Danish Offshore Technology Conference
Kolding, November 29-30, 2022

Risk Informed Decision Support – Experiences and Further Prospects

....meeting the challenges of the future with the knowledge of the past....

DHRTC CRT3 and CTR2 Risk Team
Jianjun Qin, Kashif Ali, Juan Sepulveda, Sebastian Glavind, Henning Brüske,
Yue Guan, Akinyemi Akinsanya,
John Sørensen and Michael Faber
Aalborg University, Aalborg, Denmark

Contents of presentation

- Motivation - what did we set out to do?
- Approach - basis for R&D
- What did we accomplish?
- What did we learn – contributions to the general body of knowledge
- Knowledge bears responsibility – the next offshore challenge

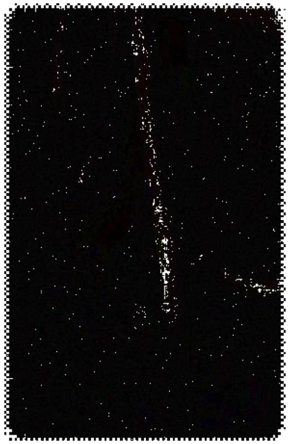
Motivation – what did we set out to do?

- Global society is dedicatedly moving towards fossil free energy provision
- In this process – there is a period of transition – during which renewables energies are ramped up – and production and use of fossil fuels are tapered out
- Our role has been to help facilitate safe production of oil and gas in the Danish sector throughout the transition period - through optimal utilization of the existing production infrastructure
- Thereby minimizing further offshore environmental impacts and reducing use of materials and energy

Motivation – what did we set out to do?

Additional challenges

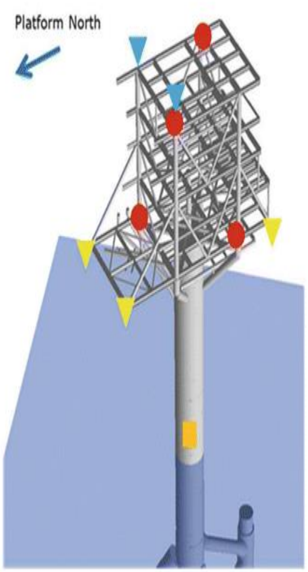
- Design wave loads are underestimated in codes
- Fields are subsiding
- Degradation due to fatigue, scale and corrosion
- Need for increased efficiency to reduce CAPEX and OPEX

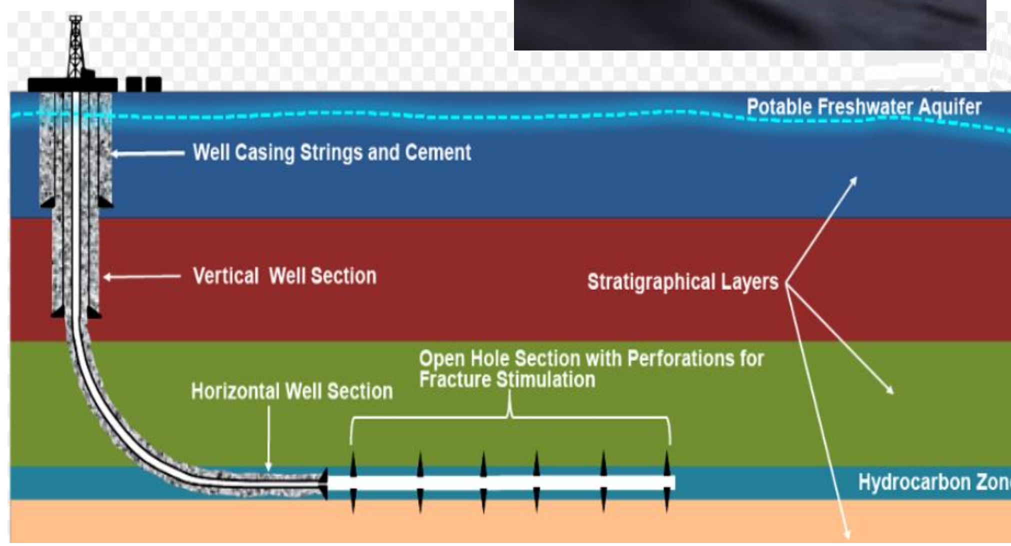


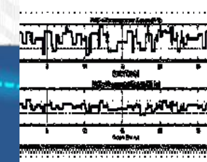
Motivation – what did we set out to do?

What types of systems have been considered

- **The wave load environment**
- **The structural systems**
- **The well systems**







Motivation – what did we set out to do?

