# The potential of Isogeometric Analysis for improved simulation of environmental impact on large structures

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# Objective of 3D models and the used 3D representations

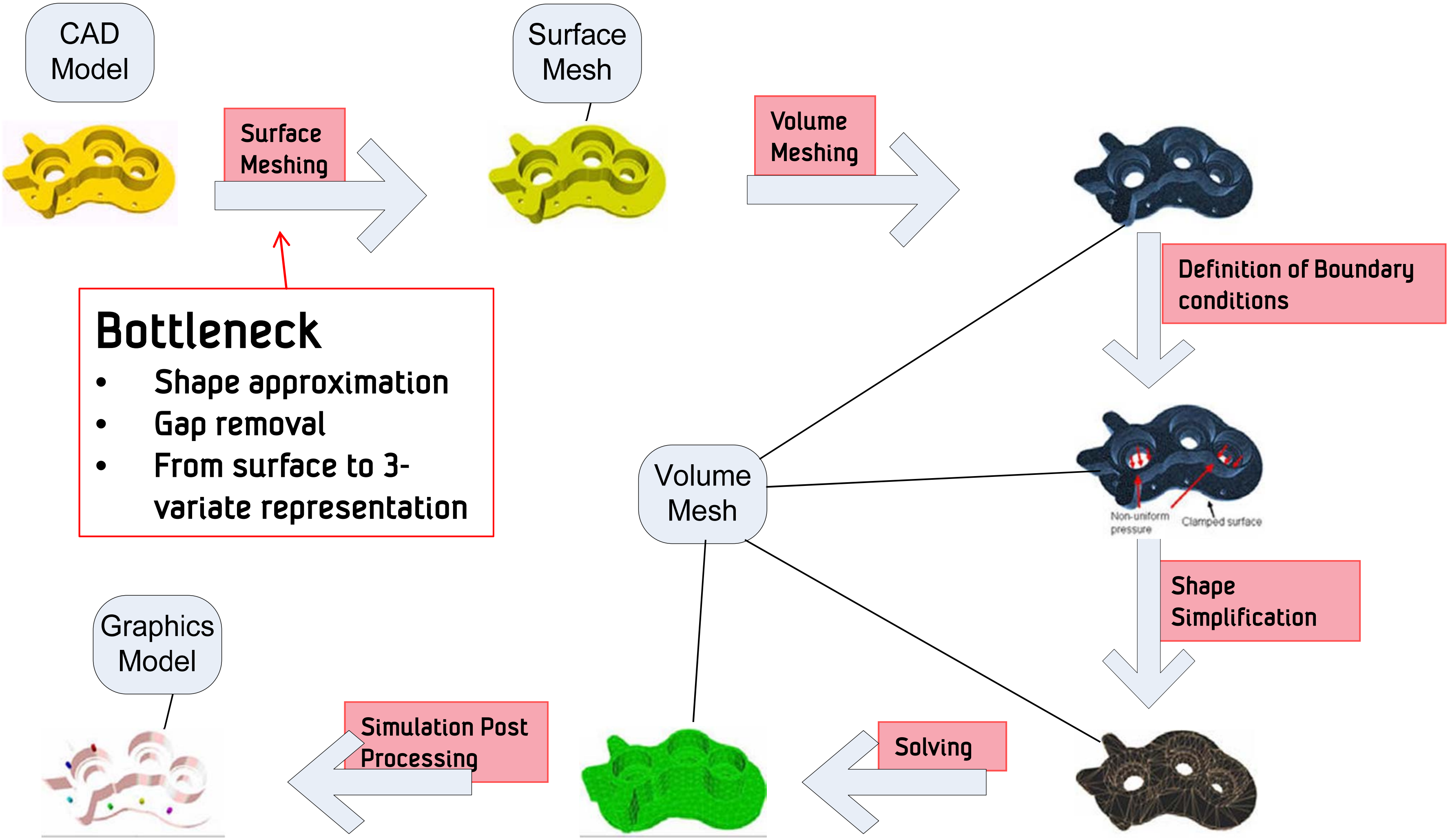
| Purpose | Quality criteria: | State-of-the-art: |
|---|---|---|
| Computer Graphics | Visual impression | Triangulations & texture mapping |
| Animation movies | Visual impression | Subdivision surfaces |
| Computer Aided Design (CAD) | Face connectivity and<br>Shape accuracy<br>Suitable for production | Boundary structures of elementary and NURBS surfaces |
| Manufacturing & robotics (CAM) | Proper control of movements | Curves to control movement<br>Shape as Triangulations (STL) or CAD-surfaces |
| Finite Element Analysis (FEA) | Volume block connectivity<br>Model refinement in critical regions | Structures of 3-variate parametric polynomials, most often of degree 1 or 2. |

In current simulation processes for large structures many instances, representations and qualities of the same information is used.

