

Framework for the Monitoring of Functional Requirements Along the Product Life Cycle

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Introduction

- Parts within mechanisms are generally specified for the assembly stage of their life cycle
- Useful values of Functional Requirements are usually defined under operating conditions (at higher temperature and strains...)
- These 2 occurrences will be referred to as product configurations in this work
- Challenge : How to study FR evolution during the product life cycle ?
- This work investigates the definition of multiple configurations to integrate part deformation in the FR calculation process

Illustration of the problem

At Assembly



Low Temperature ($\approx 20^{\circ}\text{C}$)

No Centrifugal Force on the blades

In Operation



High temperature

Important centrifugal force on the blades

How maintain the proper gap between the blades and the frame in these 2 physical states ?

Proposed approaches for tolerancing study along life cycle:

[L.Pierre] : approach based on detailed design and Finite Elements simulations

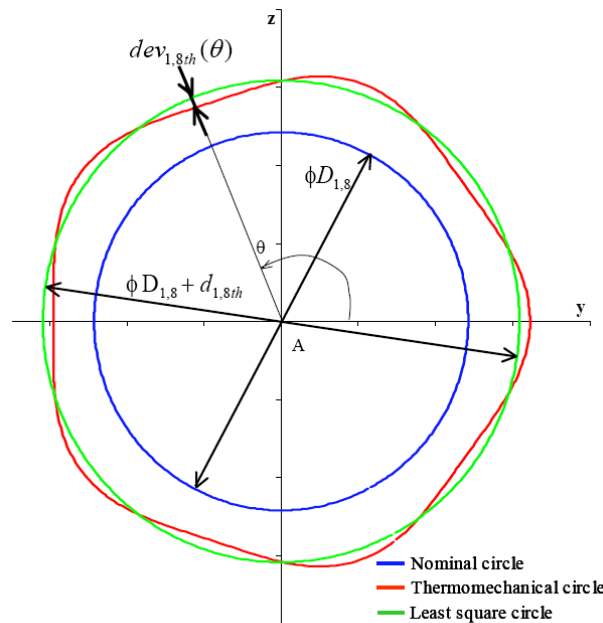
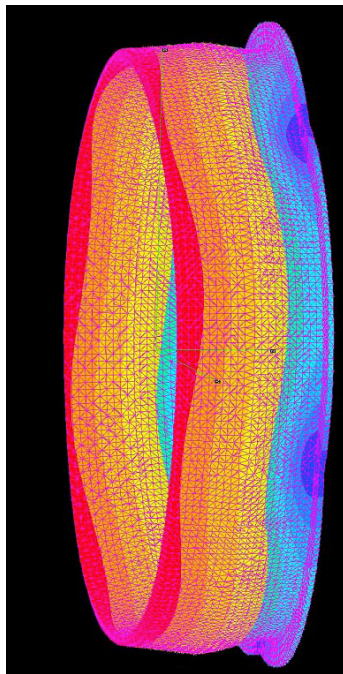


Figure 32 : Thermomechanical strain of surface 1,8 in plane

Our approach for early design stages based on :

- Early design geometric features [Socoliuc]
- TTRS (SATT) for functional association between geometric features [Desrochers]
- Parametric design and metric tensor for computations [Serré]

Products requirements across the product life-cycle

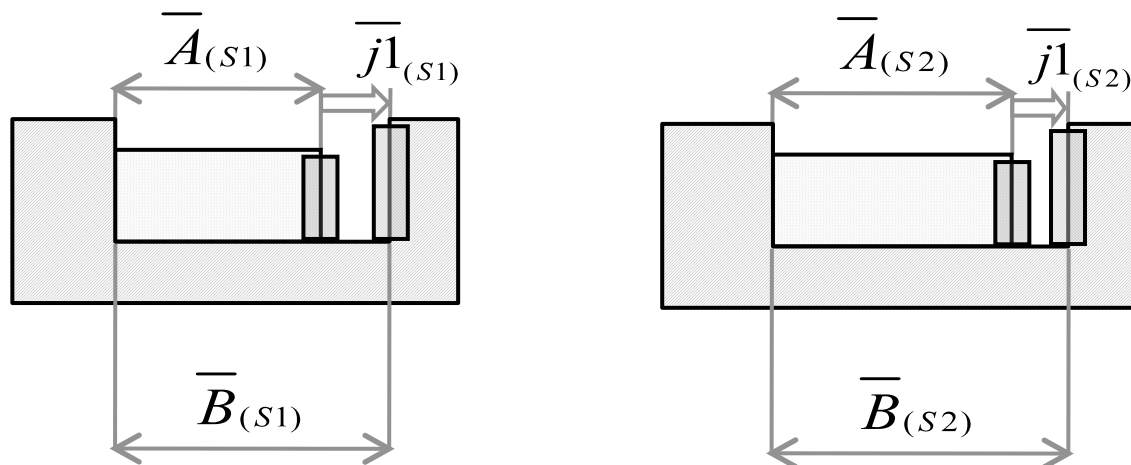
- Use of a specific set of parameters (orientations and lengths of vectors) to define the mechanism in each relevant use case.
- Calculation of functional requirements using each use case set of parameters previously defined.
- The specifications for a given requirement under two different states have to be compatible. The environment is not a design variable in itself.
- Use of a compact model for avoiding redundancies in data.

