WESEP International Experience

Computational blade design at Denmark Technical University (DTU) and Braunschweig University of Technology (TU Braunschweig)

Austin J. Herrema

Iowa State University

Wind Energy Science, Engineering, and Policy Program (WESEP)

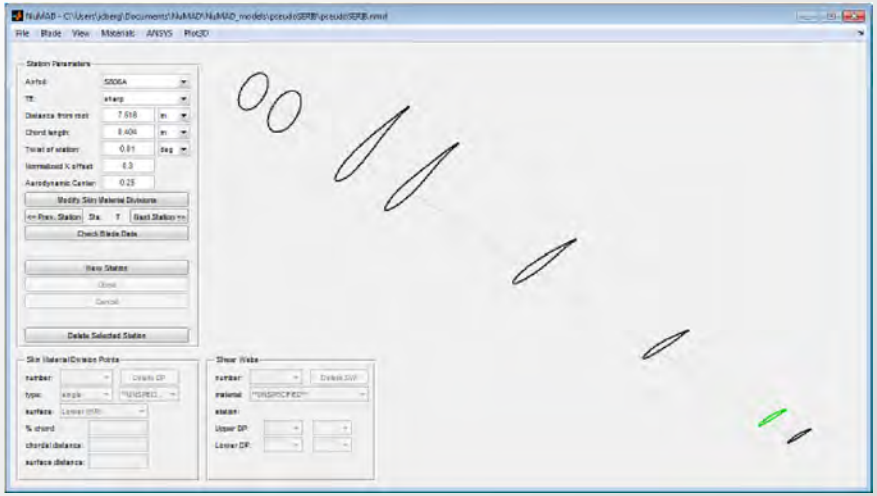
Mechanical Engineering

WESEP 594 Seminar, 20 September 2016

RESEARCH BACKGROUND

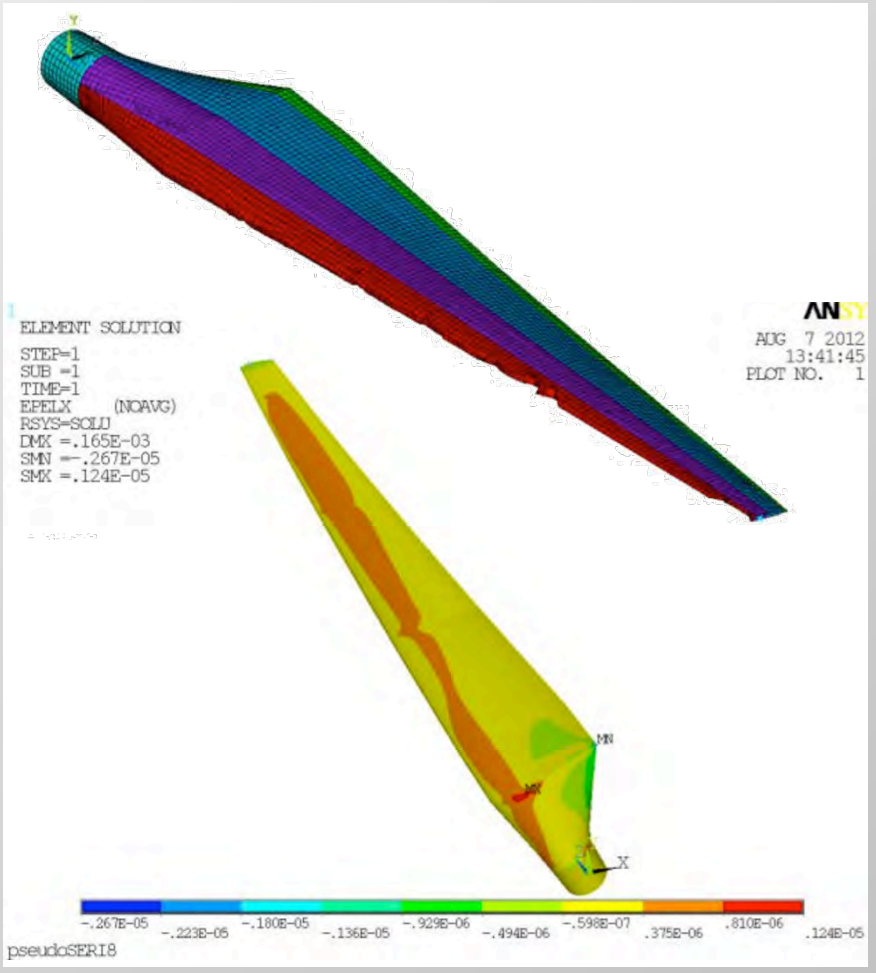
Geometry Model

NuMAD: Sandia National Labs

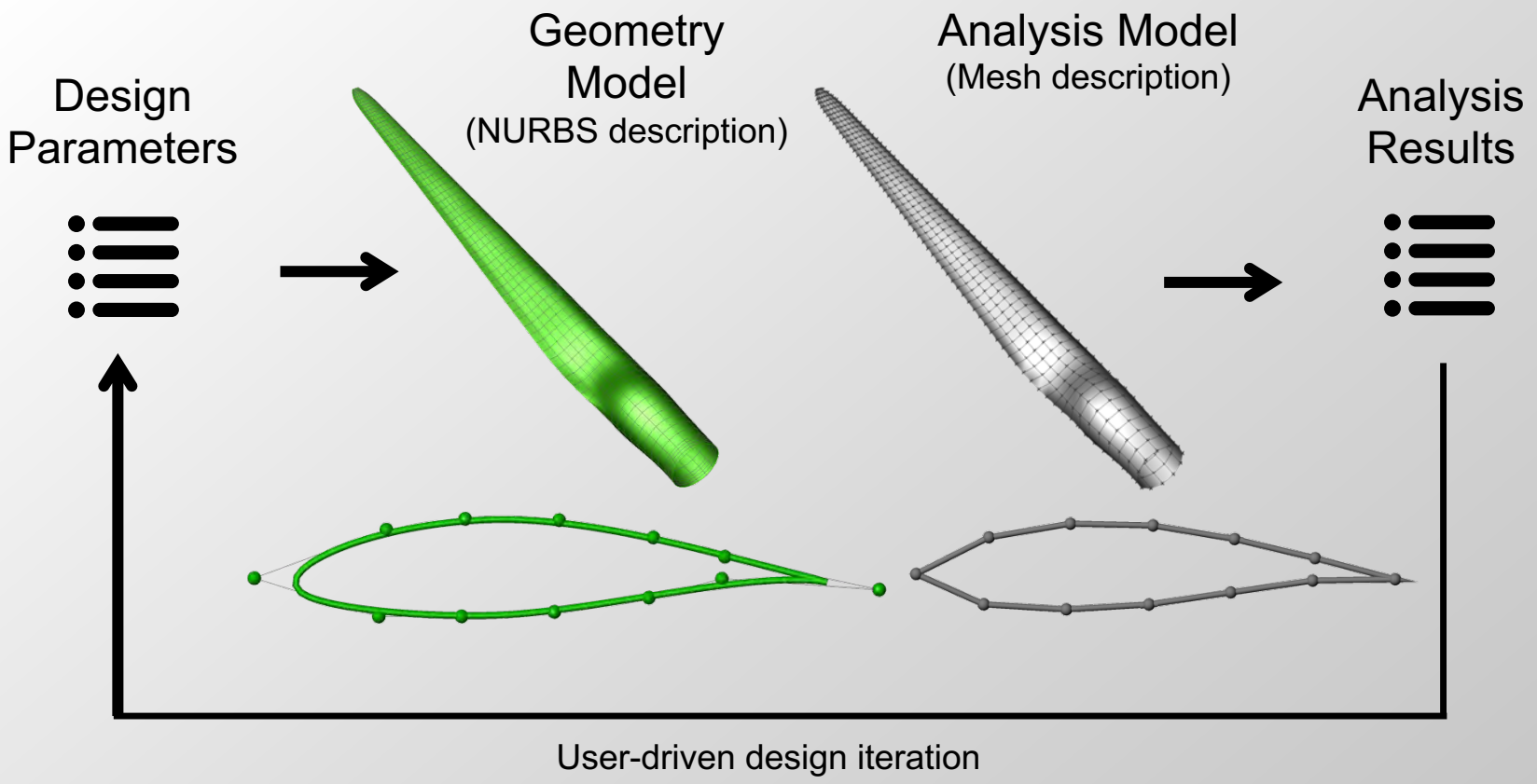


Finite Element Analysis

ANSYS



RESEARCH BACKGROUND



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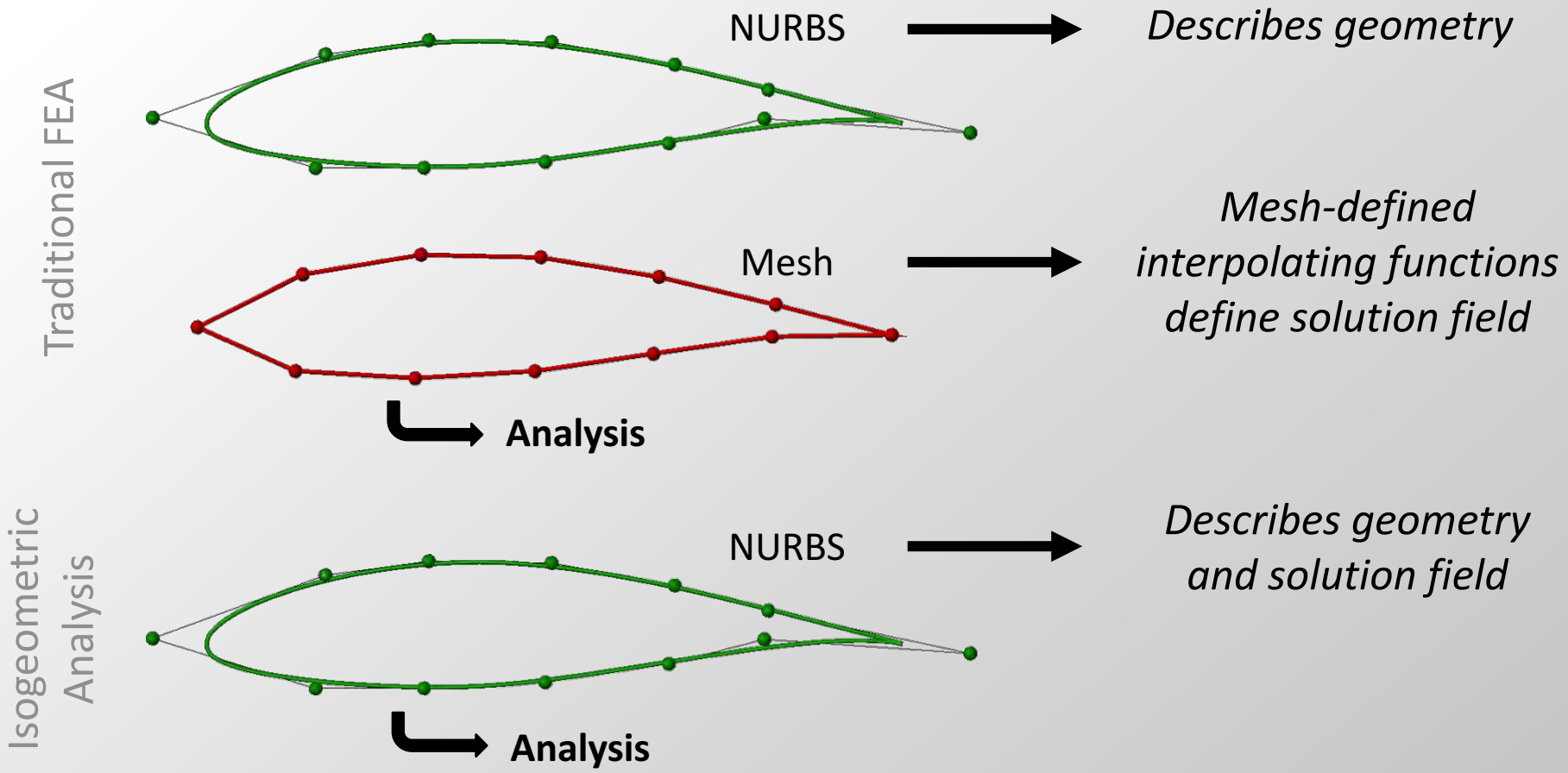

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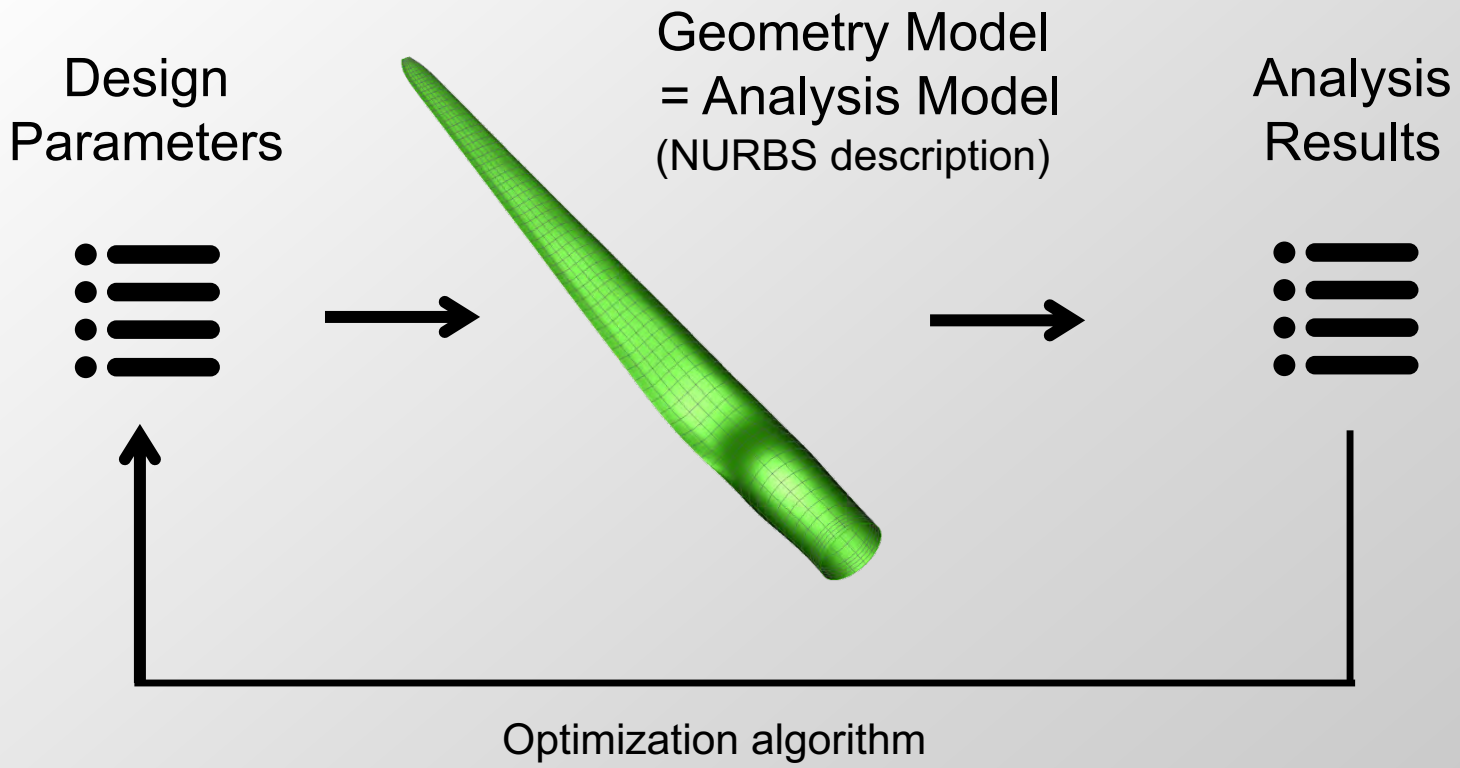