Hypothesis and objectives

Our working hypotheses have been and still are:

1) “information consistent utilization of knowledge and observations provides the optimal basis for decision support”
2) “best practices in engineering only partly facilitate for a consistent utilization of available knowledge and observations”

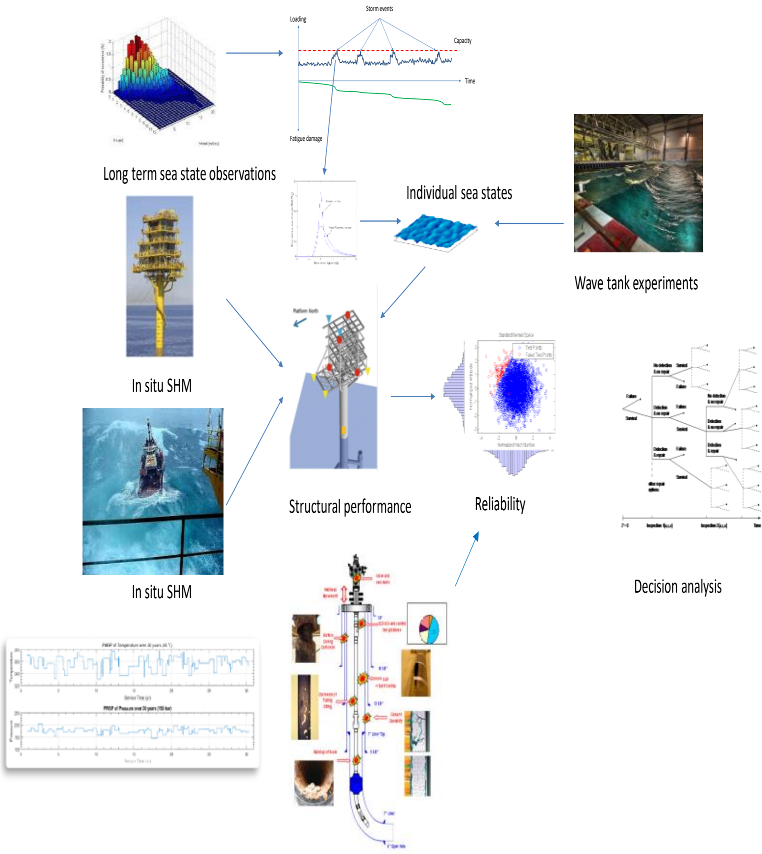
With this setting we have attempted to

i) develop an understanding of the bottlenecks/challenges for continued operations with existing infrastructures and to
ii) identify theory and methods facilitating that these challenges may be addressed and possibly overcome

Approach - basis for R&D

Knowledge – not numbers

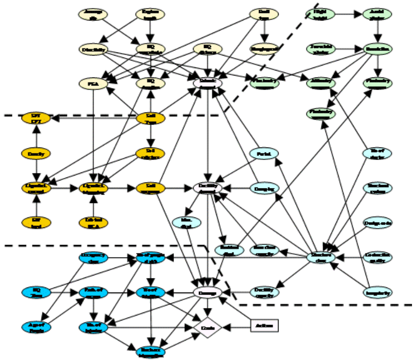
- Modelling and analysis capabilities in engineering decision analysis are expanding rapidly
- Systems modelled and analysed are increasingly complex
- The amount of information involved in systems modelling and analyses is very substantial
- The focus of probabilistic systems analysis is directed on a few selected probabilistic characteristics, probabilities and/or expected values

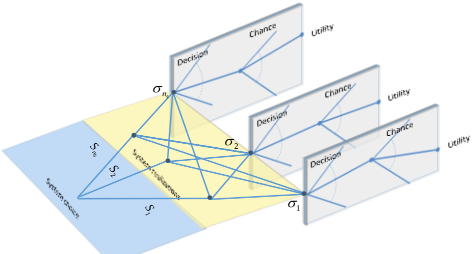


Approach - basis for R&D

Knowledge – not numbers

- We need to explore new ways of extracting knowledge from our models and analysis results, to:
- Appreciate if the physics of modelling and analysis results make sense
- Understand what governs the significant/critical performances of the analysed systems
- Inform on how best to improve models
- Guide the management of the systems

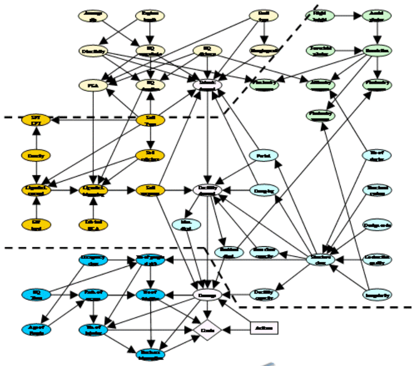




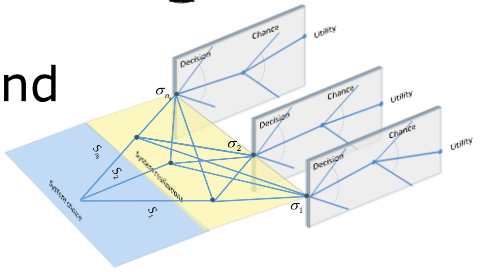
Approach - basis for R&D

Novel Information Based Perspective

Represent all available knowledge and information concerning the facilities and structures and which can be achieved through inspections and monitoring, by means of probability theory.



Optimize strategies for integrity management through the concept of Value of Information from the theory of decision analysis.



Ensure safety for people and environment – and minimize CAPEX and OPEX.

