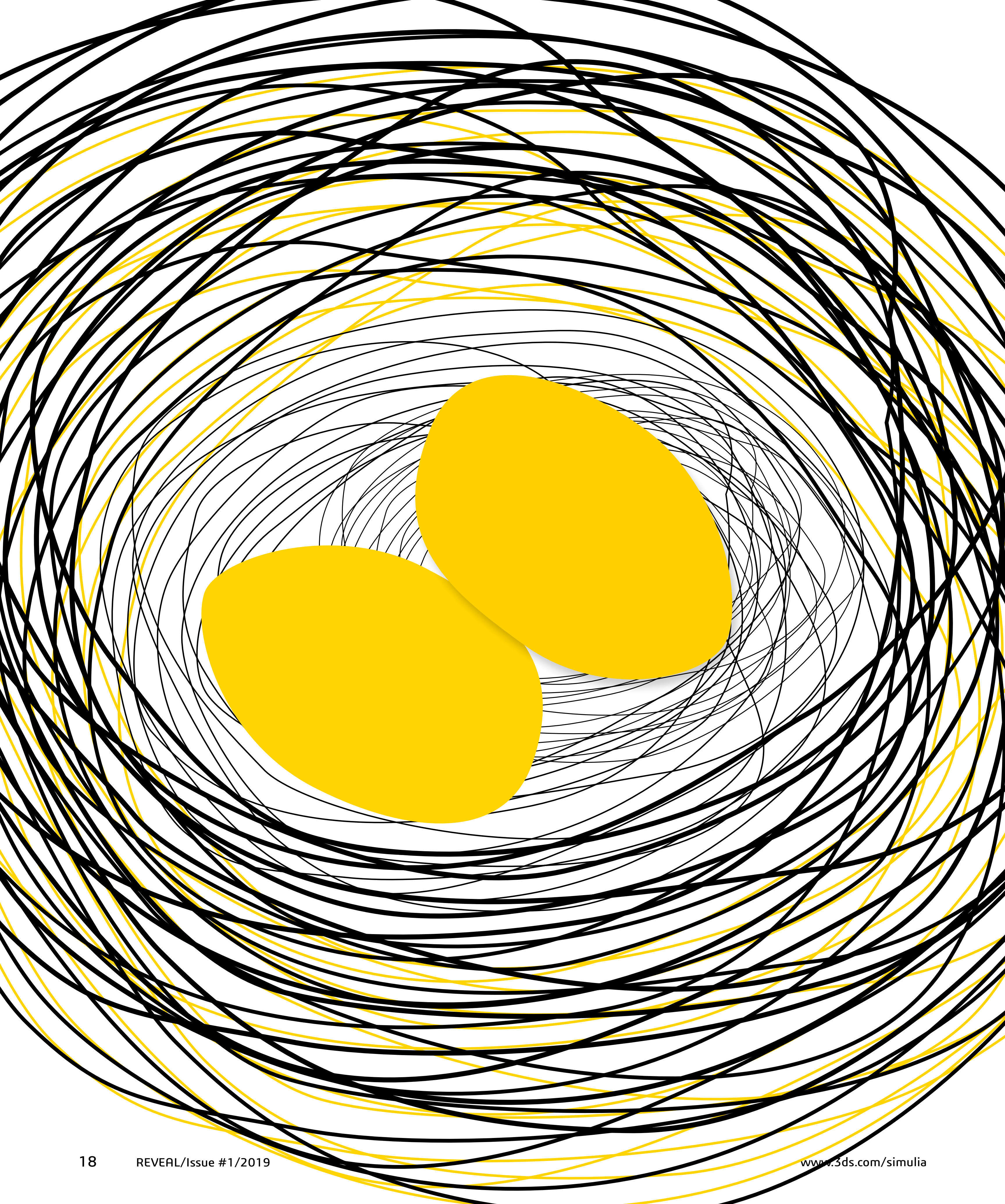


# LEARNING FROM AVIAN NESTS

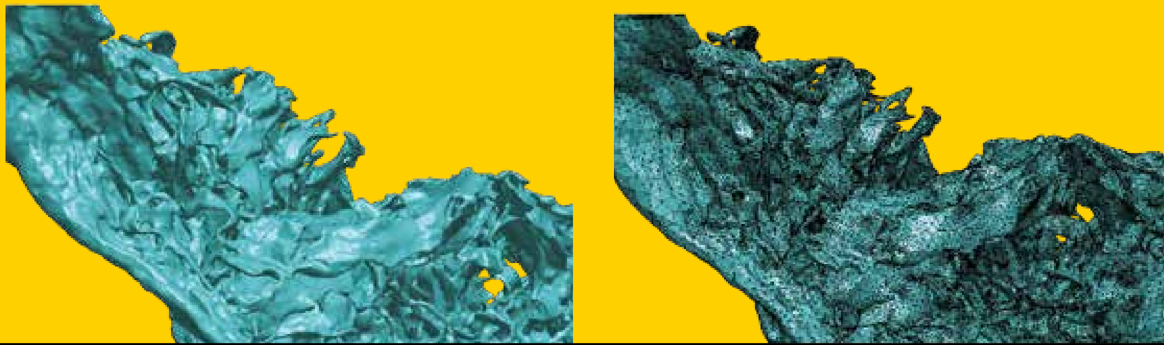
## Synopsys Simpleware Used to Gain Insights into Biomechanical Design