Sources of functional requirement variations

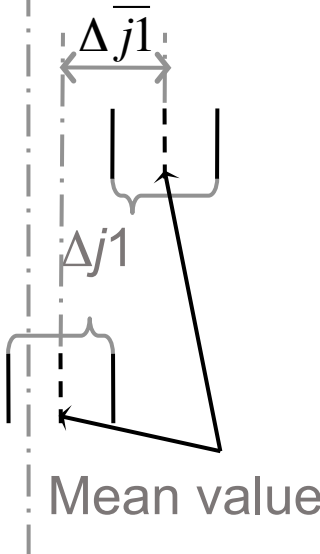
- Uncertainties due to Tolerances stack-up : analysis of tolerance zones made thanks to existing techniques
- Changing environment (variation of mechanical load or temperature) : Elastic deformation of parts.

Functional requirements variations across the life-cycle

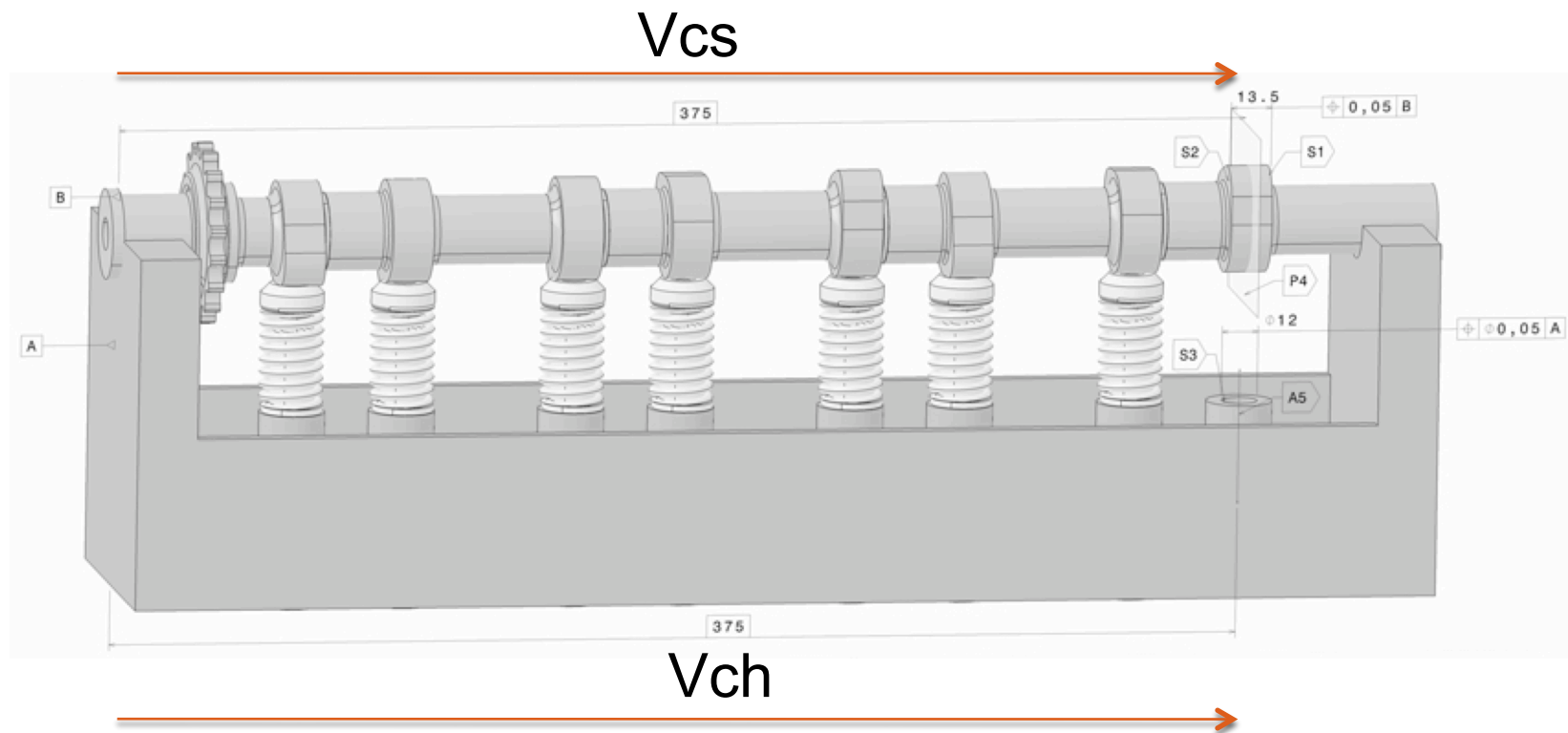
- A^{+au}
- Elastic deformation
 $au - al \ll \bar{A} \quad \Delta(au - al) \ll \Delta\bar{A} \ll \bar{A}$
- Variation of tolerance zone width is insignificant relatively to mean dimension variation.



