Proceedings of IASS-IWSS 2026 – September 14-18, 2026, Turin, Italy
"R-Evolution of Shapes: Sustainability, Re-Use, and New Design Paradigms"
Annual Symposium of the International Association for Shell and Spatial Structures
3rd Italian Workshop on Shell and Spatial Structures
A. Manuello Bertetto, S. Gabriele, F. Marmo, A. Micheletti (eds.)

A CAD Integrated Isogeometric Workflow for Thin Shell Form-finding and Analysis

Ann-Kathrin GOLDBACH*, Carlos Lázaro [a]

*Technical University of Munich
Arcisstr. 21, 80333 München
ann-kathrin.goldbach@tum.de

[a] Universitat Politècnica de València, Spain

Abstract

Integrating structural analysis during the earliest design stages is critical for achieving lightweight, efficient, and materially responsible architecture. This contribution presents an innovative CAD-integrated workflow that brings architectural design and structural engineering into a single computational environment. The approach enables the form-finding and structural analysis of thin shell structures directly on the exact NURBS-based CAD geometry by employing Isogeometric B-Rep Analysis (IBRA), eliminating the need for mesh generation or surrogate analytical models. Implemented through the Kiwi!3D plugin in Grasshopper/Rhino, the workflow supports geometrically nonlinear analysis to capture large deformations, membrane-dominated behavior, and the load-dependent shaping processes characteristic of thin shells. Designers and engineers can adjust input parameters, boundary conditions, and material assumptions and immediately assess structural performance. The result is an iterative, performance-driven loop in which geometry and structural response are evaluated in tandem rather than sequentially. Case studies inspired by historical shell structures demonstrate how this integration enables precise form-finding through digital hanging models, equilibrium-based simulations, and nonlinear load analyses. The method encourages rapid exploration of geometric variations, structural refinements, and efficient load-paths—facilitating informed decision-making during the conceptual phase. By unifying architectural modeling and nonlinear finite element analysis, the workflow fosters a closer collaboration between architects and engineers, ensuring that structural logic and design intent evolve together. Overall, this CAD-native approach enables shell design by discovering equilibrium-driven forms. The workflow supports not only expressive and efficient architectures but also lays the groundwork for future integration with construction restrictions, performance-guided detailing, and structural digital twins.

Keywords: CAD-integrated parametric design, Isogeometric B-Rep Analysis, Non-linear analysis, Shell structures

Copyright © 2026 by Ann-Kathrin Goldbach and Carlos Lázaro
Published by the International Association for Shell and Spatial Structures (IASS) with permission.

1. Introduction

Lightweight shell structures derive their efficiency from the interaction of geometry and material strength. As demonstrated by pioneers such Félix Candela, successful shell design requires a tight coupling between form generation, structural reasoning, and construction logic, [9], [11], [12]. Despite advances in parametric modeling, contemporary workflows typically separate architectural CAD modeling from structural Finite Element Analysis, requiring meshing, geometry simplification, and repeated data translation. This separation hinders early-stage collaboration and limits the use of structurally driven design methods such as form-finding. This contribution addresses this gap by presenting a CAD-integrated design-through-analysis workflow for shell structures, enabling form-finding, non-linear analysis, and performance evaluation directly on exact CAD geometry during the conceptual phase. The approach supports an equilibrium-driven design paradigm in which geometry and forces evolve simultaneously rather than sequentially, [14].

2. CAD-Integrated Workflow Based on Isogeometric B-Rep Analysis

The presented workflow is based on Isogeometric B-Rep Analysis (IBRA), an extension of Isogeometric Analysis ([5]) that operates directly on trimmed multi-patch NURBS CAD models. In contrast to conventional FEM, exact CAD geometry is preserved throughout analysis, no mesh generation or geometry conversion is required and furthermore, refinement, trimming, and patch coupling occur without changing the underlying geometry, see e.g. [15].

Mechanical properties, boundary conditions, and loads are assigned directly to CAD entities (faces, edges, vertices), thus preserving geometric continuity and enabling robust non-linear shell analysis, [3], [4]. The IBRA formulation is implemented via the Kiwi!3D plugin [7] within Grasshopper/Rhinoceros [8], creating a unified parametric environment where: geometric parameters (curvature, span) - structural parameters (material models, boundary conditions) and analysis parameters (non-linearity, refinement) can be interactively modified and evaluated. This results in a design-through-analysis loop as depicted in Figure 1, where structural feedback is immediately available during form exploration — supporting performance-based decision making already at an early concept level, [6].

