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A new rotation-free isogeometric thin shell formulation and a corresponding continuity constraint for patch boundaries

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Abstract: This paper presents a general non-linear computational formulation for rotation-free thin shells based on isogeometric finite elements. It is a displacement-based formulation that admits general material models. The formulation allows for a wide range of constitutive laws, including both shell models that are extracted from existing 3D continua using numerical integration and those that are directly formulated in 2D manifold form, like the Koiter, Canham and Helfrich models. Further, a unified approach to enforce the G^1-continuity between patches, fix the angle between surface folds, enforce symmetry conditions and prescribe rotational Dirichlet boundary conditions, is presented using penalty and Lagrange multiplier methods. The formulation is fully described in the natural curvilinear coordinate system of the finite element description, which facilitates an efficient computational implementation. It contains existing isogeometric thin shell formulations as special cases. Several classical numerical benchmark examples are considered to demonstrate the robustness and accuracy of the proposed formulation. The presented constitutive models, in particular the simple mixed Koiter model that does not require any thickness integration, show excellent performance, even for large deformations.

Keywords: Nonlinear shell theory, Kirchhoff–Love shells, rotation–free shells, Isogeometric analysis, C^1-continuity, nonlinear finite element methods

List of important symbols

$\mathbf{1}$	identity tensor in $\mathbb{R}^3$
a	determinant of matrix $[a_{\alpha\beta}]$
A	determinant of matrix $[A_{\alpha\beta}]$
$\boldsymbol{a}_\alpha$	co-variant tangent vectors of surface $\mathcal{S}$ at point $\boldsymbol{x}$; $\alpha = 1, 2$
$\boldsymbol{A}_\alpha$	co-variant tangent vectors of surface $\mathcal{S}_0$ at point $\boldsymbol{X}$; $\alpha = 1, 2$
$\boldsymbol{a}_{\alpha,\beta}$	parametric derivative of $\boldsymbol{a}_\alpha$ w.r.t. ξ^β
$\boldsymbol{a}_{\alpha;\beta}$	co-variant derivative of $\boldsymbol{a}_\alpha$ w.r.t. ξ^β
$a_{\alpha\beta}$	co-variant metric tensor components of surface $\mathcal{S}$ at point $\boldsymbol{x}$
$A_{\alpha\beta}$	co-variant metric tensor components of surface $\mathcal{S}_0$ at point $\boldsymbol{X}$
$a^{\alpha\beta\gamma\delta}$	contra-variant components of the derivative of $a^{\alpha\beta}$ w.r.t. $a_{\gamma\delta}$
b	determinant of matrix $[b_{\alpha\beta}]$
B	determinant of matrix $[B_{\alpha\beta}]$
$\boldsymbol{b}$	curvature tensor of surface $\mathcal{S}$ at point $\boldsymbol{x}$
$\boldsymbol{b}_0$	curvature tensor of surface $\mathcal{S}_0$ at point $\boldsymbol{X}$
$\boldsymbol{B}$	left Cauchy-Green tensor of the shell mid-surface
$b_{\alpha\beta}$	co-variant curvature tensor components of surface $\mathcal{S}$ at point $\boldsymbol{x}$
$B_{\alpha\beta}$	co-variant curvature tensor components of surface $\mathcal{S}_0$ at point $\boldsymbol{X}$
$\tilde{b}^{\alpha\beta}$	contra-variant components of the adjugate tensor of $b_{\alpha\beta}$

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