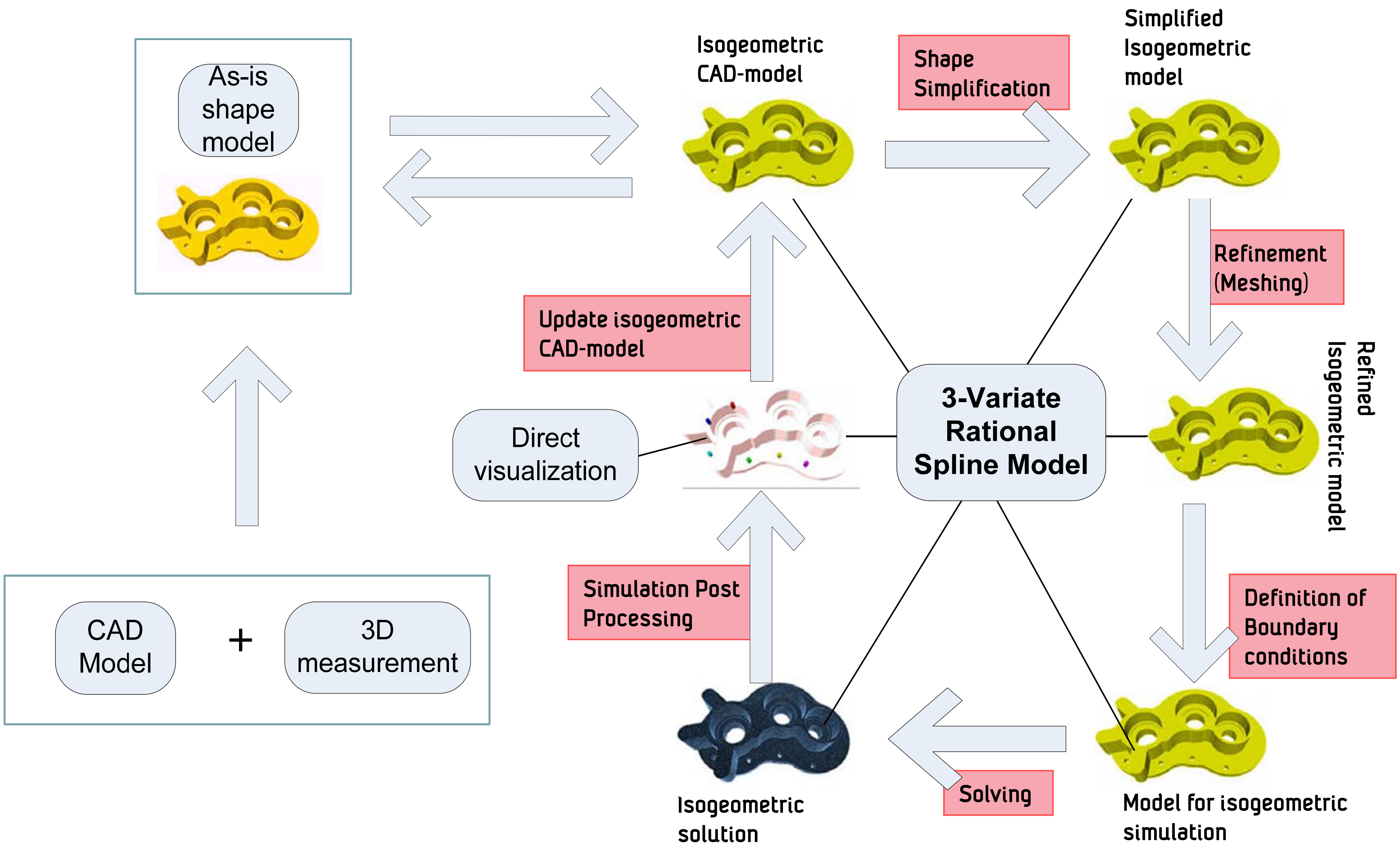
# Improved simulation of environmental impact on large structures - Requirements

- Model quality
  - CAD model shape accuracy
    - Updated to represent "As-is" (CAD-models describe "As-planned")
    - Unnecessary details removed
  - FEA model connectivity
    - Watertight models (Correct connectivity/topology)
    - Simulation model refined as needed in critical regions
    - Grids for coupled systems
- Simulation quality
  - Higher order methods to better reflect the physics involved
  - Coupled problems, systems, e.g., fluid structure interaction
- Visualization
  - High end 3D graphics
  - Visual impression as in games and movies

