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Conceptual Design of a 3D Printed Wood–Plastic Composite Boat

Finite element analysis and homogenization of a stiffened hull

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Background & Project Motivation

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- Goal: Replace wooden or composite boats with recyclable PP–wood composite boat.
- Manufacturing of wooden boats require high quality timber and laborious construction.
- Manufacturing composite (thermoset matrices) boats requires a lot of hand labour, boats are not easy to recycle
- Large scale additive manufacturing enables automated production with less waste.
- Structural analysis is needed to design with the such composite.

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Material and Manufacturing Process

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Material: Polypropylene (PP) reinforced with wood flour (bio-based pellets).

Manufactured using pellet-fed large-scale extrusion (FGF).

Robotic arm prints continuous beads layer by layer to form hull geometry.

Cooling rate, bead geometry, and print speed influence the mechanical properties.

The process creates anisotropic material.

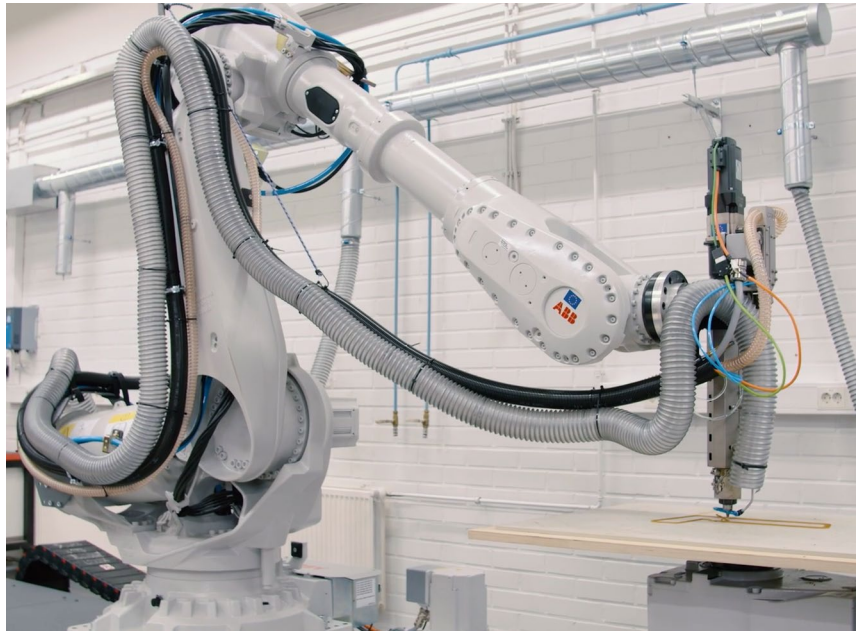

Photo J. Hanhiniemi

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Material Testing

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- Tensile coupons were cut from a 3D printed box.
- Tensile tests in the 0° and 90° directions (ISO 527-2).
- Layer stacking direction: strength 3.5 MPa; modulus 530 MPa.
- Print Direction: Strength 15 MPa; modulus 1070 MPa.

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Boat Structural Concept

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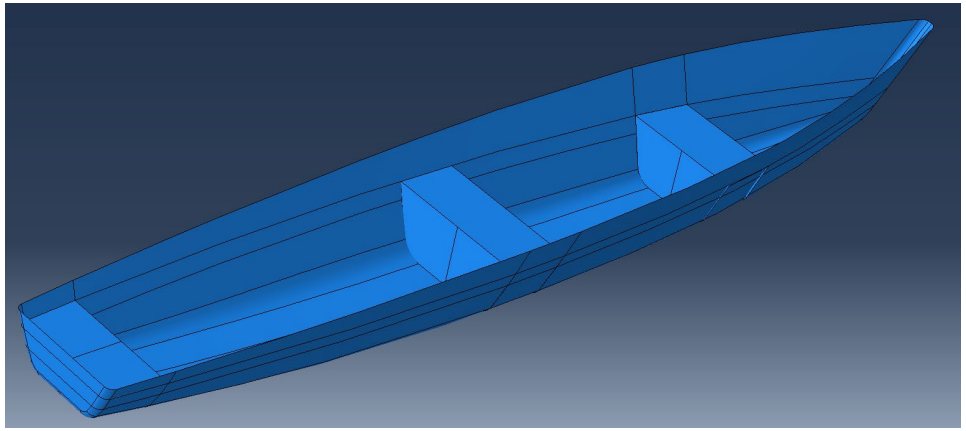
- Boat dimensions: 10 × 2 × 1.2 m.
- Sandwich like hull with a corrugated core:
  - Outer and inner plates
  - Longitudinal webs and flanges
- Stiffener number and spacing can be varied in the model.
- Benches provide transverse strength.



