CABIN-CENTRIC AIRCRAFT DEVELOPMENT APPROACH: EXPLORING POSSIBILITIES AND POTENTIALS

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Linköping University, 4.02.2026

DLR

Motivation

- Cabin: **main differentiator** in a competitive passenger aircraft market
- Currently only limited-fidelity cabin representation in the early aircraft design phase
- very restricted design space, **high customization costs**
- Innovative cabin concepts challenging to realize
- Huge **potential for truly innovative, user-focused future cabin designs**, tailored to the needs of all passengers

Fig. 1: Ambitious aircraft cabin design concept study (from [1])

State of the art:
Current early aircraft design processes

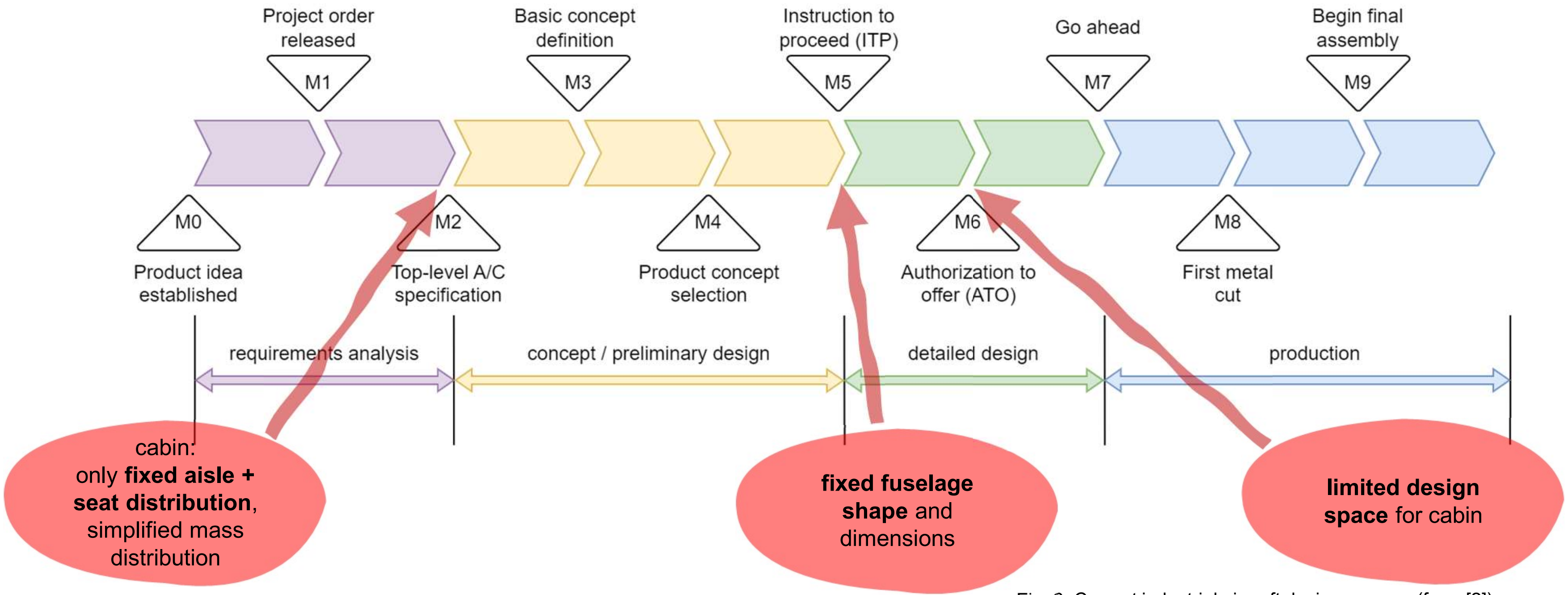
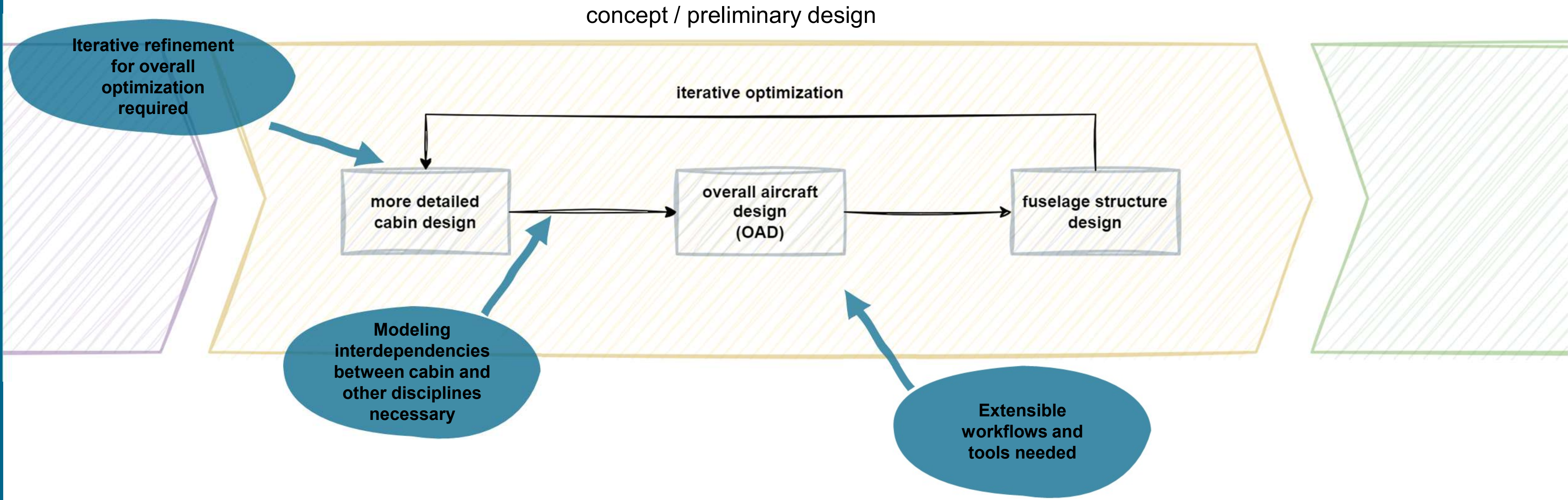


Fig. 2: Current industrial aircraft design process (from [2])

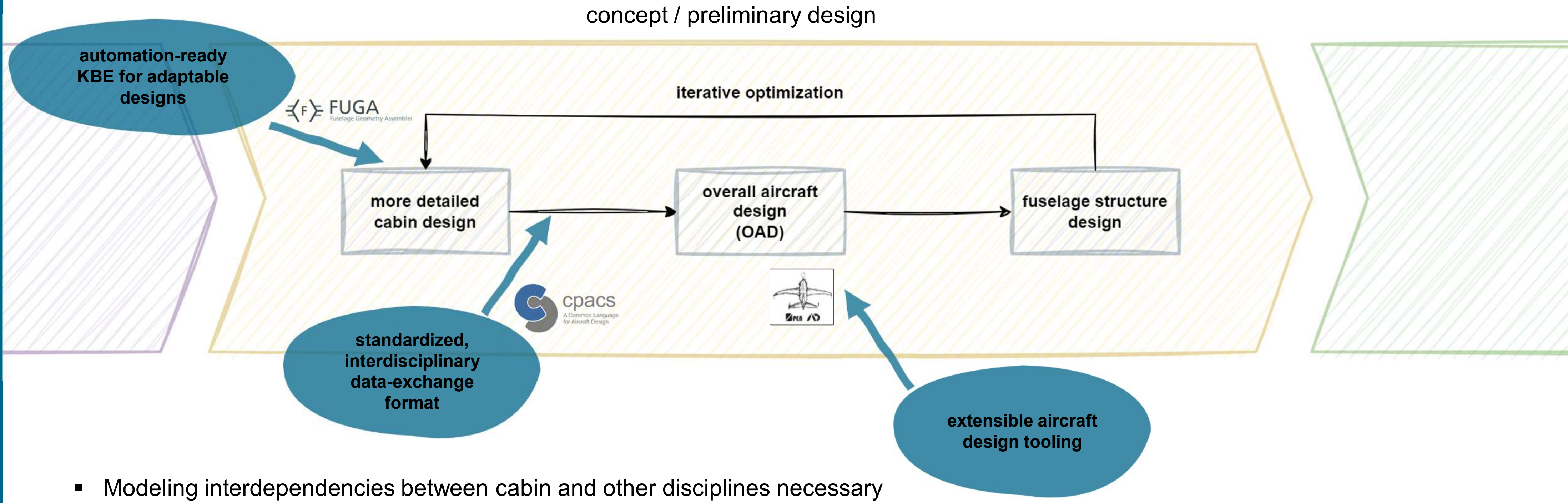
- Currently only basic incorporation of **static cabin design parameters** into early aircraft design
- Later cabin changes cause **significant engineering/coordination efforts**, more foundational changes infeasible
- **No acknowledgement of detailed cabin requirements** in early design phases, neither in industrial nor in research process models [3, 4, 5, 6]