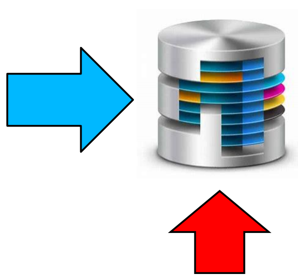
Approach - basis for R&D

Systems modelling – utilizing all relevant knowledge and all available and achivable information

Top-Down

Real world

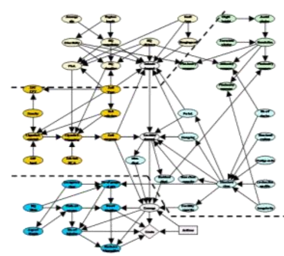
Observations



Data Mining

+

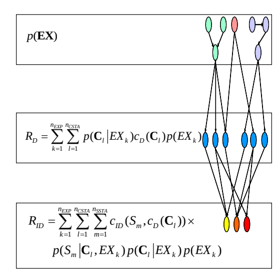
Bottom-Up



Engineering models

=

Models of real world

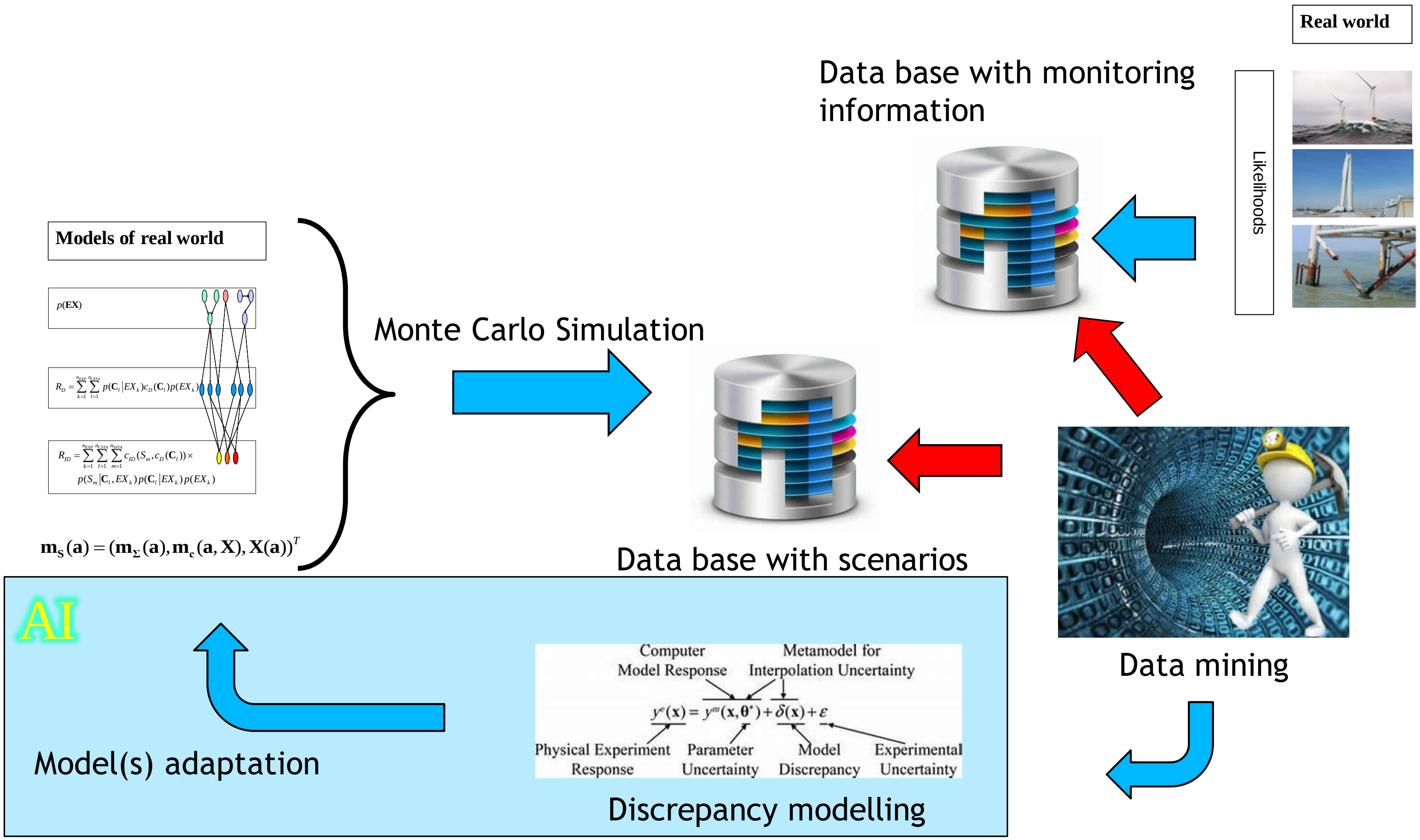


$\mathbf{m}_S(\mathbf{a}) = (\mathbf{m}_\Sigma(\mathbf{a}), \mathbf{m}_c(\mathbf{a}, \mathbf{X}), \mathbf{X}(\mathbf{a}))^T$

