Title	NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery, Deliverable D2.5 & D2.8 Modelling tools for cabin acoustic design
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NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery

D 2.5. Evaluation of the modelling tools for predicting the performance of materials and structures in cabins

D 2.8. Selected modelling methods and tools for cabin acoustic design

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Confidentiality:	Public

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Summary

Project name Advanced functional solutions for Noise and Vibration reduction of machinery	Project number/Short name 71902–1.1.2 / NOVI-SP2
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Keywords Modelling tools, modelling flowchart	

Summary

Comsol Multiphysics, Va One, Abaqus and Actran were compared to be used as the software for cabin acoustics simulations in NOVI SP2. Actran was selected to be used as a FEM program in frequency domain, using Biot’s model for absorptive materials. CAD data was simplified and repaired, and the mesh was done in Ansys.

The modes and the eigenfrequencies of empty cabin, calculated with Abaqus and Actran, are very consistent. The calculated sound field distributions with internal loudspeaker excitation are rather similar to the measured ones.

A general modeling flowchart for vibroacoustic simulations has been developed in the project.

Confidentiality	Public

Espoo 19.12.2013

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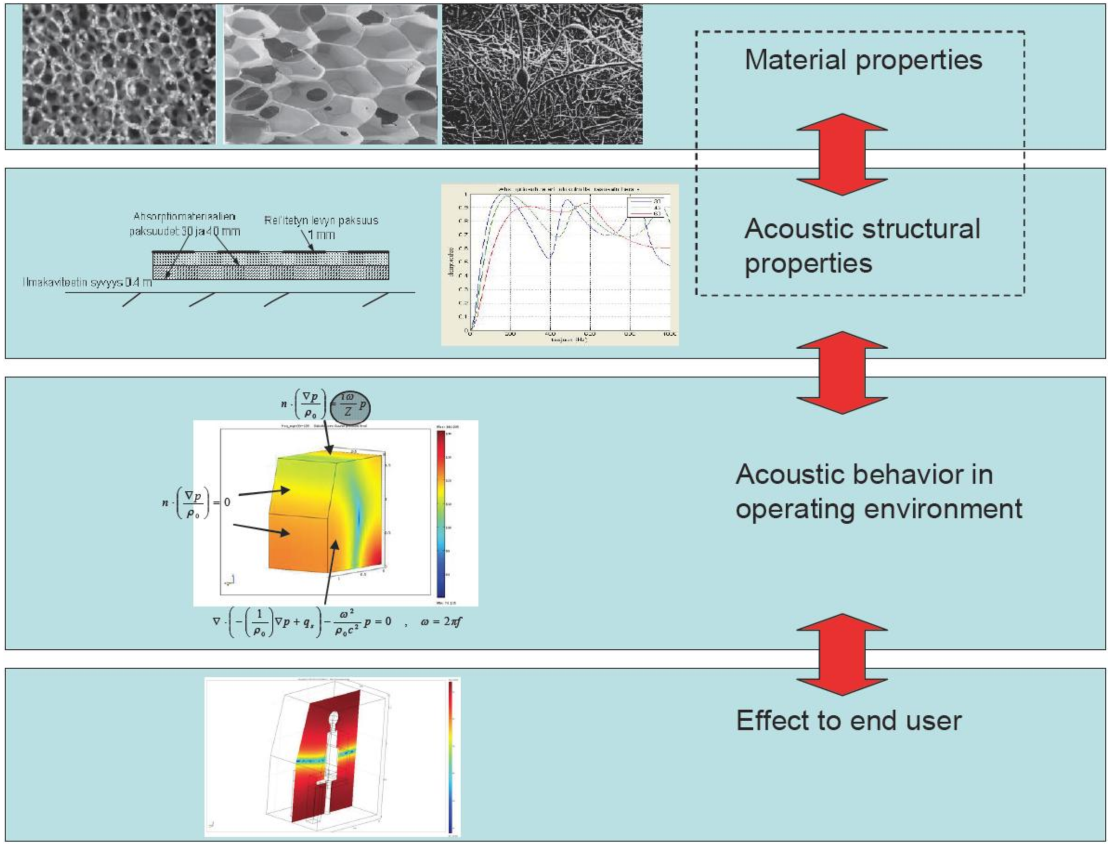
Table of content

Introduction
Cabin acoustics

- Acoustical properties of cabin interiors are often designed experimentally
- It is advantageous to approach acoustic planning by modeling
  - Modeling supports product design
  - Optimal solutions with less experimental effort

➢Acoustic FEM



Introduction
Structure-borne noise and vibration

- Acoustic and structural FEM together
  - Minimizing vibrations and sound fields due to vibration sources
  - Optimizing, e.g., structural joints in sound insulating structures
- Research needs
  - Different kind of excitations
  - Constraints and boundary conditions
  - Fast calculation methods
  - Definition of material parameters

Calculation principles

- FEM (Finite Element Method) / BEM (Boundary Element Method)
  - Sound and vibration distributions
  - Best at low frequencies
    - High frequencies need a lot of memory and calculation time
- SEA (Statistical Energy Analysis)
  - Sound and vibration mean values in subsystems
  - Best at high frequencies
    - Modal density should be high enough
- Hybrid and combined models
  - Both low and high frequencies can be modeled efficiently

Domains

- Frequency domain
  - Eigenmodes and –frequencies
  - Steady state response at different frequencies
- Time domain
  - Model auralization
  - Transient response
  - Study of nonlinear phenomena

Software for cabin modeling
Calculation principles and domains

Comsol Multiphysics
- FEM
- Frequency domain
- Time domain

Va One
- FEM/BEM
- SEA
- Frequency domain

Abaqus
- FEM
- Frequency domain
- Time domain

Actran
- FEM/BEM
- Frequency domain
- “Time domain”
  - Generated from frequency domain results

Software for cabin modeling
Absorptive materials

Comsol Multiphysics

- Delany-Bazley model
- Biot equivalents
  - Rigid frame and limp frame models available

Abaqus

- Complex material constants
  - Delany-Bazley model
    - Does not work at low frequencies
      - Real part of density and imaginary part of Young's modulus go to negative
  - Rigid frame models
    - Complex material constants must be defined by user

Va One

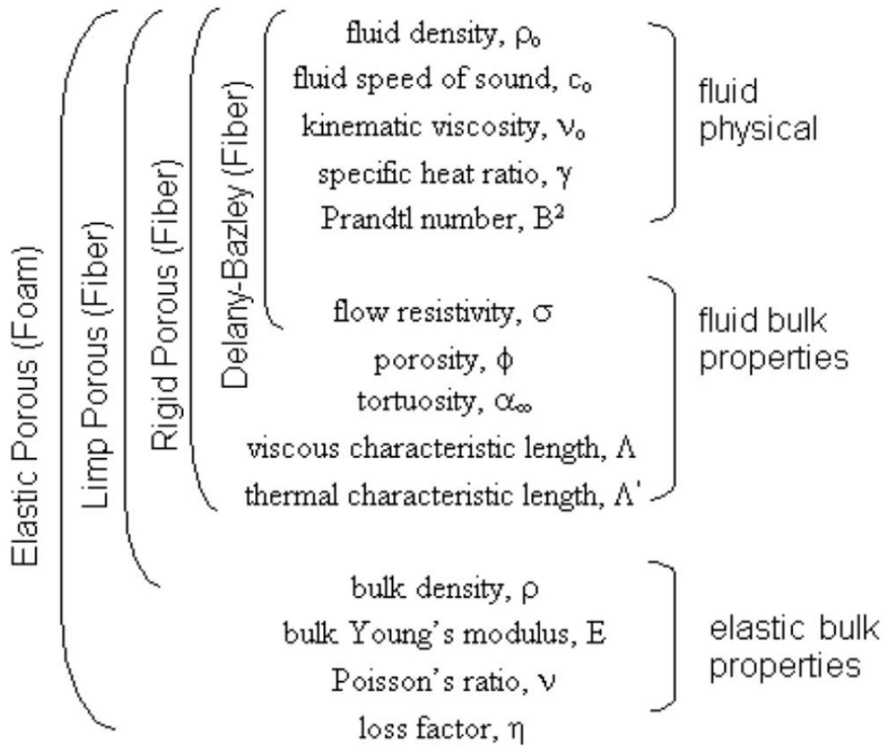
- Delany-Bazley model
- Foam module
  - Rigid frame, limp frame and Biot models available

Actran

- Delany-Bazley model
- Rigid frame, limp frame and Biot models available

Software for cabin modeling
Absorptive materials
Macroscopic parameters of absorbents needed

- Delany-Bazley model
  - Fluid parameters and flow resistivity
- Rigid frame models (Johnson's and Allard's models) (in addition to former parameters)
  - Porosity
  - Tortuosity
  - Viscous characteristic length
  - Thermal characteristic length
- Limp frame model (in addition to former parameters)
  - Density of frame material
- Biot model (in addition to former parameters)
  - Young's modulus of frame material
  - Shear modulus (or Poisson's ratio) of frame material
  - Loss factor of frame material