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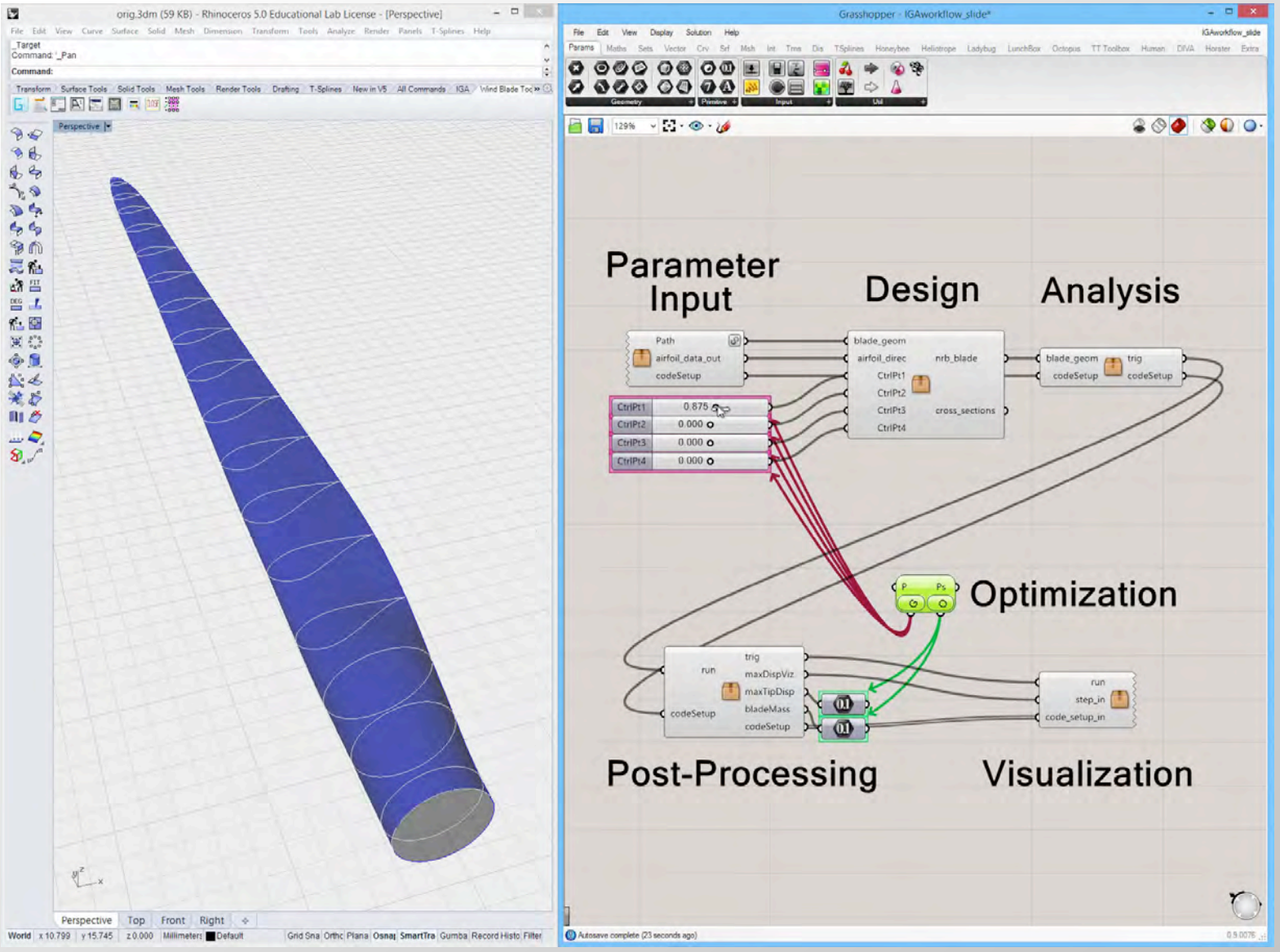

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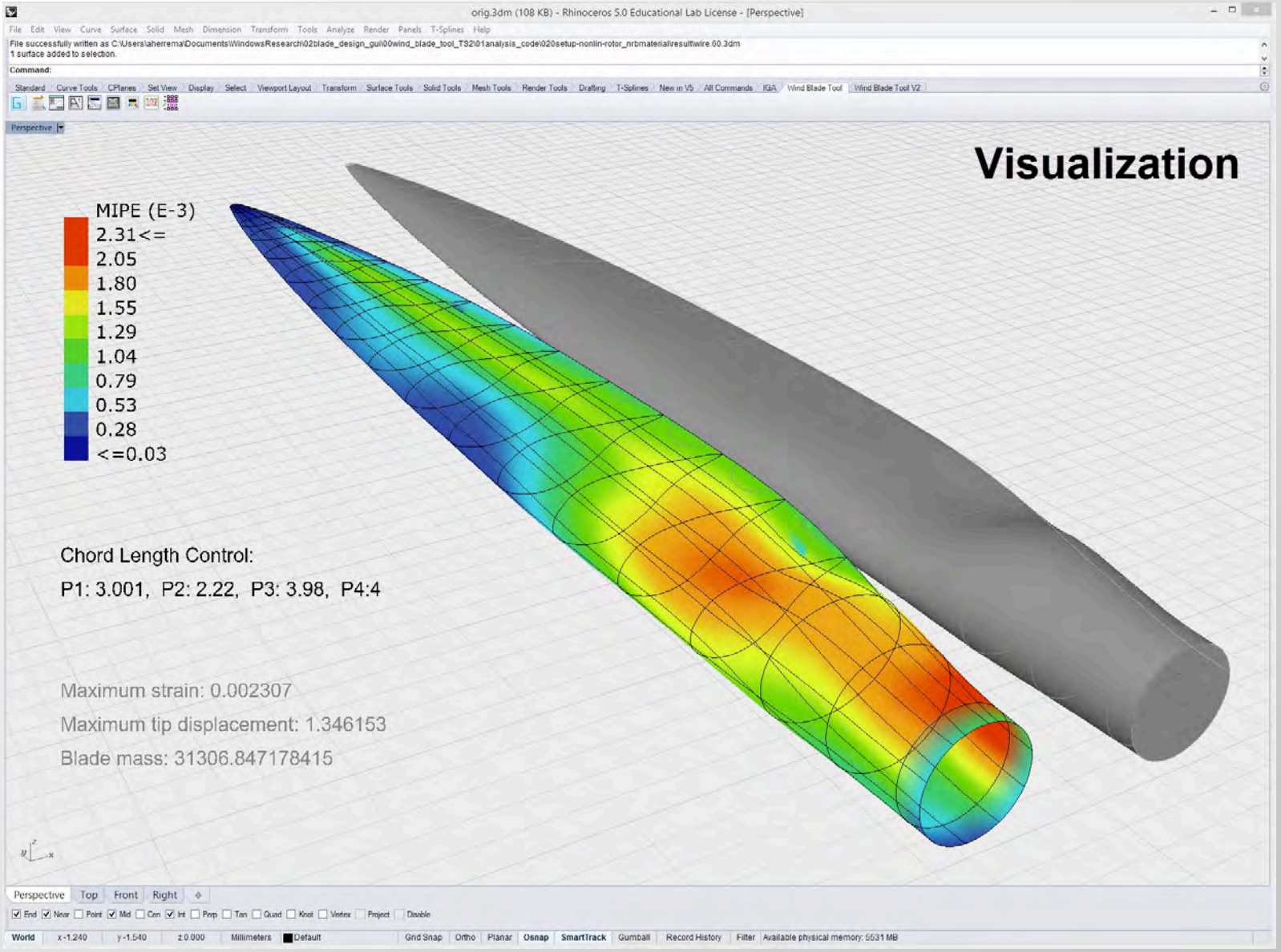

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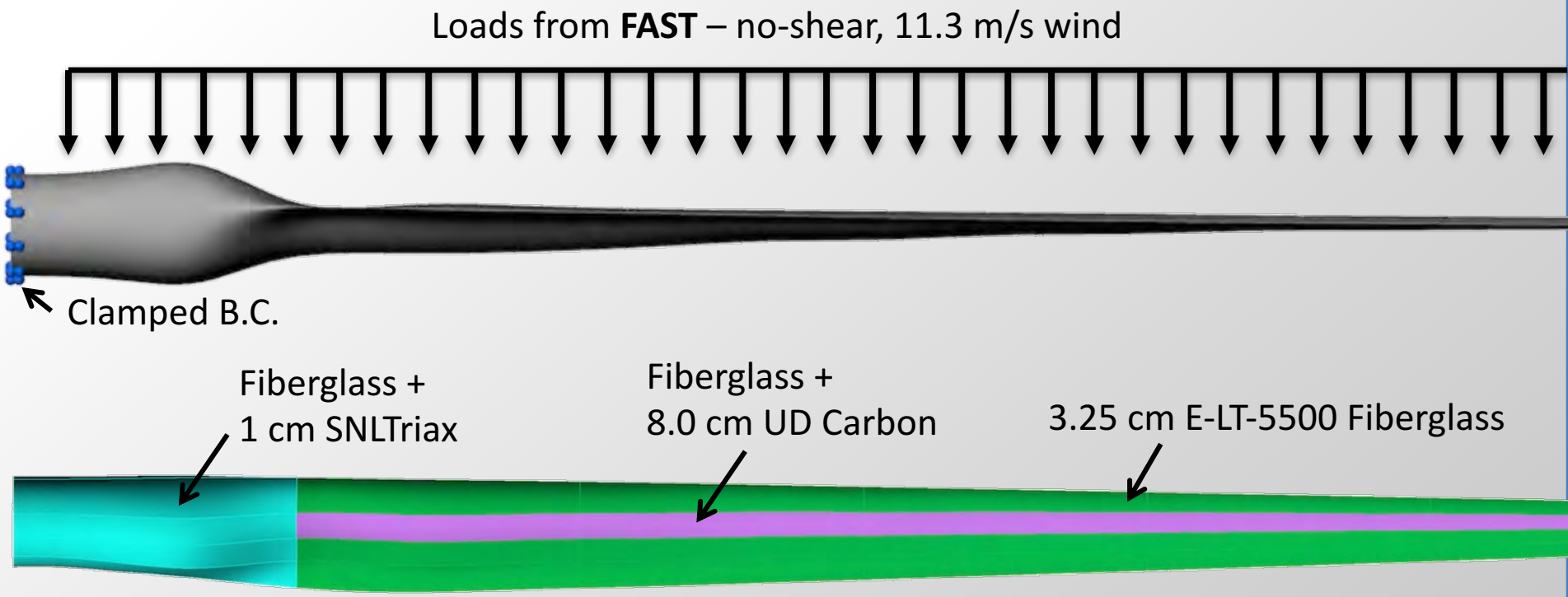
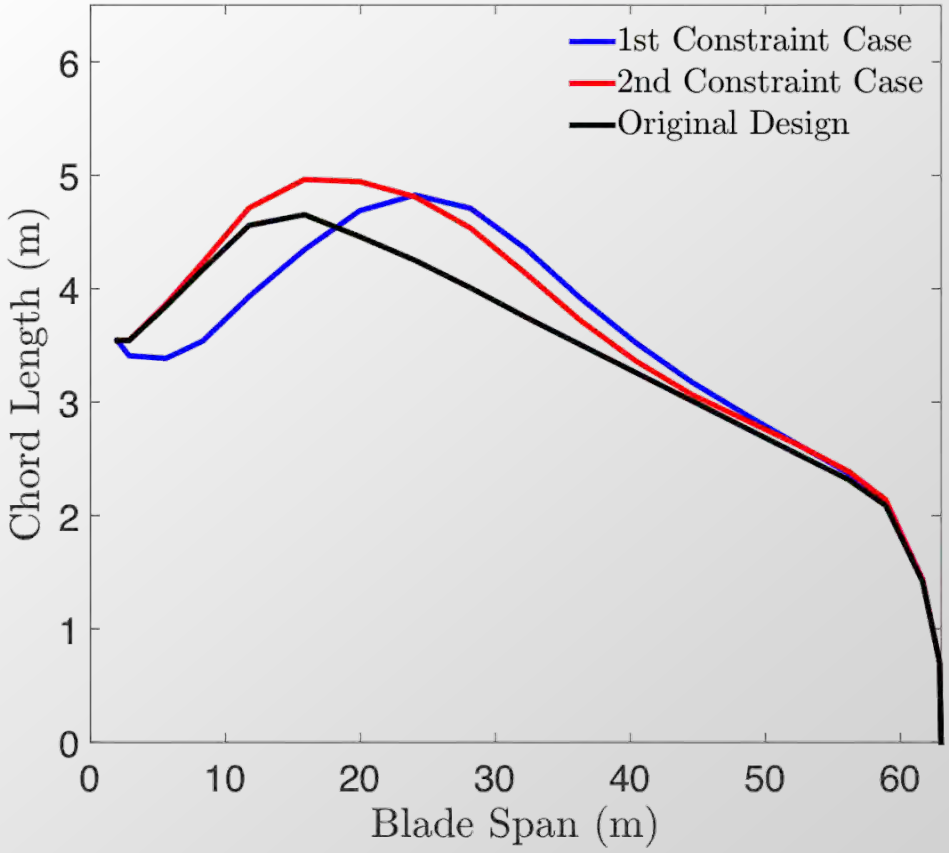