System representation

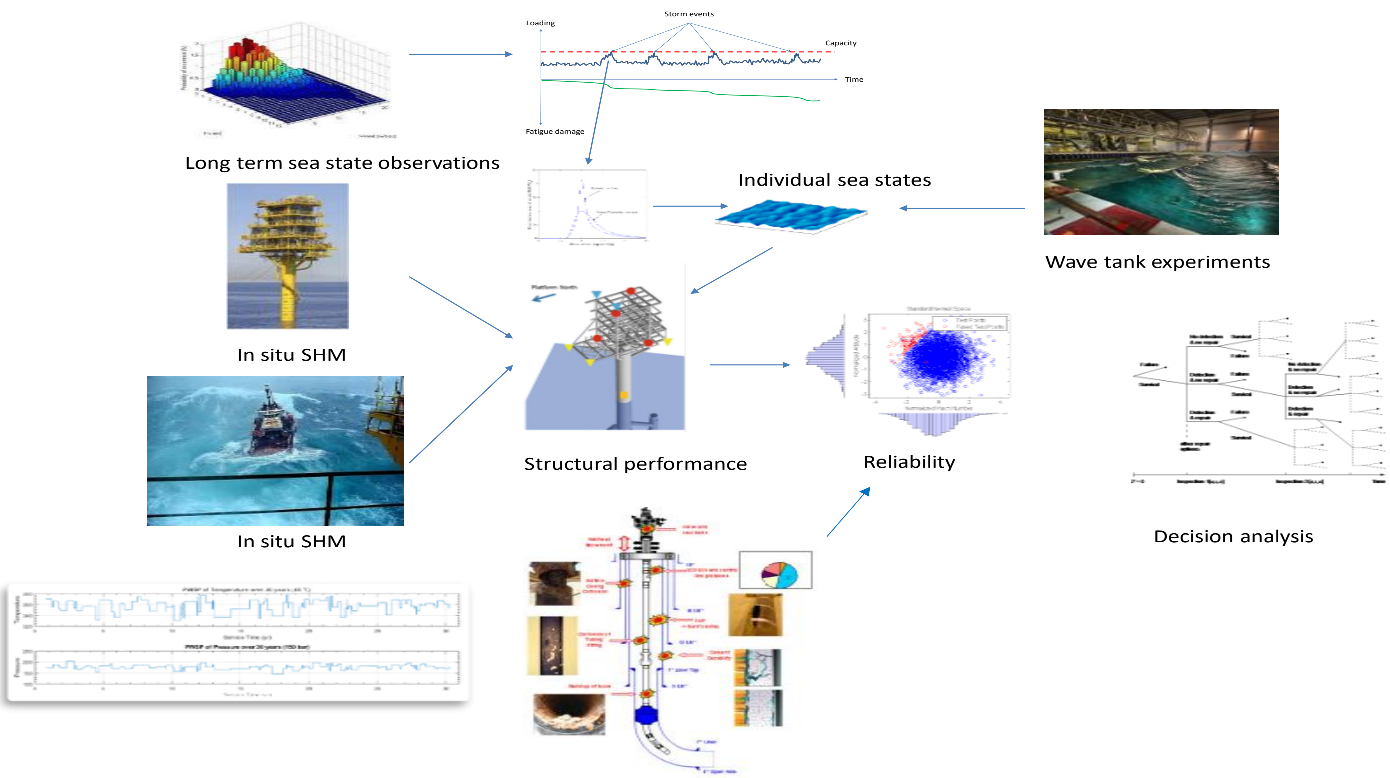
Approach - basis for R&D

Evidence based model updating/calibration



What did we accomplish?

R & D activities



Our team of 10 researchers at Aalborg University has addressed the entire value chain

What did we accomplish?

R & D activities (CTR3 + CTR2)

Henning

and structural responses (using monitoring, advanced finite element modeling and concepts of digital twins)

Sebastian

over the modeling of wave loads using wave tank and near shore test facilities

Yue, Akinyemi and Jianjun

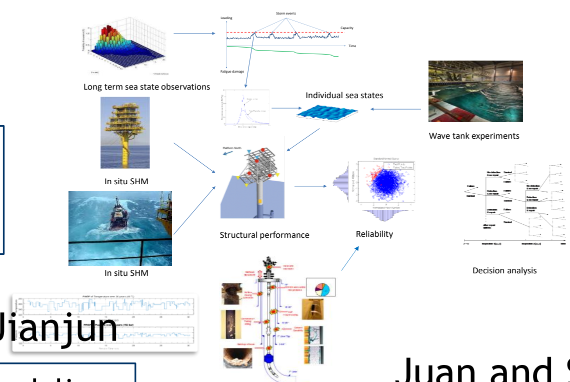
and the probabilistic process modeling for the pressure vessels (variations of pressure and temperature)

From the modeling of waves (using data mining/Big Data techniques)

Sebastian

to fatigue assessments and risk informed inspection and maintenance planning for welded details in the structures, for scaling and corrosion assessments and risk informed inspection and maintenance planning for pipes/pressure vessels in well-head facilities

Kashif, Yue, Akinyemi, Henning and Jianjun



Juan and Sebastian

to the modeling of extreme response (structural component failures, sequences of component failures and structural collapse) using advanced techniques of uncertainty propagation, sensitivity analysis and Bayesian decision analyses

What did we accomplish?