Bird nest construction offers valuable design insights, with similarities to Additive Manufacturing in terms of control over structural features and layering of materials. Edible-nest swiftlets create nests from their own threaded saliva, allowing them to closely follow design principles at a high resolution. The work described below looked at how material properties in nests integrate with structural designs, using numerical models processed in Synopsys Simpleware™ software from µCT data and Finite Element (FE) simulation of stress distributions in SIMULIA Abaqus. Results demonstrated remarkable consistency between macro and micro-scale structural patterns in nests, suggesting that a response to applied loads relies on an overdesign strategy to avoid fracture of important regions used to store swiftlet eggs.

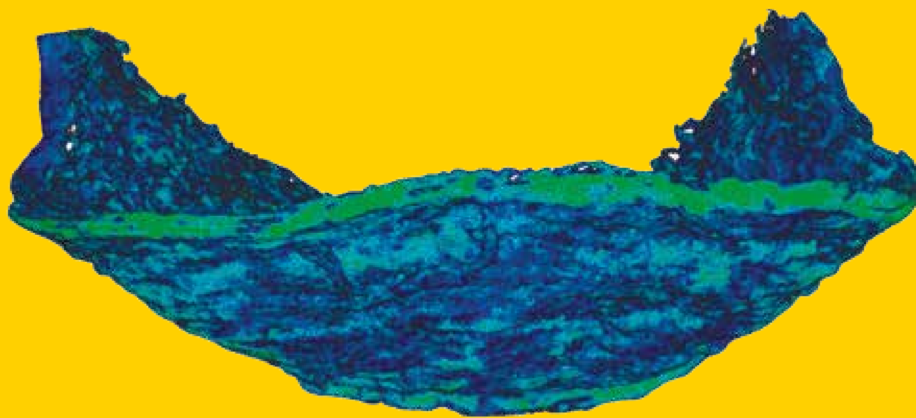
### HIGHLIGHTS

- Robust models in Simpleware software enable detailed capture of nest microstructure from µCT
- FE meshes from Simpleware software offer excellent quality for realistic simulation
- Simulation results in Abaqus provide insights into biomechanics and design strategies
- Generating Models in Simpleware Software

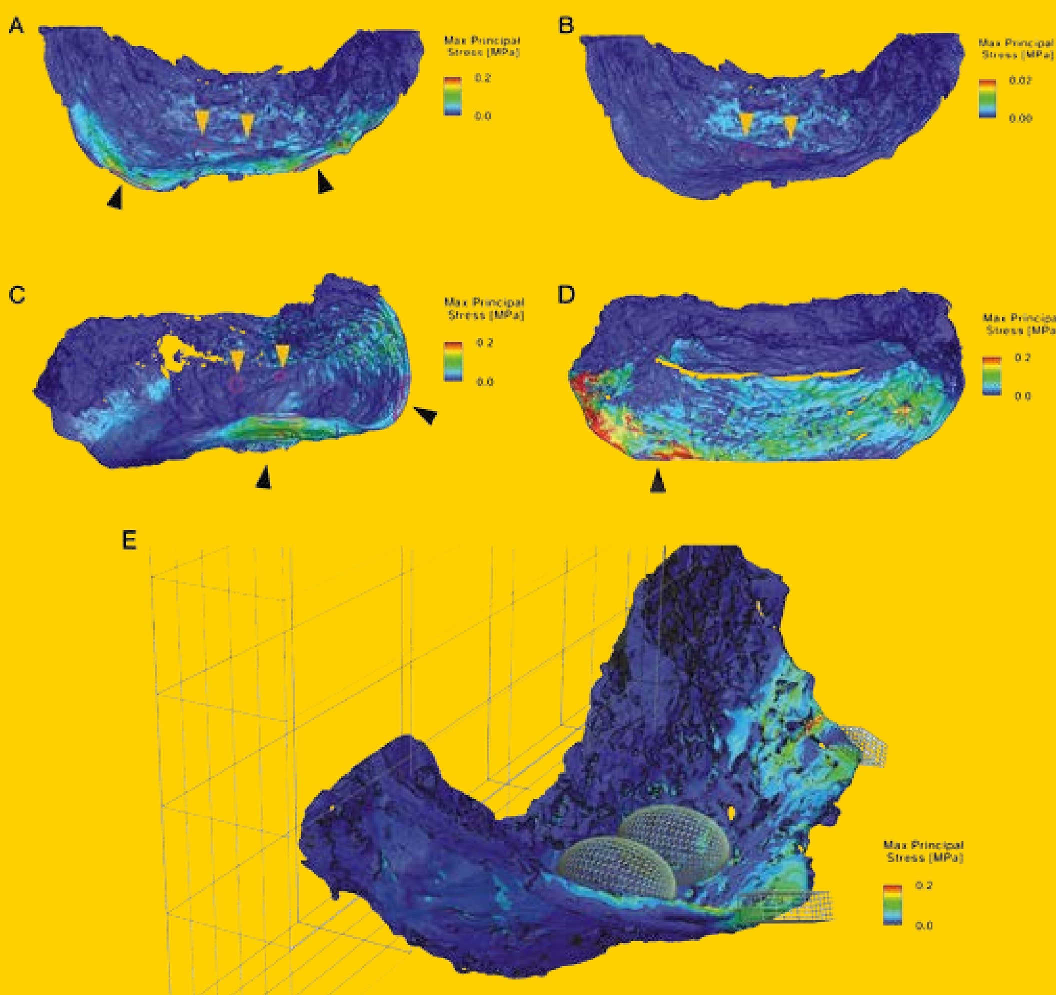
To carry out the work, five swiftlet nests were obtained from a commercial farm and scanned using a SkyScan 1176 high-resolution uCT (SkyScan, Aartselaar, Belgium) machine. The µCT data was imported into Simpleware ScanIP to visualize and segment regions of interest. The image data was resampled for efficiency, with regions of interest segmented from the background data. Artifacts and noise from µCT data were corrected—thresholding segmented the nest, excluding background noise. The flood-fill tool was used to remove non-connected mask artifacts, and a recursive Gaussian filter applied to reduce image noise and detail level. Closed pores with less than 125 voxels were selected and added to the mask to reduce computational time and increase the quality of the generated elements.