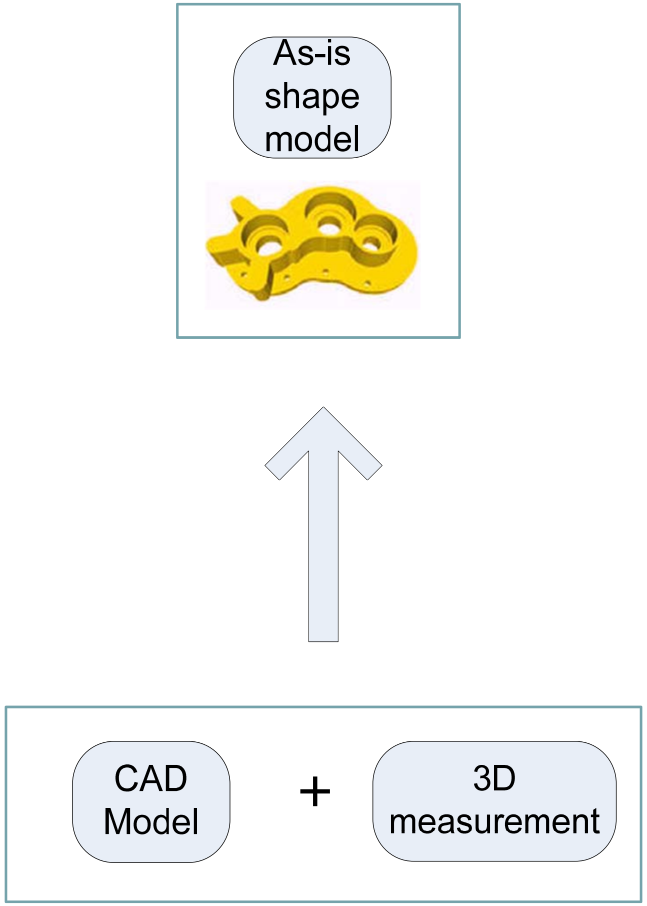
# Traditional simulation pipeline



# Simulation on large structures– Future Information flow

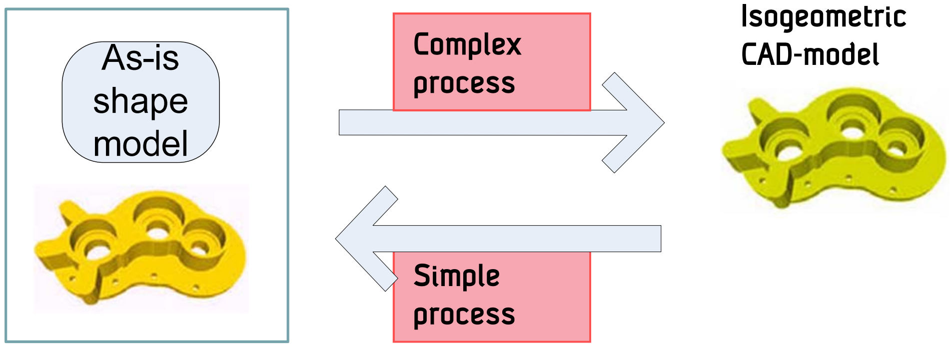


# Challenge 1: Create "as-is" model



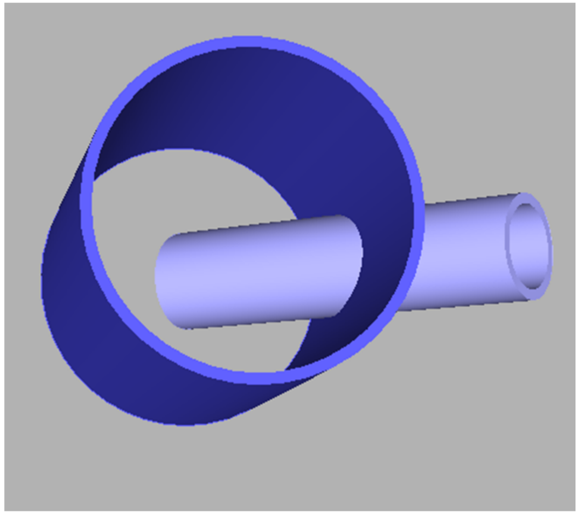

- CAD-models describes the object as planned
  - Combines elementary surfaces (plane, cylinder, cone, sphere, torus and NURBS)
- Models aimed at visual purpose most often represent shape by (texture mapped) triangulations
- Laser scanning efficiently produce millions of points on the geometry
  - Extracting information from 3D datasets is complex
  - A industry is established related to model building from laser scans
  - Using the datasets for validation and updating of 3D models (CAD) is challenging
- The project "3D Airports for Remotely Operated Towers" in SESAR JU (EU) partly addresses these challenges for airports
  - The novel Locally Refined Splines will be explored.

# Challenge 2: Create 3-variate isogeometric model

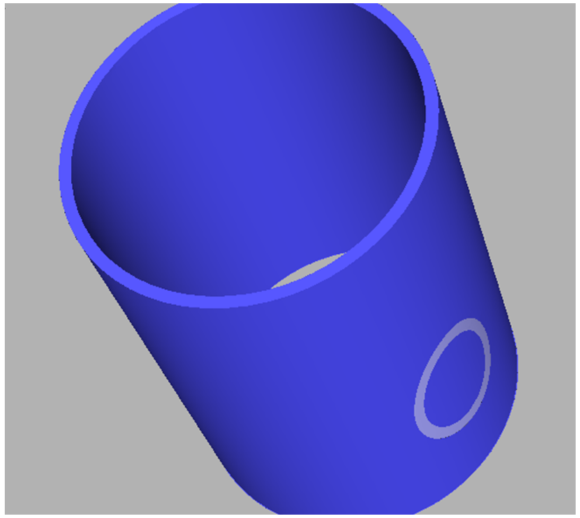



- The "As-is" shape model describes mathematically only the inner and outer hulls (surfaces) of the object using triangulations, elementary surfaces or NURBS surfaces.
- The isogeometric model is analysis/simulation suitable and describes the volumes mathematically by watertight structures of blocks of 3-variate rational splines
- Building an isogeometric model is a challenge:
  - There is a mismatch between the surface patch structure of the "As-is" model, and a suited block structure of an Isogeometric 3-variate rational spline model.
  - Augmented spline technology is needed such as the novel Locally Refined Splines.
- Projects addressing this
  - Isogeometry (2008-2012)- KMB project funded by the Norwegian Research council
  - TERRIFIC (2011-2014) – STREP funded by the EU ICT under contract negotiations