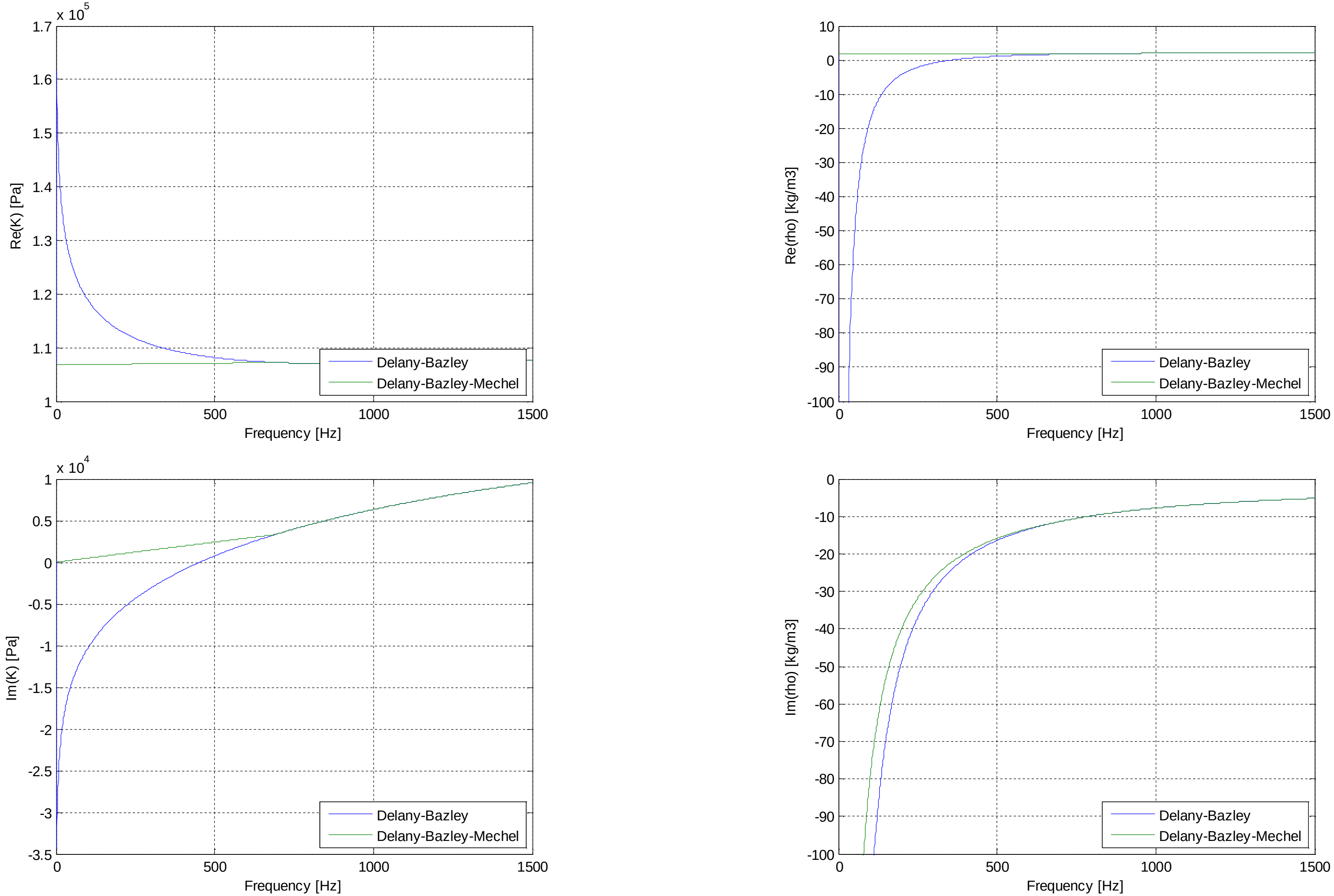


Va One 2012 Foam Module User's Quide, Theory & QA
ESI Group

Software for cabin modeling

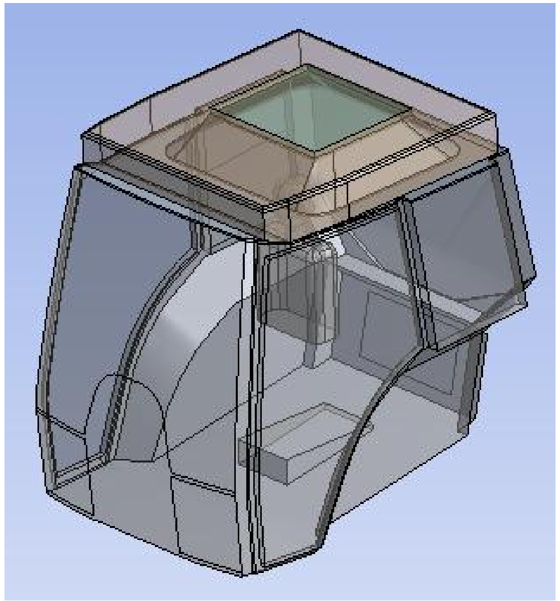
Absorptive materials

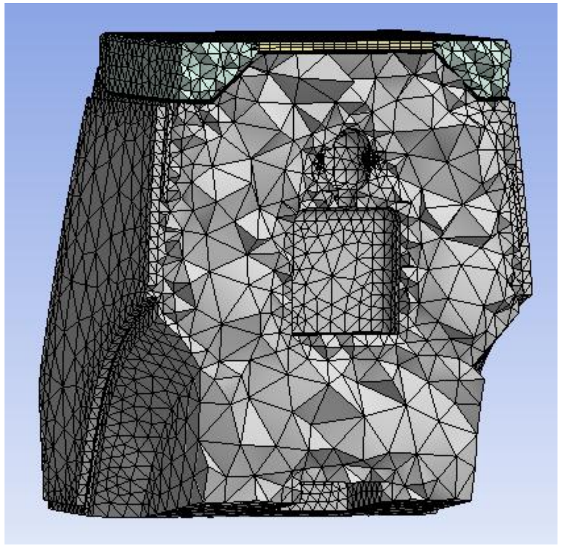
Delany-Bazley model in Abaqus (R = 50 000 Pas/m^2)



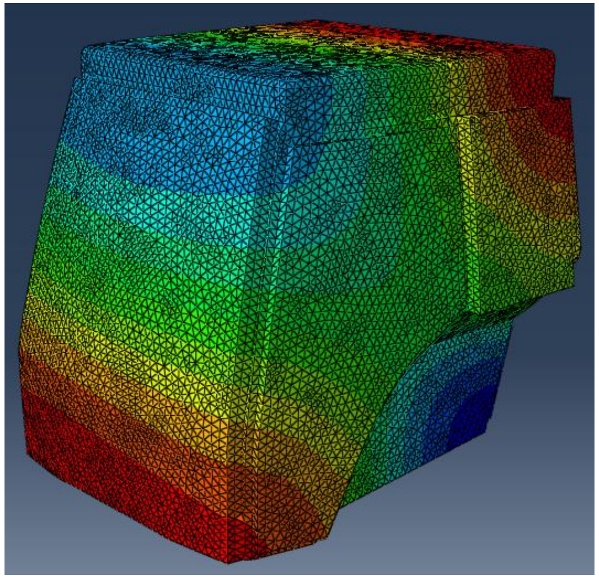
Selected tools (1)

- Basic software: Actran
  - CAD data for airspace geometry simplified and repaired in Ansys
  - Final geometry done in Abaqus
  - Mesh done in Ansys
    - MultiZone method in inner-roof meshing
      - Automatic generation of pure hexahedral mesh where possible
      - Filling more difficult regions with unstructured mesh
      - More precision along thickness
  - Calculations in frequency domain

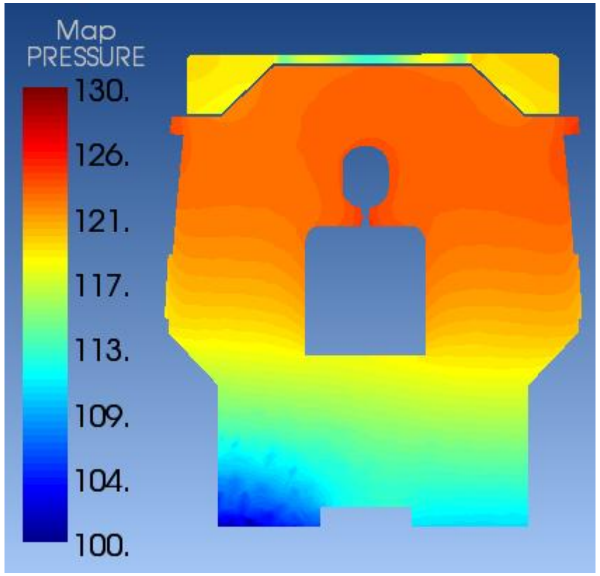




Selected tools (2)



