Repetitive Structures

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Abstract

This paper presents a theoretical framework of repetitive structures and illustrates its potential for the design and construction of strained gridshells.

Throughout the history of architecture, the use of repetitive building parts has been a key goal to simplify fabrication, ease construction, and save costs and time. This may be achieved by laying identical bricks or using identical ball joints, dividing a sphere into congruent triangles or rationalizing a curved façade to only use planar glass panels. In any case, using repetitive parts inevitably effects the overall shape and layout of a structure.

In geometry the term “repetitive” is used to describe congruent elements, such as nodes, edges or faces, within a network, while an architectural structure aims at identical building parts to achieve repetition. These two perceptions do not always coincide: In practice, adjustable joints, tolerances or deformation allow the use of repetitive parts, even for a geometrically non-repetitive element.

The paper combines insights from differential geometry and building construction to create a holistic theory of “repetitive structures” considering both the geometric and constructive parameters. This theory does not only offer an analysis of existing structures and a definition of strategies to achieve repetition. Through computational design we can systematically investigate the morphology of repetitive networks, define parametric relationships, identify fundamental principles of form and deduce parameter combinations for future designs.

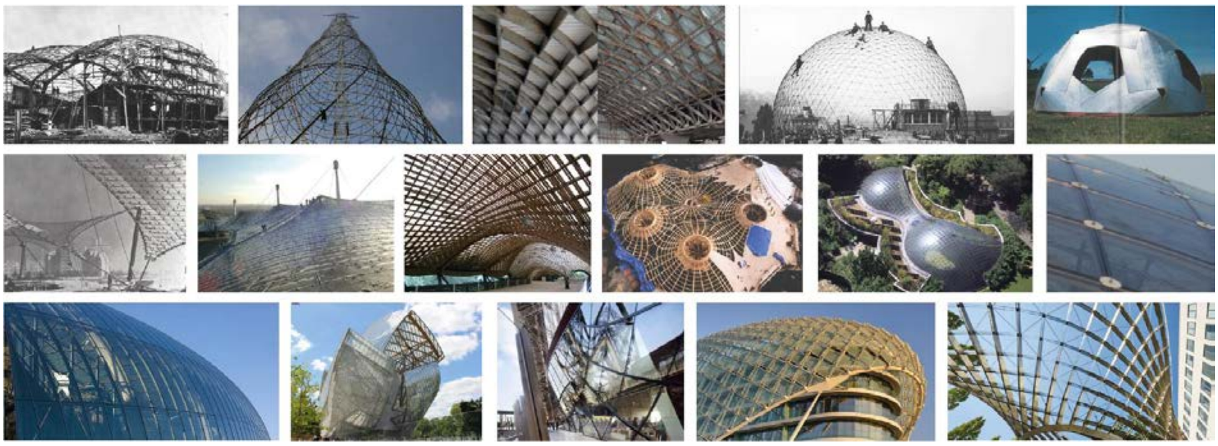

Figure 1: Architectural examples of structures exibiting a repetitive networks and/or repetitive builing parts.

Based on a review of scientific publications and built examples, a **theoretical framework** for repetitive structures is established using both geometric parameters and constructive criteria.:

To distinguish the **geometric parameters**, a separate analysis of smooth and discrete segmentations has proven especially insightful: Comparing their parameter-sets allows the definition of dependencies between the three parameters of curvature of an edge (k_n, k_g, τ_g) in a smooth network, and three respective angles (α, β, γ) at the nodes of a discrete network. Combining both sets establishes a complete table of parameters which can be used to geometrically compare even hybrid networks.

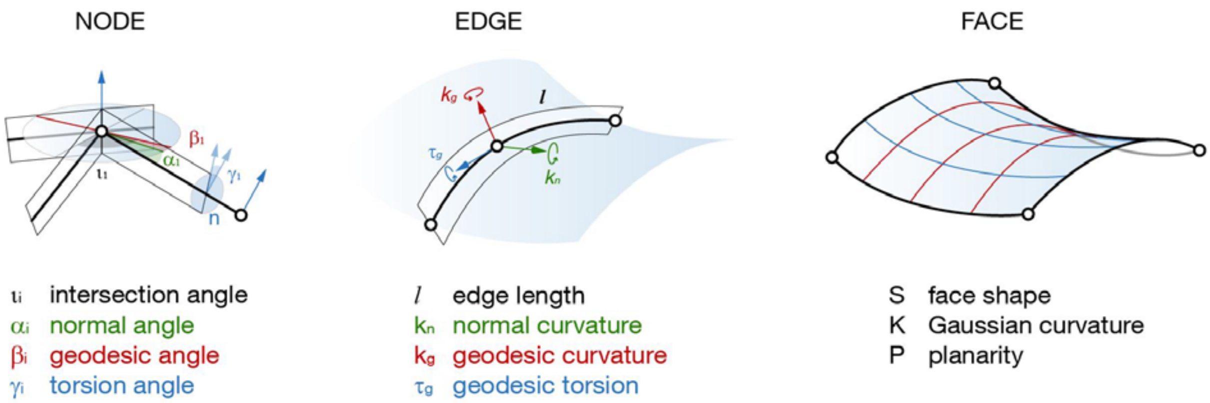

Figure 2: Table of geometric parameters for both discrete and smooth networks.