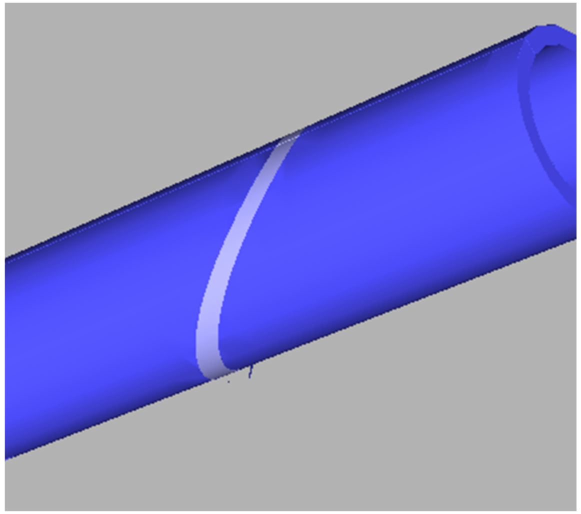
# Example: Isogeometric tube joint - Intersection



- Two independent pipes coming from CAD and described as 3-variate volumes



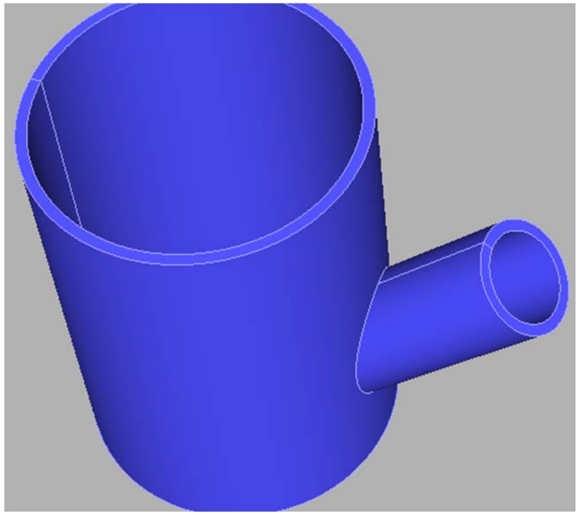
- The intersection of the pipes calculated.
- The original large pipe is split in 3 volumes



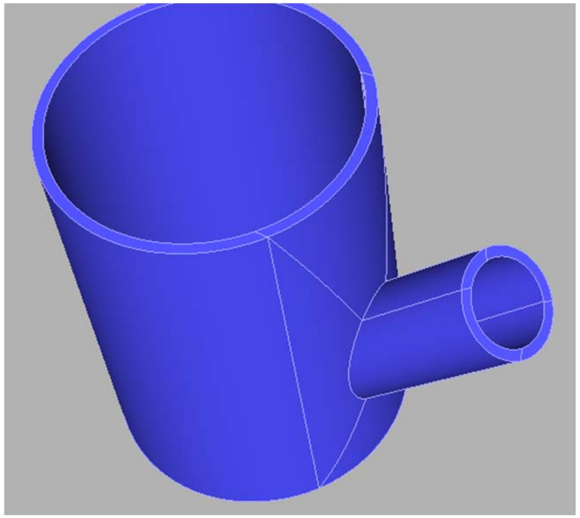
- The intersection of the pipes calculated.
- The original small pipe is split in 3 volumes

Example by:
Vibeke Skytt, SINTEF IKT

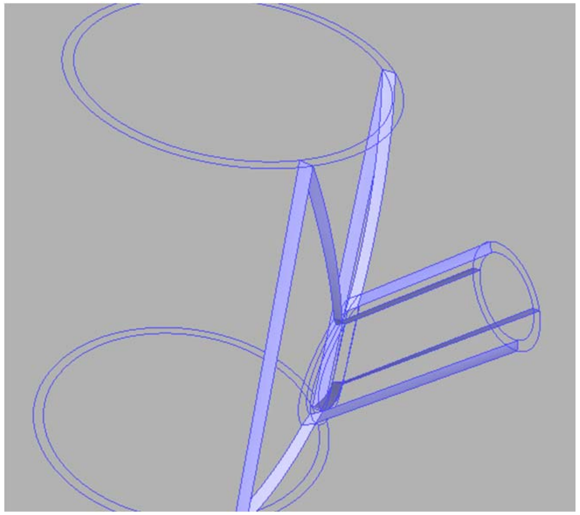
# Example: Isogeometric tube joint – Composing volumes



- The relations between the sub volumes produced by the intersection are established
- These volumes do not satisfy the hexahedral (box structure) of the need isogeometric sub volumes