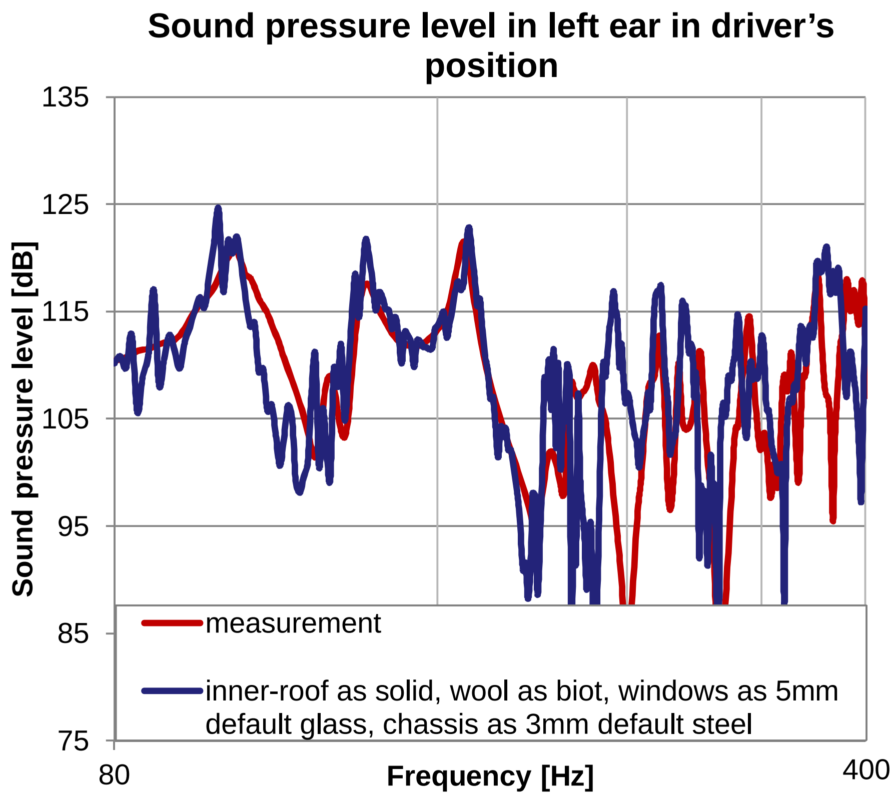
- Modes of empty cabin (Abaqus, Actran)
  - Methods used:
    - AMLS (Automated Multi-Level Substructuring)
      - Hierarchical
      - Proper for a broad frequency range
      - Reduced order models
    - Lanczos algorithm
      - Iterative
      - Requires more memory and time
- Response to acoustic or structural excitation (Actran)
  - Method: steady state dynamic, modal
- Absorptive materials: Biot's model
- Global damping: complex sound speed based on reverberation time measurements



Model validation

- Modes of empty cabin, modeled in Abaqus and Actran, are consistent
- Calculated field distributions with internal loudspeaker excitation rather similar to measured ones
  - Amplitudes do not agree very well
- Response to structure-borne sound and external diffuse sound field excitation not validated against measurements

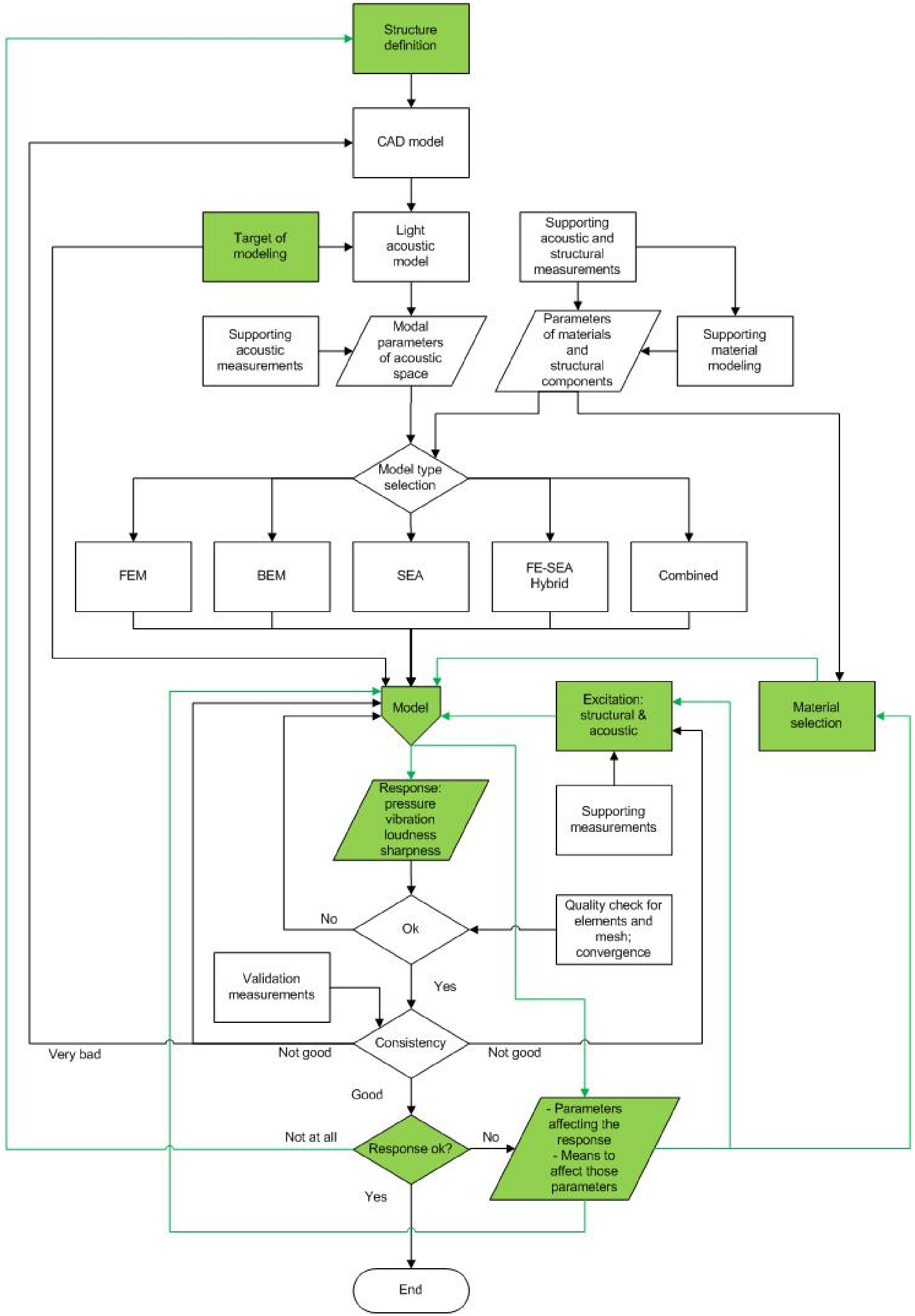
mode n.	Abaqus	Actran
1	98.3Hz	98.4Hz
2	121.4Hz	121.5Hz
3	131.0Hz	131.1Hz
4	161.5Hz	161.7Hz
5	163.8Hz	163.9Hz
6	192.6Hz	192.8Hz
7	207.5Hz	207.8Hz
8	219.7Hz	219.9Hz
9	220.4Hz	220.6Hz
10	240.3Hz	240.6Hz
11	251.2Hz	251.5Hz
12	253.5Hz	253.9Hz
13	261.3Hz	261.6Hz
14	267.4Hz	267.7Hz
15	273.6Hz	273.9Hz