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Homogenization Method

- Explicit modelling of every web and flange is computationally expensive.
- Homogenization provides equivalent stiffness for rapid design iterations.
- The hull is represented as a five-layer laminate:
  - Outer plate and inner plate
  - Homogenized webs and flanges
- The rule of mixtures scales stiffness and density.

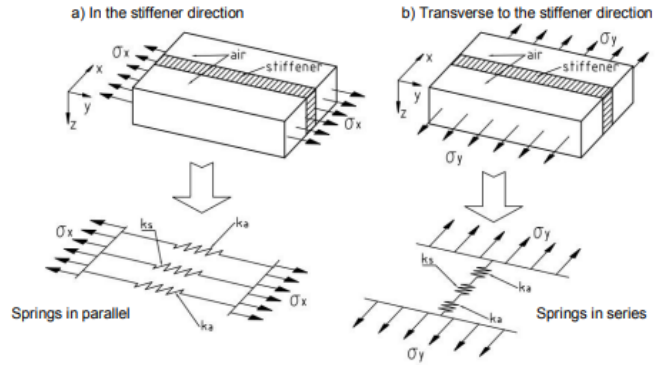
Layer	E_1	E_2	ν_{12}	G_{12}	G_{13}	G_{23}	Density
layer	1	2	12	12	13	23	
plate	535	1070	0.3	200	200	200	1.08E-09
bottom web	72.8				27.2		2.45E-10
bottom flange	303				113		1.02E-09
side web	101				38		3.43E-10
sideflange	318				119		1.07E-09

Method based on Avia & Romanoff (2013)

Web and flange layer elasticity

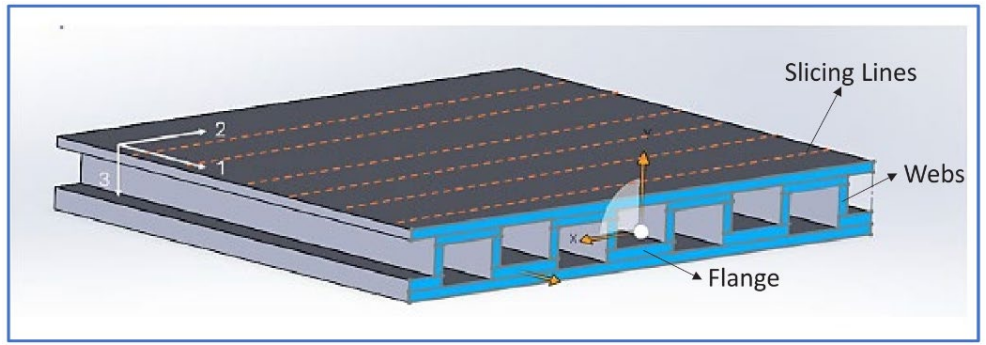
$$[E]_w = \frac{t_w}{s}\begin{bmatrix} E & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$[E]_f = \frac{b_f}{s}\begin{bmatrix} E & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$



$$G_w = G\frac{t_w}{s},$$

$$G_f = G\frac{b_f}{s}.$$



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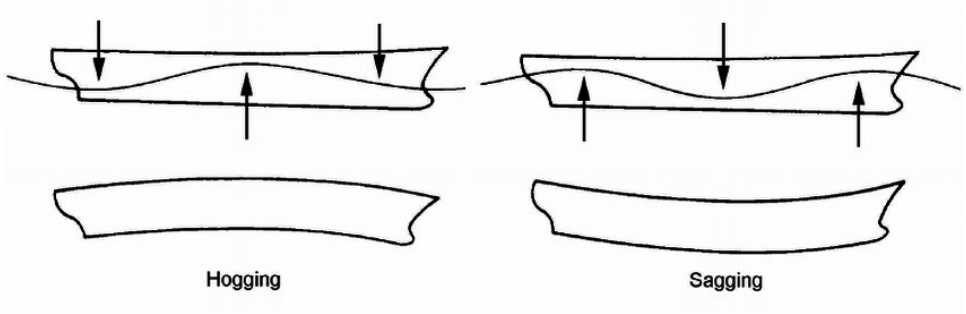
Loading Conditions

- A boat encounters several load cases:
  - Global bending: hogging and sagging
  - Torsion from asymmetric waves
  - Horizontal loads in turns and side waves
  - Slamming against the water surface
- **Slamming** was the main design load considered for this small boat.
- Slamming pressure was calculated using ISO 12215-5.
- Bottom pressure: 30.49 kPa.
- Side pressure: 12.67 kPa.
- People, batteries, motor and roof contribute about 1.1 tonnes of distributed payload.