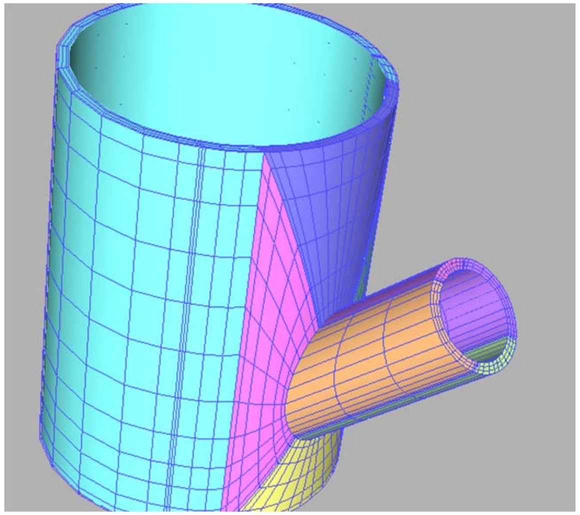
- The volumes split to produce hexahedral volumes



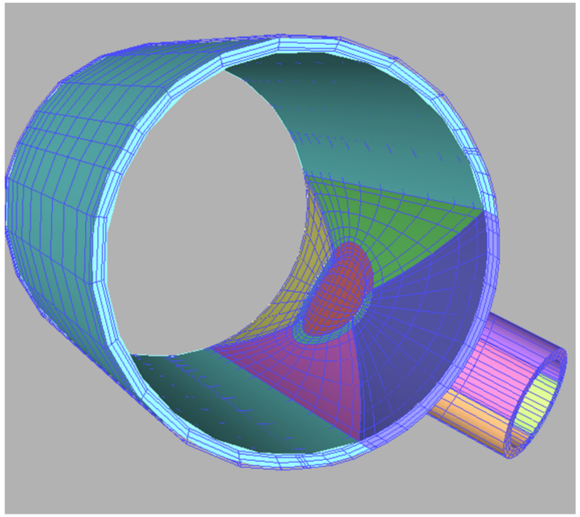
- The internal faces produced by the splitting process

Example by:
Vibeke Skytt, SINTEF IKT

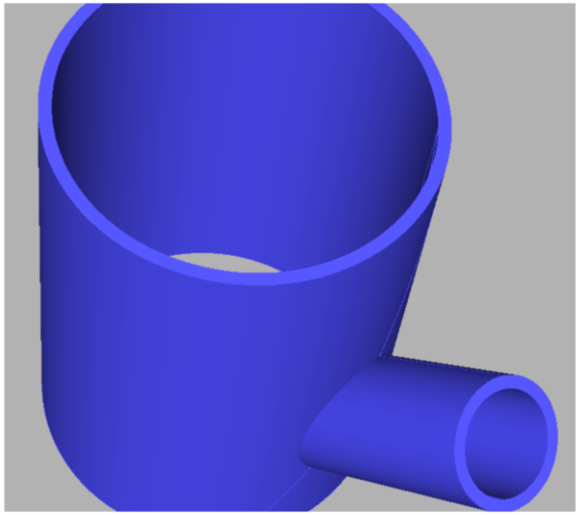
# Example: Isogeometric tube joint – match spline spaces



- Spline space refined to have matching lines in each hexahedral NURBS-block to produce a watertight representation



- Same as to the left, different view



- The final isogeometric tube joint.

Example by:
Vibeke Skytt, SINTEF IKT

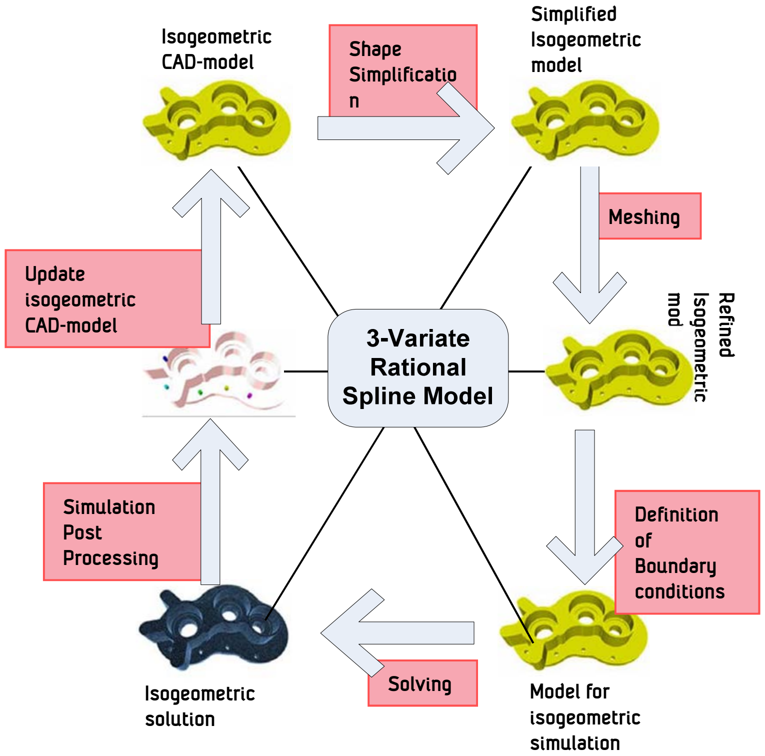
# Challenge 3: Isogeometric analysis

First introduced in 2005 by T.J.R. Hughes, Univ. Texas

- Replace traditional Finite Elements by NURBS - NonUniform Rational B-splines
- Accurate representation of shape
- Allows higher order methods
- Perform much better that traditional Finite Elements on benchmarks
- Refinement of analysis models without remeshing
- Exact coupling of stationary and rotating grids
- Augmented spline technology is needed, e.g., Locally Refined Splines