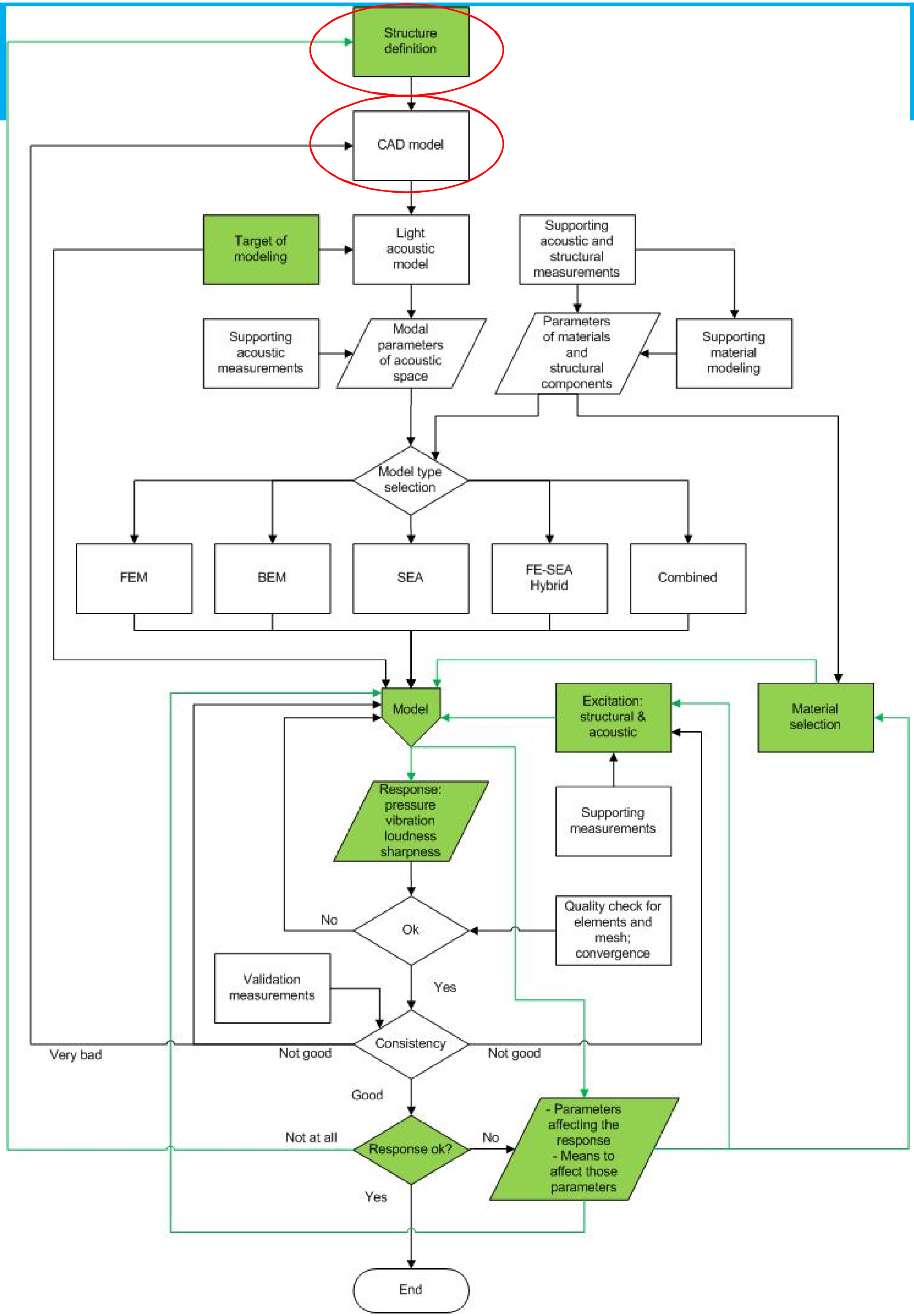
Modeling flowchart (1)

- Modeling flowchart can be used in various stages of design
  - Conceptual design
  - Embodiment design
  - Detail design
- The amount of structural details depends on the stage of design
  - In conceptual stage, model can be more simple
  - In detail design stage, all acoustically remarkable details should be included
- All parts of the flowchart are not necessary used in all stages of design

Modeling flowchart

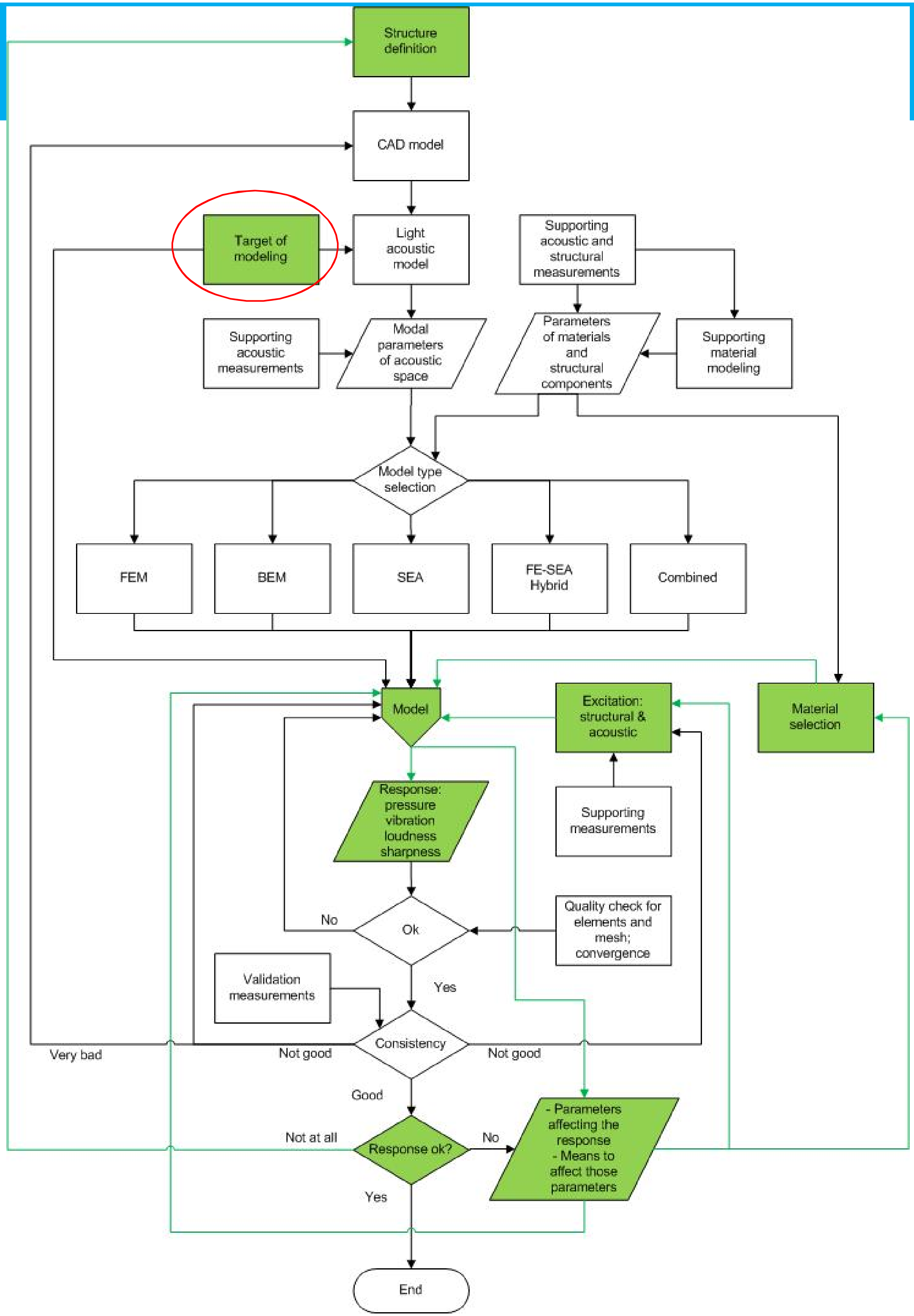


Green parts form the core of virtual simulation



Modeling flowchart (3)

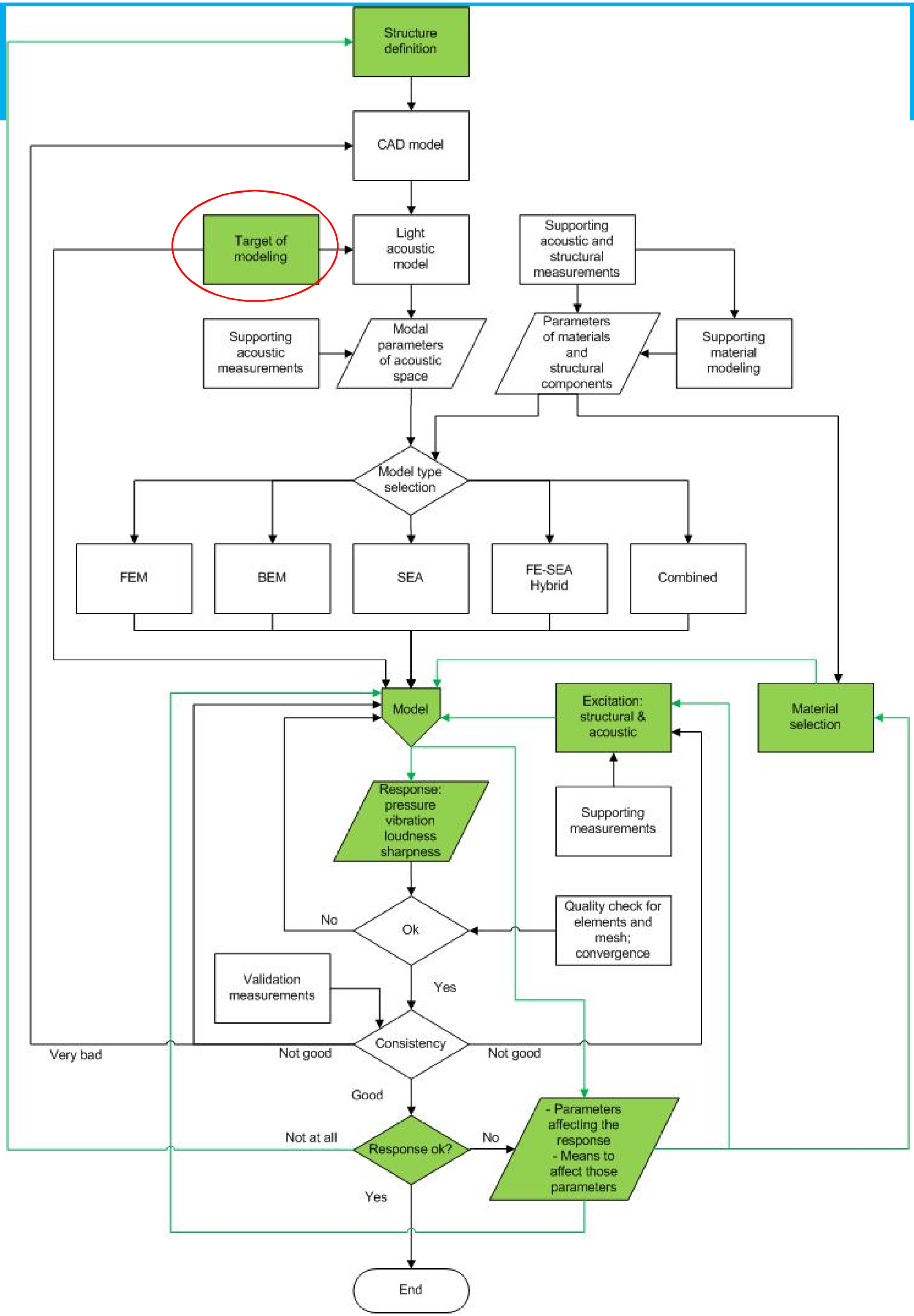
- (Core of virtual simulation presented in green)
- Structure definition
- CAD model
  - From industrial designer
  - Modified version for acoustical purposes from industrial designer and modeler



