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InNoFa 2.0 | Topological adaptive non-periodic infills for MacroSLM façade nodes

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Abstract

Thanks to the evolving CAD and modelling software the freedom of form and design is greater than ever before. The associated development, application and establishment of new manufacturing options allows for greater functional, material and cost optimization of parts. The project "Individual Node Facade" (InNoFa) examined the usability and economic viability of parametric automatically generated aluminum nodes being manufactured using current planning and SLM technologies. Based on the results, new parameters were defined and as part of a joint project which led to the development of a new printing technology, the MakroSLM, and the construction of a corresponding system. The result is demonstrated in the InNoFa2.0 prototype. Compared to other SLM processes, the new AM-technology reduced material costs ten-times by using coarse granules instead of fine powder, increased the build rate by more than five-times and the construction time by 30-times and decreased the cost per node by 20-times. At the same time, a leap in materials became possible, so the elements be manufactured in aluminum, but also in stainless steel, tool steel and, in the near future, structural steel. In addition to the new printing process, the main part of the development lies in the preprocessing, the planning and generation of the nodes geometry with a topologically adaptive internal structure. By combining all, the required material can be used optimally, unneeded material in components can be avoided and production time can be minimized. In order to design the nodes as efficient as possible and to use the laser as effectively as possible during the process, unlike other approaches, a three-dimensional non-periodic minimal surface is used as internal structure. In contrast to periodic minimal surfaces such as gyroids, this has the advantage of being able to switch between different degrees of density in the smallest space, while remaining the wall thickness constant. And unlike lattice structures the surface provides continuous movement paths for the AM process during slicing.

Keywords: additive manufacturing in architecture, complex geometry, façade, FLEX, InNoFa, MacroSLM, metall node, mono-material construction, non-periodic infill, parametric design, resource efficiency, topological optimization

1. Introduction

As a demonstrator, InNoFa 2.0 exemplifies the potential of metallic additive manufacturing (AM) in the construction industry. The contemporary planning processes and current technologies used in the AMiCo (Additive Manufacturing in Construction) [1] project showed that the requirements for corresponding processes or building components in architecture differ significantly from those in other industries that use additive manufacturing processes. Even if the limiting installation space is scaled, current metallic AM processes are primarily designed for accuracy, which, depending on the manufacturing process, results in a low build rate and high material production costs for the fine, homogeneous base material. Therefore, for application on architectural scales, it became necessary to develop an alternative technology with a high build rate, cheaper material and accuracies on other scales. The MakroSLM [2] was developed under this premise. Due to the changed and coarser AM process, there is a need to adapt the preprocessing to the geometry. At the same time, there is potential for materials that remain unused in individual components with conventional manufacturing processes until they are transferred into a new material cycle after demolition. Through smart geometric adjustments, these unused materials can be reduced, used in a more effective way or even isn't needed for the manufacturing process.

2. MacroSLM

The macro-SLM process (SLM - Selective Laser Melting) is an advanced method in the field of 3D printing that was developed to enable the production of large-volume components while increasing productivity and reducing costs. To develop this process, the previously used laser and powder bed-based 3D printing process of metal components (SLM) was enhanced. This is an already established form of additive manufacturing with which metal can be reliably used as a raw material in 3D printing, the possibility to design complex geometric products remains preserved and the material is used as effectively as possible. A major disadvantage of the conventional SLM process, however, is that currently very complex and therefore expensive systems have to be used in order to be able to maintain a high structural resolution and at the same time achieve the highest possible dimensional accuracy. An alternative to the conventional SLM process is Wire Arc Additive Manufacturing (WAAM) or Laser Metal Deposition (LMD). These also enable high application rates of up to 1,000 cm³ and have the advantage that hardly any starting material is wasted. The disadvantage here, however, is that the design options are limited by the type of production. In order to compensate for the disadvantages of the above-mentioned and already established processes and at the same time use their advantages, the Macro-SLM process was developed. By increasing the spot diameter, the layer thickness and the powder grain size, the laser power can be increased without the material evaporating. On the one hand, the macro-SLM enables structure resolutions and build rates that are similar to those of conventional WAAM or LMD and, on the other hand, it allows the implementation of complex geometries. Macro-SLM therefore makes it possible to increase productivity without restricting design freedom. Increasing productivity is necessary because larger construction volumes are required for use in architecture and construction engineering and there is a desire for faster construction processes with the lowest possible costs.