Projects:

- ICADA (2009-2014)– KMB Project funded by Norwegian Research Council and Statoil
- Exciting (2008-2011) – STREP Project EU's Transport program

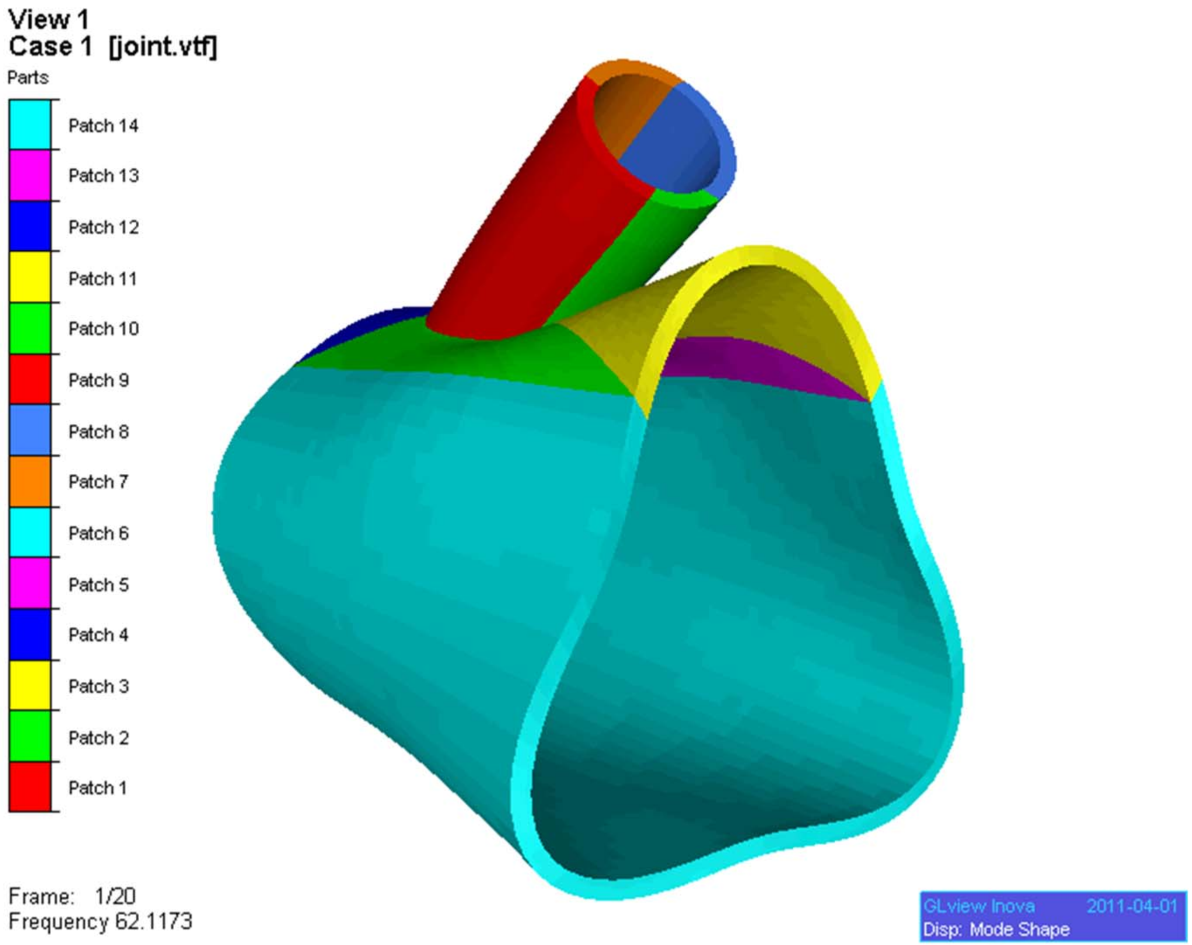


# Why has isogeometric analysis not been introduced before?

Independent evolution of CAD and FEM

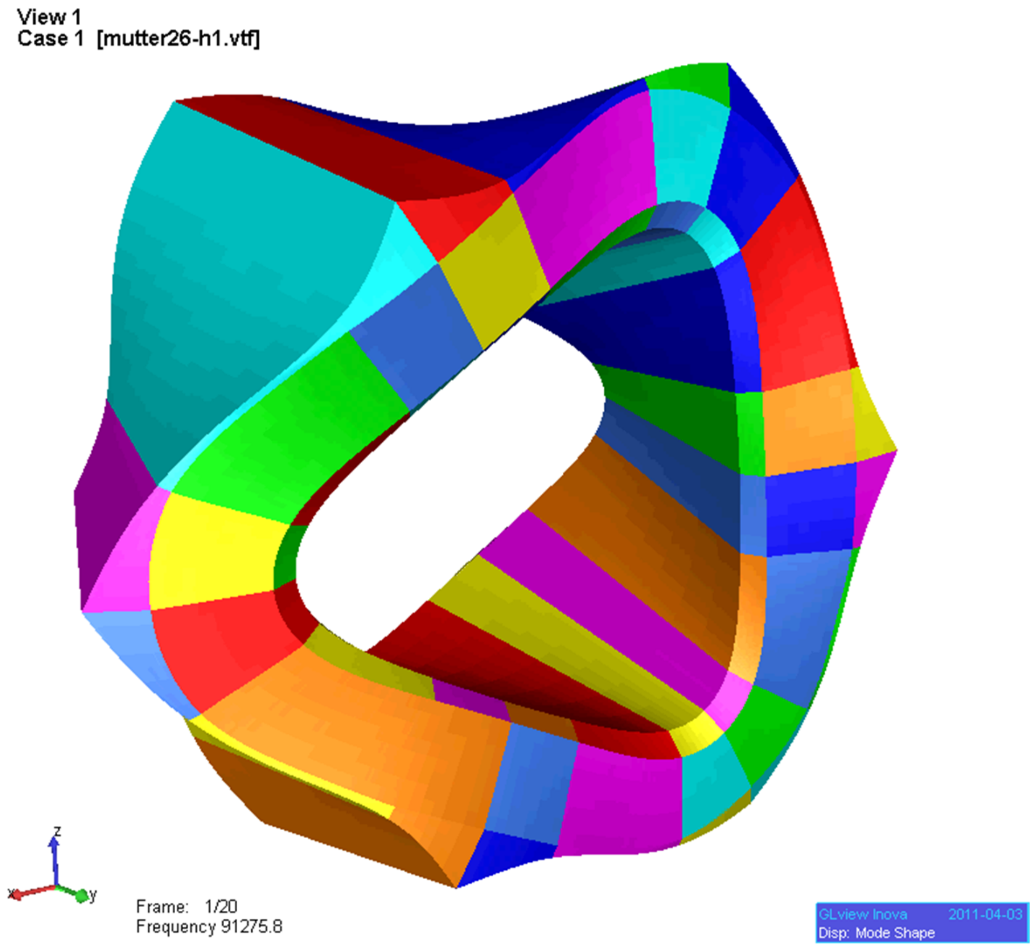
- CAD (NURBS) and Finite Elements evolved in different communities before electronic data exchange
  - FEM developed to improve analysis in Engineering
  - CAD developed to improve the design process
  - Information exchange was drawing based, consequently the mathematical representation used posed no problems