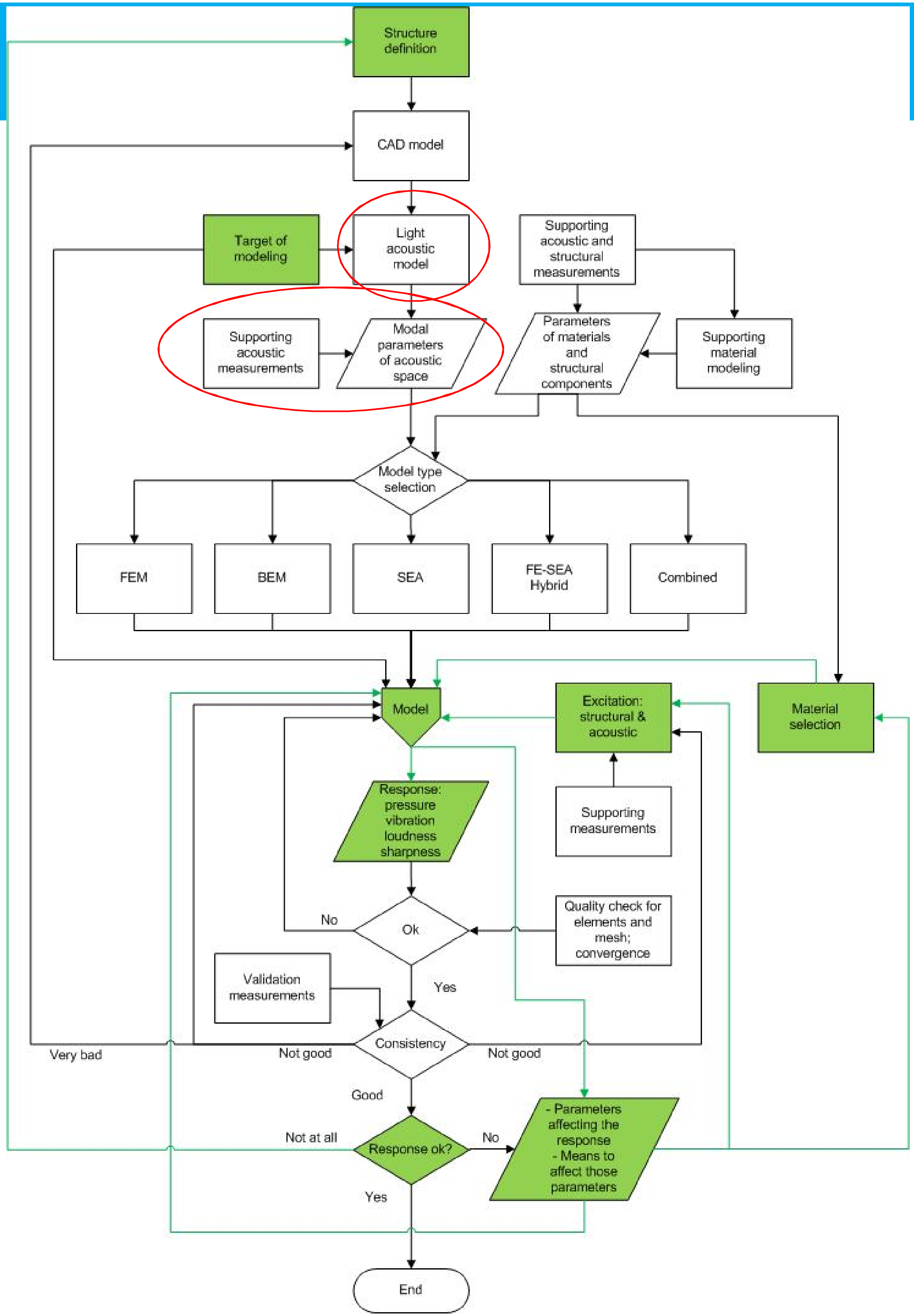
Modeling flowchart (4)

- Target of modeling from client and modeler
  - Target depends on design stage
    - Amount of structural details
    - Necessary parts of flowchart to be used
  - What questions should be answered considering materials, e.g.
    - Tailoring properties of inner roof
    - Selecting absorbents and their locations
    - Other noise control treatments and their specifications
    - Tailoring steel-bitumen structures
    - Effects of loss factors of steel structures
    - Development of acoustic glasses
    - Utilizing FE-SEA in subsystems of bones and small air cavities

Modeling flowchart (5)

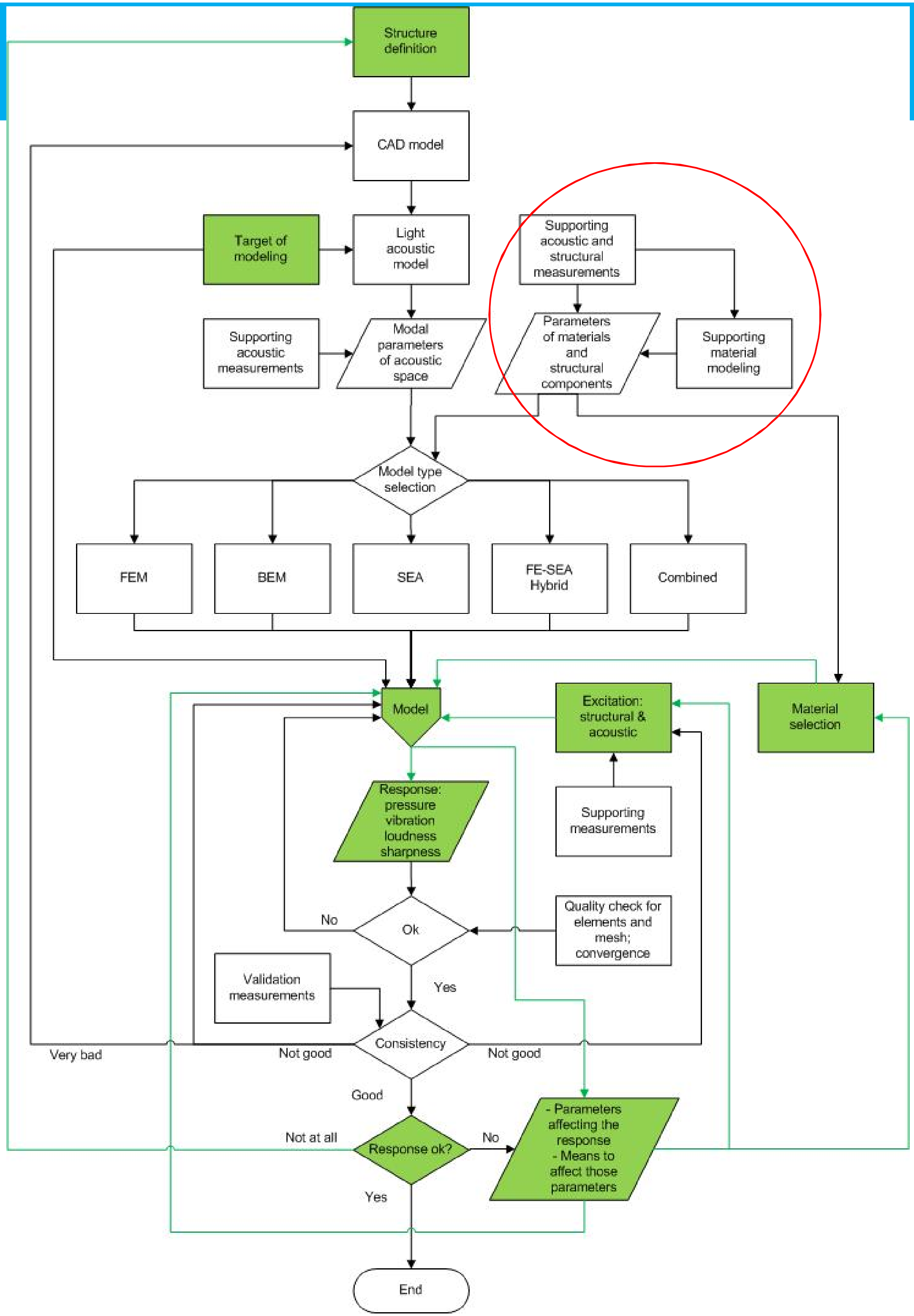


- Target of modeling from client and modeler
  - Environmental factors and proper excitation types
    - Laboratory conditions - diffuse excitation
    - Operative situation - operative excitations
    - Vibration / sound as excitation
  - Desired response quantities
    - Environmental noise / cabin interior noise
    - Frequency domain / time domain
    - Frequency range
    - Sound pressure / vibration / annoyance measures
      - Mean values / distributions