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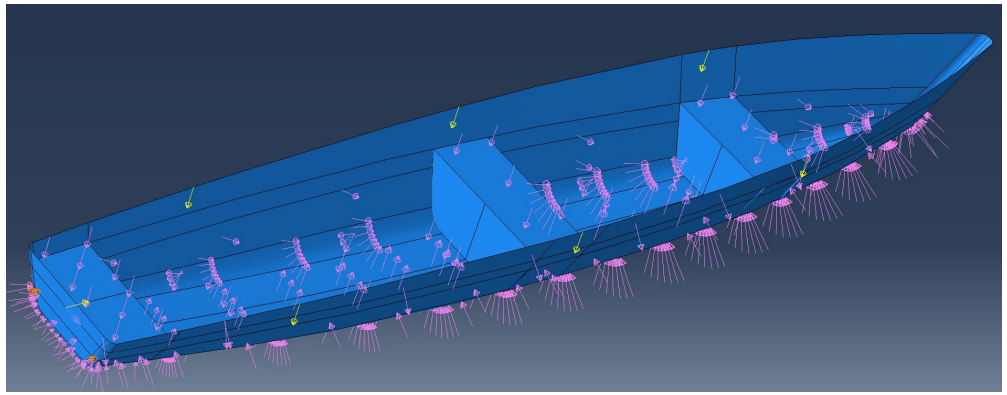

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Boundary Conditions

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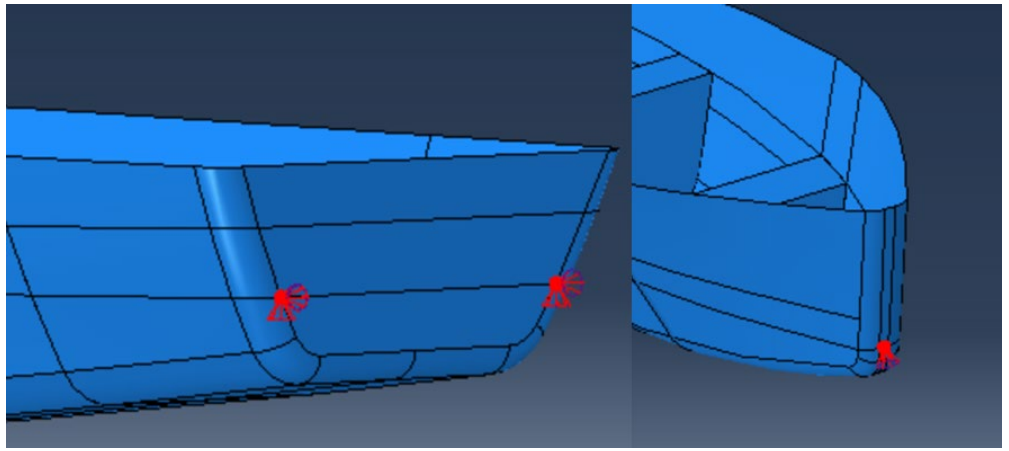
- Minimal constraints remove rigid body motion:
  - Node A: U1, U2, U3 = 0
  - Node B: U2, U3 = 0
  - Node C: U3 = 0
- Nodes A and B are at the transom; C is at the bow.
- Inertia relief also allows a free structure representation.



