Bayesian shape optimization in high dimensional design spaces using IGA-enabled solvers

S. Khan[*], K. Kostas[†], P. Kaklis[*], A. Serani[§] and M. Diez[§]

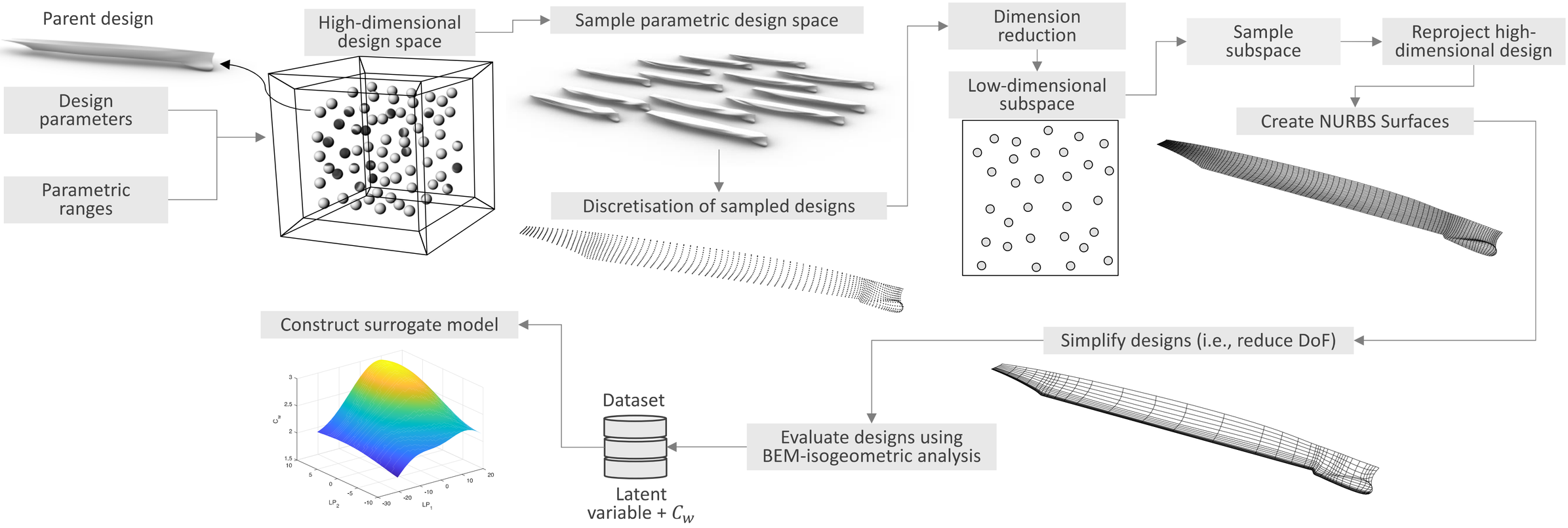
[*]University of Strathclyde, [†]Nazarbayev University, [§] National Research Council-Institute of Marine Engineering

Overview

- High-dimensional design spaces cause optimisation to suffer from the curse of dimensionality resulting in high computational cost.
- Different approaches have been proposed to overcome the computational burden:
  - **Efficient solvers** (Isogeometric Analysis)
  - **Data driven techniques**: - *Supervised* (Machine/Deep Learning) - *Unsupervised* (Principal Component Analysis, Autoencoders)
- we employ **dimensionality reduction** and a **Bayesian optimisation** approach to reduce the design space's dimensionality and ease its exploration while reducing the number of required design evaluations. (not obvious how our method is linked with the approaches above)

Proposed Method

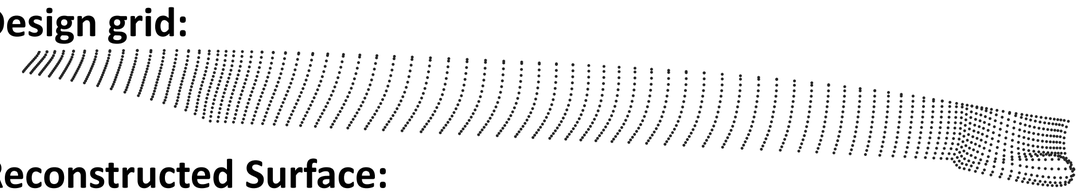
- Dimensionality reduction is performed on a discretised version of the shape modification vector.
- Design space is explored and exploited using the Bayesian approach to optimise the hull for wave resistance coefficient (C_w).
- Design during optimisation are evaluated using an IGA-BEM solver.