- **Power** prediction given by NREL's **FAST**
- MATLAB's **pattern search** algorithm drives optimization

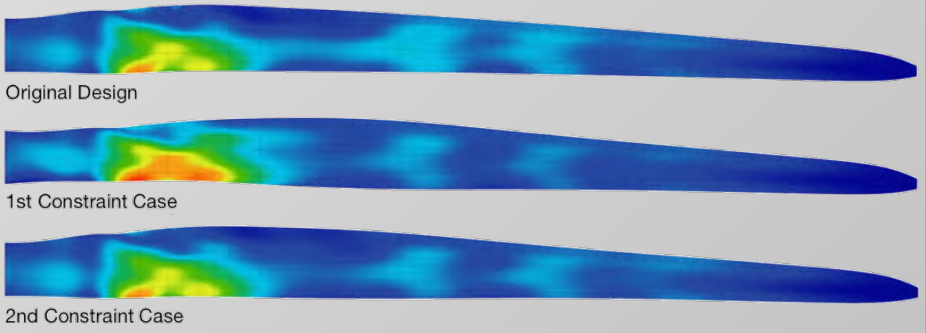
RESEARCH BACKGROUND

Design	Func. Evals	Tip Defl. (m)	Max. Strain	Mass (kg)	Power (kW)	$\mathcal{J}_b(\mathbf{y};\mathbf{x}_b)$	Add. Profit (millions $)
Original	–	5.75	0.0083	40,912	5,265	100.00%	–
Case 1	128	5.75	0.0100	41,650	5,302	99.49%	6.37
Case 2	102	5.12	0.0083	43,265	5,311	99.78%	2.75



Optimization 1: Tip deflection constrained

Optimization 2: Tip deflection and strain constrained



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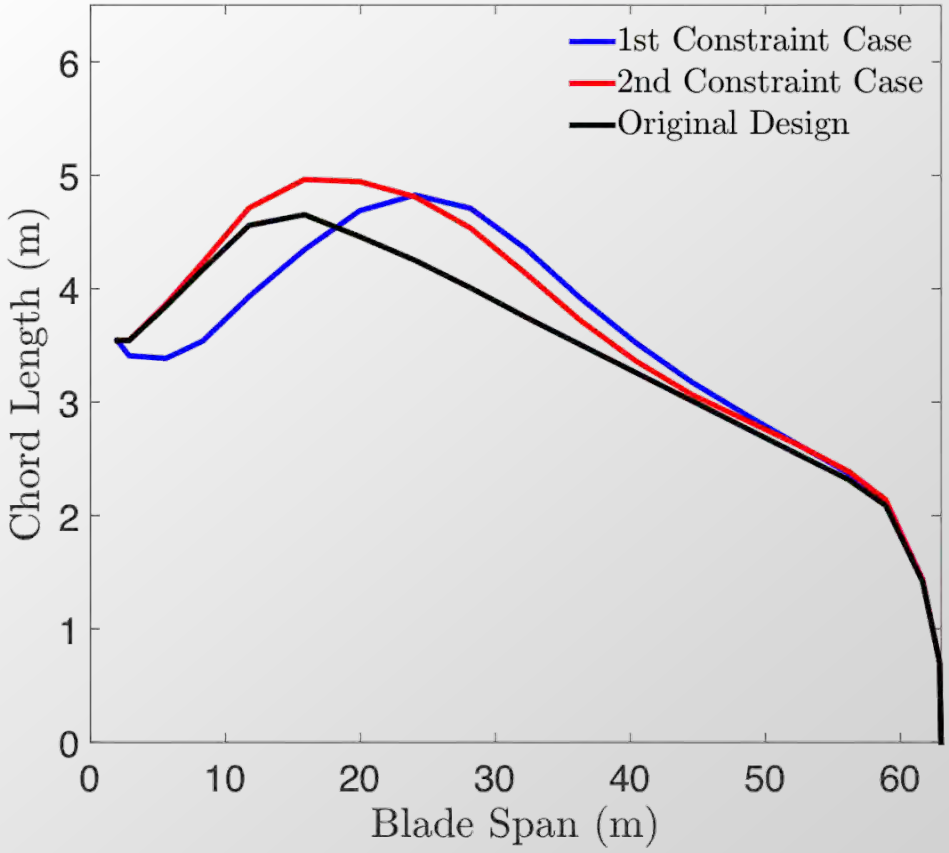


Proof of concept—can't trust these results!

- **Blades don't have shear webs**
- **Analysis is performed for only one wind condition**

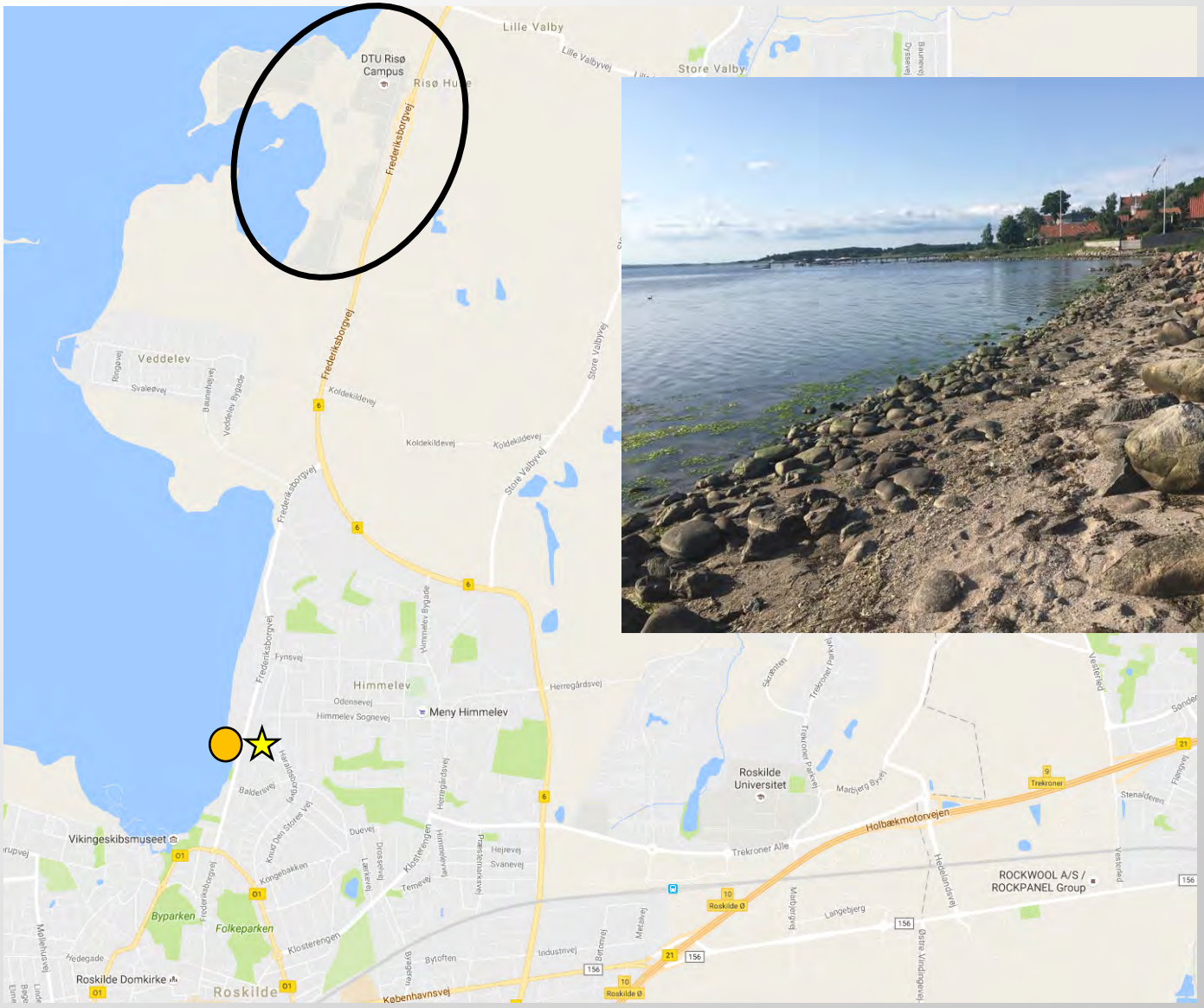
INTERNATIONAL EXPERIENCE TIMELINE

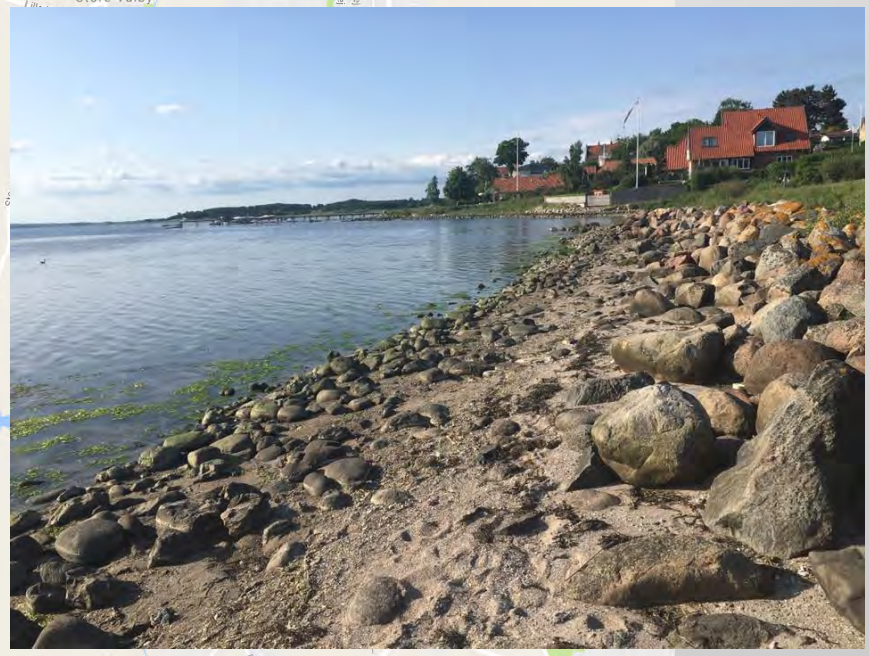
- **Fall 2015**: Discussions with major professor, confirm interest with collaborator in Germany
- **Mid-December 2015**: Email DTU Section Head of Aerodynamic Design, Flemming Rasmussen
  - "…I am fully funded for this experience and would not require compensation…"
  - Response a week later, put in contact with senior researcher Frederik Zahle to find relevant project
- **February 2016**: Confirm AirBnB housing in Roskilde, Denmark
- **February 2016**: Purchase flights
- **March 2016**: Confirm university guest housing in Braunschweig, Germany
- **May 27, 2016**: Depart for Roskilde, Denmark
  - Approximately 7 week stay
- **July 15, 2016**: Take train from Roskilde to Braunschweig
  - Approximately 4 week stay
- **August 13, 2016**: Return to Des Moines