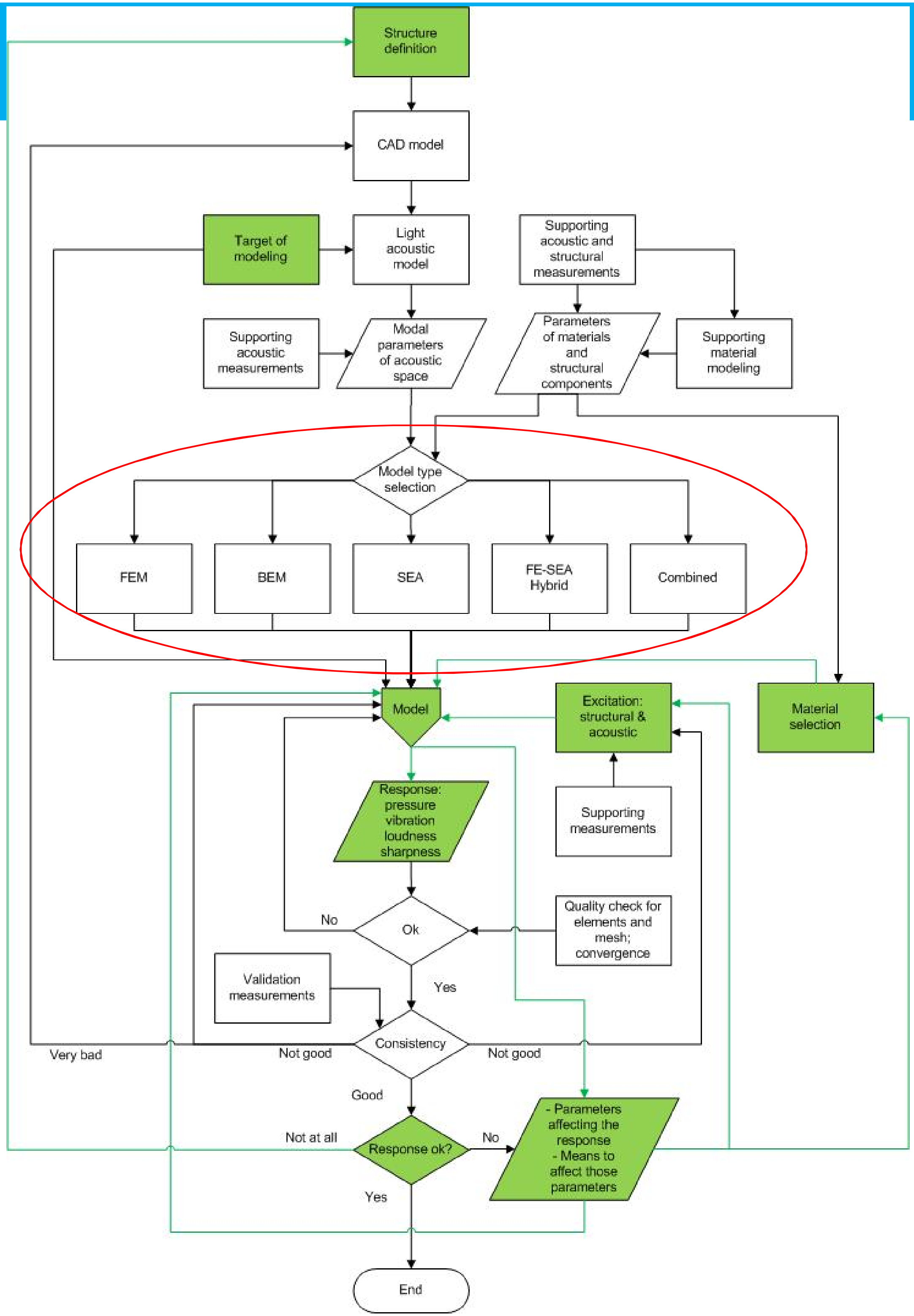
Modeling flowchart (6)

- Light acoustic model + supporting acoustic measurements
  - Output: modal parameters of acoustic space
    - Lowest eigenfrequencies and modes ⇒ modal density
    - Schröder frequency



Modeling flowchart (7)

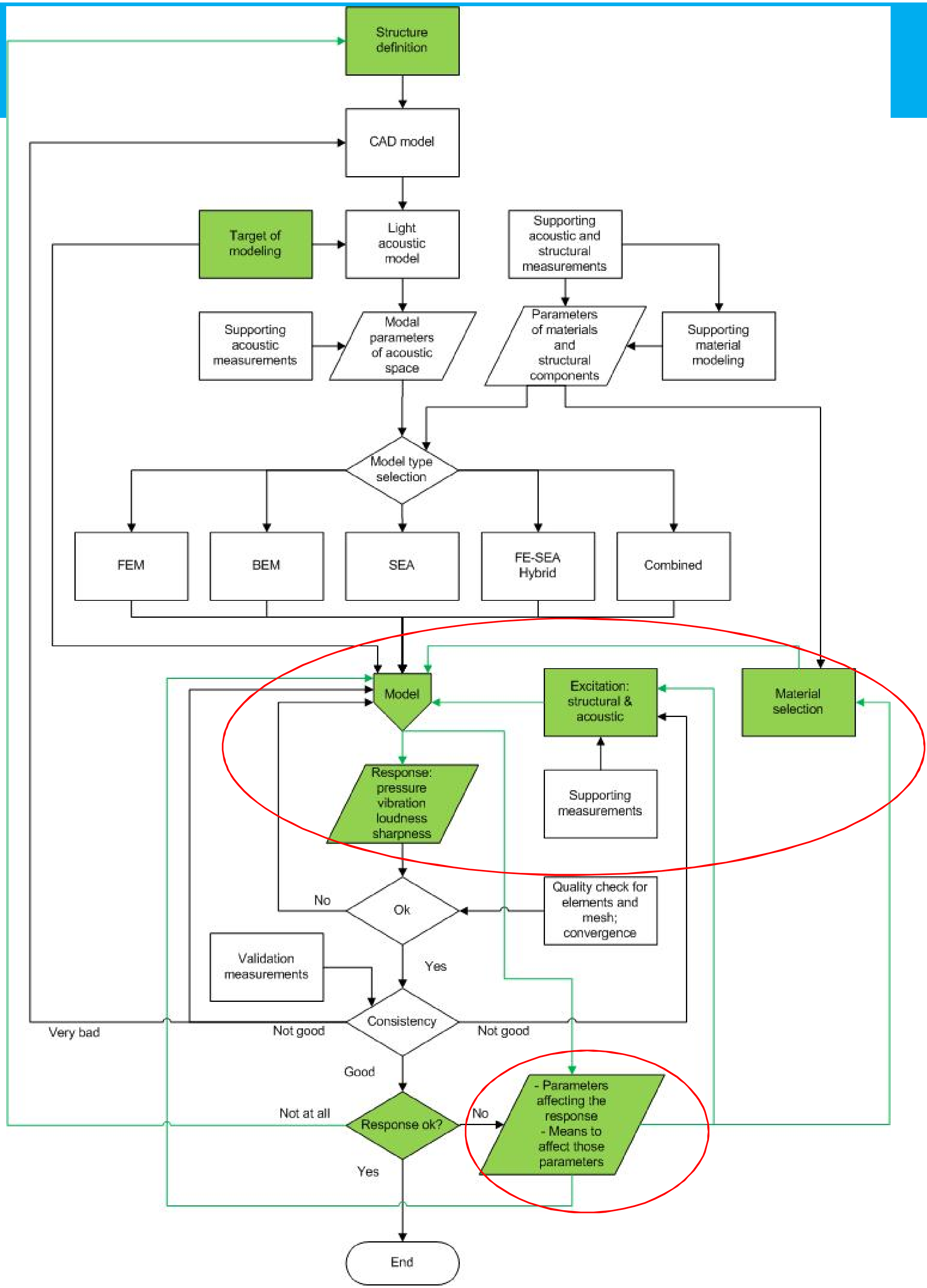
- Supporting acoustic and structural measurements by client and/or modeler & supporting material modeling
  - Parameters of materials and structural components from client and/or modeler, and from measurements and modeling above
    - Loss factors $\Rightarrow$ modal overlap factors
    - Elastic and other parameters for later use