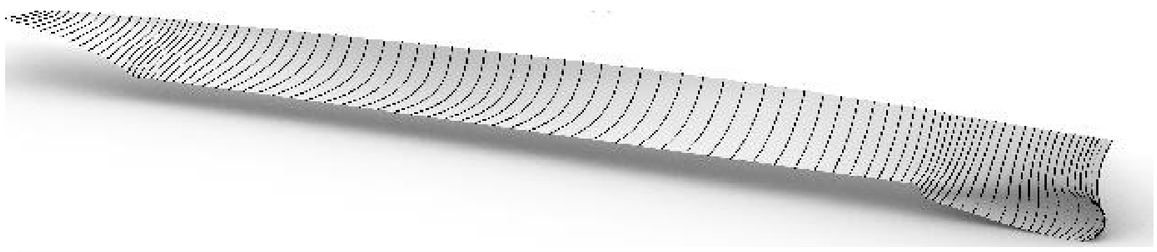
Design Reconstruction From Subspace

Design is reconstructed first by fitting NURBS curves along the grid sections and then filling the grid patches with Coons patches to obtain the surface.

Design grid:

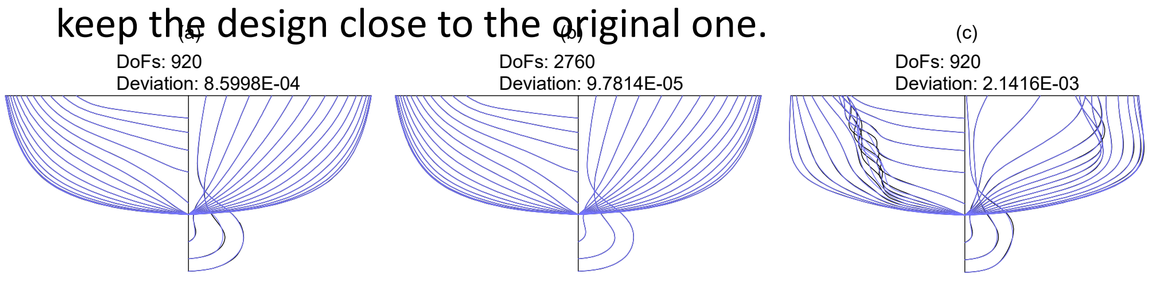


Reconstructed Surface:

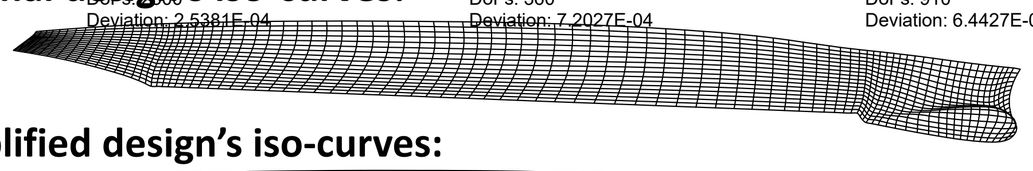


Surface Simplification

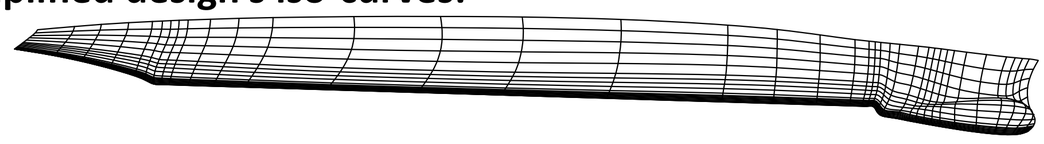
- Resulting NURBS approximation is composed of 7636 control points that is directly linked to degree of freedoms (DoFs) employed in IGA.
- Design evaluation with many DoFs is time-consuming.
- Surface is simplified to reduce the number of control points and keep the design close to the original one.