ROSKLIDE, DENMARK

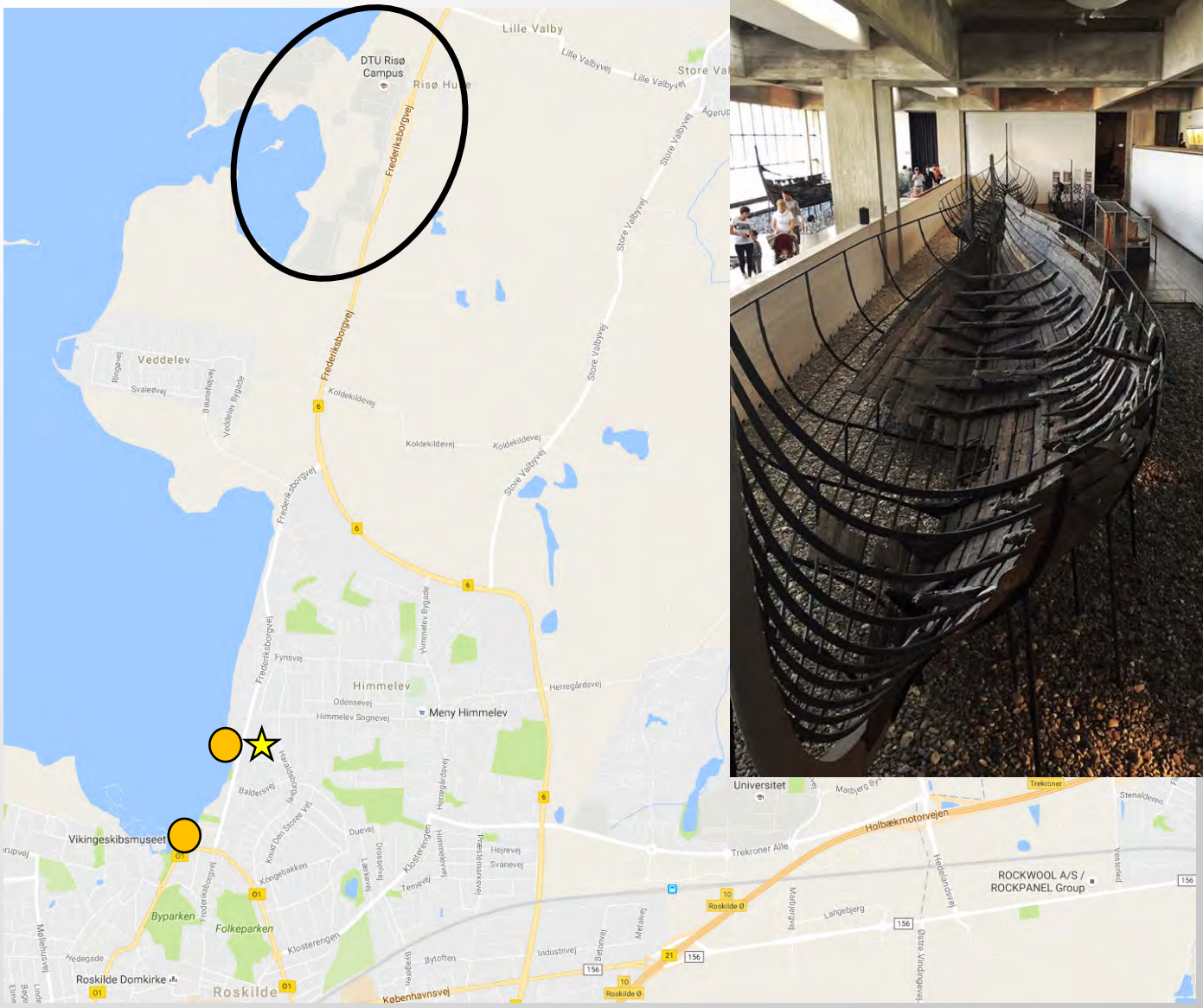
ROSKLIDE, DENMARK

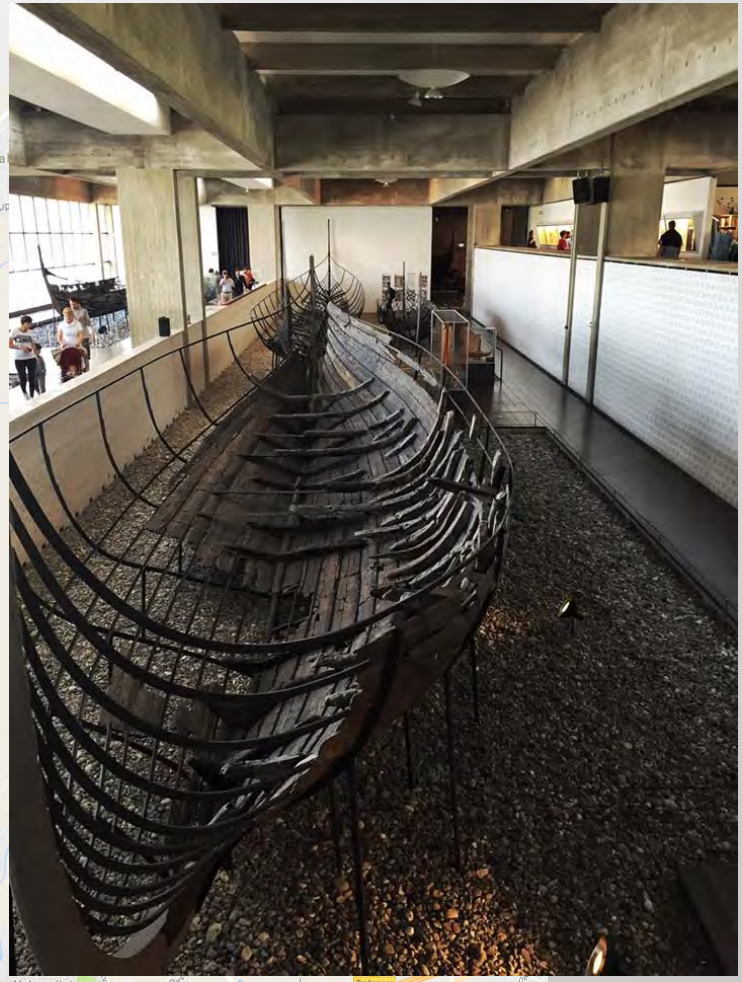
ROSKLIDE, DENMARK



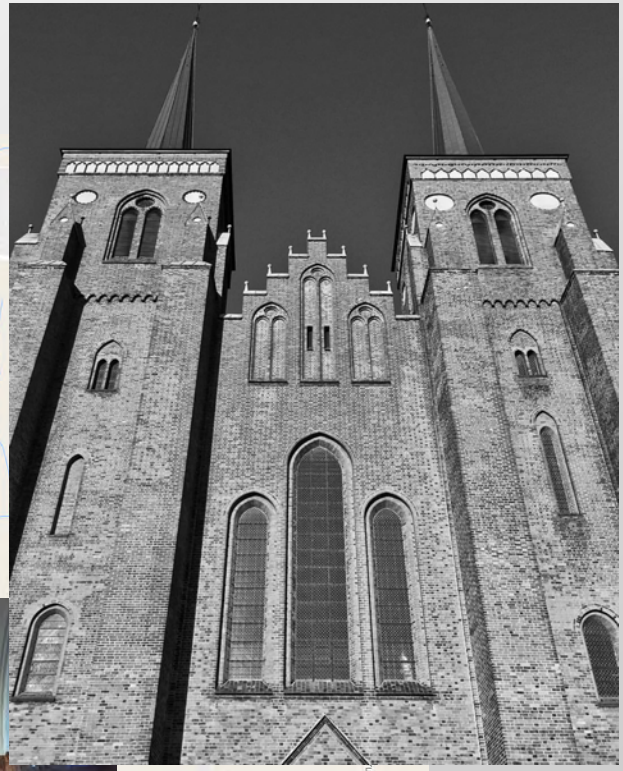


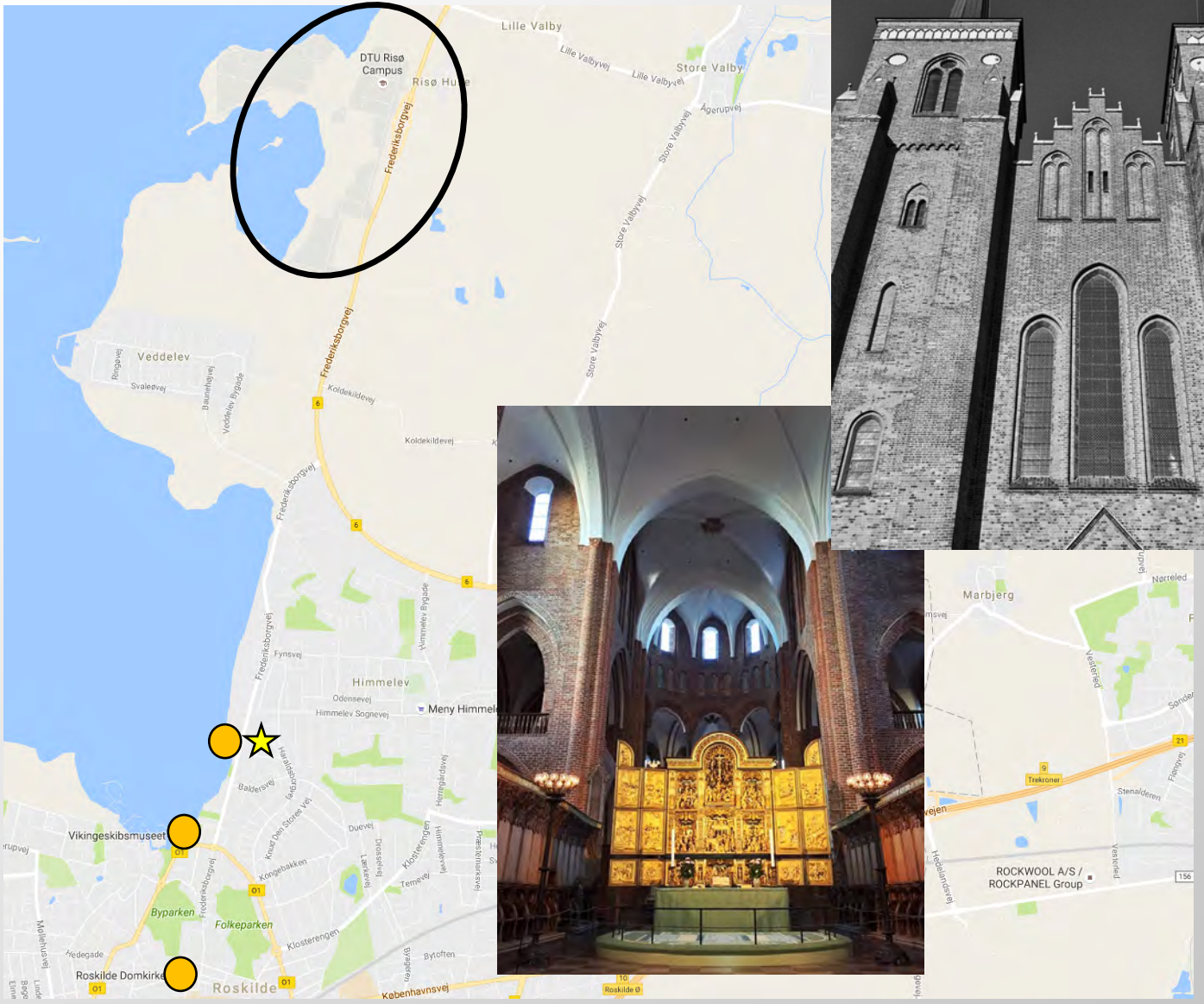
ROSKLIDE, DENMARK



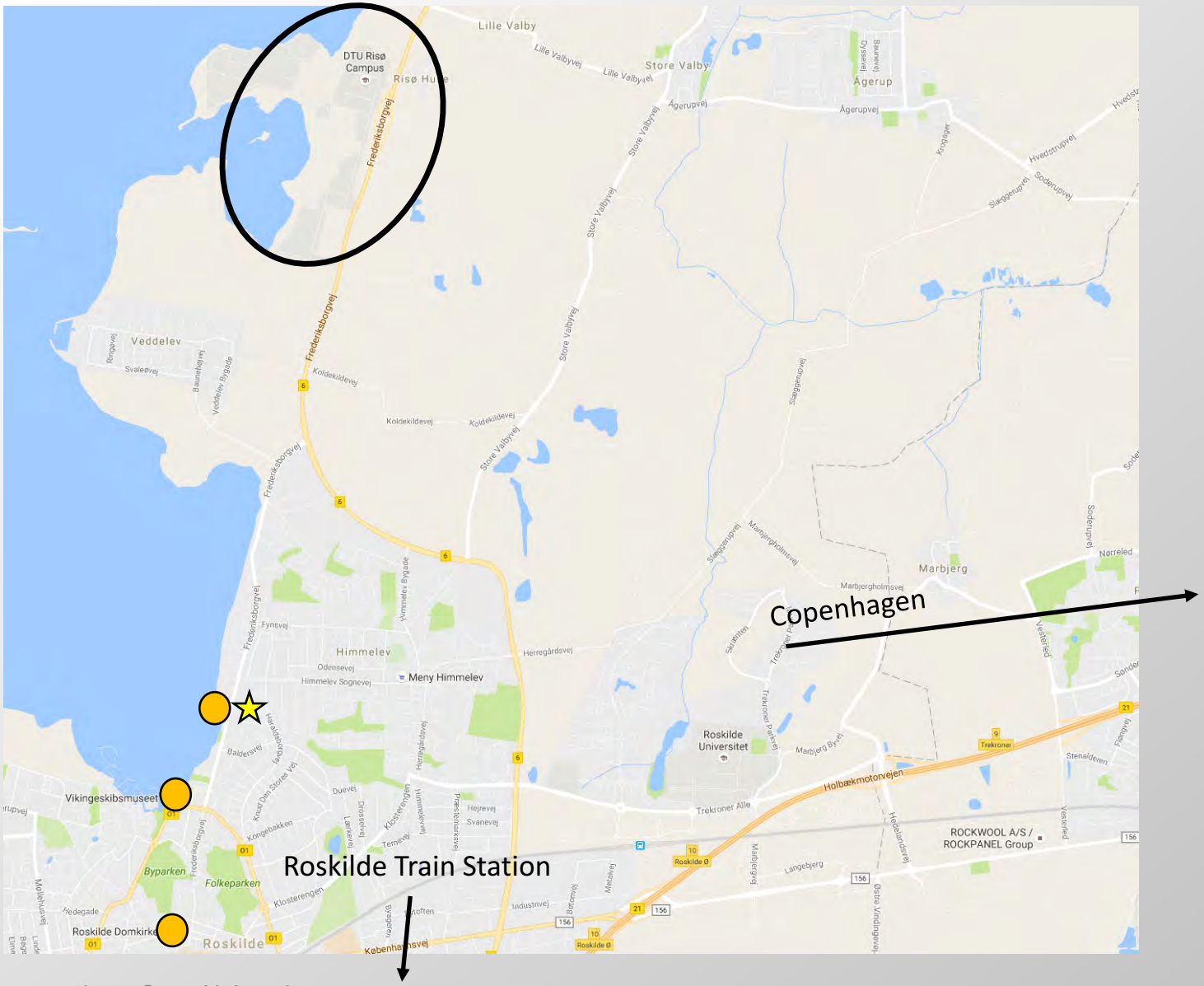


ROSKLIDE, DENMARK





ROSKLIDE, DENMARK



HOUSING IN ROSKILDE

HOUSING IN ROSKILDE

HOUSING IN ROSKILDE

HOUSING IN ROSKILDE

DTU EXPERIENCE

DTU EXPERIENCE

DTU EXPERIENCE

DTU EXPERIENCE

DTU EXPERIENCE

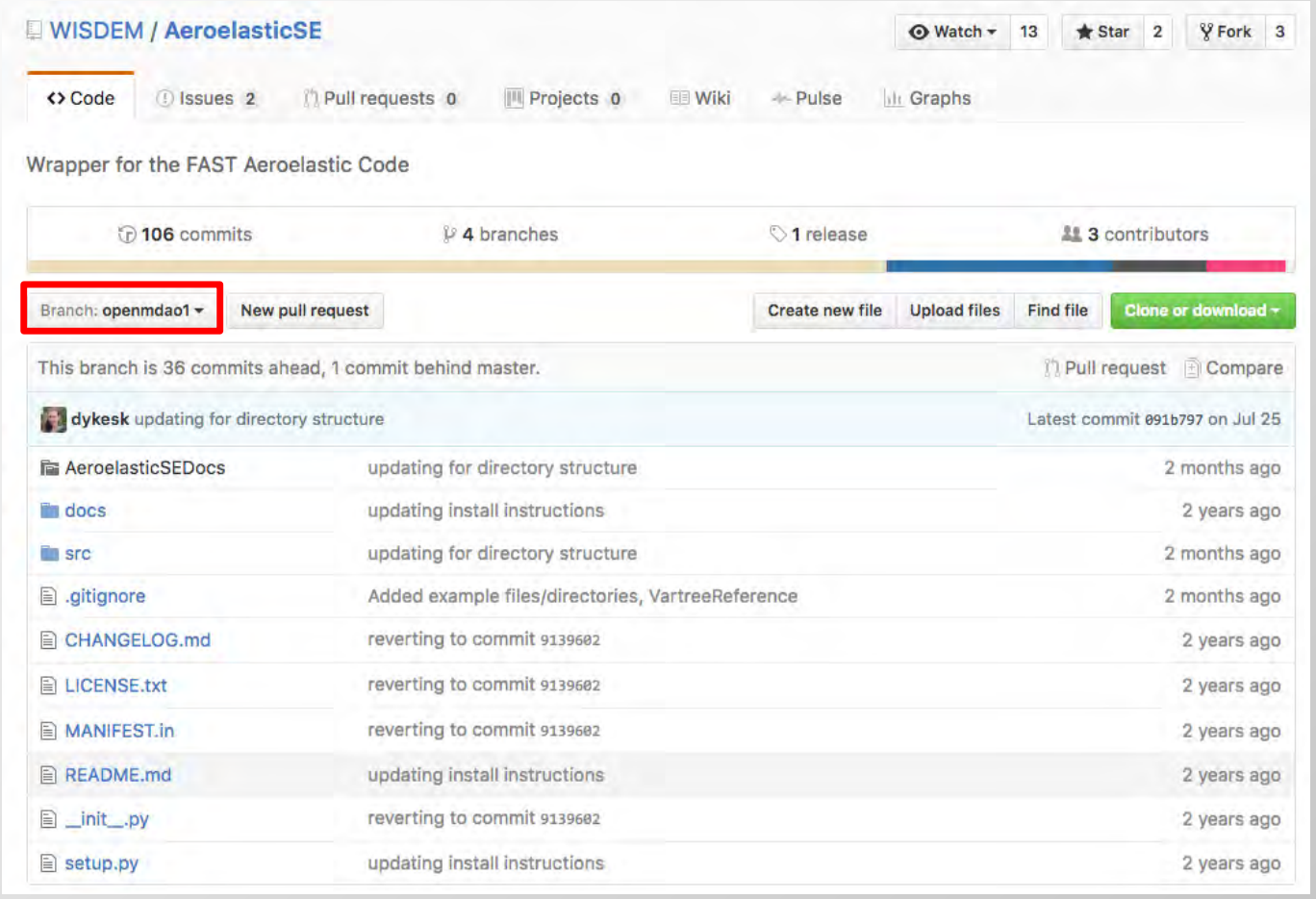
OTHER THINGS IN DENMARK

RESEARCH AT DTU

- Advanced computational blade design techniques
  - IEC standard-based rotor optimization—about 1000 load cases
  - 10 MW blade design
  - Close relationships with Siemens, LM, Vestas
- FUSED-Wind
  - Collaboration with NREL
  - HAWC2 or FAST
  - Development of programmatic wrapper for FAST

RESEARCH AT DTU

- Development of FAST wrapper for FUSED-Wind with Katherine Dykes (NREL) and Frederik Zahle (DTU)

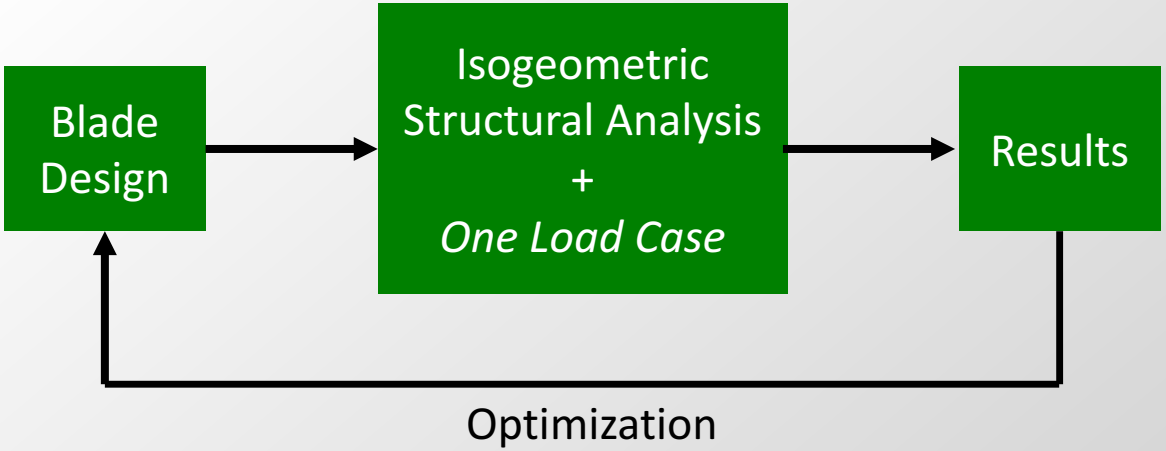


RESEARCH AT DTU