R & D activities

Input 1: PIPA project – Total Energies

Henning

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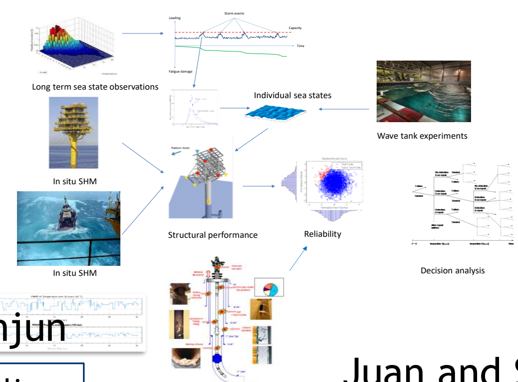
to fatigue assessments and risk informed inspection and maintenance planning for welded details in the structures, for scaling and corrosion assessments and risk informed inspection and maintenance planning for pipes/pressure vessels in well-head facilities

Kashif, Yue, Akinyemi, Henning and Jianjun

Sebastian

over the modeling of wave loads using wave tank and near shore test facilities



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and the probabilistic process modeling for the pressure vessels (variations of pressure and temperature)

Juan and Sebastian

to the modeling of extreme response (structural component failures, sequences of component failures and structural collapse) using advanced techniques of uncertainty propagation, sensitivity analysis and Bayesian decision analyses

From the modeling of waves (using data mining/Big Data techniques)

Sebastian

Input 2: AWARE – Total Energies

What did we accomplish?

R & D activities

Spin off 1: Corrosion/Fatigue project

Henning

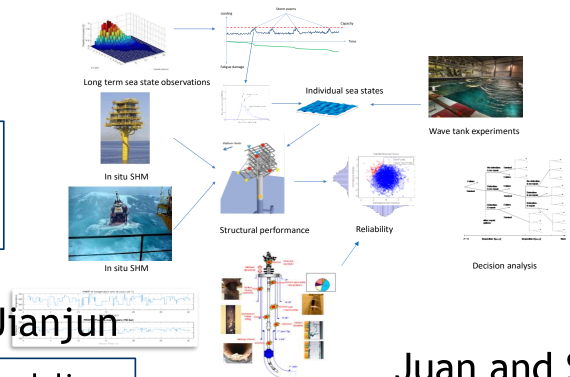
and structural responses (using monitoring, advanced finite element modeling and concepts of digital twins)

to fatigue assessments and risk informed inspection and maintenance planning for welded details in the structures, for scaling and corrosion assessments and risk informed inspection and maintenance planning for pipes/pressure vessels in well-head facilities

Kashif, Yue, Akinyemi, Henning and Jianjun

Sebastian

over the modeling of wave loads using wave tank and near shore test facilities



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From the modeling of waves (using data mining/Big Data techniques)

Sebastian

Spin off 2: InnoSHM

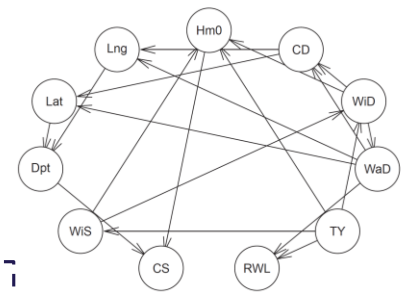
Spin off 3: DLL project

What did we accomplish?

Wave load environment modeling

- Modern big data methodologies
- Multi-scale modeling
- Data mining

Bayesian network model representation



Wave-tank experiments

- Hindcasts
- Forecasts / predictions
- ...

Processing
Probabilistic systems modeling

Decision

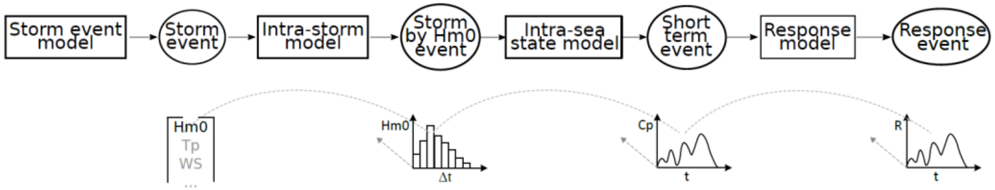
Strategy for information harvesting and inclusion, e.g.
- conduct large-scale CFD study,
- collect onside observations of wave characteristics for a given offshore location,
- perform new wave tank experiments
- ...

Inputs

- Data, e.g. onsite observations, simulation and experimental results ...
- Knowledge, e.g. domain expertise, which can act as a prior in modeling

Outputs

- Multi-scale load environment modeling, as apparent from the figure below.
- Toolboxes and tutorials for state-of-the-art system representations and analysis, see link below, e.g.
  - R toolboxes for system representations and inference using Bayesian networks
  - Python implementation of normalized fatigue crack growth model



What did we accomplish?

Probabilistic mechanics

- Probabilistic mechanics modeling and analysis for structural systems
- Probabilistic Digital Twins and sensitivity analysis
- Probabilistic system and damage identification

Processing
Probabilistic systems analysis

Decision

Strategy for information harvesting and inclusion, e.g.
- conduct simulation of a given load case for a structure, collect monitoring results of response characteristic for a given structure

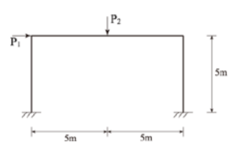
Inputs

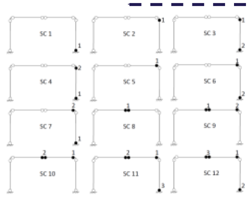
- Data, e.g. simulated and observed response characteristics for given load cases.

