SH.OP. - ROMs: SHip OPtimization with Reduced Order Methods

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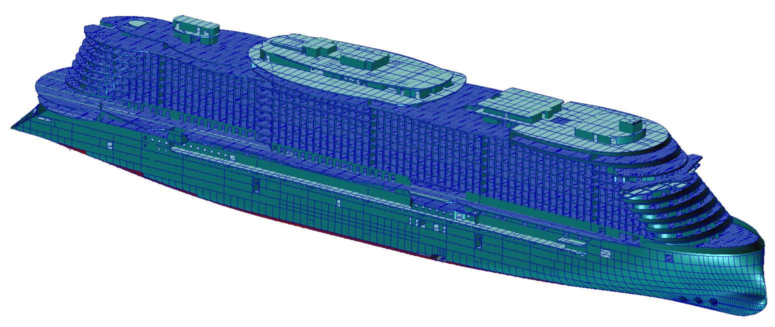
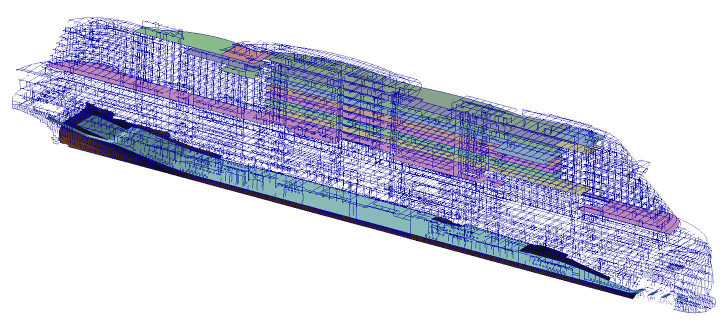
Introduction

The structural design process of cruise ships hulls aims to produce a configuration of pillars, crossbeams, steel panels and stiffeners which can sustain the loads from the hydrostatic equilibrium, extreme waves, equipment and cargo. The problem can be restricted to the choice of the steel panels thickness, in particular those which form the decks and longitudinal walls. Thicker panels have higher resistance to stress and thus deformation, but increase the weight and cost of the ship. It is of interest to minimize the usage of resources, while subject to the regulatory and industrial constraint on the hull response. The commercial solvers used for computing the hull responses do not implement a suitable optimization process. The SHOPROMs project aims to provide a non-intrusive surrogate-based optimization pipeline which can partially automate the initial phase of the hull design.

