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3D Parametric Modeling Toolset as a Part of the Architectural Design Pipeline

This paper proposes the usage of parametric design as an acceleration for the architectural design pipeline by the example of Blender software and its Geometry Nodes Editor. Parametric sketching is considered as an alternative to physical architectural modeling in order to quickly obtain a model for structural analysis.

Research subject and objective.

Parametric design approaches and methods have been known to AEC design specialists for quite some time. But one major downside is that such designs mostly stay on paper. When such designs are implemented, they usually are decorative elements of a structure that has been modeled in a traditional way or are seen as a part of amenity spaces like parks. With technology development in this field new opportunities arise. Some of the design applications known worldwide, e.g., Revit or ArchiCAD, already have their own functionality to create the parametric elements in the project. For instance, ArchiCAD's Param-O extension offers visual scripting techniques, but mainly focused on creating adaptive and configurable GDL-objects [1]. Revit and its Dynamo allows users to create parametric geometry and AI-enhanced generation of the objects. Both tools serve very specific purpose — to make a step towards automation in design process. Dynamo, however, is a more advanced tool that offers vast utilization within specific boundaries. Even though these tools can create custom geometry and place structural elements at the designated curves or coordinates or generate the most efficient situation of the furniture in a room, they come at a cost of consumed time and machine resources. Even though its visual scripting is pretty self-explanatory, new users may find experience with this add-in somewhat challenging. But the main drawback of this approach using mentioned toolsets is inability to sketch in real time. The efficient utilization of either Param-O or Dynamo is only possible when users know what they need to design and how.

Some toolsets may be overrated or underestimated. The perception of this fine line lies within the specialist's personal preference and depends heavily on their expertise and skills. But when looking for a more lightweight and accelerated solution some other options of similar toolsets may be preferred. A good example of such an alternative is Blender, a free open-source software with the capacity to handle parametric design, traditional 3D modeling, material creation, rendering and it has a huge library of free and paid add-ons that accelerate some of the design processes when using this software.

The objective of this research was to find a solution to achieve a quality parametrically designed structure model that can be exported into various design environments to polish the idea and its representation. Target environments for this research primarily were SAPFIR-3D and LIRA-SAPR in order to quickly achieve analytical model for the further structural analysis. The object of the research was a simple engineering structure — a water tank tower (Fig. 1).

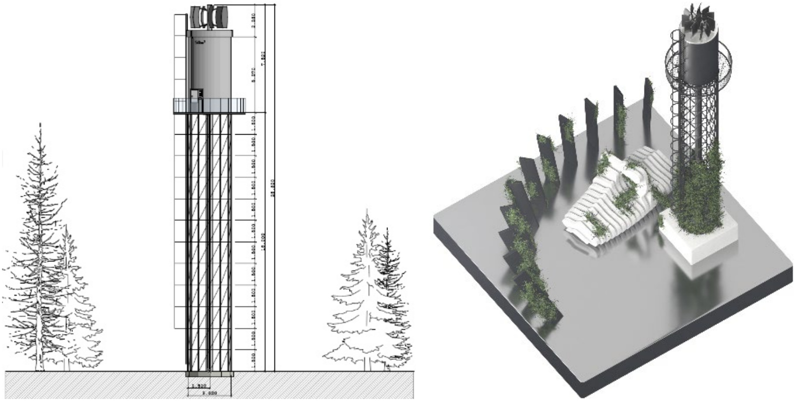
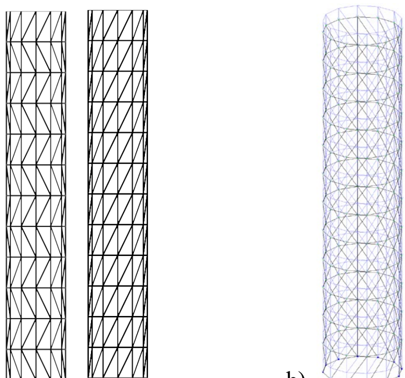


Fig. 1. A water tank tower concept

Design process.