3. Form-Finding of Shell Structures in a CAD-Native Environment

3.1. Equilibrium-Driven Design of Thin Shells

For shells to achieve minimal thickness and material efficiency, loads should be carried predominantly through in-plane membrane stresses. Form-finding techniques aim to discover such equilibrium geometries for a given set of loads and boundary conditions, [1], [2]. The presented workflow enables numerical hanging models using geometrically non-linear IBRA shell analyses:

The shell is analyzed in an inverted configuration under self-weight, while bending stiffness is reduced to enforce membrane behavior. The resulting equilibrium shape is re-inverted to obtain a compression-only shell.

Unlike many existing methods, this approach supports trimmed, multi-patch NURBS geometries investigated in subsequent non-linear analysis steps on the same parametric model, with continuous refinement and geometric modification.

3.2. Advantages Over Mesh-Based Form-Finding

Because IBRA operates on exact CAD geometry, no remeshing is required after shape updates. Hence geometric fidelity is preserved across iterations and form-found geometries are immediately usable for further design and analysis. This supports an iterative, exploratory workflow closely aligned with architectural design practice.

4. Case Studies Inspired by Félix Candela

Three case studies demonstrate the workflow's applicability to architecturally relevant shell geometries inspired by Félix Candela's hyperbolic paraboloid shells, [10].

4.1. Parametric Hypar Umbrella Structure

A shell roof composed of four hypars is parametrically generated and analyzed. Boundary conditions, shell thickness and loading are assigned within NURBS-based CAD. A geometrically non-linear analysis evaluates deformation under surface loads. Structural feedback informs geometric refinement and array configurations, illustrating the full CAD - analysis - evaluation loop in a single environment, see Fig. 1.

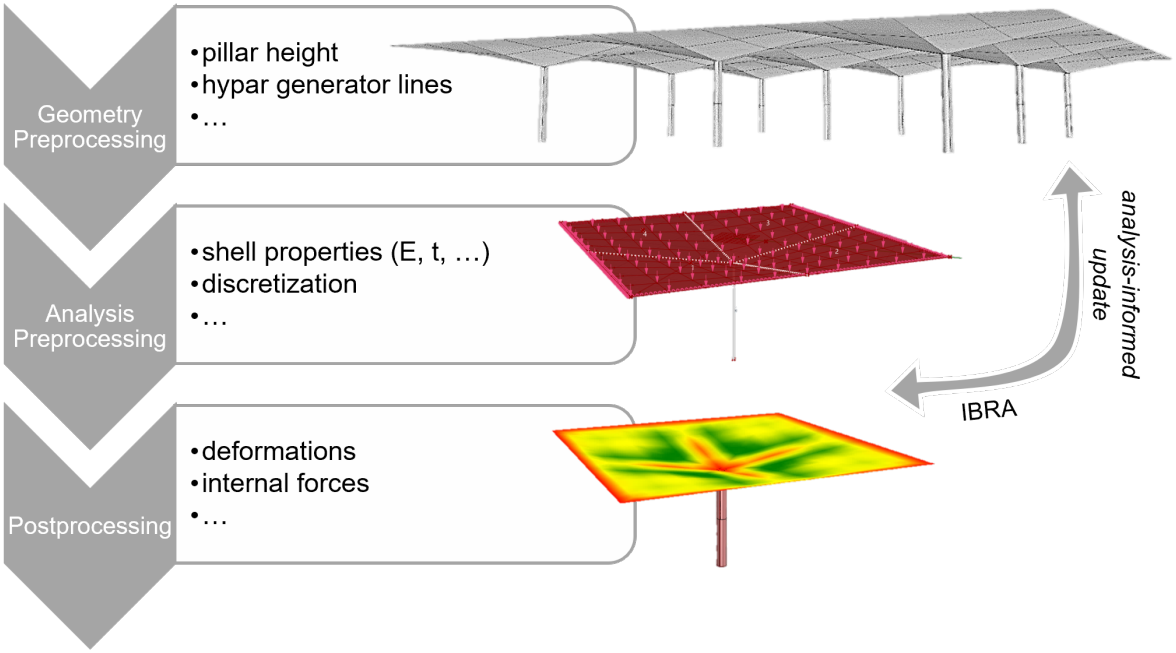


Figure 1: Design-through-analysis workflow in a parametric CAD-environment with Isogeometric B-Rep Analysis, adapted from [14].