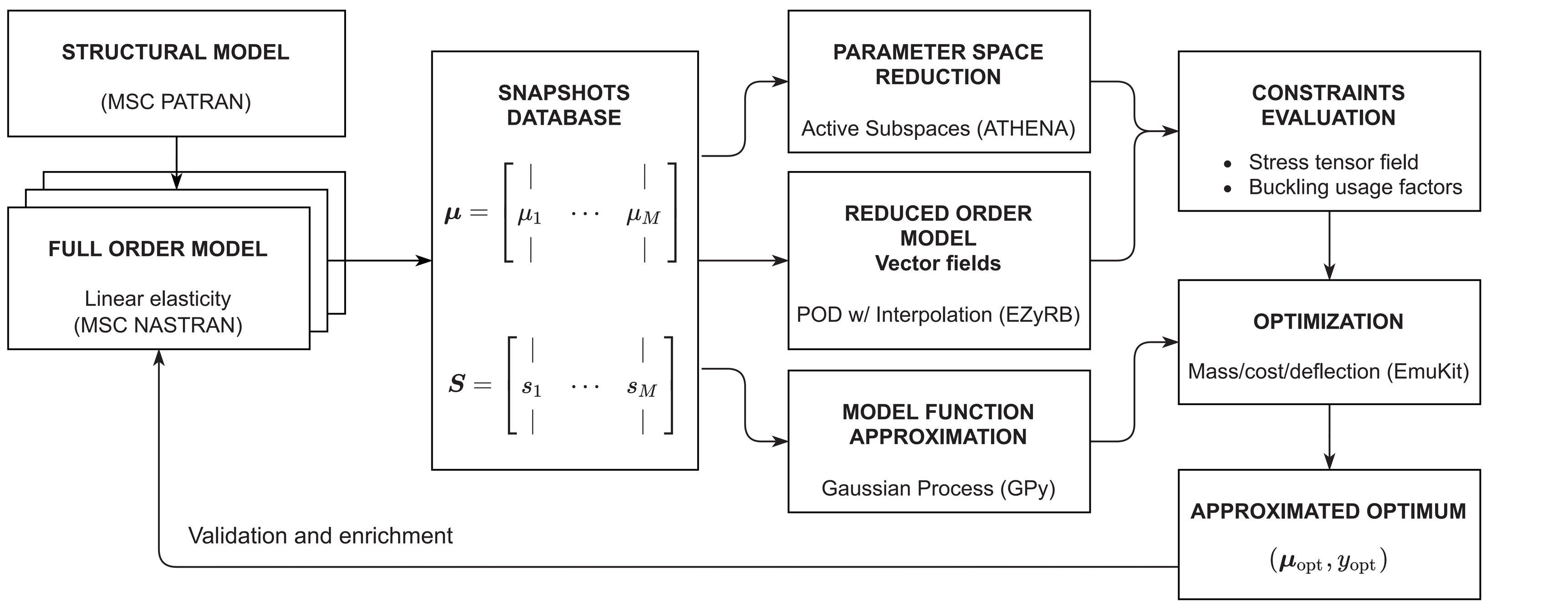
Pipeline overview

The pipeline life cycle is composed of:

- creation of the mesh, allocation of loads and parameterization of the panels

- surrogate models of the panels' structural response, using POD with interpolation
- Bayesian Optimization of the surrogate, subjected to various constraints
- selection of the next samples to enrich the database with
- regeneration of the surrogate models and reiteration until convergence

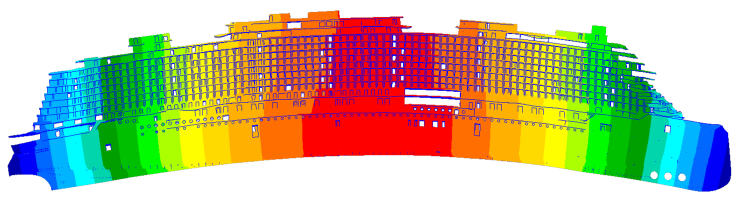
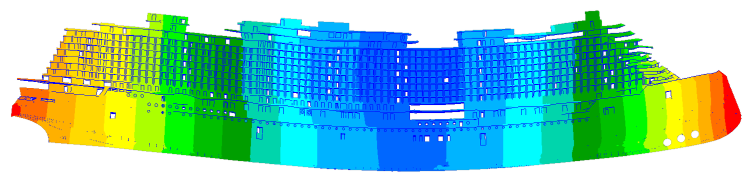


The automated pipeline has enabled the designer to greatly shorten the initial design phase of a uniquely shaped hull.

Surrogate modeling

Goals of a quasi real-time surrogate of the high fidelity commercial solver:

- retrieve the stress tensor of each panel of the hull, for each of two wave load conditions