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Orientation and Meshing

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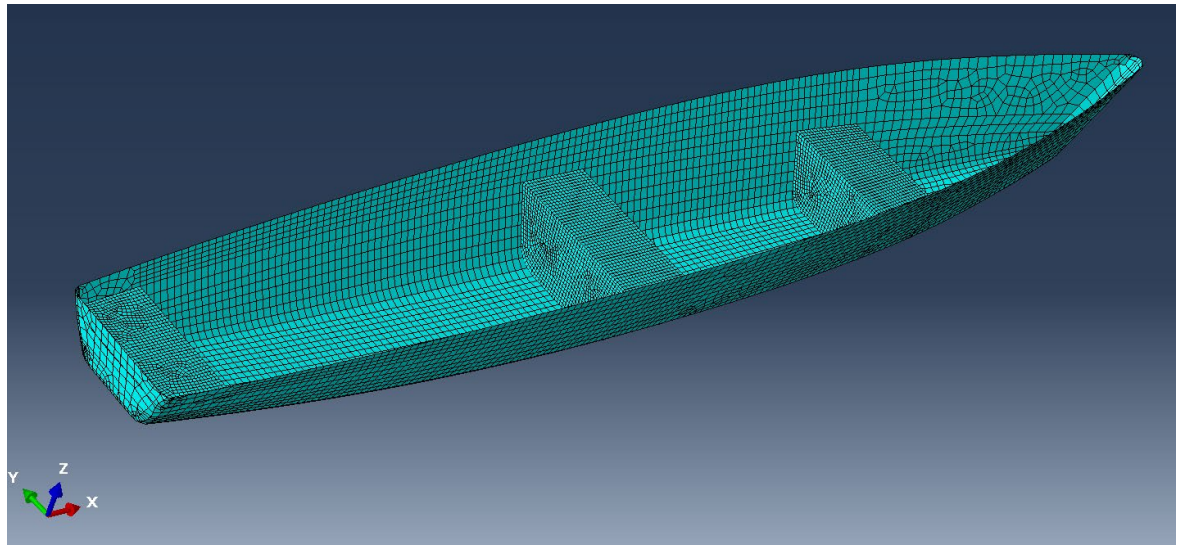
- Material orientations were aligned with the global axes.
- The mesh size was smaller than the stiffener spacing.
- Different orientations and properties were assigned to the transom, bow, bottom, sides and benches.
- Static analysis was used.



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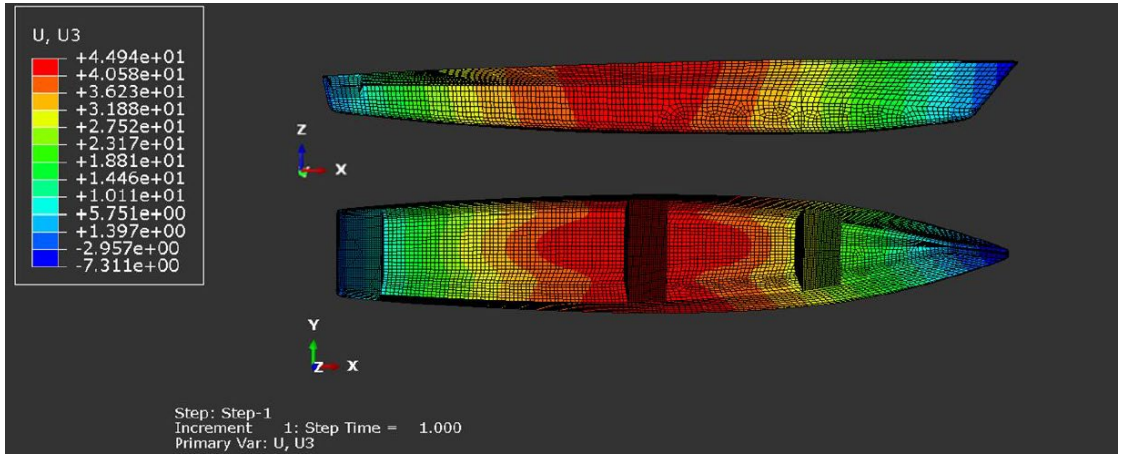
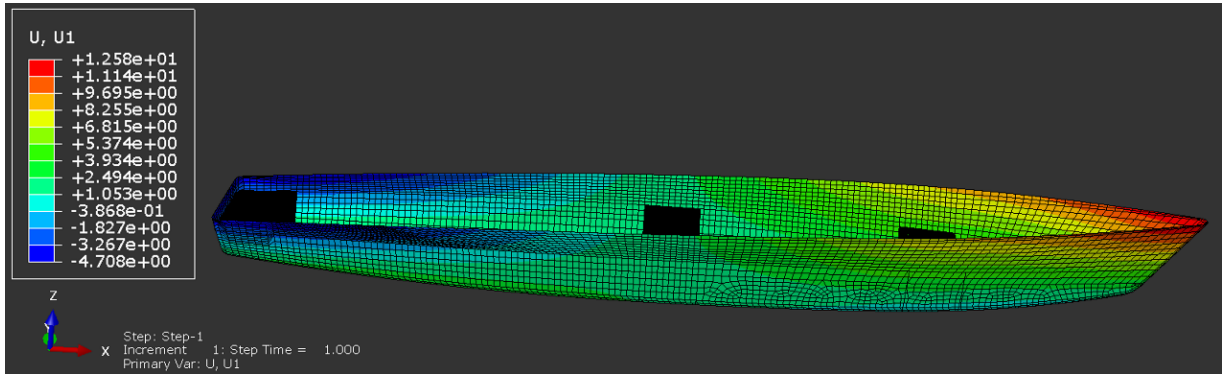
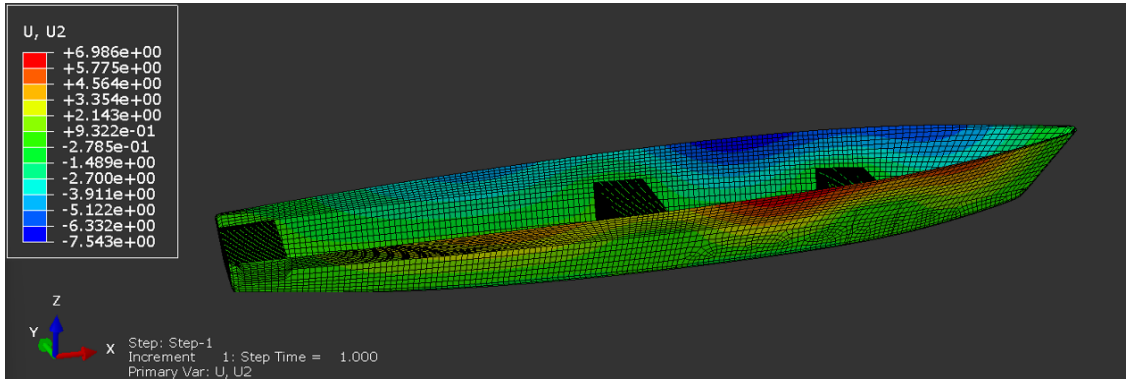
Deformation Results