Vision:
Cabin-centric design process



- Detailed **cabin design as starting point**
- **Complete design freedom** for cabin innovations
- Different **challenges for integration** into concept design phase

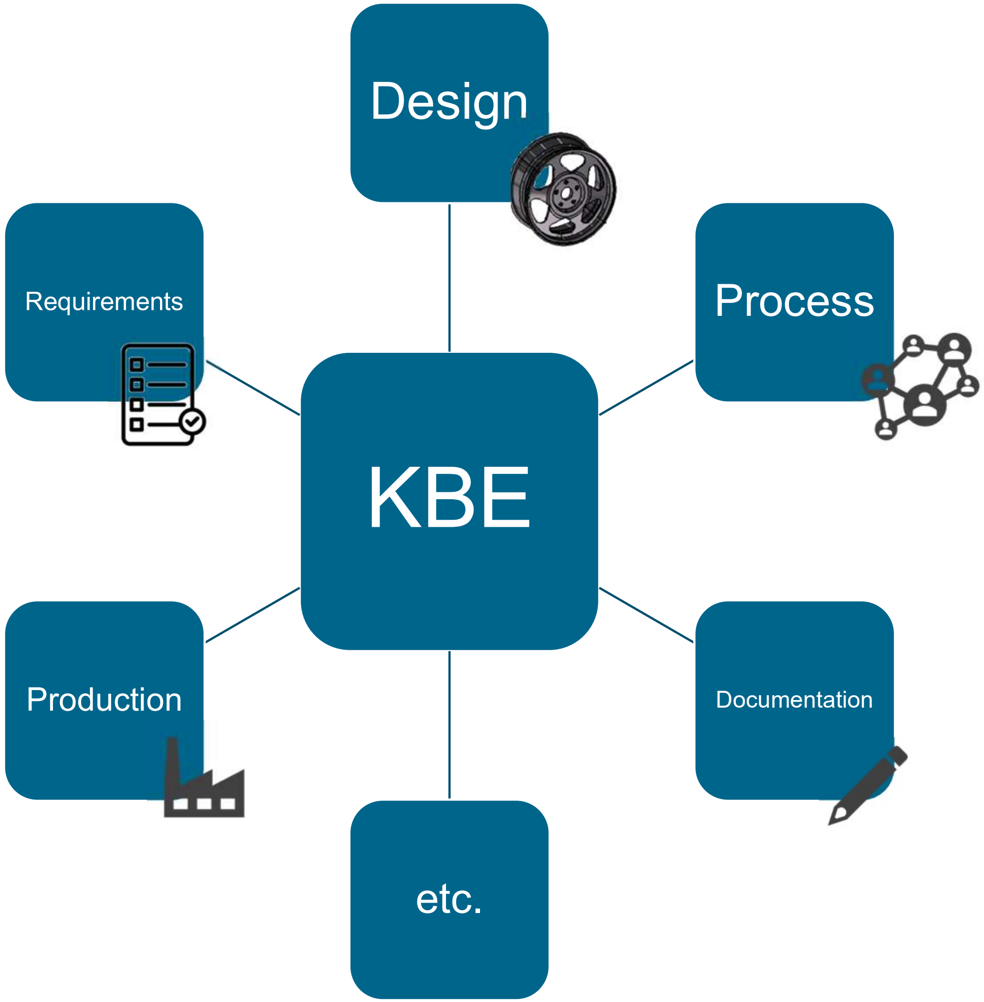
From vision to implementation: Challenges and solutions



- Modeling interdependencies between cabin and other disciplines necessary
  → **Standardized data formats** and interfaces (e.g. CPACS)[7]
- Iterative refinement for overall optimization required
  → Automatic **cabin evaluation and adaptability** (KBE: e.g. FUGA, param.CAD)[8]
- Extensible workflows & tools needed
  → **Accessible tooling** for early aircraft design (e.g. OpenAD)[9]

Knowledge Based Engineering (KBE)

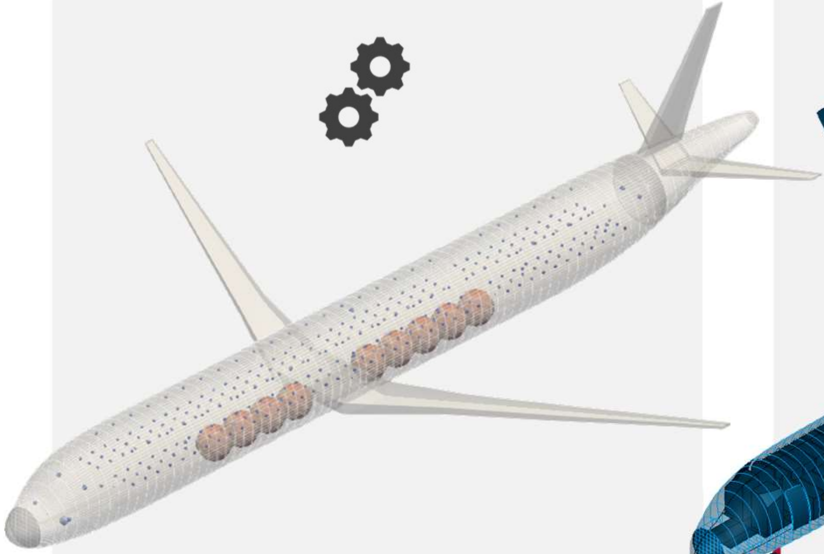
- **Capture knowledge**
- **Reuse of existing solutions**
- **Automate repetitive tasks**
- Accelerating the Engineering Design Process



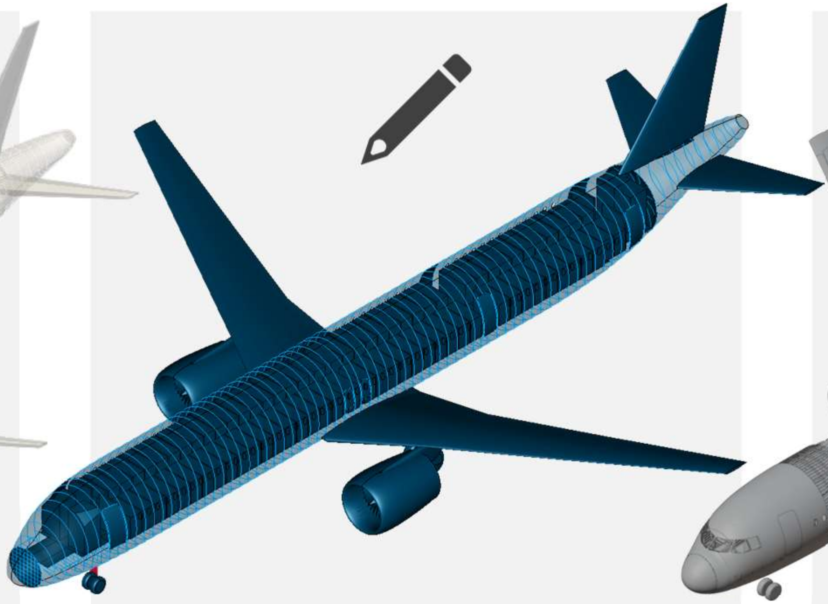
FUGA –modern KBE-Implementation from DLR-SL