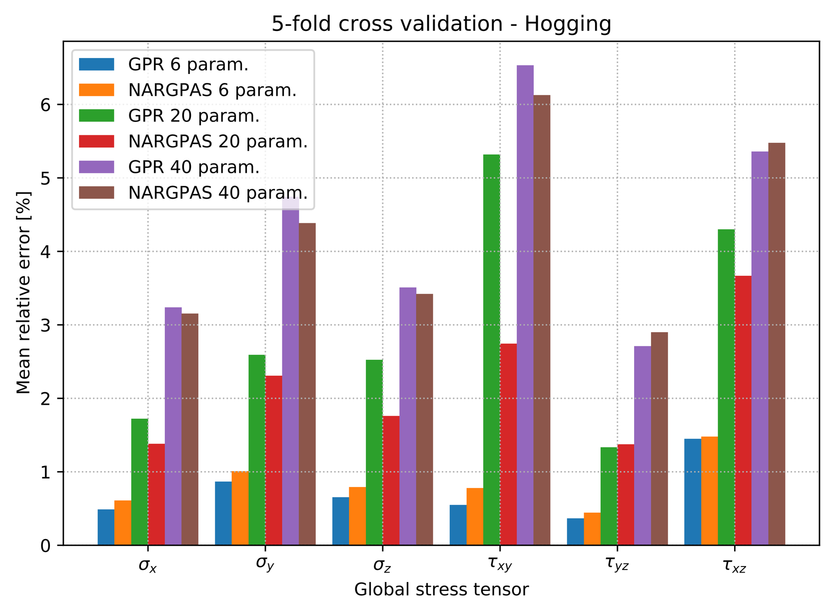
- compute the derived, nonlinear measures to find the number of yielded and buckled panels

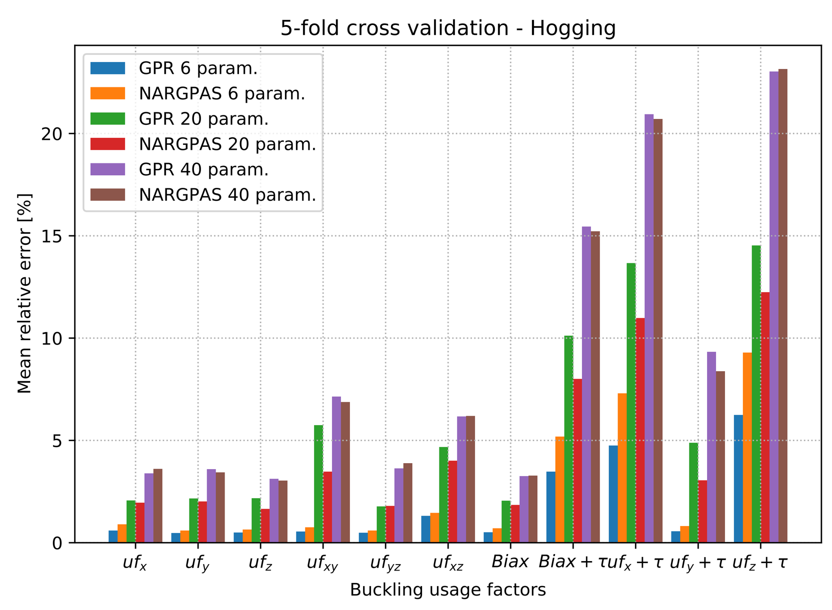
Non-intrusive Proper Orthogonal Decomposition

- SVD of the snapshot matrix, for each stress tensor component and load condition
- truncation of each modal matrix, based on singular values decay
- retrieval of the modal coefficients of each snapshot
- construction of a mapping from the parameter space to the modal coefficients

Two regressions techniques were employed:

- **Gaussian Process Regression**
- **Nonlinear Auto Regressive Gaussian Process with Active Subspace**
  - multi-fidelity predictor - low fidelity samples are retrieved by augmenting existing ones, without new simulations
  - in presence of an AS, deviations along inactive dimensions have negligible influence the observed function





Optimization

Objective functions and constraints

- discrete domain - feasible parameters configurations are restricted to commercially available panel thicknesses
- panels buckling is corrected by application of stiffeners, increasing mass and cost
- soft constraining of the number of yielded and buckled panels is integrated in the objective function through quadratic penalization
- mass and cost computations are dominated by a linear term - maintenance of a linear inequality constraint is crucial to search performance