  - Manual modelling of the element grid
  - Implementations used approaches that best exploited the limited computational resources and memory available.
- FEA was developed before the NURBS theory
  - FEA evolution started in the 1940s and was given a rigorous mathematical foundation around 1970 (E.g, ,1973: Strang and Fix's An Analysis of The Finite Element Method)
  - B-splines: 1972: DeBoor-Cox Calculation, 1980: Oslo Algorithm

# Free vibration of a Tubular Joint
# – 3-variate NURBS elements




Example by: Knut Morten Okstad, SINTEF IKT

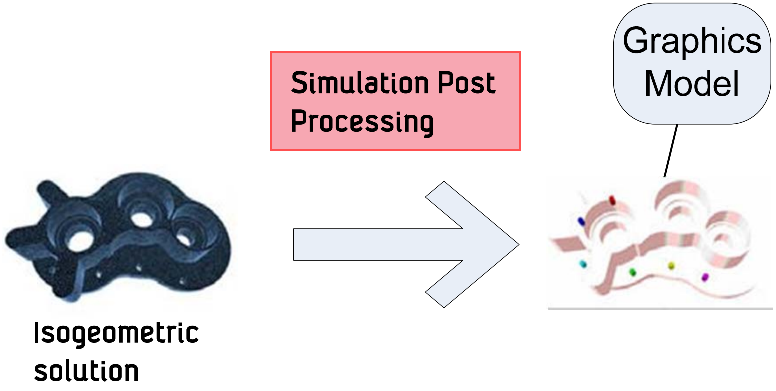
# Free vibration of a Nut
# – 3-variate NURBS elements