4.2. Influence of Refinement on Structural Response

A groined vault geometry demonstrates the effect of isogeometric refinement. The CAD geometry remains unchanged while increased refinement improves displacement accuracy and has to be performed in order to reach converged results, see Fig. 2. However, reliable results are achieved without manual (re-)meshing, highlighting both the power and responsibility of refinement control in CAD-integrated analysis.

4.3. Integrated Form-Finding and Analysis of a Groined Vault

A complex shell inspired by Candela's L'Oceanogràfic roof, [13], in Valencia is used to demonstrate the flexibility in parametric generation of intersecting hypars. CAD-integrated non-linear analysis is used to perform numerical hanging model–based form-finding, see Fig. 3. Re-analysis of the equilibrium geometry under gravity loads can be investigated consecutively. The form-found shell exhibits reduced displacements and improved membrane behavior, confirming the effectiveness of equilibrium-driven shaping within the integrated workflow. More complex loading scenarios can be investigated for design enhancement in the same manner.

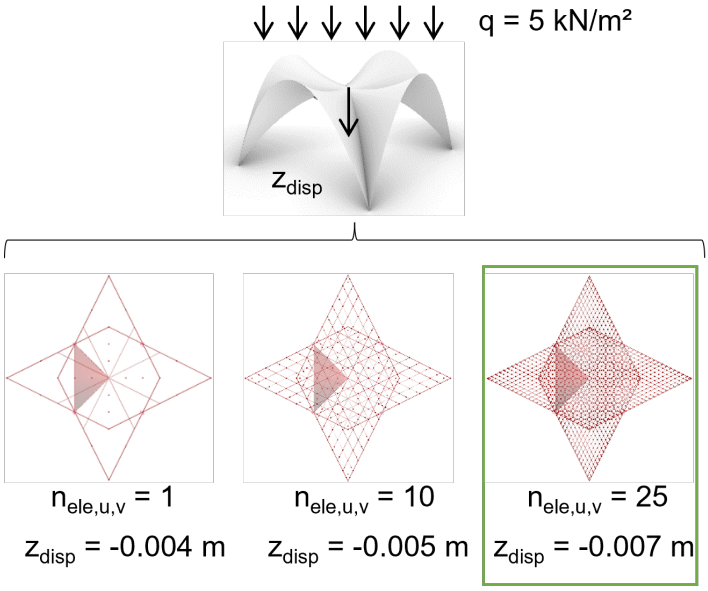


Figure 2: Refinement to reach sufficient detail in discretization of an isogeometric vault model subjected to 5 kN/m² loading, adapted from [14].