Original design's iso-curves:



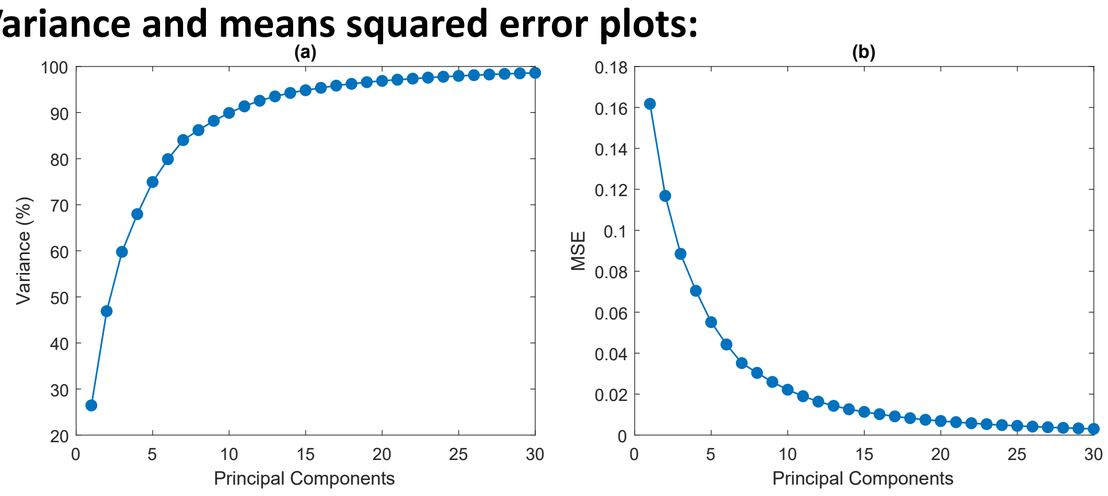
Simplified design's iso-curves:



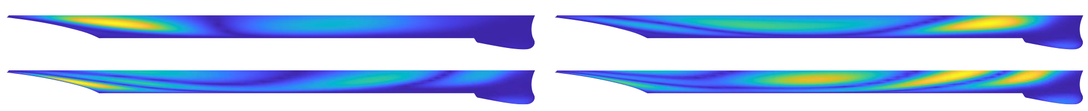
Results – Dimension Reduction

Dimension of the original design space reduced from 27 o 16-dimensions, while capturing 95% variance.

Variance and means squared error plots:

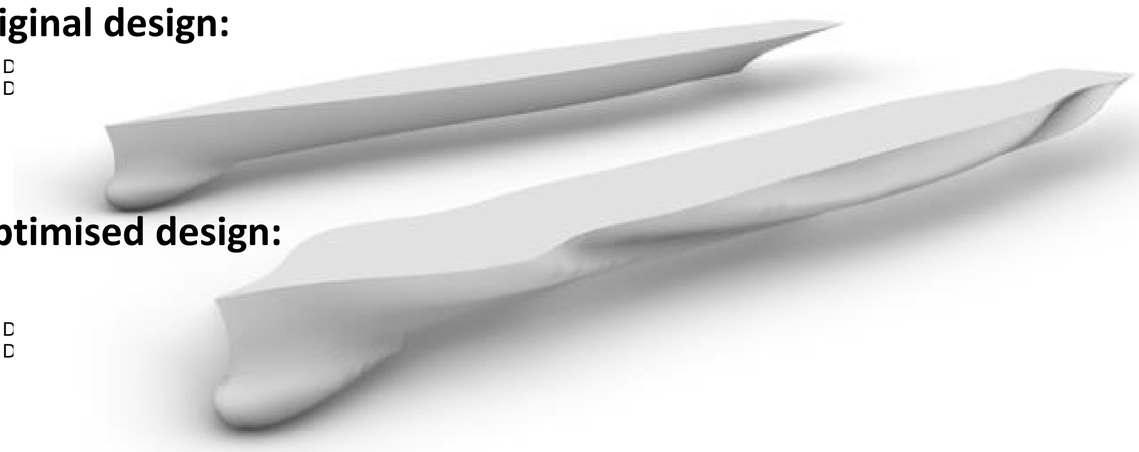


First four eigenvectors:



Results – Optimisation

Original design:



Optimised design:

- **C_w of original design: 8.099231E-03**
- **C_w of optimised design: 3.86351E-03**