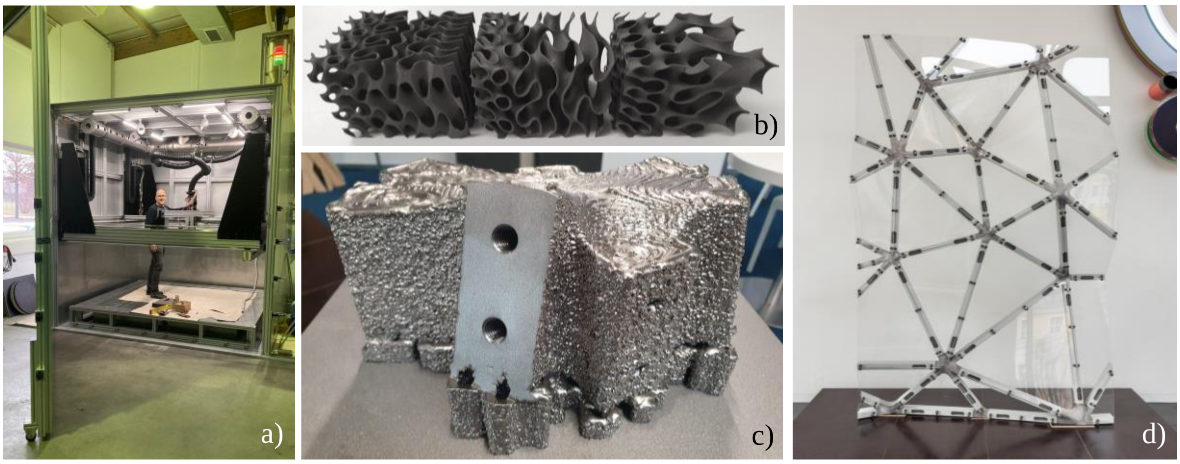

Figure 2: a) MacroSLM machine b) topologic-optimzed Infill Structure Testcubes c) MacroSLM Testprint d) InNoFa 2.0 with MacroSLM Testnodes, photos: FLEX @ HTWK-Leipzig and Laserinstitut Hochschule Mittweida (LHM)

3. Geometry Preprocessing

Basic data from the planner serves as input for the developed planning process. For facade planning, the pure facade surface can be used on the one hand and existing networks or segments that correspond to the planner's design wishes can be used on the other. The pure facade surface can then be segmented using a wide variety of division algorithms. Since the Paraknot3D concept [4] on which InNoFa is based describes a construction of serially manufactured straight simple rod elements between complex, individual and additively manufactured node elements and these not only allow triangular subdivisions, as shown in the demonstrator, but also square and n-angular segmentations planarization [5] of the segments is necessary to enable a simple, efficient completion of the complex segmented facade. Using the resulting division network, three-dimensional enveloping bodies of the individual nodes are generated at the intersections in accordance with the adjacent rod profiles. In the further process, the geometry is detailed according to a structural design. On this basis, as in the example of the standard front connection used in the demonstrator, the connection detail is created and its geometric characteristics are used and taken into account for the further processing steps such as the FEM calculation and topology optimization as well as filling structure design.