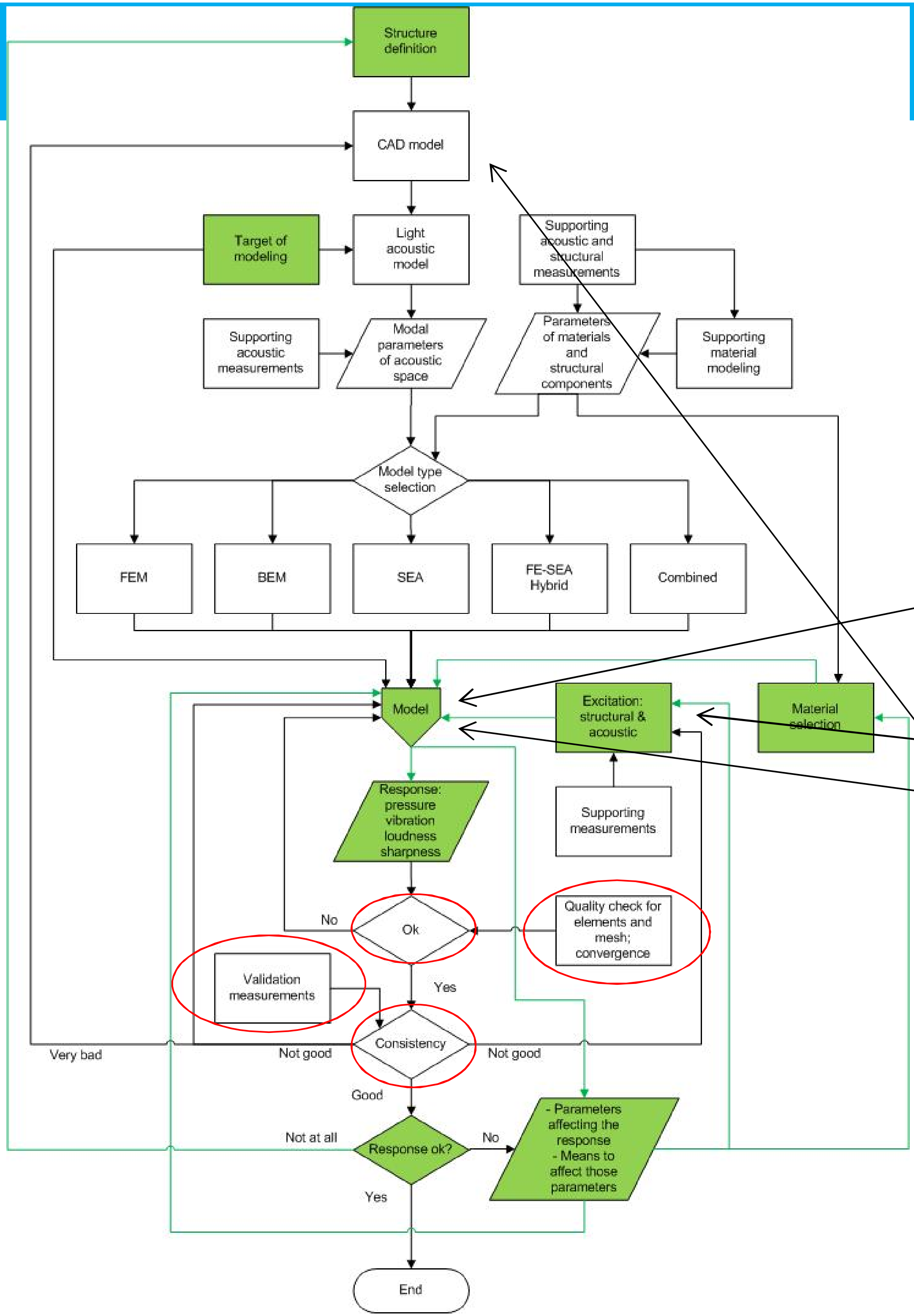
Modeling flowchart (8)

- Model type selection
  - FEM
  - BEM
  - SEA
  - FE-SEA Hybrid
    - FEM and SEA subsystems at the same frequency bands
  - Combined model
    - FEM at low frequencies
    - SEA at high frequencies

Modeling flowchart (9)

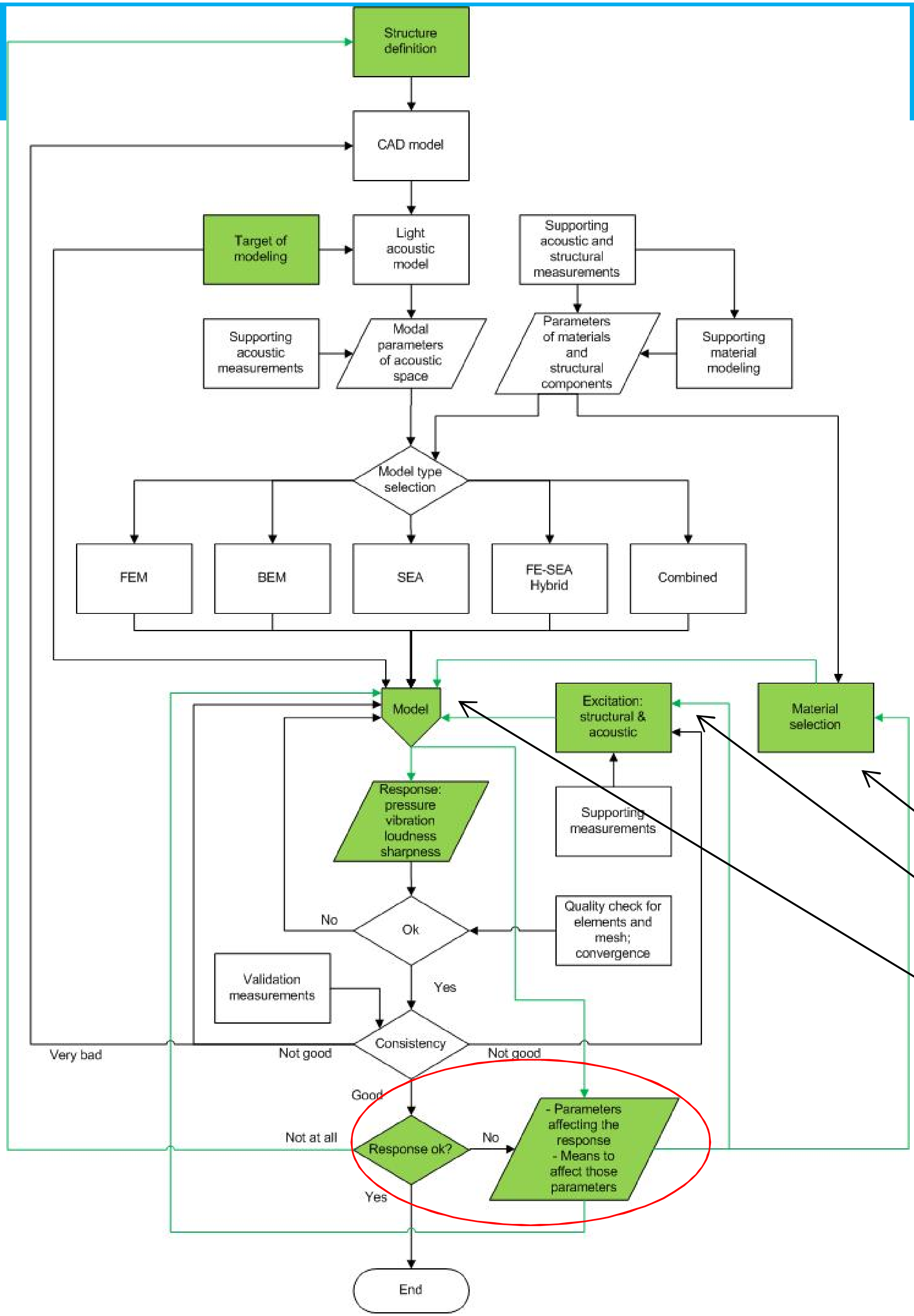


- Material selection by client and/or modeler
- Supporting measurements by client and/or modeler
  - Structural and acoustic excitation definitions by client and/or modeler and from measurements above
- Model definition
  - Output response: sound pressure, vibration, loudness, sharpness
  - Other output for later use