- **Knowledge-based design methodology**
- XML-based data schema **CPACS** as a product data model
- Rules and execution engine in **Python**
- Geometry creation using **OpenCascade** Technology

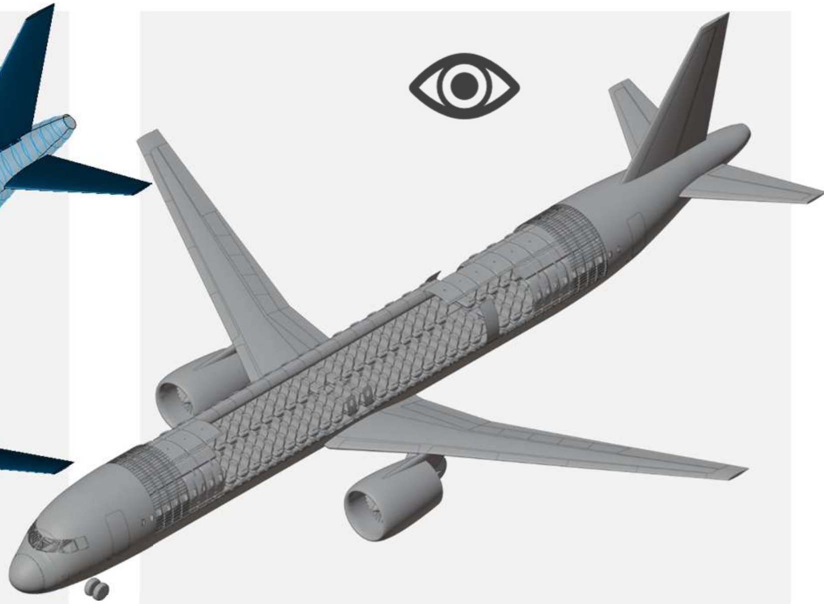
Multi-fidelity aircraft models for specific areas



Geometry model for
structural design



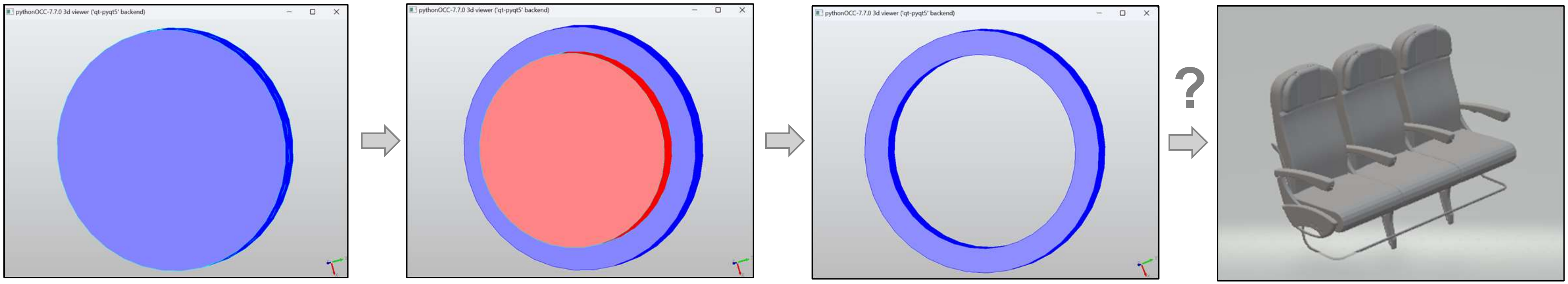
CAD Modell for overall
aircraft design



Detailed design for
Human Factors &
Industrialisation

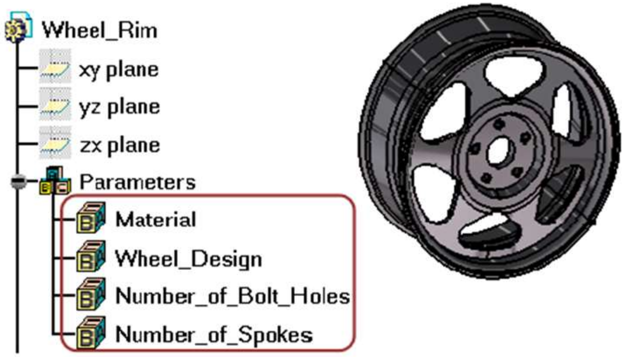
Code-based geometry creation

- Example of a ring geometry created by cutting two cylinders via OCCT
- More complex geometries are challenging to create



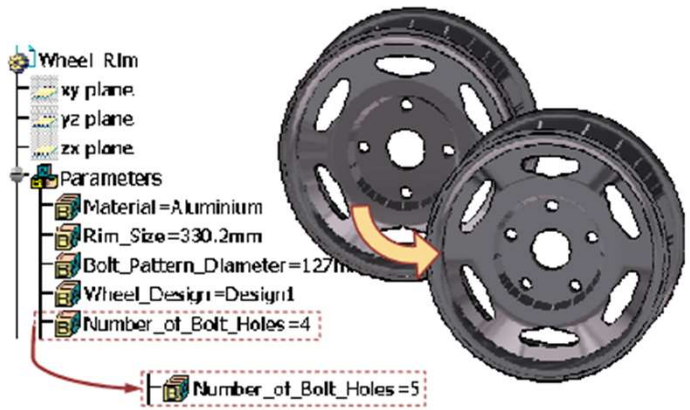
Parametric Associative Design (PAKo) as an established industry standard