Blender allows users to quickly create a complex and unique shape by using so-called Geometry Nodes [2], that is a built-in toolset for non-destructive workflow parametric design using intuitive visual scripting. Having an aim to generate a simple, yet rigid structure, a basic shape of cylinder with twelve vertices at the curvature was chosen. Using parameters “Array”, “Triangulate” and “Wireframe” the initial shapes were created. The value of the “Triangulate” modifier parameter “Quad Method” changes the direction of the division in the polygons. By altering the value two options of one structure were obtained (Fig. 2a). It is worth mentioning that Geometry Nodes are becoming more powerful with application of predefined modifiers from the other menu — “Modifier Properties” of a selected object. For instance, property "Triangulate” refers to a Geometry Node, while “Array” and “Wireframe” are modifiers. The resulting structure appears to be somewhat less sophisticated, yet it was rapidly generated in three steps (Fig. 3).



a) b)

Fig. 2. a) options of model; b) resultant analytical model of the structure

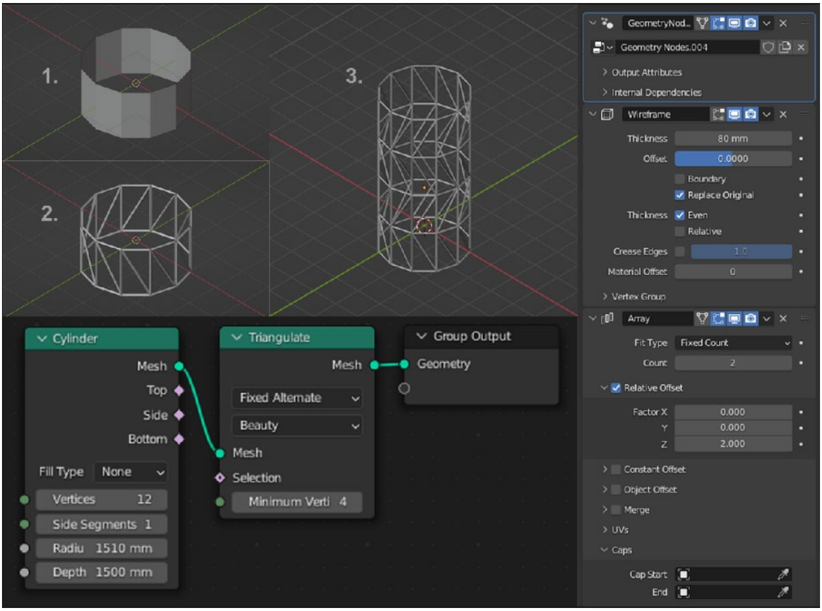


Fig. 3. A truss modeling algorithm

The time spent on the generation is approximately equal to 2 minutes, that is way quicker than modeling each node and bar manually. Even though Blender allows users to achieve CAD-like experience and precisely modeled objects, its rigid body simulation functionality is not applicable to AEC needs. That is why export to SAPFIR-3D was one of the primary objectives. In-depth analysis of such a structure is possible, when its members are actually defined finite elements. Using a mesh only makes it possible to carry out the plate analysis, which means the model has to be exploded into primitives to act as a complex structure of bars that are parallel in the XOY plane with a diagonal crosspiece in each segment of the generated truss.

Interoperability.

SAPFIR-3D 2022 has a built-in extension called Generator that is primarily focused on interoperability with the *.ifc or *.obj (Wavefront) format of 3D models and is capable of creating parametric geometry in place, however with another approach compared to the similar toolset in Blender. After importing the model, it is possible to subdivide an array of elements into lines from the mesh surface and into points, then into line segments within a truss of the determined height of 1500 mm. Newly created line segments are now classified as structural beams and then designated as the finite elements — bars with specified cross-section (Fig. 4). Using these nodes to override existing geometry took nearly as much time as its creation.

Next step was the application of loads, which are wind, snow and seismic activity loads. Dead load is applied automatically based on the input stiffness type of the elements, which in this research was a box pipe 80 × 60 × 4 from the assortment of steel rectangular pipes according to DSTU EN 10219 [3]. The analytical model, obtained and ported to LIRA-SAPR, is fully eligible to run structural analysis on (Fig. 2b).