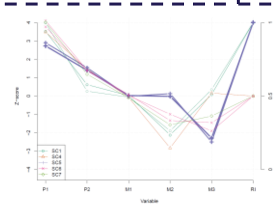
Outputs

- Systems analysis tools for e.g.
  - Damage detection using e.g. supervised classification
  - Sensitivity analysis using e.g. variance decomposition
  - Failure scenario identification via e.g. cluster analysis
  - Definition of characteristics values for e.g. code-based design of structures
- Note that many of the implementations (mainly Python) are assessable via the link below.

https://github.com/SebastianGlavind/PhD-study







ANCOVA

Input	S_i	S_i^U	S_i^C
P_1	0.933	0.932	0.001
P_2	0.001	0.003	-0.002
M_1	≈ 0	≈ 0	≈ 0
M_2	≈ 0	≈ 0	≈ 0
M_3	0.067	0.064	0.003
$\sum$	1.000	0.999	0.001

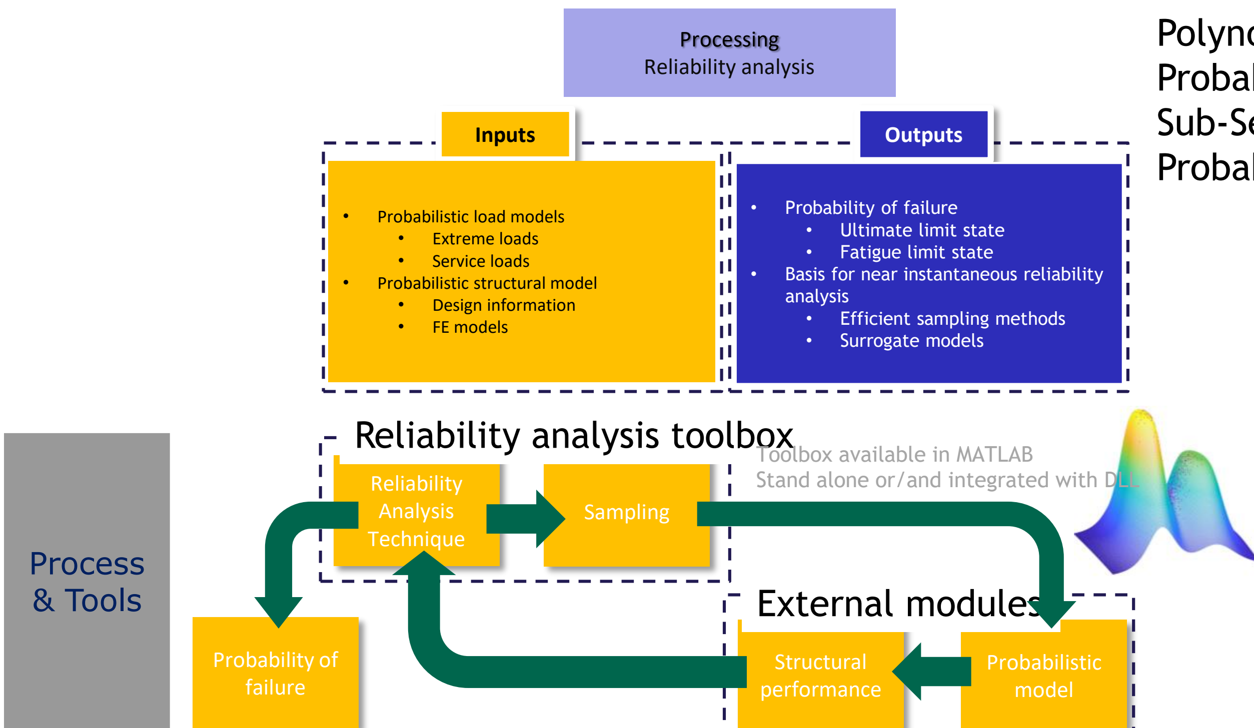
ANOVA

Input	S_i	S_{T_i}
P_1	0.935	0.935
P_2	0.003	0.003
M_1	≈ 0	≈ 0
M_2	≈ 0	≈ 0
M_3	0.062	0.062
$\sum$	1.000	1.000

What did we accomplish?

Efficient schemes for probabilistic analysis

- Identification of efficient schemes for probabilistic systems analysis
- Benchmarking of different efficient schemes – in different applications
- Applying and testing promising schemes



Polynomial Chaos Expansion Method
Probability Density Evolution Method
Sub-Set Monte Carlo Method
Probability Extrapolation Technique

What did we accomplish?