- **Parameterizable model**

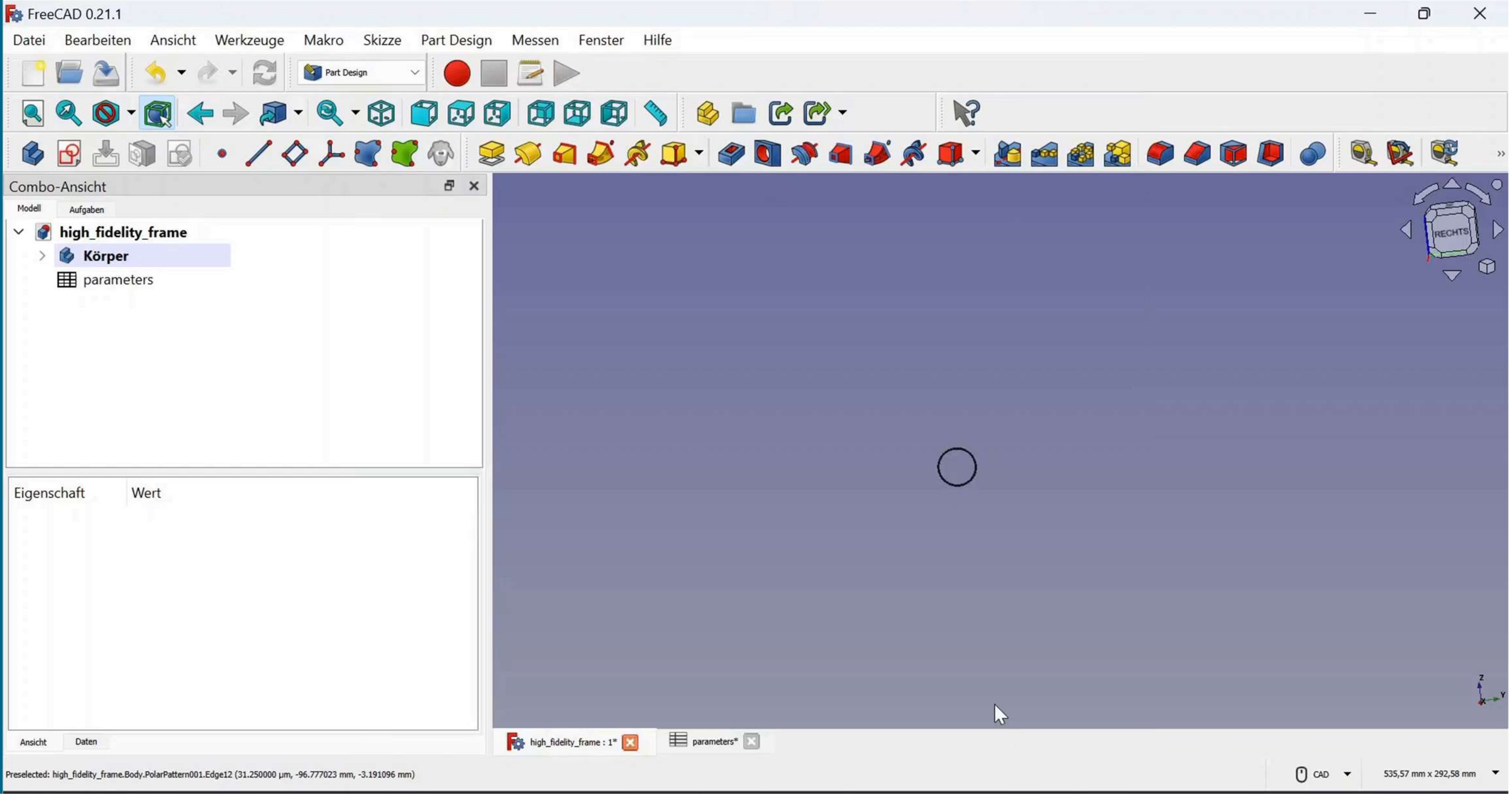


- **Adjustment of the number of spokes**

- **Adjustment of the holes**



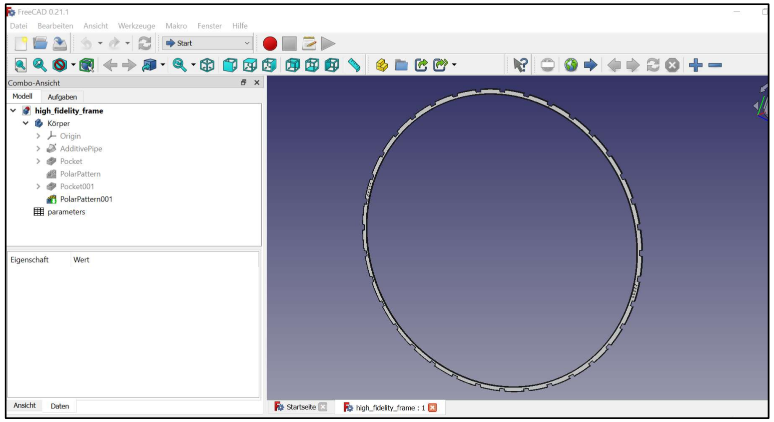
CAD-based geometry creation



Merging Code-Based & CAD-Based model generation for productivity and interactivity

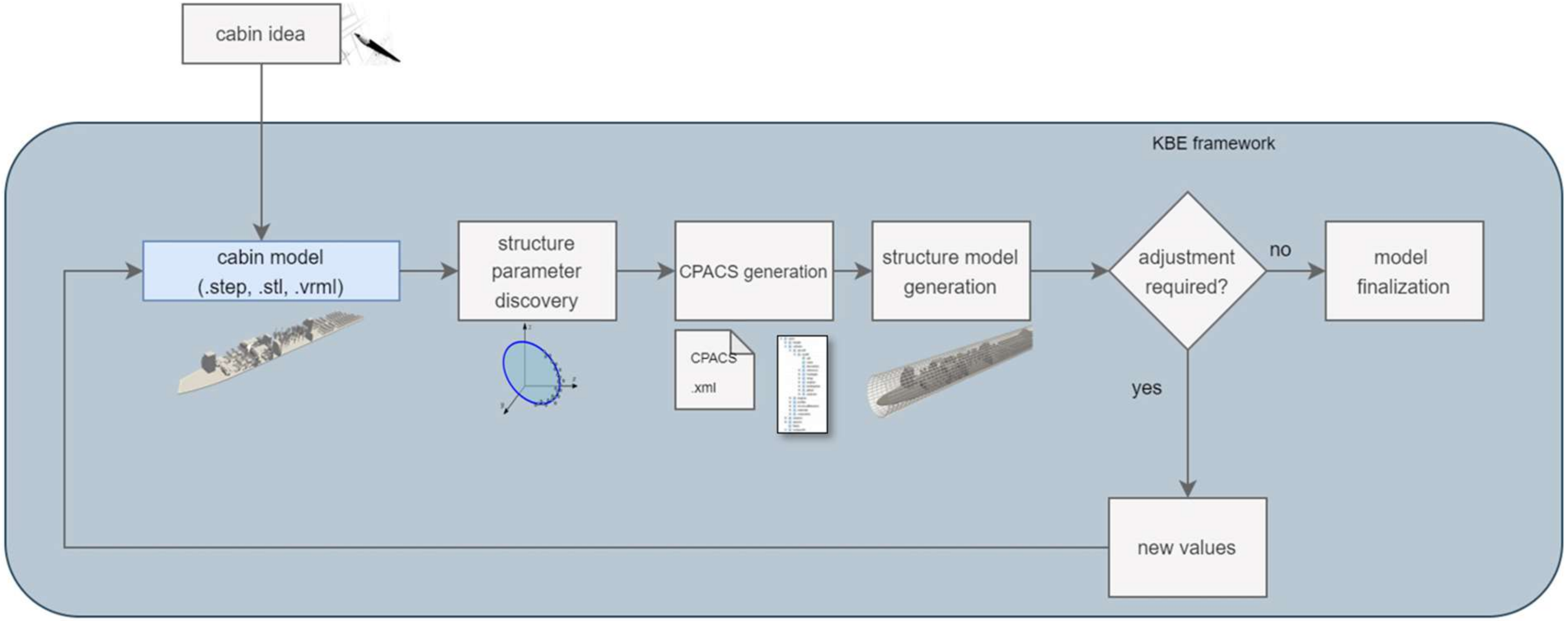
- **CAD-based:**
  - Easy creation of complex, parameterizable part geometries
  - Assembly rules only supported to a limited extent, depending on the tool

- **Code-based**:
  - Well suited for integration of data sources, mapping of complex assembly rules possible
  - Dynamic CAD-models parameterization




```python
@components.register
class FrameExtrusion(ExtrudedCurveGeometryComponent):
    label = r"/yacgl/frameExtrusion"
    requires = {
        r"/yacgl/structuralFuselageSurface",
        FrameCurve.label,
        r"/yacgl/framePCurvesOnFuselage",
        ConcatenatedFrameDefinitions.label,
        ProfilePolygons.label,
    }
```

Concept of a cabin-centric design workflow



- Parameterized cabin layout as input
- Based on a given 3D geometry cabin model, the shape of the fuselage is derived by segment-wise projection and determination of area-minimal hull curve function parameters