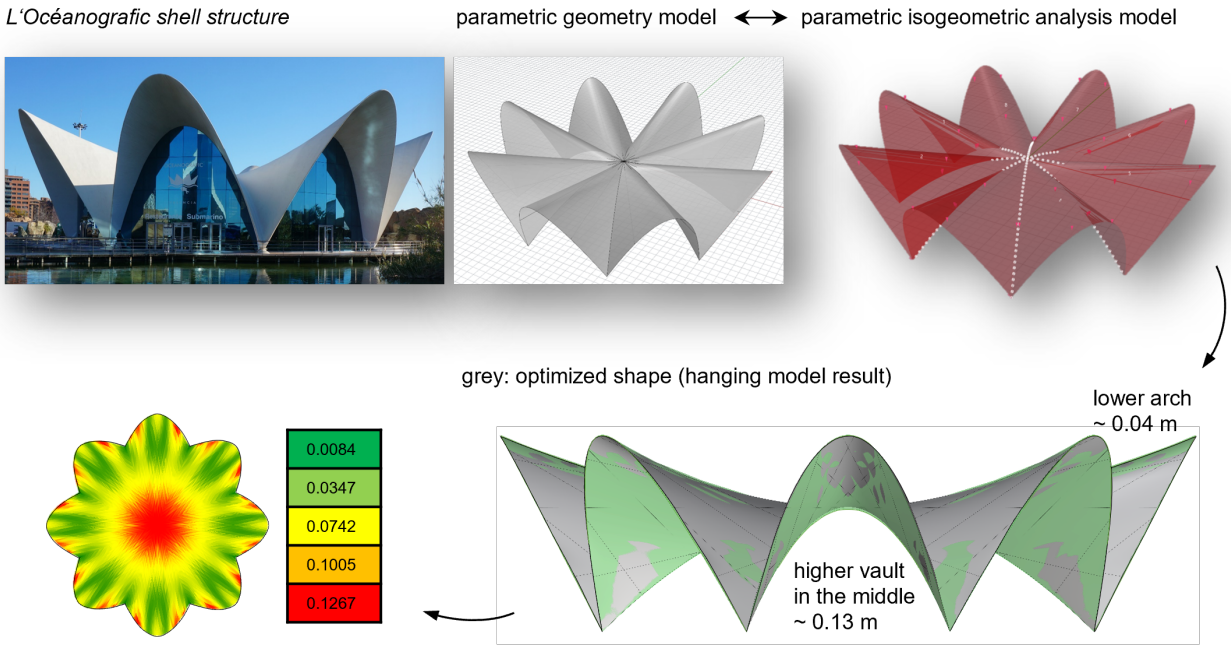


Figure 3: CAD-integrated design and analysis of the L'Océanografic concrete shell, adapted from [14].

5. Conclusion

This contribution demonstrates that CAD-integrated isogeometric analysis enables a fundamental shift in shell design — from form making to equilibrium-based form discovery. By unifying parametric modeling, non-linear analysis, and form-finding in a single environment, the workflow allows geometry and structural performance to evolve together from the earliest design stages. Future developments may include the integration of construction constraints and staging analysis, optimization and data-driven design loops, as well as coupling the analysis model with monitoring data toward structural digital twins.

The presented method provides a scalable foundation for lightweight shell design that is structurally informed, architecturally expressive, and computationally robust.

6. Acknowledgments

Carlos Lázaro gratefully acknowledges the support for his stay at the Technical University of Munich provided by the Universitat Politècnica de València and the retraining grant of the Spanish Ministry of Universities (RD 289/2021 and UNI/551/2021) funded by the European Union NextGenerationEU program.

References

[1] K.-U. Bletzinger et al., "Computational methods for form finding and optimization of shells and membranes", *Computer Methods in Applied Mechanics and Engineering*, 2005.

[2] S. Adrianssens et al., *Shell Structures for Architecture: Form Finding and Optimization*, Routledge, London and New York, 2014.

[3] M. Breitenberger et al., "Analysis in computer aided design: Nonlinear isogeometric B-Rep analysis of shell structures", *Computer Methods in Applied Mechanics and Engineering*, vol. 284, 2015.

[4] A.-K. Goldbach, A. Bauer and K.-U. Bletzinger, "CAD-integrated parametric lightweight design with isogeometric B-Rep analysis", *Frontiers in Built Environment*, 2020.

[5] T. J. R. Hughes, J. A. Cottrell and Y. Bazilevs, "Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement", *Computer Methods in Applied Mechanics and Engineering*, 2005.

[6] A.-K. Goldbach, A. Bauer and K.-U. Bletzinger, "Advantages of isogeometric B-Rep analysis for the parametric design of lightweight structures", in *Proceedings of the IASS Annual Symposium*, 2021.

[7] Kiwi!3D, "Kiwi!3D – CAD-integrated structural analysis", available online: `https://www.kiwi3d.com`, accessed May 2026.

[8] Rhinoceros, "Rhinoceros 3D", available online: `https://www.rhino3d.com`, accessed May 2026.

[9] M. Moreyra-Garlock and D. Billington, *Félix Candela: Engineer, Builder, Structural Artist*, Yale University Press, New Haven, 2008.

[10] J. Del Cueto Ruiz-Funes, "Félix Candela, el mago de los cascarones de concreto", *DC Papers – Revista Crítica de Arquitectura*, 1999.

[11] F. Candela, "Structural applications of hyperbolic paraboloidical shells", *ACI Journal Proceedings*, 1955.

[12] F. Candela, "General formulas for membrane stresses in hyperbolic paraboloidical shells", *ACI Journal Proceedings*, 1960.

[13] A. Domingo, C. Lázaro and P. Serna, "Design of a thin shell steel fibre reinforced concrete hypar roof", in *Proceedings of the IASS Annual Symposium 1999: Shells and Spatial Structures – From Recent Past to the Next Millennium*, Madrid, 1999.

[14] A.-K. Goldbach and C. Lázaro, "CAD-integrated parametric design and analysis of lightweight shell structures", *Structures*, 2024.

[15] A. M. Bauer, "CAD-integrated Isogeometric Analysis and Design of Lightweight Structures", *Dissertation at Technical University of Munich*, 2020.