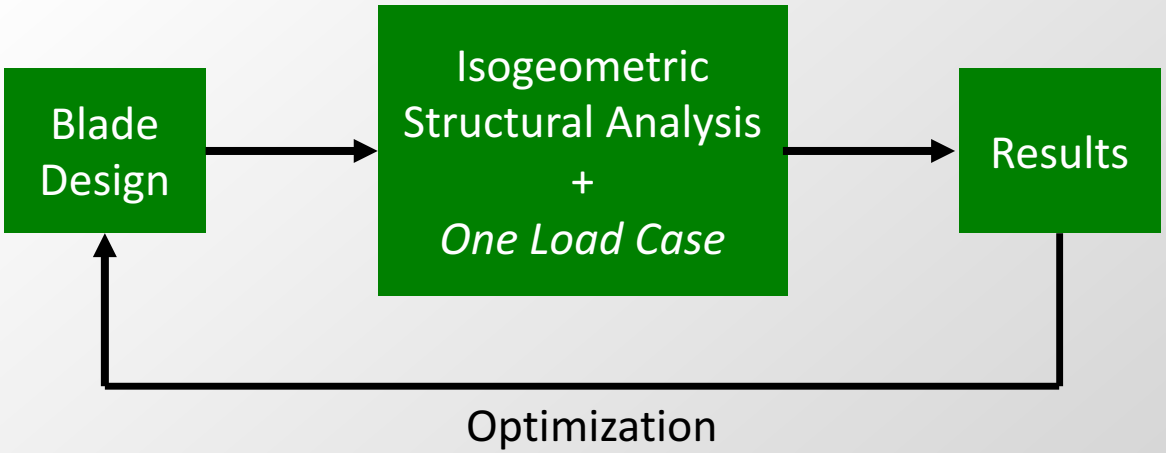
- Parallel execution of FAST cases within OpenMDAO

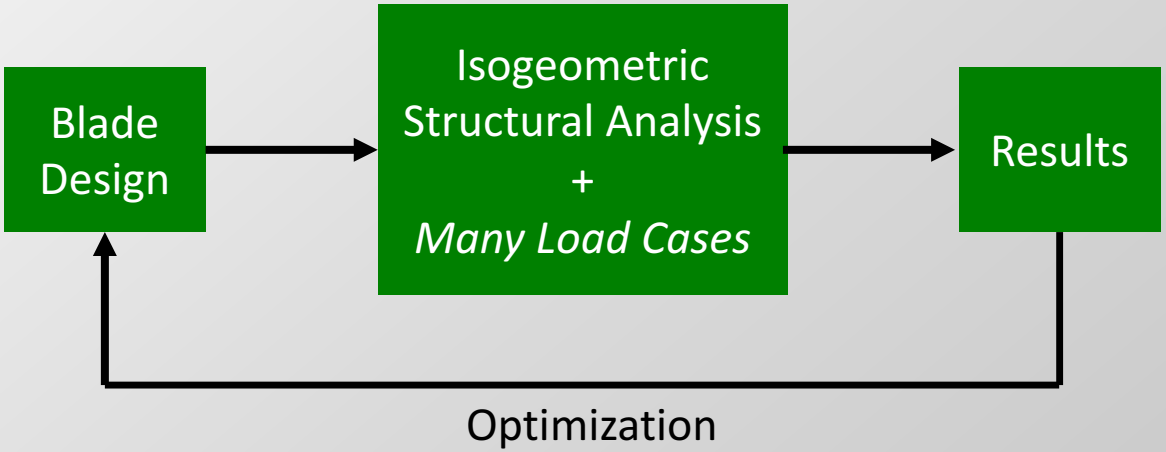
```
# Setup input config dictionary of dictionaries.
cfg_master = {} #master config dictionary (dictionary of dictionaries)
caseids = ['case1','case2','case3','case4']
TMax = [30, 22, 40, 45]

for i in range(4):

    # Create dictionary for this particular case
    cfg = {}
    cfg['fst_runfile'] = '{0}.fst'.format(caseids[i])
    cfg['fst_rundir'] = os.path.join('./rundir/',caseids[i])
    cfg['TMax'] = TMax[i]

    # These parameters the same for all cases
    cfg['fst_masterfile'] = 'Test01.fst'
    cfg['fst_masterdir']= './FST8inputfiles/'
    cfg['fst_exe'] = '../../../../../FAST_v8/bin/FAST_glin64'
    cfg['libmap'] = '../../../../../FAST_v8/bin/libmap-1.20.10.dylib'
    cfg['ad_file_type'] = 1

    # Put dictionary into master dictionary, keyed by caseid
    cfg_master[caseids[i]] = cfg

# Add parallel group to omdao problem, pass in master config file
root.add('ParallelFASTCases', FST8AeroElasticSolver(cfg_master, caseids))
```

