

TOWARDS MODELLING COLD-WATER CORAL REEF CRUMBLING

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Introduction

The structural complexity of cold-water corals (CWCs) is threatened by ocean acidification [1]. Increased porosity in the *dead* skeleton and weakening of structurally critical parts of the reef framework may lead to physical collapse on an ecosystem scale, reducing their potential for biodiversity support [1,2]. The implementation of computational models into a predictive tool that allows us to determine risk of reef collapse remains missing, partially due to the lack of 3D information of CWC skeletal structure. Here, we investigate the limitations of homogenized models for *Lophelia pertusa* CWCs based on the morphological variations of *live* and *dead* skeletal structure to advance suitable mechanical surrogate models of their complex architecture.

Materials and methods

We performed computed tomography (CT) of $n=42$ *L. pertusa* *dead* and *live* skeletal fragments. We segmented CWC skeletons and branches (Fig 1a) and quantified the morphology of (i) CWC colonies and (ii) skeletal branches to (i) explain how CWCs occupy the space and (ii) characterize the branching structure of *L. pertusa*. We used the FE method to determine the size of a representative volume element of CWC skeleton that allow us to use a mechanical homogenization approach. We created 64 FE models (edge lengths 11.5 to 3.4 cm) from two CWC specimens and 217 FE models from a mirrored (periodic) CWC structure (edge lengths 22.5 to 4.5 cm). We used isotropic hexahedral linear elements ($E=65.7\text{GPa}$, $\nu=0.29$ [2]), kinematic boundary conditions, and six independent load cases to derive the stiffness tensor, \mathbb{S} , via the apparent stresses and strains [3]. Then, we analyzed the size dependency of the elastic symmetries and properties of the structure through an optimization procedure where the best orthotropic representation of \mathbb{S} , \mathbb{S}^{OPT} , was found [4]. The accuracy of the orthotropic assumption was quantified using Eqn. (1), where \mathbb{S}^{ORT} is the orthotropic representation (i.e., off-axis terms $\rightarrow 0$) of \mathbb{S}^{OPT} .

$$\text{Err} = \sqrt{\frac{(\mathbb{S}^{\text{OPT}} - \mathbb{S}^{\text{ORT}}) :: (\mathbb{S}^{\text{OPT}} - \mathbb{S}^{\text{ORT}})}{\mathbb{S}^{\text{OPT}} :: \mathbb{S}^{\text{OPT}}}} \quad (1)$$

Results

Live CWC fragments showed greater surface area to volume ratio and a more compact structure compared to *dead* specimens. Skeletal branch morphology was highly variable, with *dead* CWC framework branches shorter and thicker than *live* specimens. The error of the orthotropic approximation of \mathbb{S} decreased with increasing specimen size and converged to $<3\%$ at ~ 9 cm edge length (Fig 1b). Volume elements >13 cm showed $\text{Err} < 1.5\%$ and reduced variability.

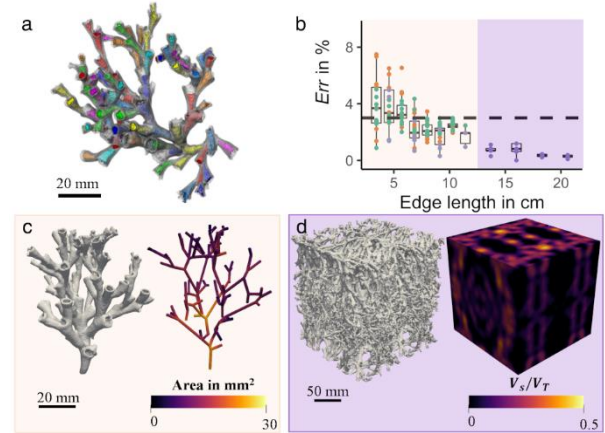


Figure 1: (a) Segmented CWC skeleton and branches (b) Error of orthotropic approximation of *L. pertusa* CWC skeletal structure. (c-d) Realms of mechanical surrogate models for *L. pertusa* CWC. (c) Modelling small colonies need to account for morphological variability of the structure whilst (d) large colonies may be modelled using homogenized finite element models based on skeletal volume fraction (V_S/V_T).

Discussion

We observed large morphological variations between *dead* and *live* *L. pertusa* colonies and branches. We determined a critical size of ~ 13 cm from where homogenized models of *L. pertusa* skeletons at the structural level may be used, which corresponds to ~ 5 times the mean interbranch spacing. This is in line with other heterogeneous structures, such as trabecular bone [5]. We identified possible surrogate models to represent the branching structure of *L. pertusa* CWC (Fig 1c,d). For length scales >13 cm, a continuum finite element mechanical approach can be used to analyse mechanical competence whereas at smaller length scales, mechanical surrogate models need to explicitly account for the statistical differences in the structure. Current work is undergoing to implement these models for a CT database of >300 CWCs from 1 cm to 30 cm. This will allow us to scale up the analysis to entire reef systems to investigate reef crumbling due to the time CWCs are exposed to acidified waters.

References

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