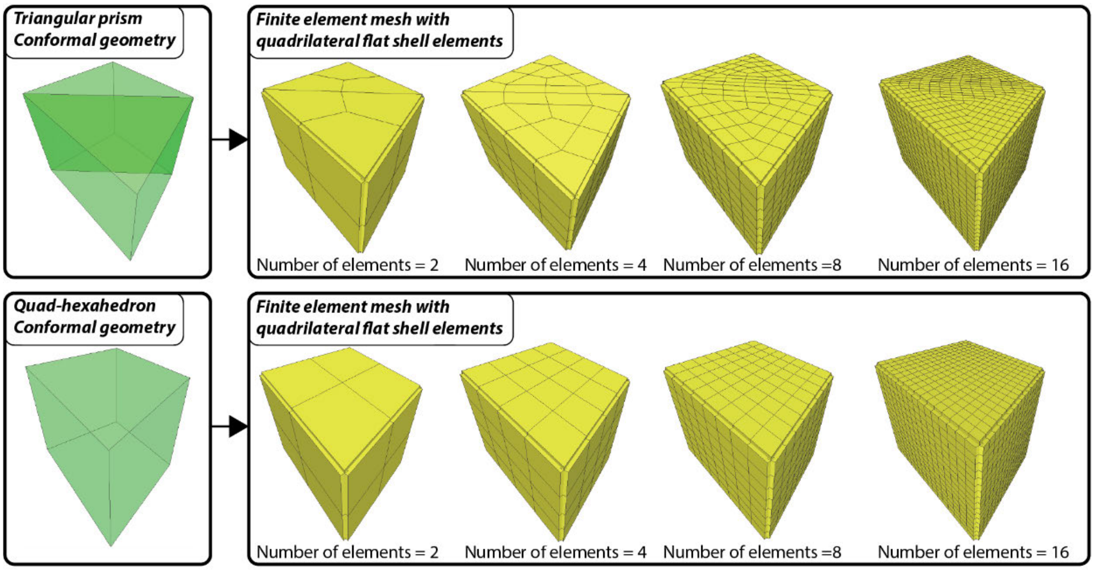

Figure 5: Automatically meshed structures having increasing mesh densities, based on either triangular prism or quad-hexahedron geometries.

Number of elements	New mesh; Total strain energy, triangular prism conformal geometry [Nmm]	Original mesh; Total strain energy, quad-hexahedron conformal geometry [Nmm]
2	1774	1472
4	1799	1807
8	1808	1814
16	1806	1808

Table 1: overview of total strain energy for meshes based on triangular prisms vs. quad-hexahedrons.

4 Conclusions and Contribution

In this paper, it has been shown that a base geometry in combination with a conformal geometry can serve as a good base to define a discipline specific model. Specifically, the conformal geometry, among others, offers a generalized platform to (1) define properties, loads and components in a correct manner, (2) solve finite element connections and intersection problems within a mesh, and (3) allows for the grouping of sub-parts of the BSD into zones for spatial layouts that are more logical from a discipline point of view [11].

Previous research indicated that the TP method is the most versatile method of all tested methods [20] to define such a conformal geometry. The method can be applied to any possible base geometry with horizontal floors and vertical walls, since a triangular prism is the most elementary polyhedron shape. Hence, it can be applied to a wide range of BSDs, thereby supporting simulation and optimization for multiple disciplines.

The definition of a finite element model with the help of a triangular prism conformal geometry has been demonstrated. Specifically for this application, a conformal geometry has been found very useful since it is difficult to define a functional mesh, and to correctly apply loads and constraints for complex multi-body geometries.

A first indication of the related mesh quality has been given, by a comparison of meshes found for quad-hexahedron conformal geometries (found from a partitioning method and accompanying meshing strategy for rectangular BSDs [19]) and for triangle prism conformal geometries (which result by the new partition method that is also applicable to non-rectangular shapes). Both types of geometries result in similar mesh qualities, if measured for the total strain energy.

Future research will first develop procedures to use the triangular prism conformal geometries for thermal and lighting discipline models. Then existing modification strategies for rectangular BSDs will be adapted and tested to see whether they work with non-rectangular BSDs. Finally, multi-disciplinary optimisations and design simulations will be carried out in a hybrid fashion, to study and support building design processes.

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