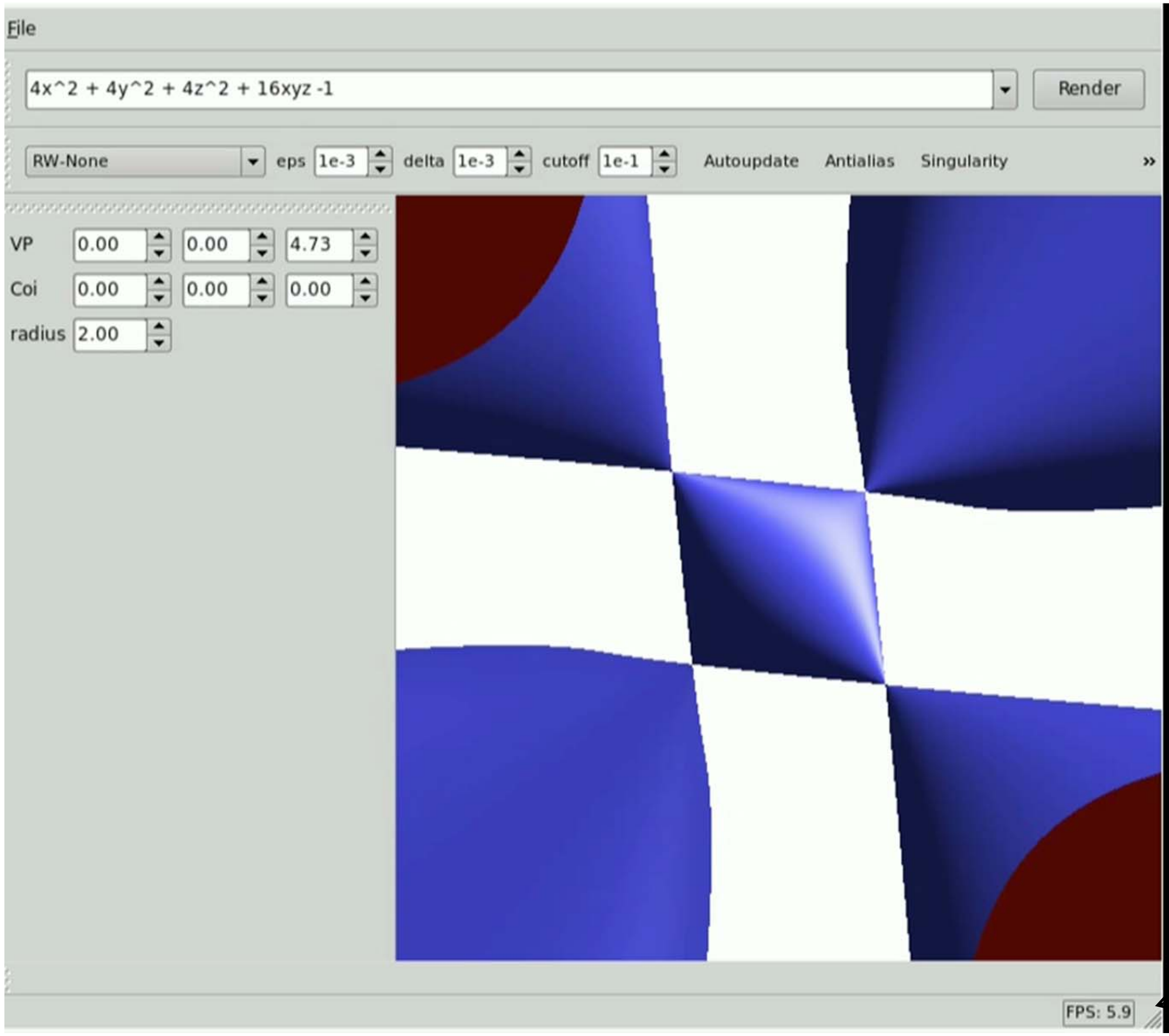

Example by: Knut Morten Okstad, SINTEF IKT

# Challenge 4: Isogeometric visualization

- Current visualization technology address low order elements
  - Currently the isogeometric model has to be approximated with lower order representation (elements) for visualization
  - Results are degraded and information lost
- Need for visualization solutions exploiting the higher order representations
  - Higher order representations are more advanced and can better represent singularities in the solution
  - Direct ray tracing on the GPU:
- Cloudviz (2011-2014) – KMB project funded by Norwegian Research Council, Statoil, Ceetron,….



# Direct rendering of advanced shapes on the GPU – avoiding tesselation

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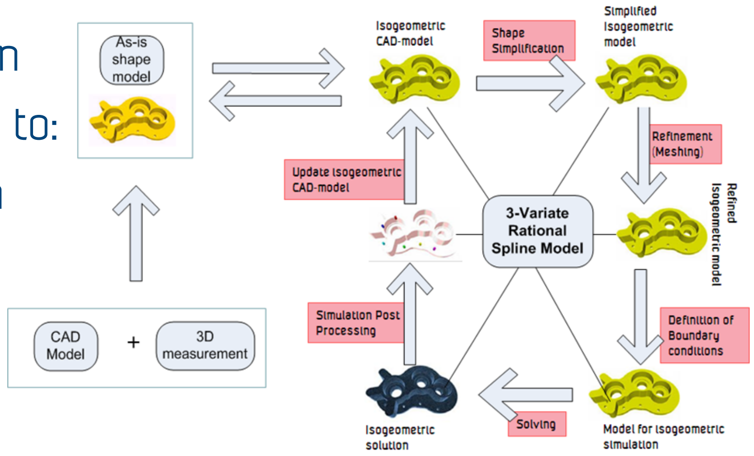
Eurographics 2008
Video : Johan S. Seland, SINTEF IKT, and Martin Reimers, UiO

Frames per second

# Summing up:

- Efficient simulation of environmental impact on large structures requires an holistic approach to:
  - Creating a validated structure description
  - Creating an analysis suitable model
  - Handling coupled models and system
  - High quality visualization




- Current technologies are fragmented and requires significant human intervention to work in an integrated way

- Isogeometric analysis has a potential of providing interoperability of shape representation (CAD) and FEA. However, augmented technology is need for
  - Locally Refined Splines
  - Combining measurements of shape "as-is" with existing synthetic models (CAD)

# Isogeometric Eigen frequency analysis of Chess Queen

Animation by:
Kjetil A. Johannessen
PhD-fellow, NTNU

- The Eigen frequency analysis and consequently the animation is based on an isogeometric volumetric NURBS representation. Consequently the surface is a NURBS surface at all times, and can be translated back to CAD exactly as it is for any time step
.