We further distinguish tolerances, hinges and deformation as **constructive criteria** to achieve repetition and relate them to specific geometric parameters. Our focus is set on **deformation** which creates a curved structure from straight or flat building parts. Measuring the geometric parameters of curvature of a strained gridshell allows us to directly deduce the inherent residual stress introduced by the construction process.

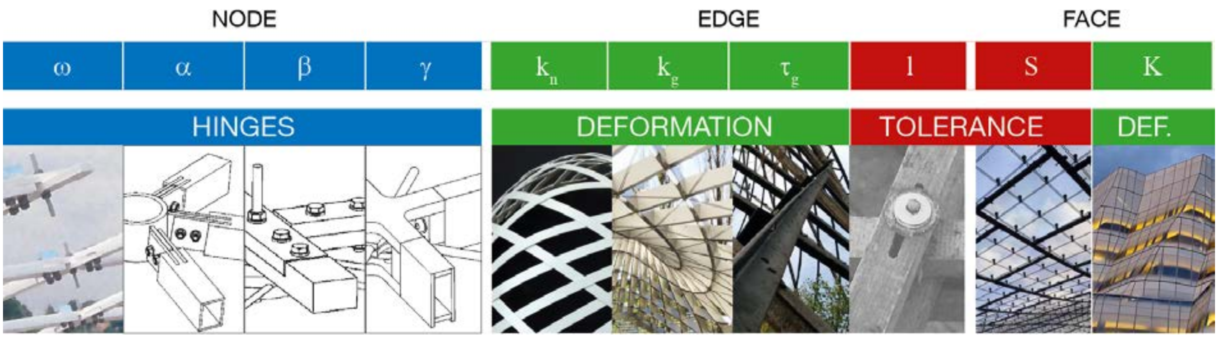

Figure 3: Table of constructional criteria and their related geometric parameters.

This theory is first applied to **analyse existing structures**, such as the gridshells of Vladimir Šuchov and Frei Otto and is further used to generate an overview of current and future **possibilities of parameter repetition**.

In a second step, we investigate the impact of repetitive faces, edges and nodes on form and network. This inductive study beautifully illustrates the **morphological behaviour** of repetitive grids. The effects on construction are visualized through reference projects and experimental models.

Finally, we relate the parameters of curvature to the deformation behaviour of individual beams. Based on this dependency, we can deduce the **shape spectrum and natural networks of elastically bent lamella grids.** This study has been used to develop new design methods. One of which, asymptotic curves on a minimal surface, has already been presented at the last Structural Emmbranes Conference in Munich, and has since been used in academia and practice around the world.

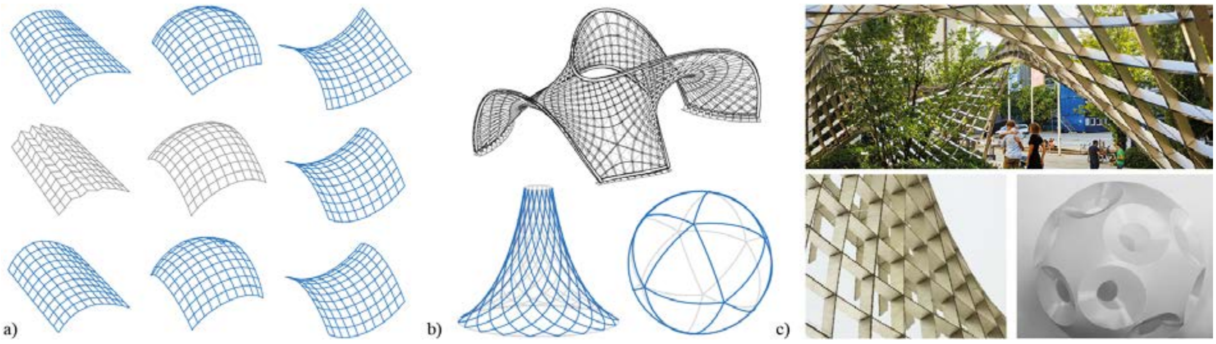

Figure 4: Design spectrum of repetitive nets: a) Quadrilateral grid with planar and/or euqilateral mesh. b) Constant curvature networks as digital and c) physical models

References

[1] Pottmann, Helmut; Eigensatz, Michael; Vaxman, Amir; Wallner, Johannes (2015): Architectural Geometry. In Computers and Graphics 47, pp. 145–164. DOI: 10.1016/j.cag.2014.11.002.

[2] Schling, Eike (2018): Repetitive Structures - Design and construction of curved support structures with repetitive parameters. Dissertation in Engineering. Technische Universität München, Fakultät für Architektur, Lehrstuhl für Tragwerksplanung. DOI: 10.14459/2018md1449869

[3] Schober, Hans (2002): Geometrie-Prinzipien für wirtschaftliche und effiziente Schalentragwerke (Teil 1). In Bautechnik 79 (1), pp. 16–24. DOI: 10.1002/bate.200200030.

[4] Schober, Hans (2016): Transparent shells. Form, topology, structure. With assistance of Claudia Schaffert. Berlin: Ernst & Sohn.

[5] Tang, Chengcheng; Kilian, Martin; Bo, Pengbo; Wallner, Johannes; Pottmann, Helmut (2016): Analysis and design of curved support structures. In Sigrid Adriaenssens, Fabio Gramazio, Matthias Kohler, Achim Menges, Mark Pauly (Eds.): Advances in Architectural Geometry 2016. 1. Auflage. Zürich: vdf Hochschulvlg, pp. 8–23.