- Overall deformation was acceptable at this design stage.
- More flexible regions appeared near midship and between wider spaced webs.
- These regions are candidates for detailed modelling.







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Design benefits and Care

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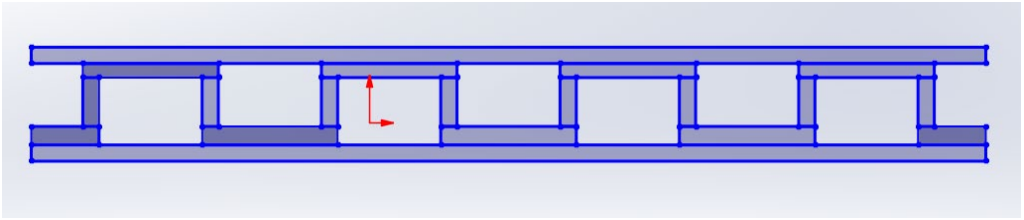
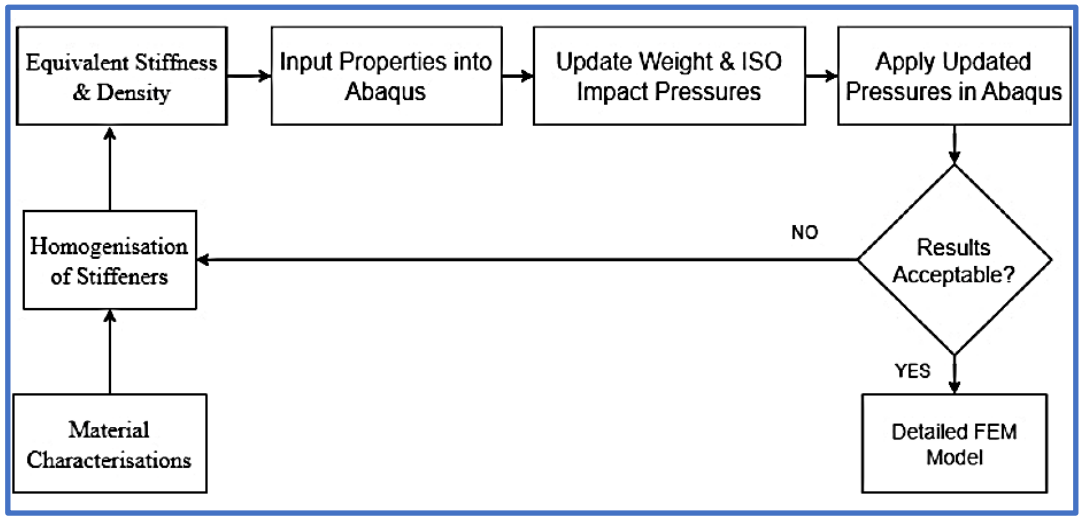
- The global model supports quick changes to web count, spacing, thickness and flanges.
- Each revision gives immediate feedback on global deformation.
- It also provides an estimate of boat weight.
- Homogenization must be applied and interpreted carefully as Equivalent stiffness is approximate and local stress values are removed.
- Homogonization is most useful for evaluating global deformation.
- Manufacturing, testing and finite element analysis must be linked.





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Thank you

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