Cabin as input for aircraft design

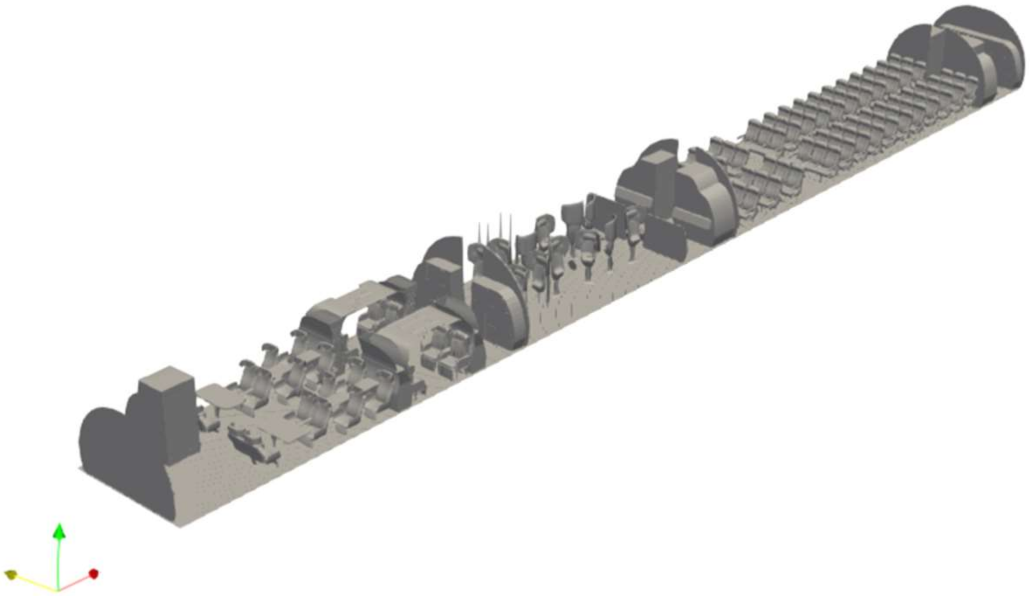


Fig. 4: Example of a novel cabin design

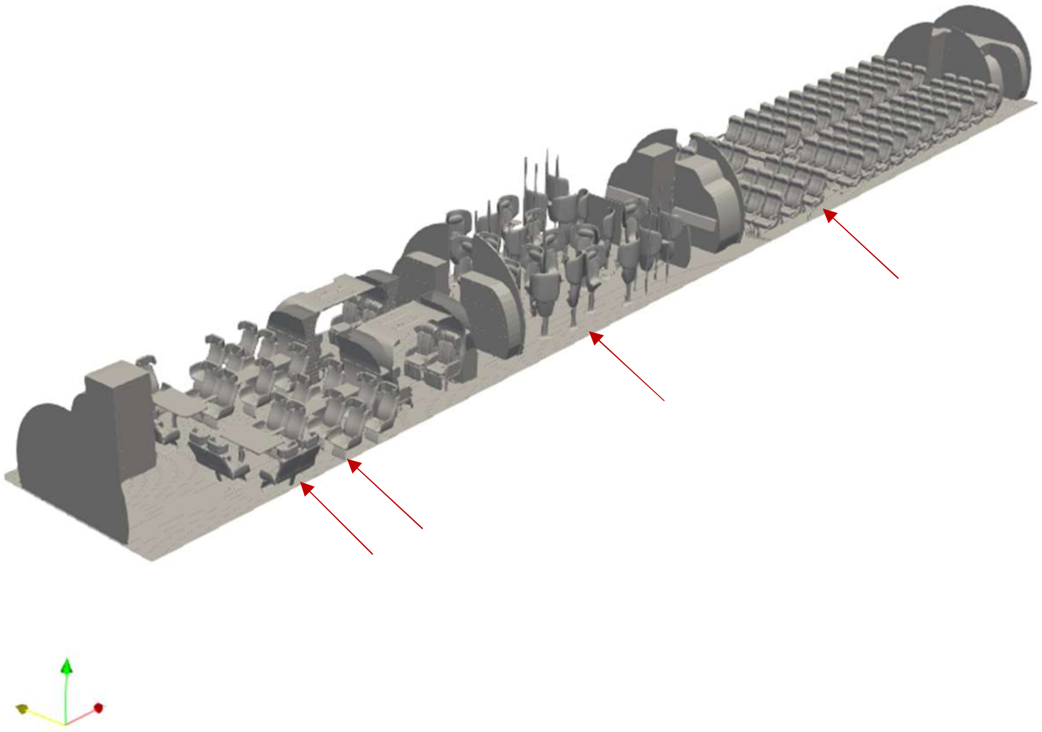


Fig. 5: Modified novel cabin design

Dynamically generated structural models

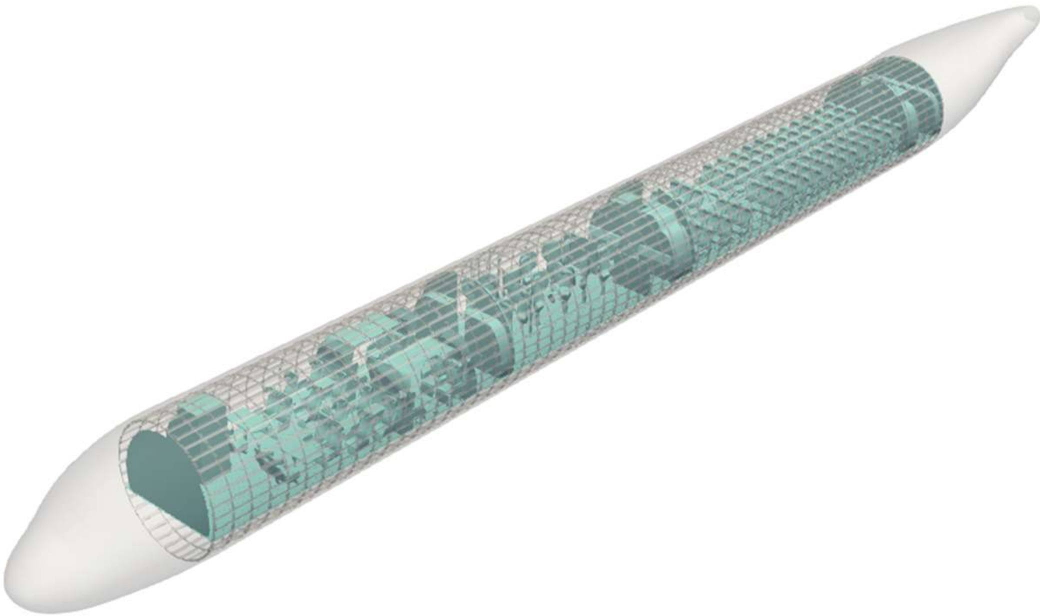


Fig. 6: Dynamically generated structural model for a novel cabin design (~6min)