Simpleware software segmentation and FE mesh of birds nest showing level of detail



High-resolution FE mesh of the nest from the 3D model using mechanical measurements, with color scale showing different material densities




FE simulation results showing maximum principal stress at each linear static loading scenario (A,C,E), as well as worst case loading scenarios (A-D)

Morphometric parameters of the whole nest were calculated using Simpleware ScanIP measurement and statistics tools, including: mass density, the volume of the nest, nest surface area, and pore analysis. Measurements were taken of a segmented mask for the nest and a separate mask for the closed pores. A slice-by-slice script was written for slicing the masks in yz, xz and xy coordinate planes. The data of the pore and nest masks were analyzed in every slice, and a multi-label mask generated of the closed pores. This mask was created to interactively visualize and analyze the pore mask containing several regions, for example scattered pores in between the saliva strands. The pore multi-label mask was obtained by labelling disconnected regions within the pore mask, assigning each region a separate color.

## EXPORTING FE MODELS FOR SIMULATION

High-quality FE meshes showing microstructure features were generated in Simpleware software for simulation of different loading scenarios. The FE Free meshing algorithm was used to ensure high geometric accuracy of the highly detailed nest microstructure, with a true representation of porosity in the structure. The meshes were smoothed and exported as all-tetrahedral FE models containing approximately 5 million elements with a mean edge length aspect ratio of 4-5 and a mean in-out aspect ratio of 0.8-1.

Contact entities and node sets were defined in the software before exporting a mesh in a dedicated Abaqus solver, with the node sets selectable in the solver for applying boundary conditions and loads. Material properties for strains and stresses were obtained using in-situ uniaxial tensile testing through scanning electron microscopy.

## SIMULATING STRESS AND STRAIN

In Abaqus (6.14), the FE meshes were modeled using the material properties from the tensile test data. Input data was set up following the nominal stress-strain curve, as well as a linear elastic model to account for small deformations. The material was assumed to be isotropic at the fiber level, where structural anisotropy is arising due to the geometric arrangement of the fibers as captured from the μCT scans. Simulations assumed a worst-case scenario with two birds and two eggs applying body forces (gravity), with additional testing being performed with just the eggs to compare results.

Loading areas predefined in ScanIP contained a certain number of nodes, including two defined areas on the rim where the force of a bird is applied and two areas where the force of an egg is applied to the center of the nest. For each FE model of the nest, the node sets in the geometrical locations where the nest is in contact with the wall, were constrained as fully pinned (zero displacements in all directions), when calculating stress and strain distributions. FE simulation results showed maximum principal stress at the end of each linear static loading scenario. The central 'egg-region' experiences lower values of stress, allowing for protection of the anchoring region.

## CONCLUSIONS

The edible nests created from saliva show a remarkable similarity in macroscopic (weight, shape) and microscopic (pore area and distribution) properties, suggesting that nests are constructed by the species using specific design principles. The studied nests also indicate that they were constructed with the goal of supporting two birds and two eggs. Management of peak stresses ensures an optimized structure that successfully bears stress levels without fracturing the nest when carrying eggs and birds.

Taken further, the study shows how a single material, distributed properly across a specific structure, can create a sustainable and resilient structure. These design principles from animal-made structures provides insight into how complex structures can be built using only local or self-produced materials, sharing commonalities with Additive Manufacturing techniques.

**For More Information**
www.synopsys.com/simpleware.html