RESEARCH AT DTU

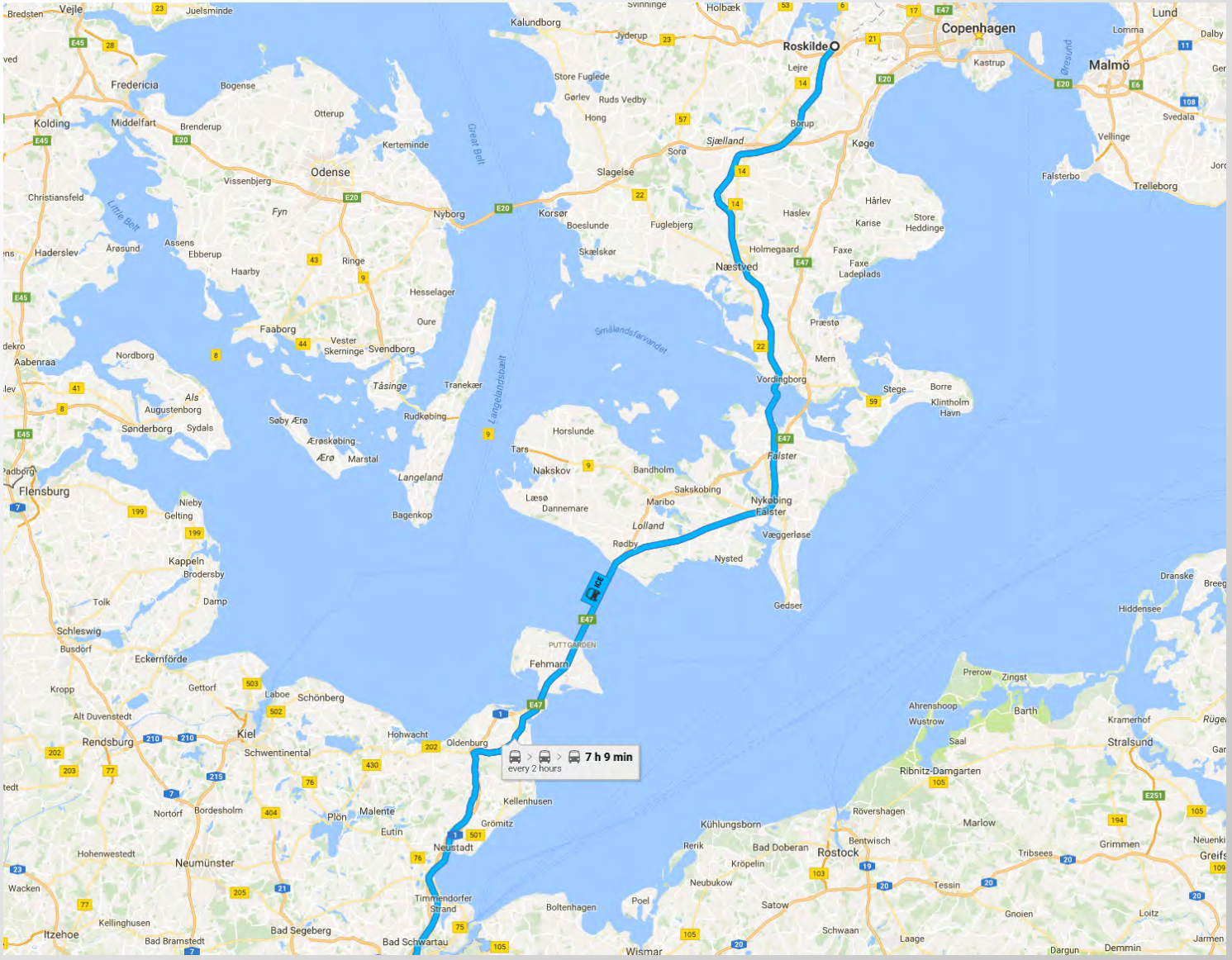


RESEARCH AT DTU



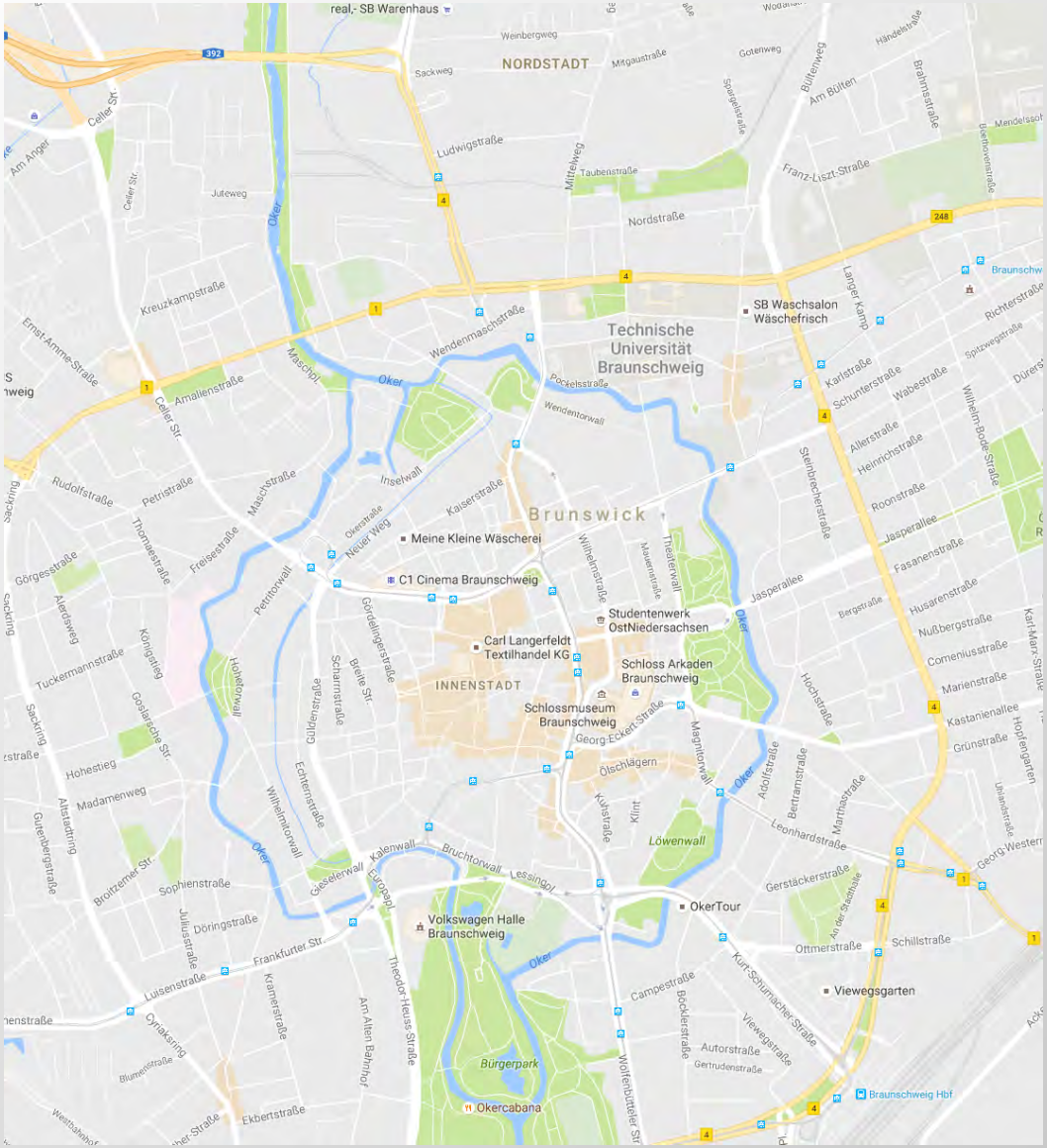


TRIP TO BRAUNSCHWEIG



TRIP TO BRAUNSCHWEIG

BRAUNSCHWEIG, GERMANY



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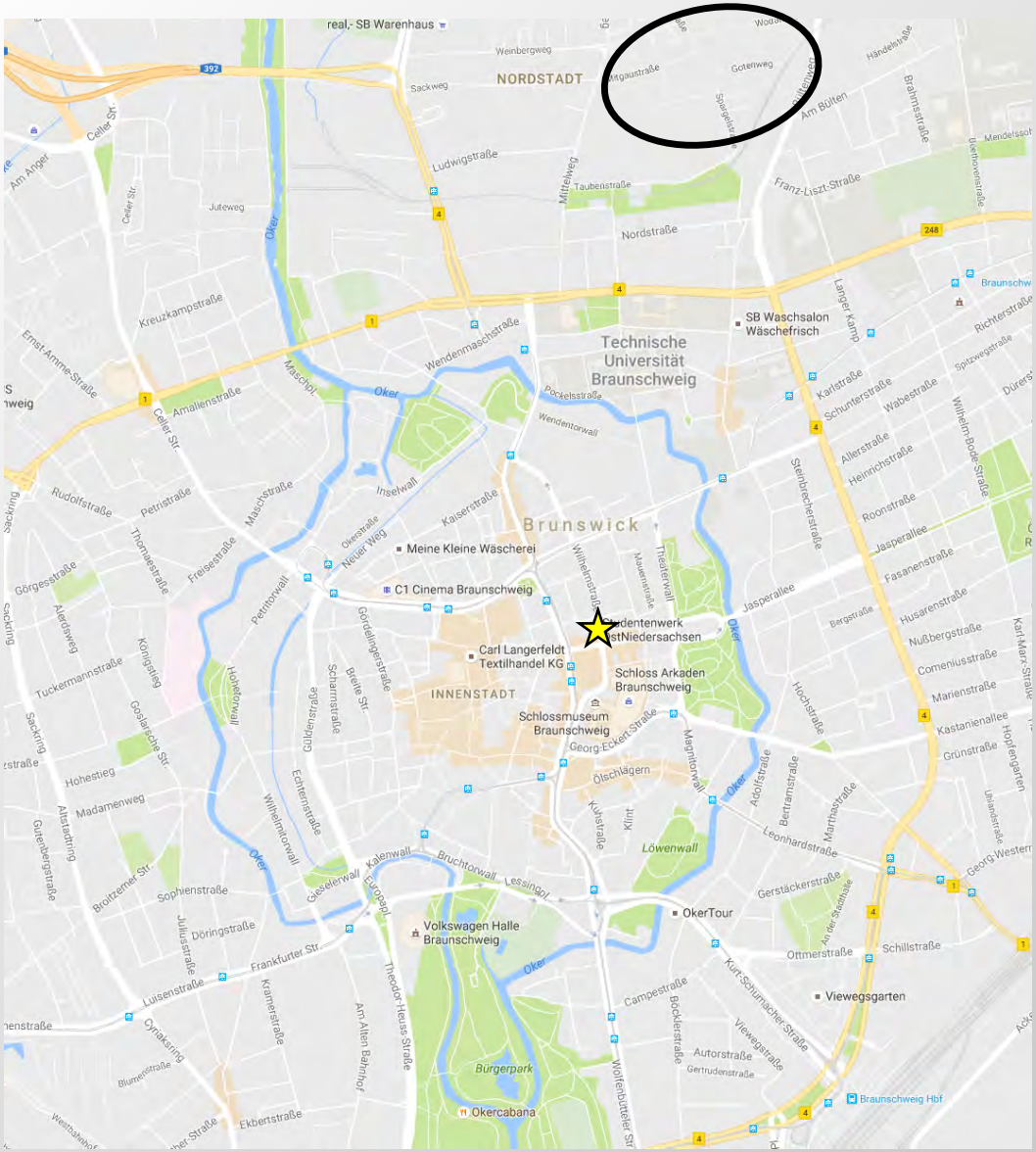
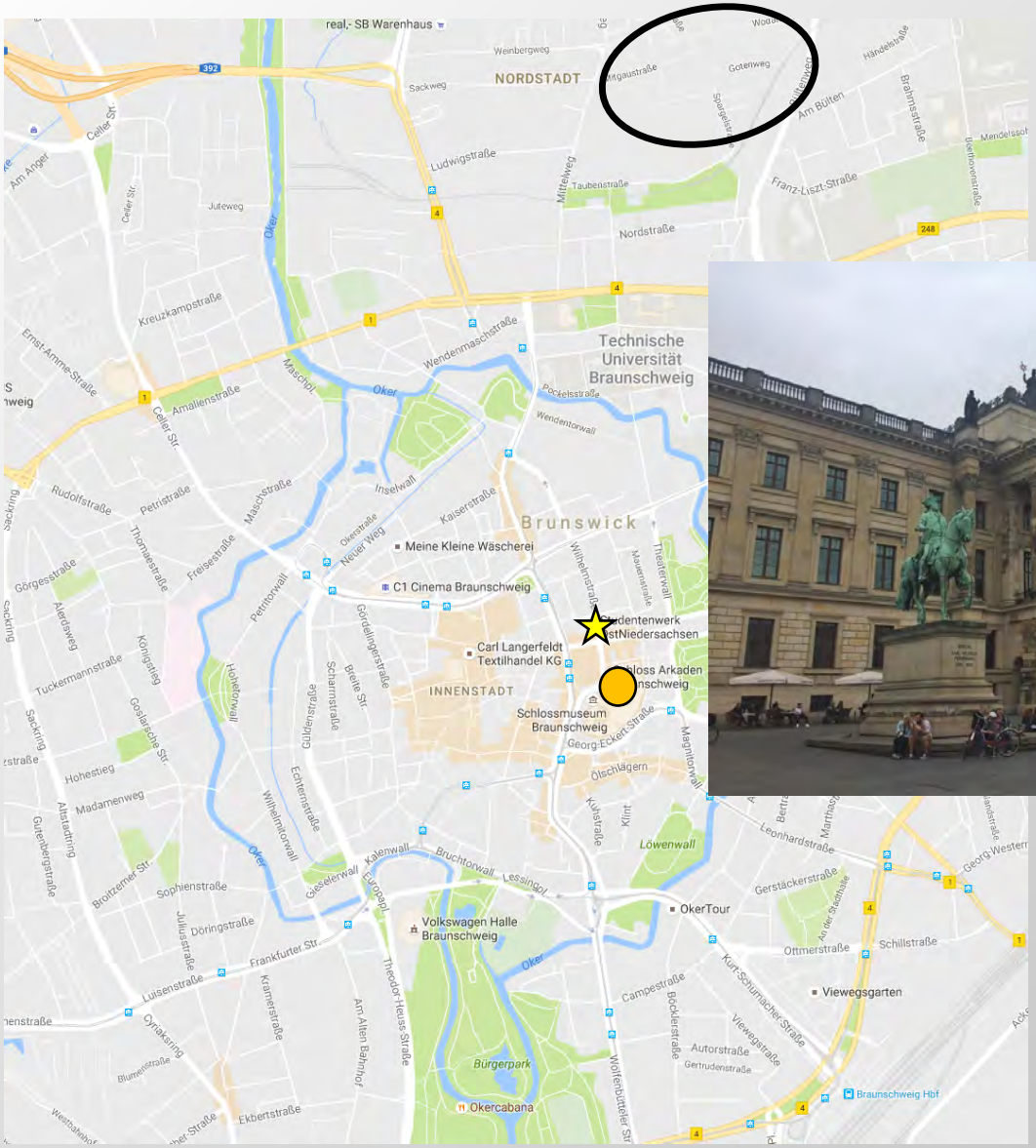


BRAUNSCHWEIG, GERMANY



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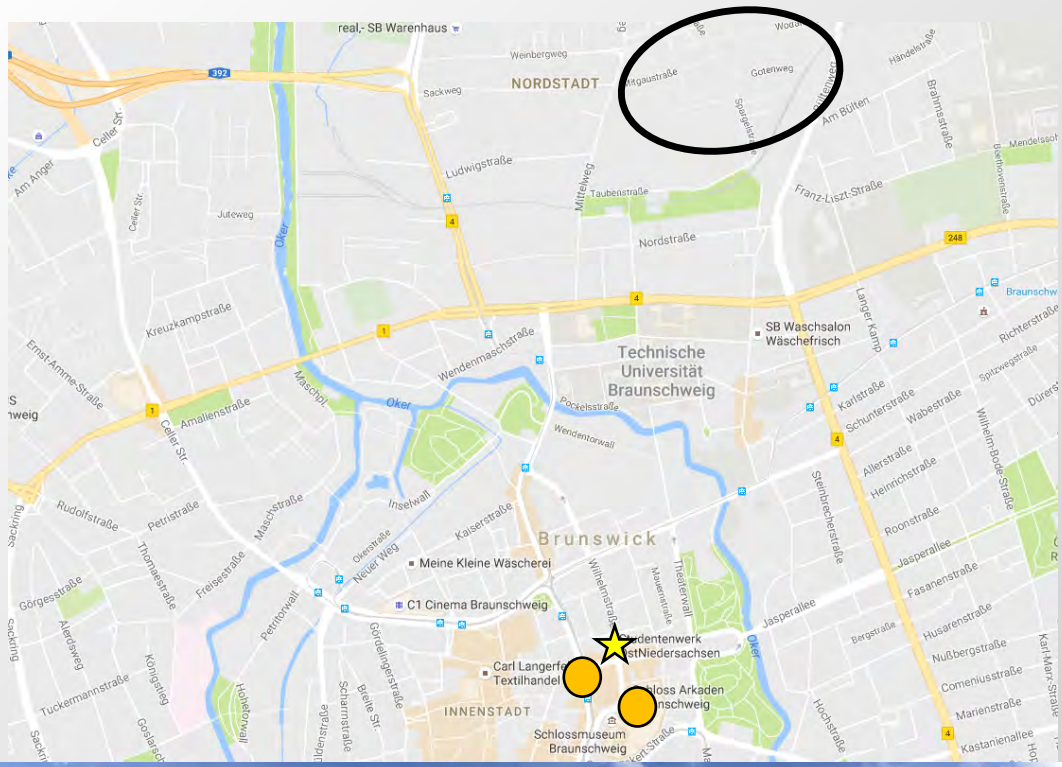