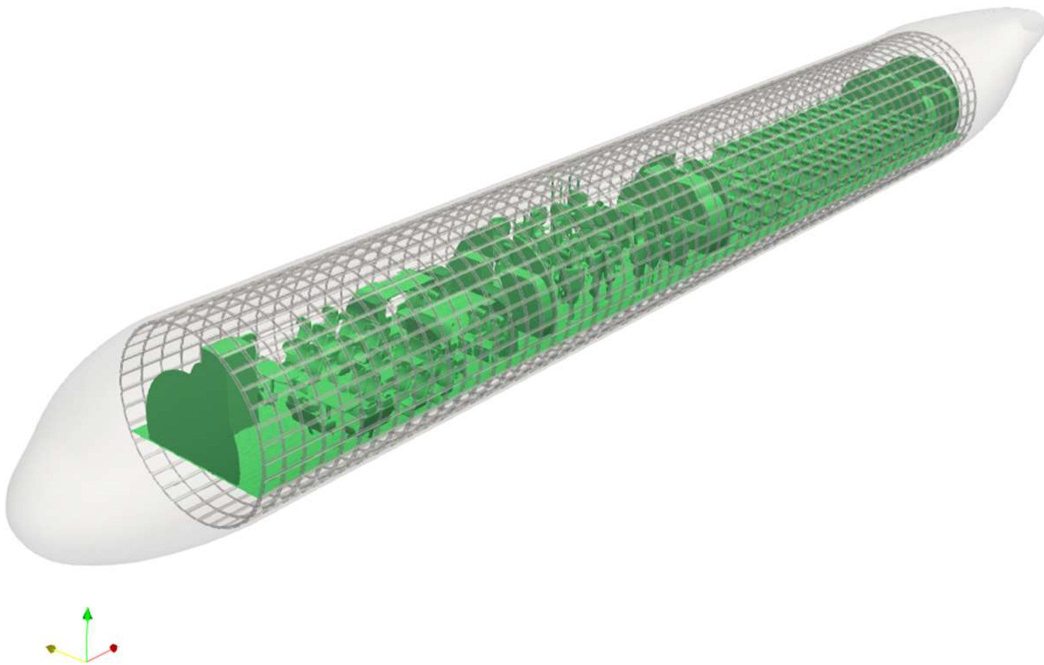
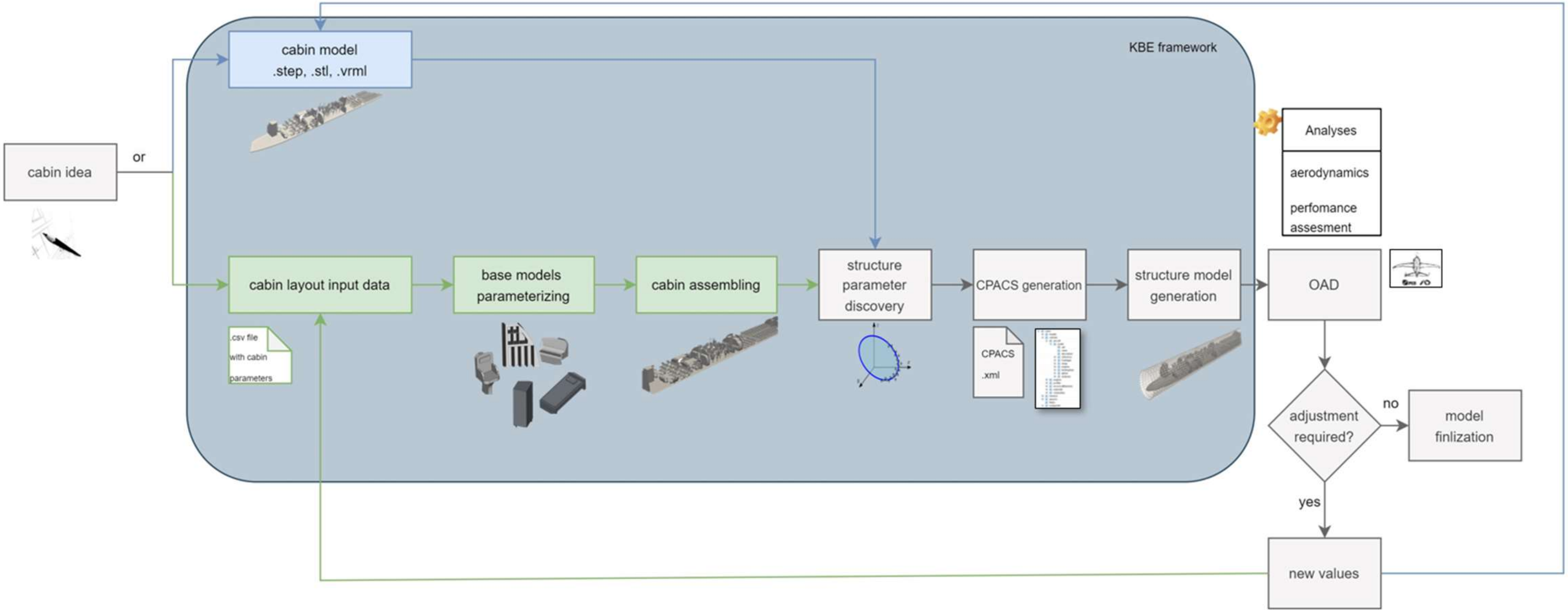


Fig. 7: Dynamically generated structural model for a novel cabin design (~10min)

Outlook


cabin model
.step, .stl, .vrml
KBE framework
cabin idea
or
Analyses
aerodynamics
perfomance
assesment
cabin layout input data
base models
parameterizing
cabin assembling
structure
parameter
discovery
CPACS generation
structure model
generation
OAD
.csv file
with cabin
parameters
CPACS
.xml
adjustment
required?
no
model
finlization
yes
new values

THANK YOU FOR YOUR ATTENTION

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8. Woehler, Sebastian & Atanasov, Georgi & Silberhorn, Daniel & Fröhler, Benjamin & Zill, Thomas. (2020). Preliminary Aircraft Design within a Multidisciplinary and Multifidelity Design Environment.
9. Hofmann, Katerina; Hesse, Christian; Biedermann, Jörn; Nagel, Björn (2024): Integration code-basierter und CAD-basierter parametrisierter wissensregeln für die Generierung von multi-fidelity-Flugzeugmodellen. Deutscher Luft- und Raumfahrtkongress 2024, Hamburg, Deutschland.
10. Rethinking the aircraft design process using a cabin-centric development approach / Publications / Knowledge Base / The Design Society

Backup

- Forschungsfragen / Hypothesen, Objective statement
- 1 Folie pro Beitrag (DLRK, CFX)
- Timeline

Objective:

Develop and validate a cabin-centric design methodology that integrates passenger needs and cabin requirements at the earliest stages of aircraft development, enabling more innovative, efficient, and user-focused aircraft designs.

Research questions

1. What more fundamental cabin innovations would be possible (and useful)?
   (→ radically different, unconventional cabin layouts, with various fuselage shapes)

2. How could an integration of the detailed cabin design into the preliminary design process look like, including consideration of the interactions between fuselage and cabin?
   - How can cabin geometry models be created efficiently, flexibly, and automatically?
   (→ FUGA KBE engine + parametric CAD-rules)
   - How can dependencies between cabin and fuselage be represented?
   (→ automatic fuselage fit based on geometric cabin model)

3. How can automatic optimization of the overall design be carried out (+consideration of interactions layout + fuselage)? What placement rules can be used for the automatic creation/adjustment of layouts?
   (→ heuristics, hierarchies, RL? Placement via coordinates / order along axis /?)
   - How can designs / cabin layouts be evaluated automatically?
   (→ criteria definition and quantification)

From vision to implementation: Current progress and next steps

- Automatic adaptability:
  Automated geometry model generation
  based on FUGA + param.CAD
  (DLRK 2024, CEAS-Journal wip)[9]

- **Modeling interdependencies**:
  cabin geometry → CPACS generation
  → fuselage fit + model generation
  (DFX Symposium 2025)[10]

- Iterative optimization:
  first **fully parameterized cabin geometry** model, next step:
  evaluation function definition & integration with OpenAD
  (tbd)