Structural Health Monitoring and Risk Informed Inspection

- Establishing probabilistic schemes for estimating parameters for the normalized Crack Growth Model
- Applying SHM and OMA for structural identification and assessment of fatigue stresses
- Risk Based Inspection

Processing
Probabilistic systems degradation modeling and analysis

Decision

Strategy for information harvesting and inclusion
- Monitoring and inspection techniques
- Sensor placement
- Uncertainty treatment
- Model fidelity

Value of information as decision support method

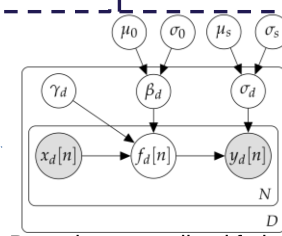
Inputs

- Data, e.g. modal responses, fatigue inspections, lab experiments, and simulation
- Knowledge, e.g. design assumptions, domain expertise, which can act as a prior in modeling
- Costs, e.g. inspection, monitoring, repair, maintenance

Outputs

- Python libraries
- (Lib I) Monitoring informed fatigue damage estimates.
- (Lib II) Bayesian normalized fatigue crack growth model.
- **Improved crack growth model for fatigue RBI planning.**
  - Can be included in Total RBI software.
  - Model learning possible in- or outside of RBI software.

Monitoring uncertainty aware data analyses



Bayesian normalized fatigue crack growth model

$$P(a(t) \geq a_c | a(t) < a_d(t)) = \frac{P(a(t) \geq a_c \cap a(t) < a_d(t))}{P(a(t) < a_d(t))}$$

Crack inspection

What did we accomplish?

Value of Information analysis (CTR3 + CTR2)

- Identification of different means of collecting new knowledge
- Modeling the quality and costs of collecting new knowledge
- Assessing the CAPEX/OPEX costs reductions associated with collecting new knowledge

Processing
Bayesian pre-posterior analysis

Decision

Strategies to collect information including
What to collect(e.g.) :
- Hotspots crack inspections
- Corrosion measurements
- SHM

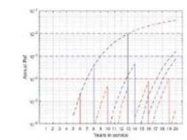
When to collect(e.g.):
- Annual PoF threshold
- Periodic

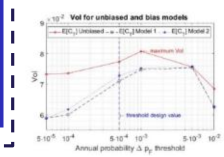
How to collect(e.g.):
- NDT type and techniques
- Multi fingers calipers

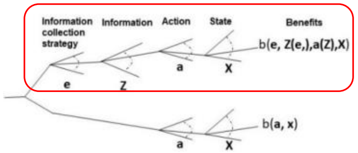
The decisions are based upon for e.g. improve digital twin model, reduce OPEX.

Inputs
- Uncertainties (errors) associated with measurement.
- Costs associated with each information technique.
- Cost associated each repair strategy.
- Constraints for inspection and repair.
- Prior knowledge e.g. design model, pervious inspections & repairs, assumptions.

Outputs
- VoI for each strategy for collection of information.
- Optimal inspection and repair plan for platforms, process equipment, pressure vessels etc.







What did we learn

Contributions to the best practice

- Efficient and consistent modeling of the wave load environment using Bayesian Probabilistic Nets
- Decision support on evacuation in the event of approaching storms
- Identification of a consistent scheme for estimating model parameters for the normalized SN experiment based crack growth model
- Coupling of SHM, OMA and RBI as a means for optimizing inspection and maintenance with respect to fatigue crack growth in welded joints
- Benchmarking of efficient techniques for probability calculations – providing insight on when to use what technique
- Development of Probabilistic Digital Twins of structural systems and Big Data enhanced sensitivity analysis – e.g. for assessing design values
- Utilization of SRA and RBI as basis for integrity management of well systems under degradation due to scale and corrosions
- Insights to the degree to which additional knowledge may reduce service life costs – and how the quality (bias/noise) of SHM affects the VoI

What did we learn

Contributions to the general body of knowledge

- New paradigm for modelling – context driven modeling – identifying the trade-off's in Occam's Razor
- Big Data generated by prior probabilistic modeling as means for development and updating of Probabilistic Digital Twins
- Use of Probabilistic Digital Twins as means for Big Data and SHM based system identification and modeling – such as in damage detection after extreme wave load events

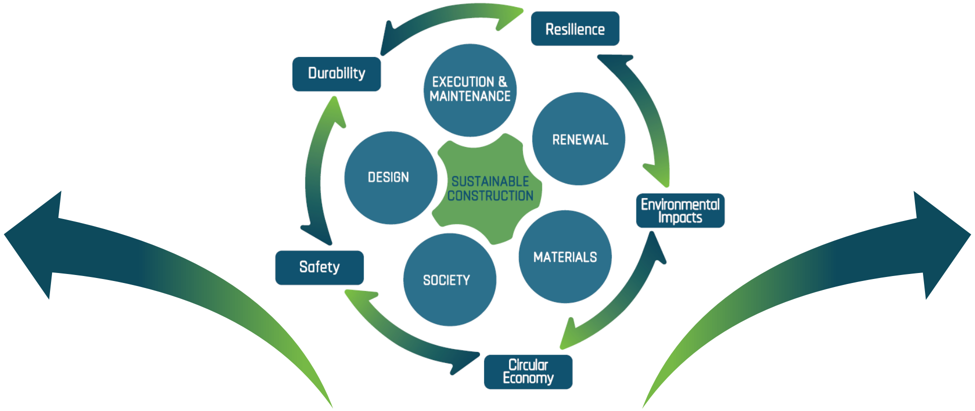
Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