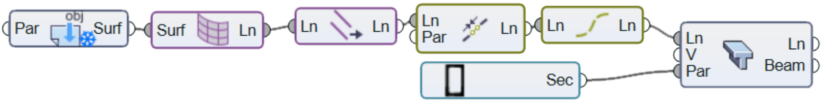


Fig. 4. Converting the geometry into an analytical model

Further design process can be carried out by exporting an IFC model with SAPFIR-3D and processing the building information model into the BIM software like Revit or ArchiCAD or natively inside the SAPFIR, depending on the design specialist's preferences or the requirements to the model. Afterwards, the structural model inside the BIM software may gain additional levels of detail. Such models can be ported back and forth to ensure all changes being made are performed on all levels of development.

Realtime sketching.

Further research expands towards more general application but not its initial subject. Experimental approach of doing a parametric sketch in 3D resembles the process of making an architectural cardboard model, but with ability to revert and change every and each parameter of the project [4]. For this experiment free addon "Landscape" was used, which allows to generate parametric terrain with designating values for noise texture, dimensions etc. Then transformation of mesh primitives like cubes and cylinders takes place (Fig. 6). For example, one instance of cube was subdivided into needed number of sections like a building would normally be sectioned by the axis grid, then the existing faces were deleted and the faces from the edges were extruded and filled (Fig. 7). By using various combinations and merging the objects geometry it is possible to obtain very complex structures to serve as an overall idea, or a vector to move towards in the design process.

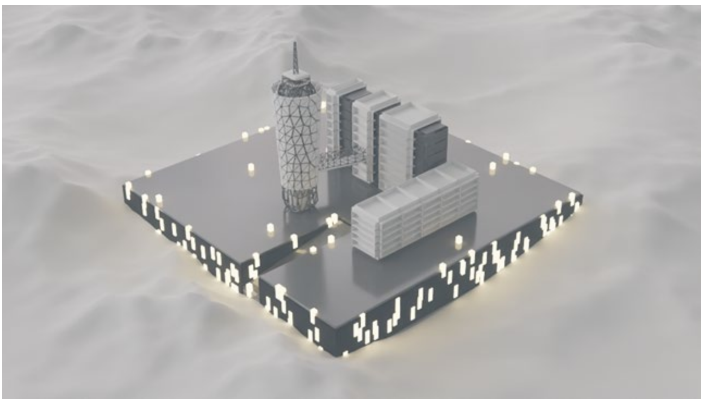


Fig. 6. Parametric sketching in action

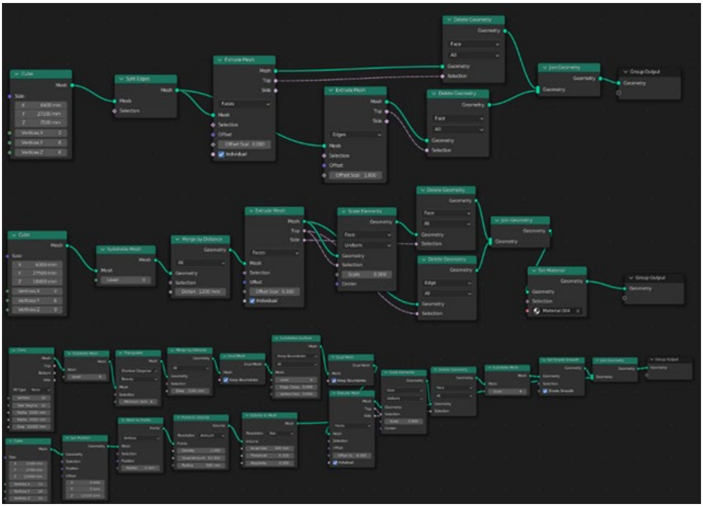


Fig. 7. Examples of the geometry nodes used for sketching

Summary

While most design processes are carried out in industry standard applications like ones from Autodesk, there is still room for improvement and experiments in the design pipeline. Using open-source applications with plugins that automate various stages of the design process can be a beneficial experience. While intuitive and easy to use, Blender can be suitable for the AEC field, being able to natively export models into the format recognizable by the other design environments. It can be utilized for creating quick parametric sketches of individual structures or whole complex facilities, amenity space improvements, decorative and structural elements, shells of custom shape and curvature, rendered visualizations, simulations and its boundaries of application may only grow wider with time. By integrating such a toolset into the traditional pipeline, it is possible to reduce time needed to create a number of options to choose from and to gain more opportunities in the parametric architectural design.

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