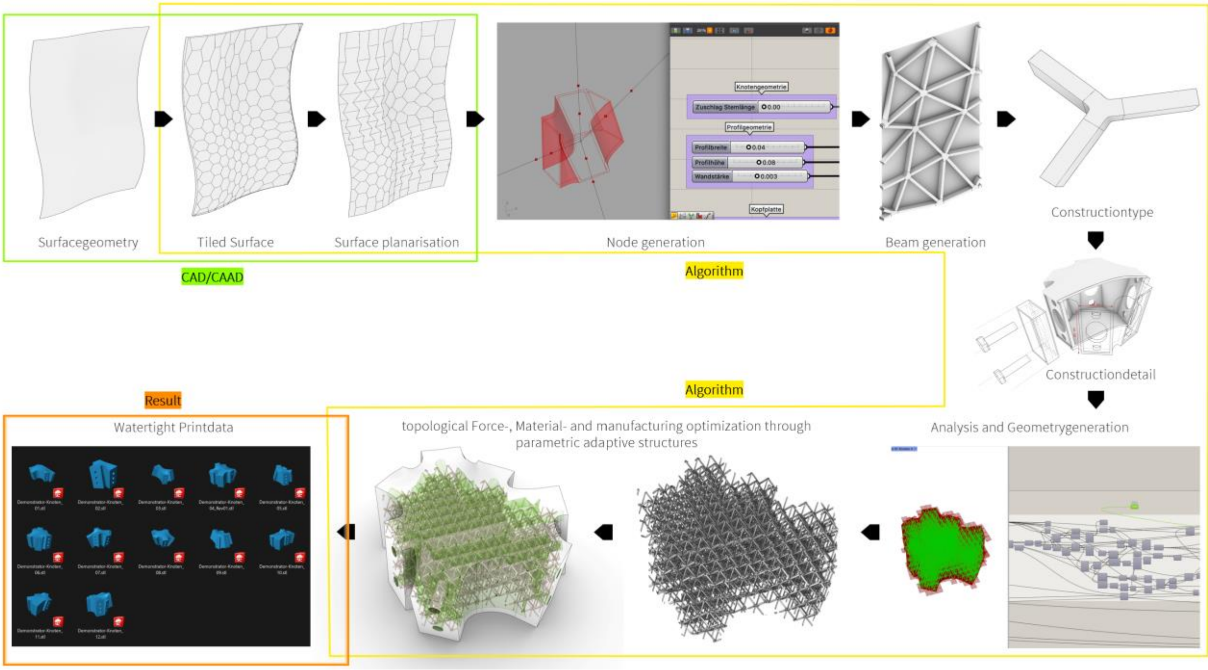

Figure 3: Preprocessing Process from Façade Surface (top left corner) to individual Node Design (top right corner), to topological optimized Infill and printable file (bottom left,corner), FLEX @ HTWK-Leipzig, Martin Dembski

3.1. Topological Values

The envelope structure and its global installation situation serve as the basis for the voxel-based FEM calculation of the topological values of each node. The envelope structure results in the void - the local three-dimensional spatial boundary in which the topological values can be calculated and in which the filling structure can be created -, the force introduction surfaces - end faces of the rods and core drill holes - as well as, corresponding to the global facade area and the orientation of these Building, the wind load to be applied, as well as, due to the materiality and the structural design, the dead load of the facade that acts on the respective node. Together, this results in the applied FEM calculation model. The topological investigation [6] can be made more and more precise by increasing the number of voxels. Based on this calculation, the individual value of each voxel can be used for further infill structuring.

3.2. Geometric-Technological Impacts on Infills

Since the laser power in the MacroSLM process is significantly higher than in standard SLM processes and the granules initially absorb a lot of energy during the construction process, for efficient production it is necessary to generate movement paths that are as continuous as possible and have little to no jumps. Otherwise, process errors can occur in which the initial areas of the manufacturing paths are not fused together as desired. Due to this geometric-technological interaction of the process, rod-shaped internal structures are largely unsuitable. Also unsuitable are highly differentiated wall thicknesses of flat filling structures, which arise, for example, when linked to the topological values, since these also create path pieces during slicing that cause the laser to jump.

For this reason, options were investigated based on flat filling structures to create differentiated structure densities while maintaining constant wall thickness while incorporating topological optimization.

3.3. Voxel-Structure-Morph-Method

The voxel structure morph method developed in this context [7], which represents a coupling of triperiodic infill structures, a deformed voxel grid and an adaptive box morph, showed an initial approach to solving this problem, but is strong when it comes to rapid density changes in geometrically narrow or small areas depends on the resolution of the underlying voxel grid and is therefore relatively sluggish or computationally intensive.