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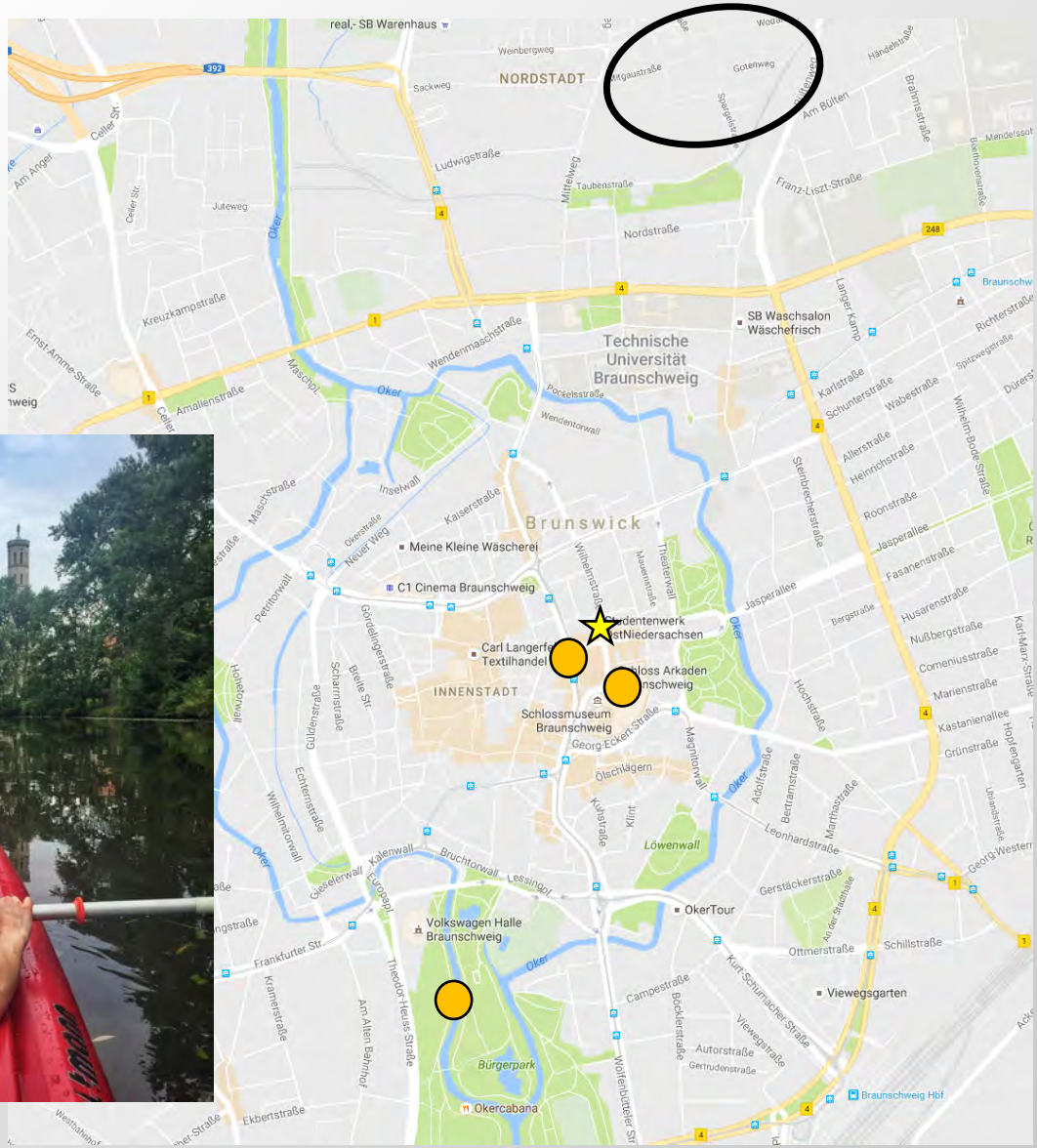

HOUSING IN BRAUNSCHWEIG

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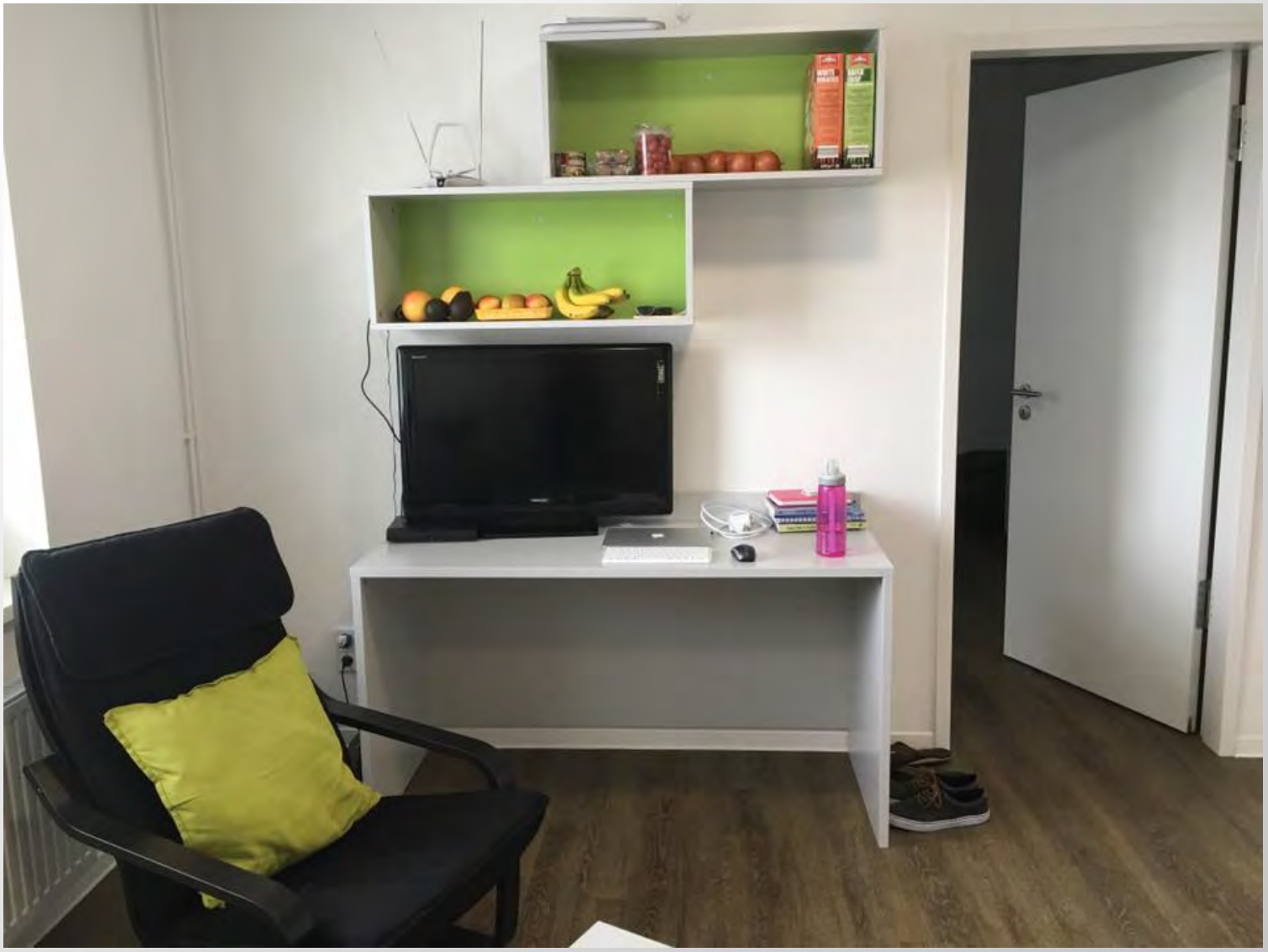

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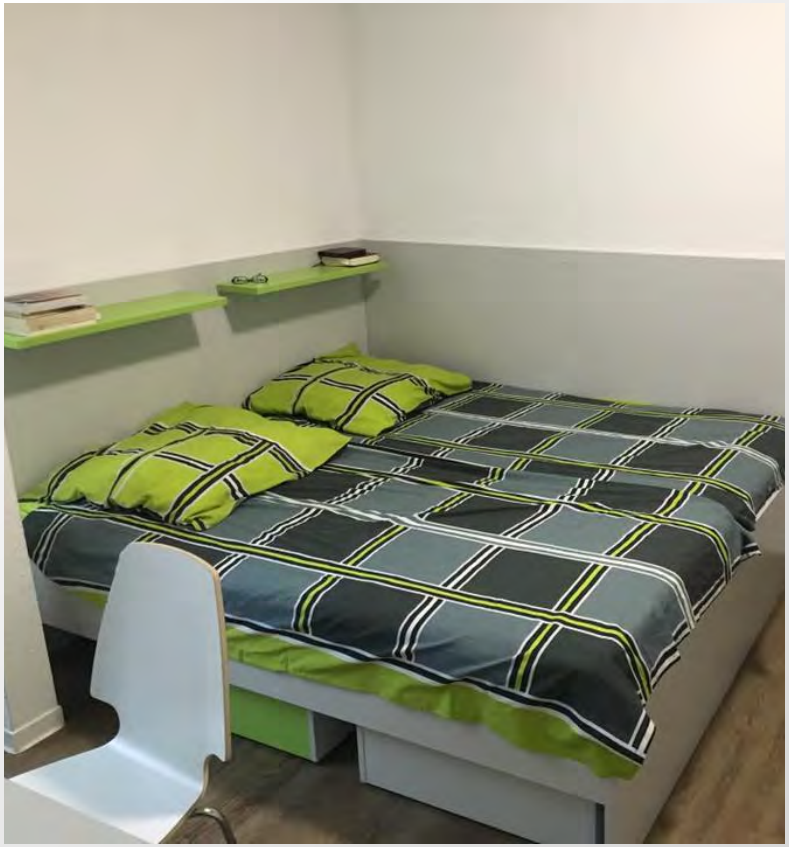


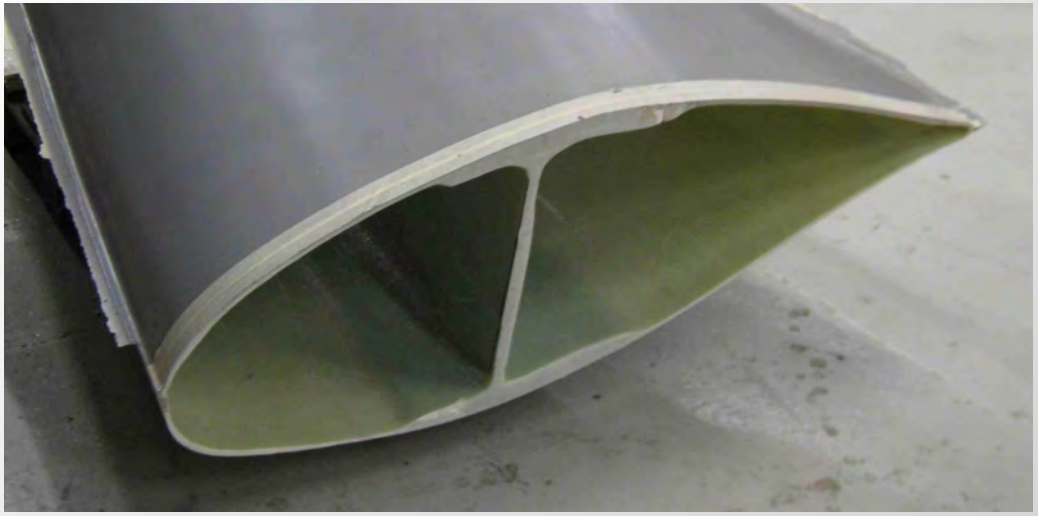
TU BRAUNSCHWEIG EXPERIENCE

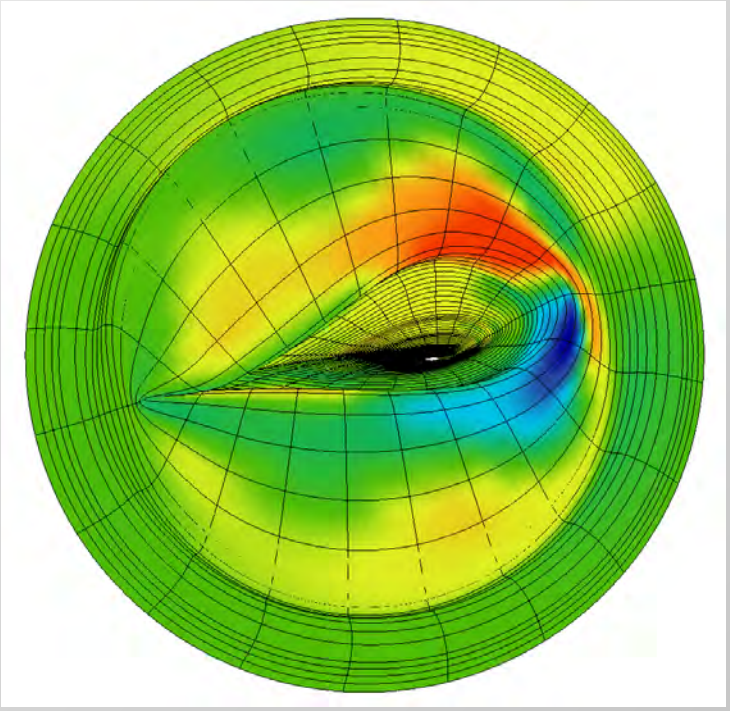
TU BRAUNSCHWEIG EXPERIENCE

TU BRAUNSCHWEIG EXPERIENCE

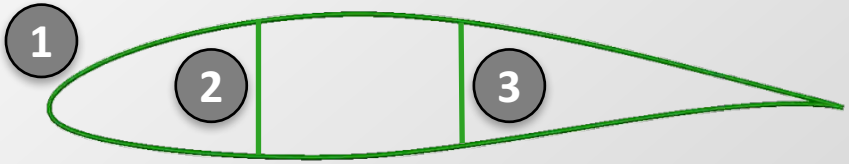
- Josef Kiendl
  - Expert on isogeometric analysis, thin shell analysis

RESEARCH AT TU BRAUNSHWEIG





RESEARCH AT TU BRAUNSHWEIG



Traditional FEA	Multiple Surfaces	→	FEA Mesh	→ One Solution Field
Isogeometric Analysis	Multiple Surfaces	→	Multiple Solution Fields	

RESEARCH AT TU BRAUNSHWEIG

Deformed configuration — Undeformed configuration

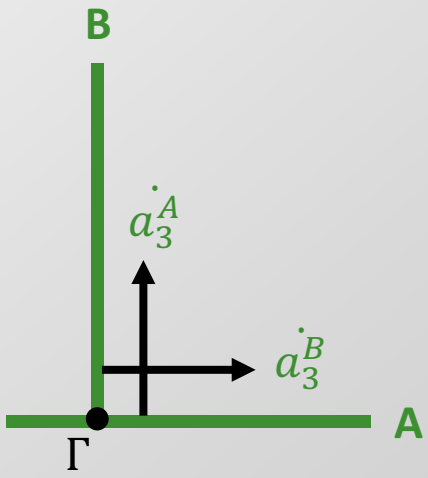
$$W^p = \gamma \int_\Gamma (a_3^A \cdot a_3^B - \dot{a_3^A} \cdot \dot{a_3^B})^2 ds = 0$$