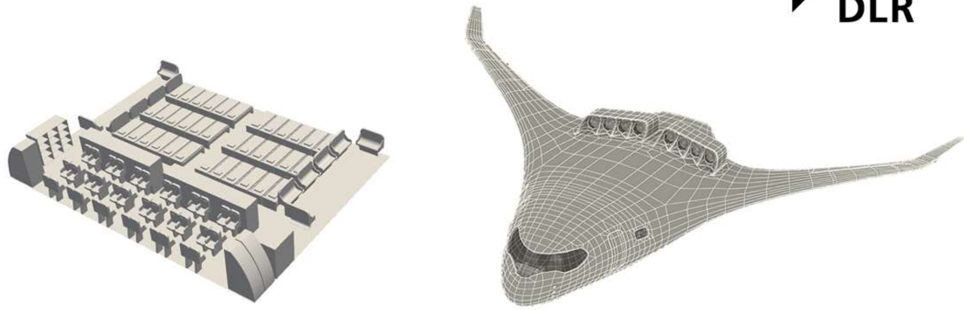

Fig. 4: Fully parameterized cabin geometry model for BWB

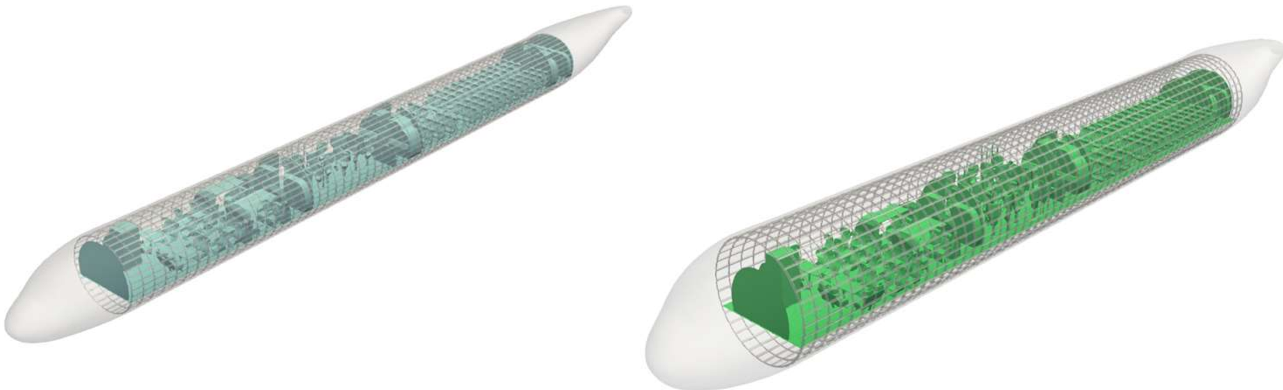

Fig. 5: Dynamically generated fuselage models based on varied cabin designs (DFX 2025)