4. Topological adaptive non-periodic Infill

To counteract this, an alternative method was developed that creates a topologically adaptive non-periodic surface or minimal surface infill. Unlike triperiodic minimal surfaces commonly used in 3D printing, such as gyroids, these minimal surfaces are not repetitive but are created individually from cell to cell or voxel to voxel and at the same time react to the surrounding cells or voxels. The values from the topological optimization of the component serve as the values for generation, so areas with 100% density are completely solid, areas with 50% density are only filled to half of the actually possible volume and areas with 0% density are completely empty. Thanks to individual creation, rapid geometric density changes are possible in the smallest of spaces. Two variants of the non-periodic infill were developed.

4.1. Non-periodic 3D Voronoi Infill

According to the name, the non-periodic 3D Voronoi infill is based on 3D Voronoi cells, which are created on the basis of directed three-dimensional point clouds and thus show the density differences in the component in the 3D cell structure. The voxels with the data from the topological investigation are used for the directed distribution of the points in and on the interfaces of the geometry void. Small cells are formed in areas of high density and therefore high utilization or stress, while large cells are formed in areas of low density and therefore low utilization or stress. Based on the cells, a cell dual is generated after the distribution, which is linked to the other cells and, as a whole, creates a network of connected free-form surfaces that resemble connected Schwarz D or Schoen D minimal surfaces.

4.2. Non-periodic Minimalsurface Infill

In contrast to the previous structure, the non-periodic minimal surfaces are actual minimal surfaces that basically represent the negative of a spherical surface. Combined fields are built up in the voxel grid, which create a continuous isosurface. Areas of high density have an attractive effect in the fields and are therefore integrated into the isosurface, while areas of low density have a repulsive effect and are excluded from the isosurface.

5. Conclusion

Both approaches result in a functional, non-periodic, flat infill structure that takes into account the manufacturing characteristics of the MakroSLM process and thus enables preprocessing and production of efficient components. Instead of voxels, the use of quadtree algorithms represents a potentially more efficient development of the non-periodic surface infill structure. However, based on the size of the components, difficulties arise when emptying the loose, coarse granules from high-density structural areas. The integration and transitions to solid areas for screw holes, for example, present similar manufacturing challenges, but can be geometrically easily integrated using the same process as the remaining surface creations.

References

[1] M. Dembski, M. Höhne, T. Reinhardt, F. Eidner, "AMiCo - Additive Manufacturing in Construction" Aug. 2021. [Online]. Verfügbar unter: https://flex.htwk-leipzig.de/flexforschung/amico

[2] M. Erler, S. Weinhold, M. Pfeifer, A. Streek, "Entwicklung zum Makro-SLM für die additive Fertigung großvolumiger Metallbauteile", *FabCon2023*, Jan. 2024.

[3] M. Ahmadi, S.A.A. Bozorgnia Tabary, D. Rahmatabadi, M.S. Ebrahimi, K. Abrinia, R. Hashemi, „Review of selective laser melting of magnesium alloys: advantages, microstructure and mechanical characterizations, defects, challenges and applications", in *Journal of Materials Research and Technology*, Vol. 19, S. 1537.1562, Jul.-Aug.2022.

[4] M. Dembski, C. Dijoux, A. Stahr, "Paraknot3D - Ein hybrides Konzept für Leichtbaustrukturen in der Architektur", *IWKM Mittweida*, 2018.

[5] W. Wang, Y. Lin, D. Yan, B. Chan, R. Ling, F. Sun, „Hexagonal Meshes with Planar Faces", 2008.

[6] M. P. Bendsøe, O. Sigmund, *Topology Optimization - Theory, Methods and Applications*, 2004.

[7] M. Dembski, A. Stahr, „Die Voxelstrukturmorphmethode - Topologisch optimierte Füllstrukturen zur Fertigung und Bauteiloptimierung von makroskopischen additiv gefertigten Bauteilen", *3D Druck Forum 2023*, 2023.