Education and training

Global body of knowledge

Regional workshops



High level policy advice

Standards and codes

Best practices

The Joint Committee on the GLO*BE* Consensus

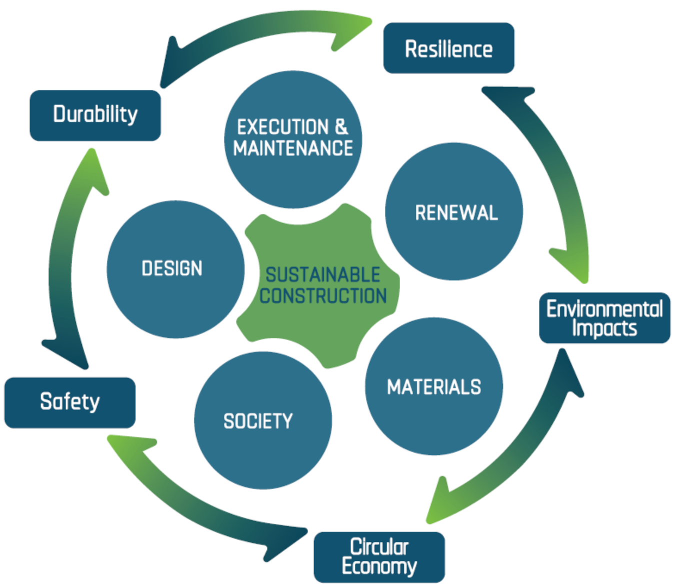
Liaison Committee

Industry, researchers, educators, committees, working parties, model codes, conferences - with 5000+ members representing more than 150 nation states

Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

The GLOBE Consensus



The Challenge

Nothing less than a transformative and united worldwide effort from all stakeholders of the construction sector is required for human society to be successful in sustainable development, and in the mitigation of the disastrous consequences of climate change at global and local scales.

Knowledge bears responsibility

Pathways to sustainable construction

In the past

Societal demands and trends		Objectives for structural engineering
Welfare	}	Safety
Efficiency		Reliability
		Risk

Knowledge bears responsibility

Pathways to sustainable construction

In the future

Societal demands and trends	Objectives for structural engineering	Technological facilitators
Welfare Efficiency	Safety Reliability Risk	Cyber-physical systems Big Data Industry 4.0 . . .
Globalization Population growth Urbanization	Resilience Sustainability	

Knowledge bears responsibility

Pathways to sustainable construction

In the future

Societal demands and trends	Objectives for structural engineering	Organizational facilitators
Welfare Efficiency	Safety Reliability Risk	Knowledge Accountability Culture Incentives ...
Globalization Population growth Urbanization	Resilience Sustainability	

Knowledge bears responsibility

Pathways to sustainable construction

In the future

Societal demands and trends	Objectives for structural engineering	Regulatory facilitators
Welfare Efficiency	Safety Reliability Risk	Laws Standards Design codes ...
Globalization Population growth Urbanization	Resilience Sustainability	

Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

It is planned that 150 GW (10000 OWT) is to be installed in the North Sea by 2050 – covering about half of the EU inhabitant demands for electricity (one quarter of which in the Danish part of the North Sea).

If - the CO2e emissions per GW offshore wind is in the order of 1 million ton of CO2e – we are facing an up-front investment of about 150 million CO2e – this compares to a total annual of 3000 million CO2e per year at EU level – corresponding to about 5%.

The normal life-time of OWT is in the order of 25 years – meaning that there will be a very high level of activities associated with new installations, O&M, decommissioning, renewals, circular economy (reuse/recycling) in the years to come.

Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

Presently the embedded CO2e emissions from construction contributes with about 20% of global CO2e emissions

We are struggling to put a lid on these emissions – and the Global South will comprise the major future source – and challenge in this regard

The Global North has a special obligation to reduce CO2e emissions and we must adequately contribute to the global community

Offshore wind energy appears to be key in meeting this challenge – but we must do all we can to avoid any unnecessary emissions in the transition process

This calls for "**turning every stone**" to find means for optimization

Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

Potentials for improvements in present best practices include:

Decisions on (modular) design, strategies for operation and maintenance and decisions for decommissioning and “end of life” are to be coupled and optimized jointly (circ. econ. 30-35% reduction of embedded CO2e).

The potentials of coupling the technological advances in SHM, Probabilistic Digital Twins and Risk Informed Inspection and Maintenance Planning are systematically exploited as a means for reducing CO2e emissions, and costs. Sharing publicly available data is reasonable.

Operations and integrity management of the many OWT parks and installations is addressed as one overall activity for which in principle all activities are jointly optimized (using Digital Twins also for O&M).

Knowledge bears responsibility

Meeting the challenges of the future with the knowledge of the past

Based on the technological developments achieved within the within the Danish Offshore Technology Center and the experiences and expertise on how to bring together research environments with the needs of the industry it appears reasonable to exploit the possibility of establishing a

Joint European/(or Nordic) Research and Development Center for Offshore Wind Energy

….in a collaboration between the Public (EU), investors and the stakeholders of the industry.

A 1000 billion investment is assumed for the 10000 OWT's – and it is more than plausible that joining forces around an investment of 0.1% for the activities of such a center can achieve a CAPEX/OPEX cost reduction in the range of ?1-5 %? - on top of reduced environmental damages.

Danish Offshore Technology Conference
Kolding, November 29-30, 2022

Thank You for Your Attention ☺

Michael Havbro Faber

E-mail: mfn@build.aau.dk