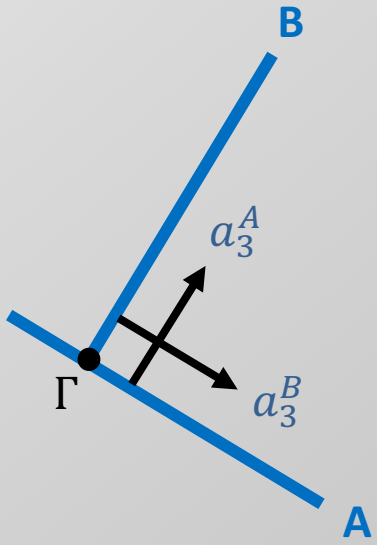
a_3 = normal unit vector

$$a_3^A \cdot a_3^B = \|a_3^A\| \, \|a_3^B\| \cos(\theta) = \cos(\theta)$$

(angle between two patches)

$$\dot{a_3^A} \cdot \dot{a_3^B} = \|\dot{a_3^A}\| \, \|\dot{a_3^B}\| \cos(\dot{\theta}) = \cos(\dot{\theta})$$





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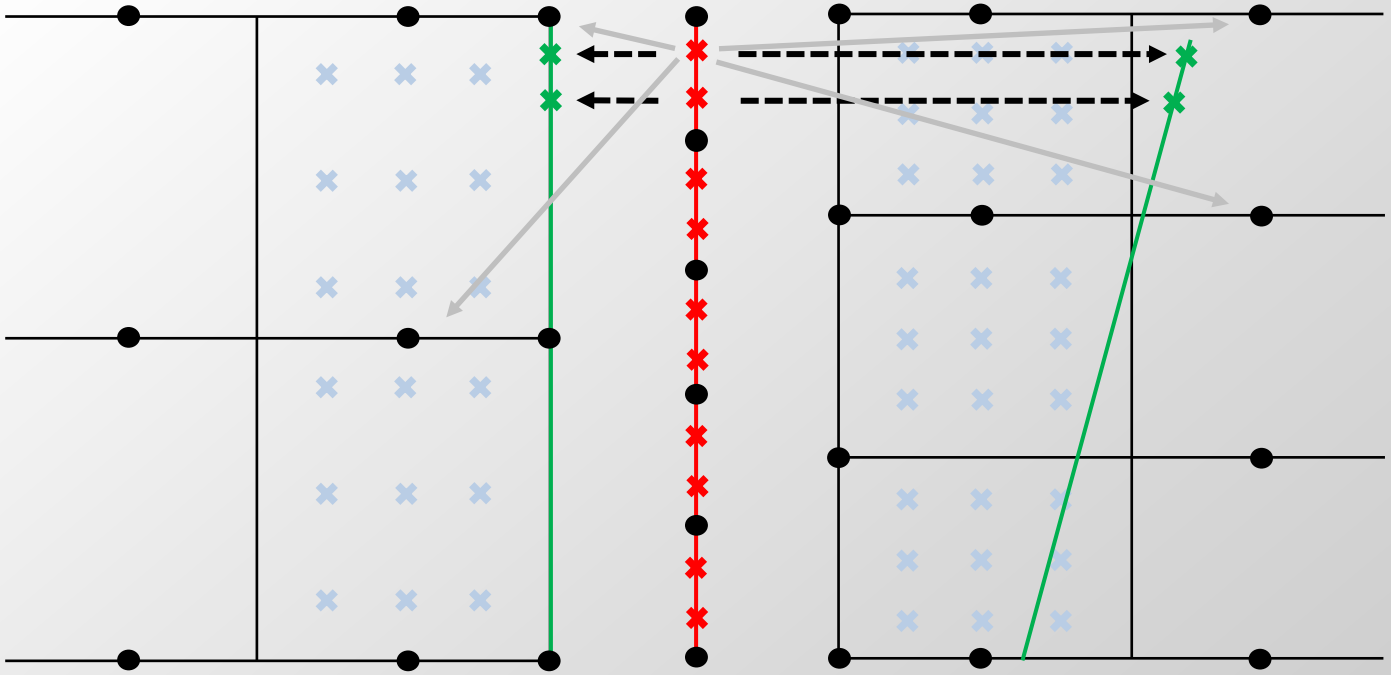
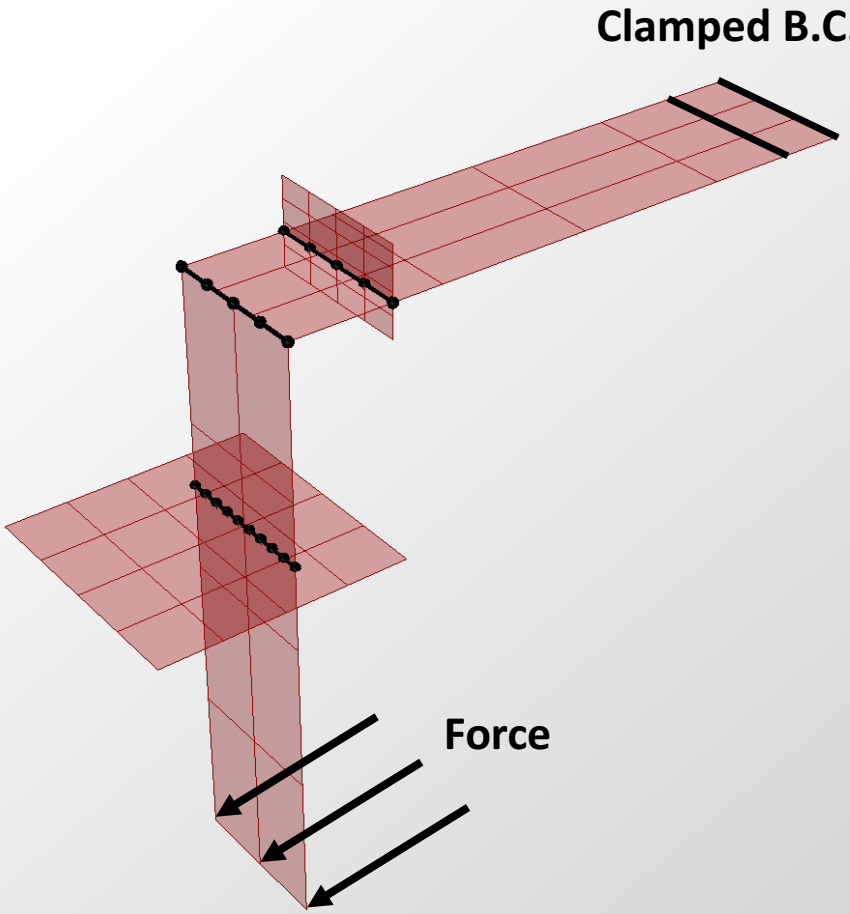
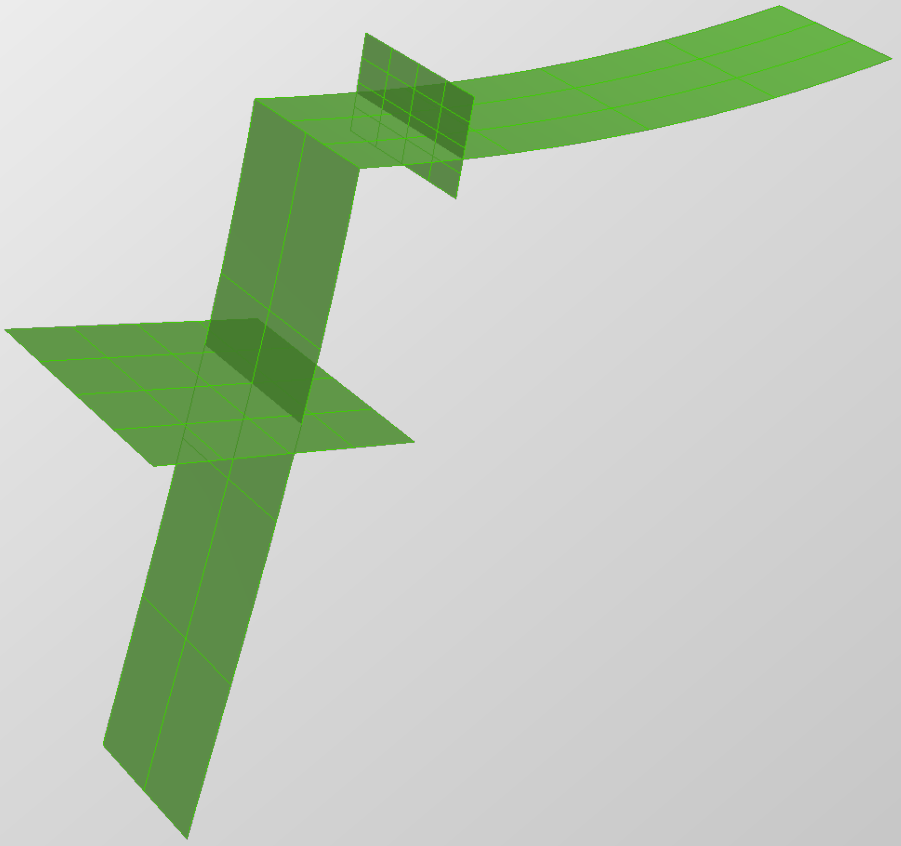


Each gauss point:

1) Project curve gauss point to each patch
2) Calculate normal vectors
3) Calculate penalty contribution
4) Assemble to global degrees of freedom

RESEARCH AT TU BRAUNSHWEIG





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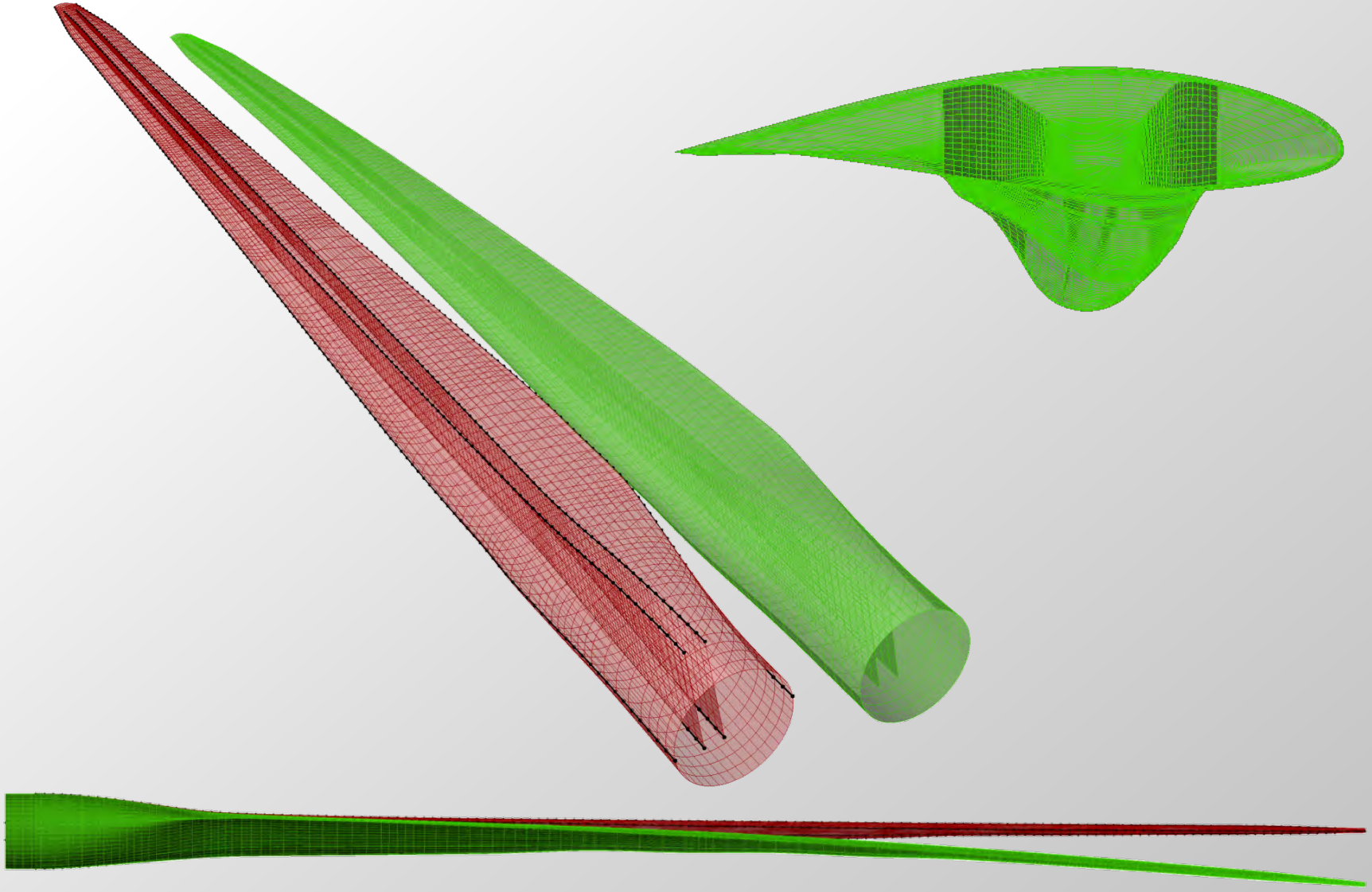


SUMMARY

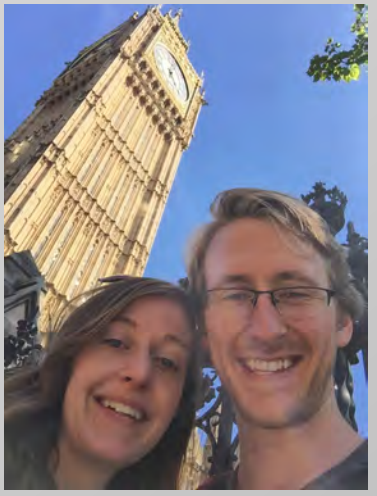
- Highly recommend taking advantage of opportunity!
  - Beneficial to research
  - Beneficial for networking
  - Beneficial to résumé/CV
- Creates opportunities to experience new places

Rome

Malmö, Sweden

Berlin

London



TIPS

- Check with DTU if you're interested!
- Try to have a good idea of what work you will accomplish beforehand, but be flexible
- Don't be afraid to ask questions
- Travel insurance – Iowa State Study Abroad
  - Danette Bontrager
- Register trip with U.S. Department of State
  - step.state.gov
- Consider AirBnB for housing needs – good to have another local contact

Thank you!

QUESTIONS