Airbus A380: „Flying palace“

Kabine als Input für Flugzeugentwurf

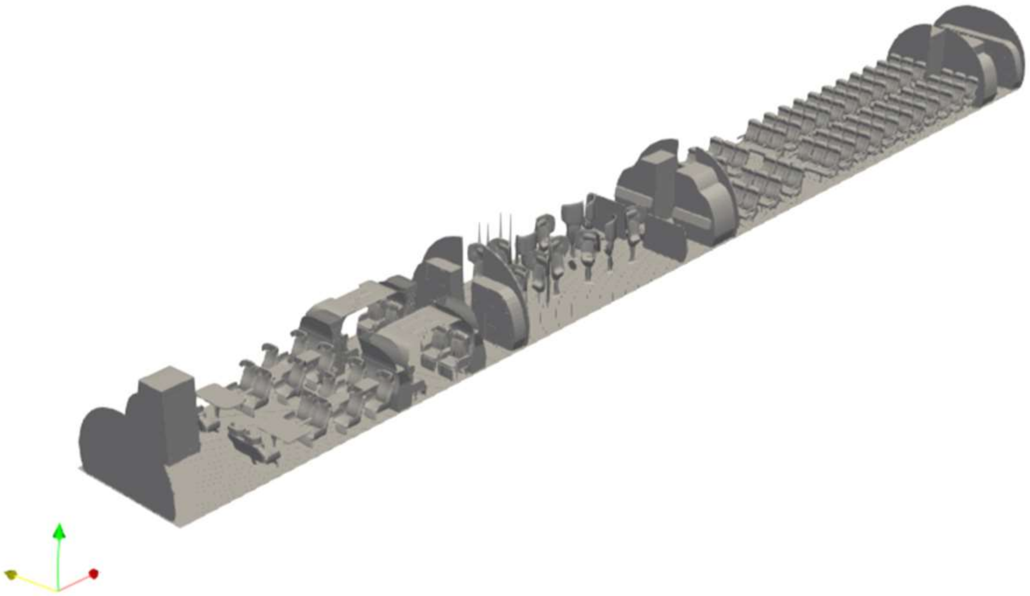

Bild 1: Innovatives Kabinenlayout

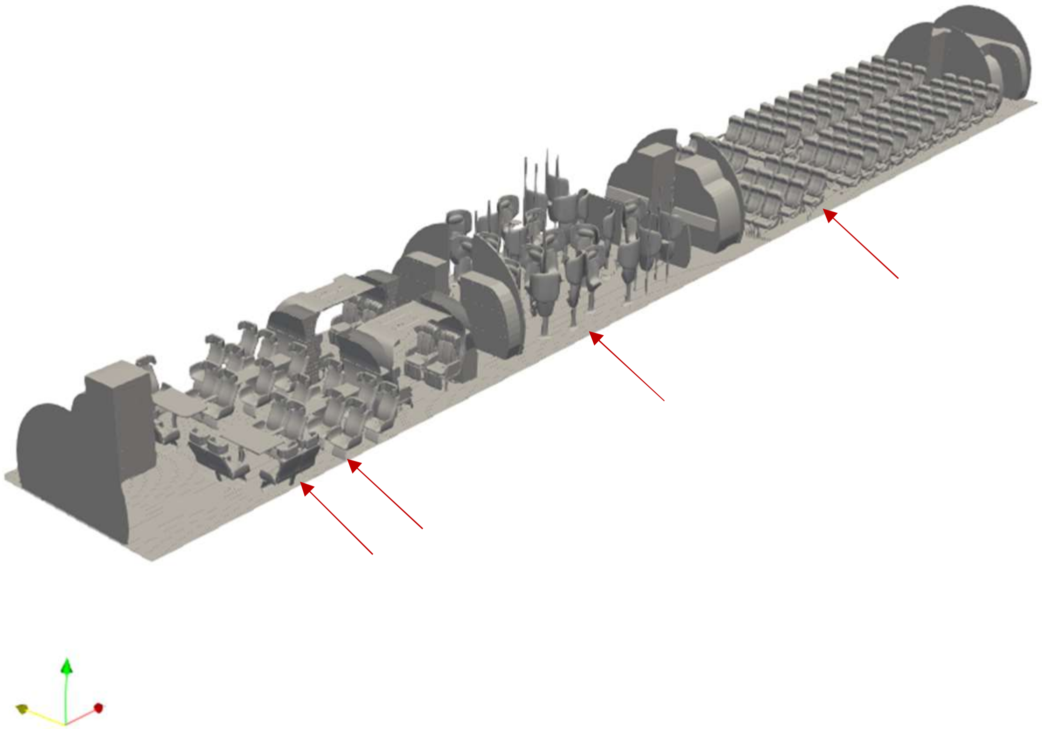

Bild 2: Innovatives Kabinenlayout leicht geändert

Dynamisch generierte Strukturmodelle

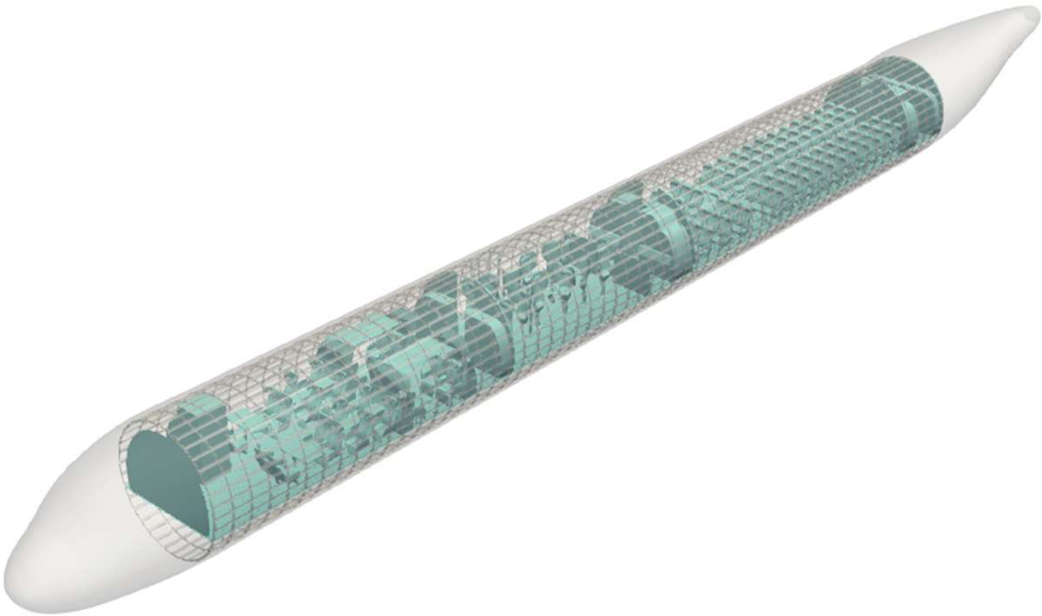

Bild 3: Dynamisch generierte Strukturmodelle für neuartiges Kabinendesign(~6min)

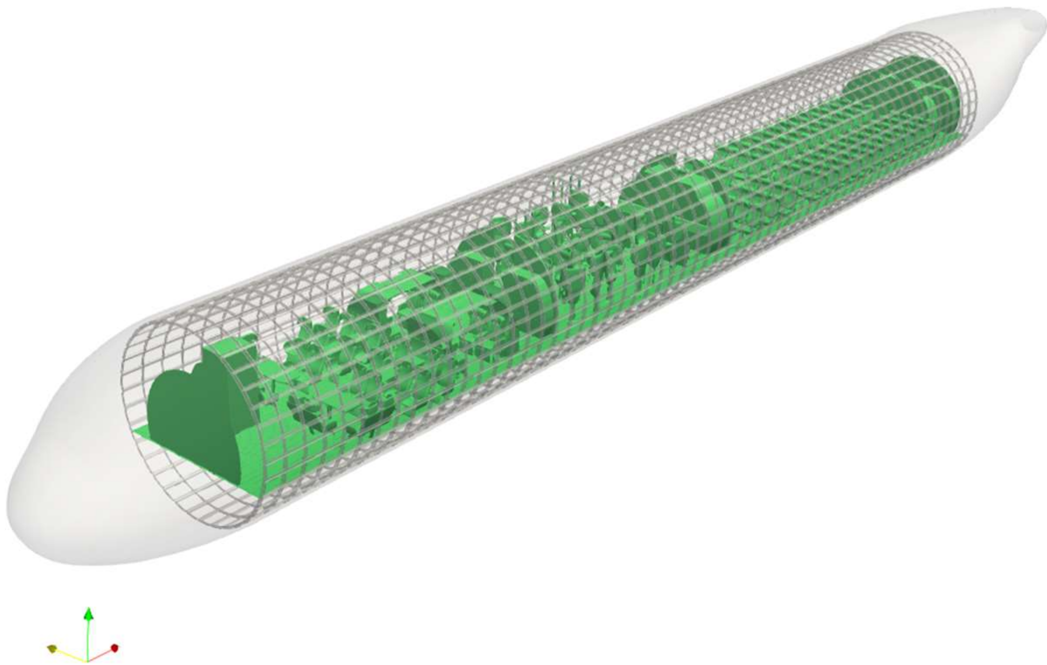

Bild 4: Dynamisch generierte Strukturmodelle für neuartiges Kabinendesign(~10min)

Dynamisch generierte Strukturmodelle: ovales Cross-Section

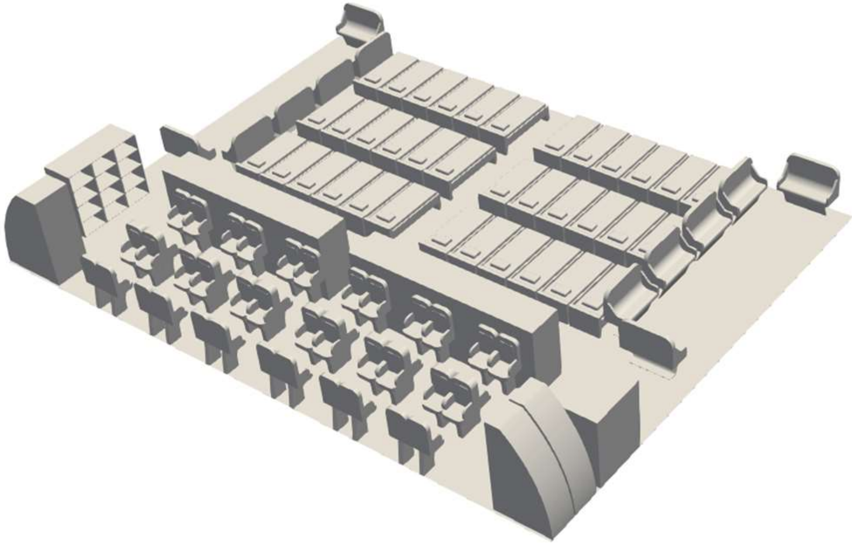

Bild 5: Innovatives Kabinenlayout für ovales Cross-Section

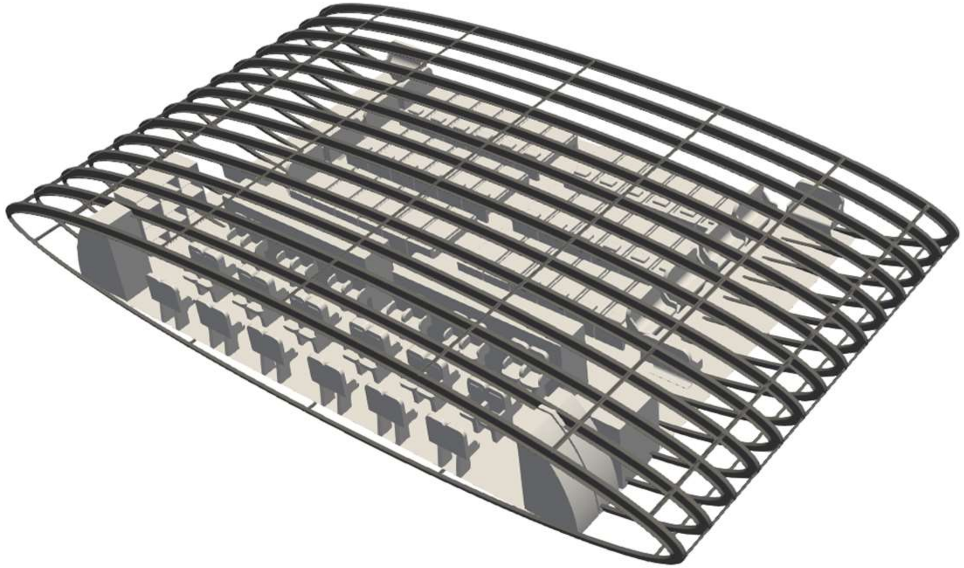

Bild 6: Dynamisch generierte Strukturmodelle

Methodical approach

- Data-centric description of the cabin
- Deriving of structural parameters based on cabin layout
- Integration of CAD software with parametric models for high fidelity and flexibility
- Further use of generated files for OAD, aerodynamic analyses and optimization

Next steps

- Cabin segments: capture different diameters
- Aerodynamic analysis with OpenAD
- Cabin adjustment depending on the results
- Iterative, global overall aircraft design optimization