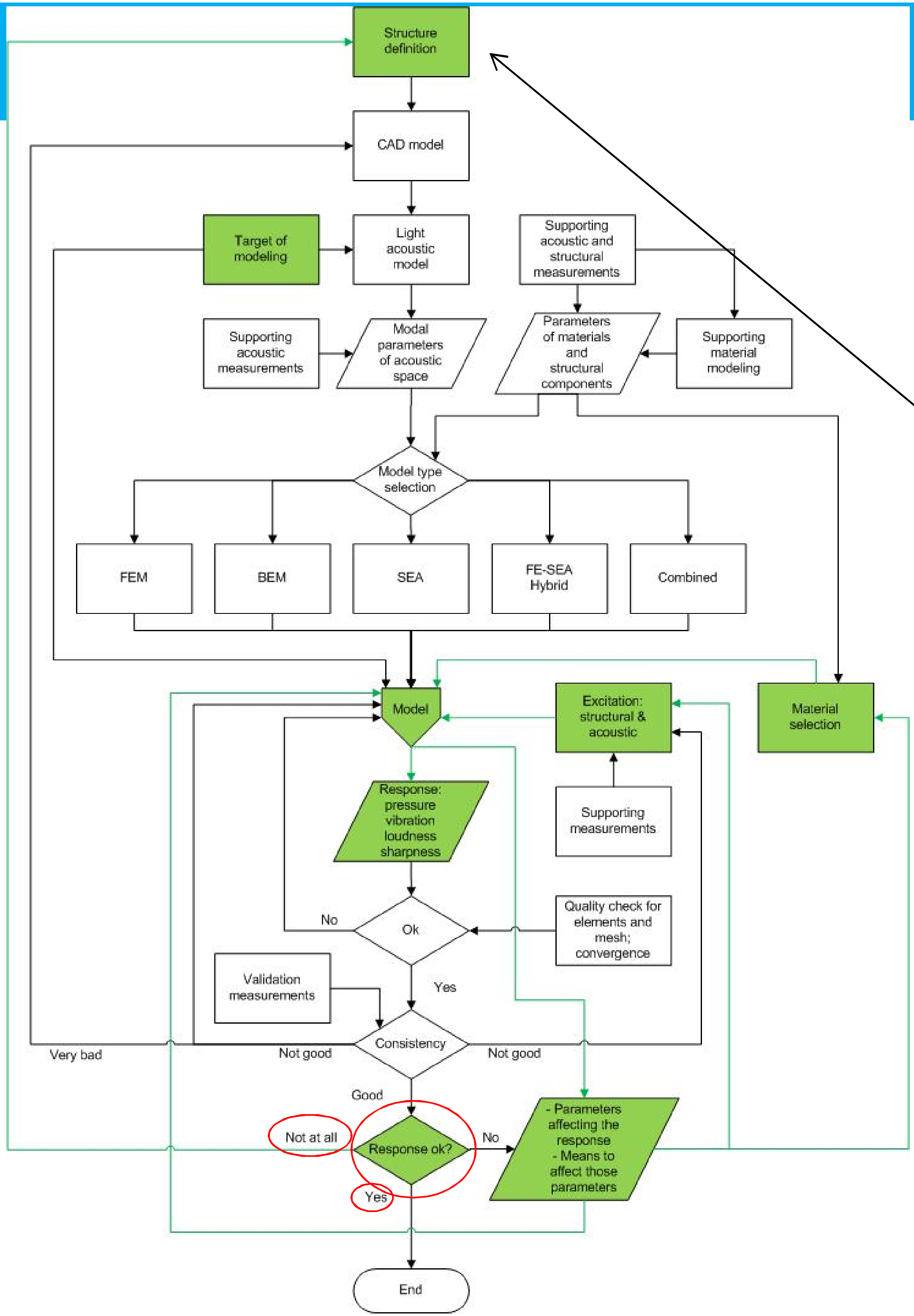
Modeling flowchart (10)

- Quality check for elements and mesh, convergence study
  - If not satisfactory, back to model definition
- Validation measurements
  - If consistency not good, back to excitation and model definitions
  - If consistency is very bad, back to CAD model definition



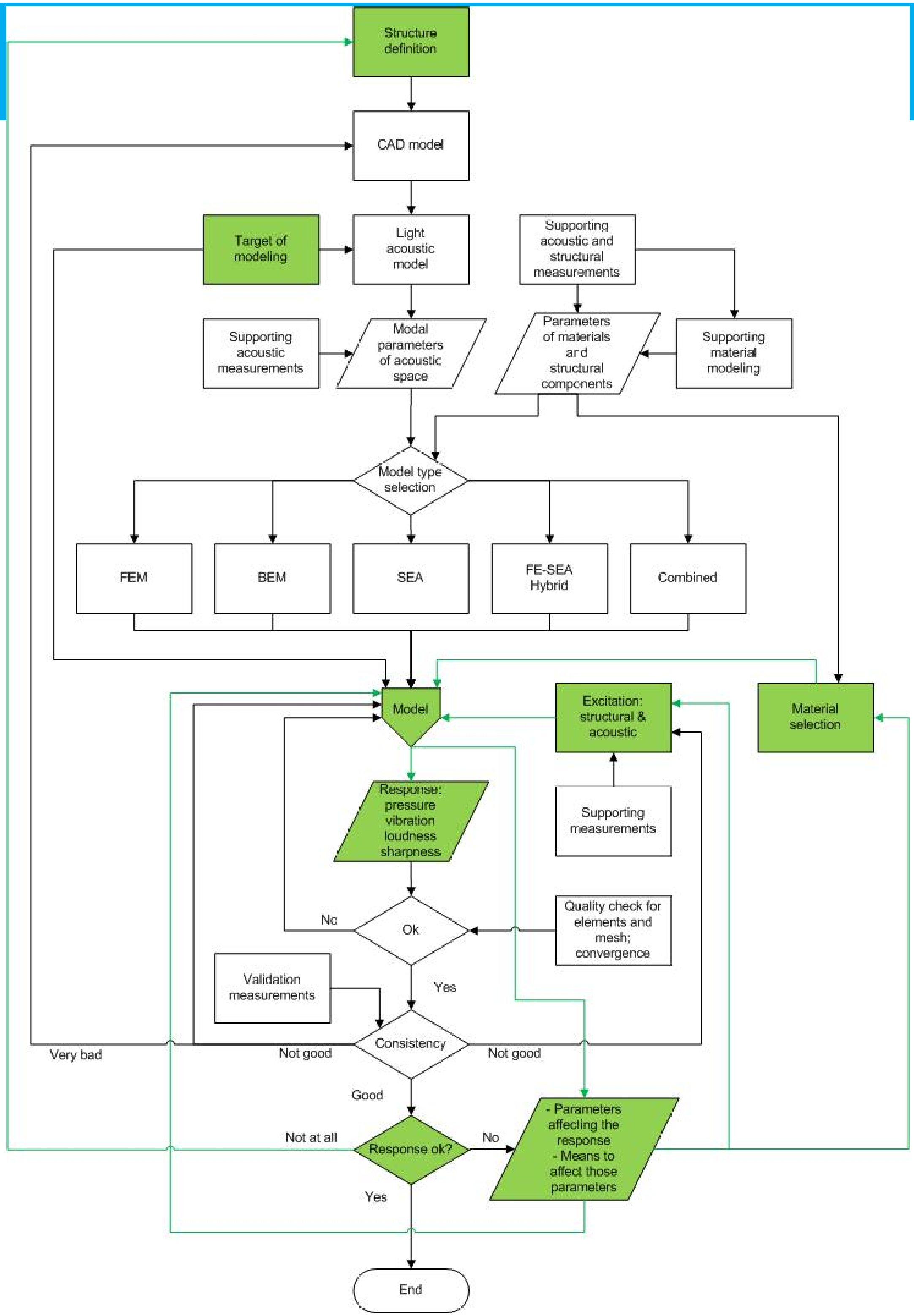
Modeling flowchart (11)

- Output response study
  - If response not satisfactory
    - Other output study
      - Check parameters affecting the response
      - Check means to affect those parameters
      - Back to material selection, and excitation and model definitions



Modeling flowchart (12)

- If response not satisfactory at all, back to structure definition
- If response ok, virtual simulation can be ended



Modeling flowchart (13)

Core of virtual simulation

- Structure definition
- Target of modeling
- Material selection
- Structural and acoustic excitation definitions
- Model definition
  - Output response: sound pressure, vibration, loudness, sharpness
  - Other output
- Output response study
  - If response not satisfactory
    - Other output study
      - Check parameters affecting the response
      - Check means to affect those parameters
      - Back to material selection, and excitation and model definitions
  - If response not satisfactory at all, back to structure definition
    - Changes in structure

Conclusions

- Compared software:
  - Comsol Multiphysics, Va One, Abaqus, Actran
- Basic software selected:
  - Actran
    - FEM in frequency domain
    - Biot’s model used for absorptive materials
  - CAD data simplified and repaired, and mesh done in Ansys
- Modes and eigenfrequencies of empty cabin, Abaqus vs. Actran, are consistent
- Calculated field distributions with internal loudspeaker excitation rather similar to measured ones
- General modeling flowchart for vibroacoustic simulations has been developed

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