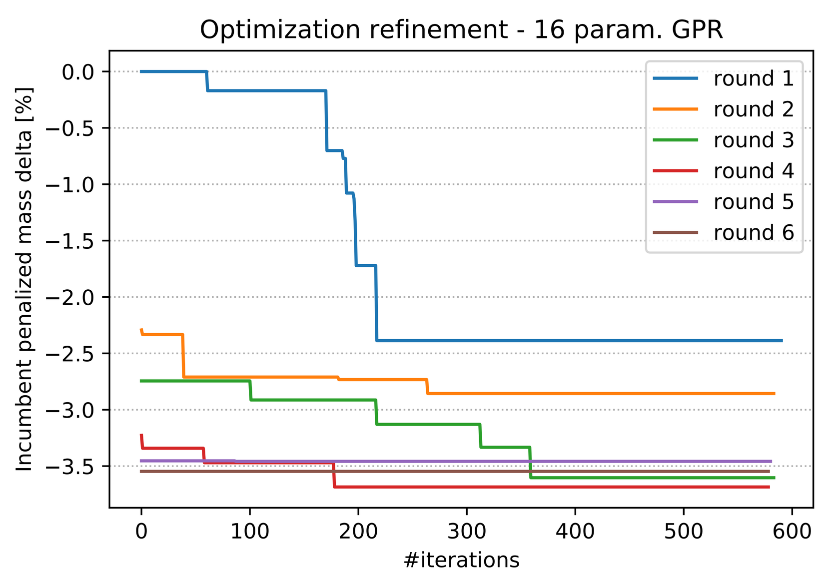
Bayesian optimization

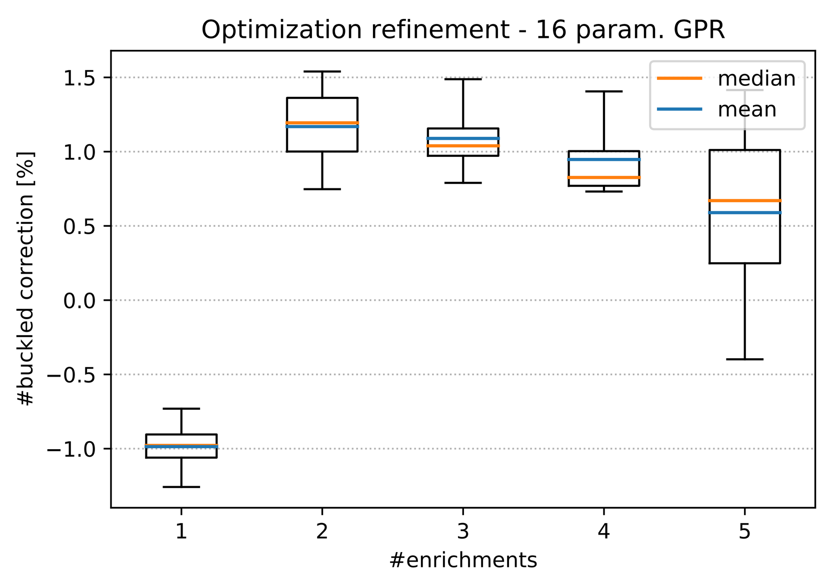
- suitable for black box, or expensive to evaluate, objective functions
- based on the construction of a probabilistic model of the objective
- optimizes an acquisition function, which scalarizes the objective and its uncertainty
- updates the model with the (actual) surrogate prediction, repeats until exhaustion of a computational budget

Convergence

As long as the optimization step finds a candidate optimum which has yet been processed by the high fidelity solver:

- from all evaluation in an optimization round, a small set of the best performers is selected for addition to the high fidelity database
- the surrogate model is refined in proximity of the optimum candidates, the accuracy increases
- BO's acquisition function balances exploitation and exploration, is able to escape local optima





References and Acknowledgements

[1] M. Tezzele, L. Fabris, M. Sidari, M. Sicchiero, and G. Rozza. A multi-fidelity approach coupling parameter space reduction and non-intrusive pod with application to structural optimization of passenger ship hulls. *arXiv preprint arXiv:2206.01243*, 2022.

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