Functional requirements variation across the life-cycle

Life-cycle stage	Value of Functional Requirement - 0 + Interference possible motion
Initial State (S1)	
Final State (S2)	

1D Application Case:



1D Application Case: Hypothesis

- Assembly temperature 20°C
- Cylinder head made of aluminium :
 - Thermal expansion coefficient $2.38 \times 10^{-5} \text{ K}^{-1}$
 - Service temperature : 90°C
- Camshaft made of steel :
 - Thermal expansion coefficient $1.20 \times 10^{-5} \text{ K}^{-1}$
 - Service temperature : 80°C
- One dimensional thermal expansion

1D Application Case: Computations & Results

- Analysis : calculation of FR with initial dimensions

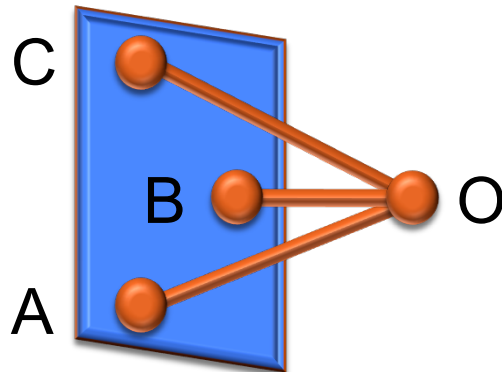
Vector	Service temperature	Norm at 20°C	Norm under service temperature
V _{cs}	80 °C	375 mm	375.270 mm
V _{ch}	90 °C	375 mm	375.625 mm
V _{cs} – V _{ch}		0 mm	0.355 mm

- Synthesis : minimisation of the misalignment in service.

Vector	Service temperature	Norm at 20°C	Norm under service temperature
V _{cs}	80 °C	375.355 mm	375.625 mm
V _{ch}	90 °C	375 mm	375.625 mm
V _{cs} – V _{ch}		0.355 mm	0 mm

Generalization to 3D application case :

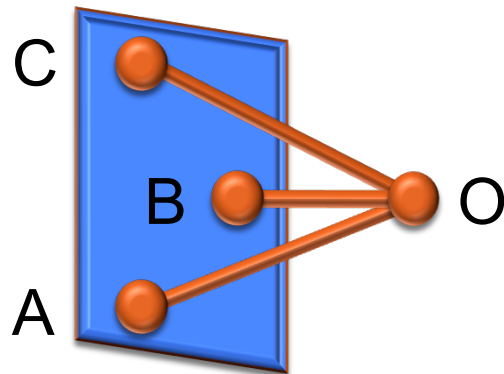
- Extension to 3D :
Study 3 articulated bars disposed as a tetrahedron.



- Use of a vectors as geometrical model.
- Use of a metric tensor for the calculation of displacements, configuration under different loads.
- Use of thermal dilatation as load variation.
- Points A, B and C are supposed to be fixed.

Method for 3D calculation :

- Initial configuration

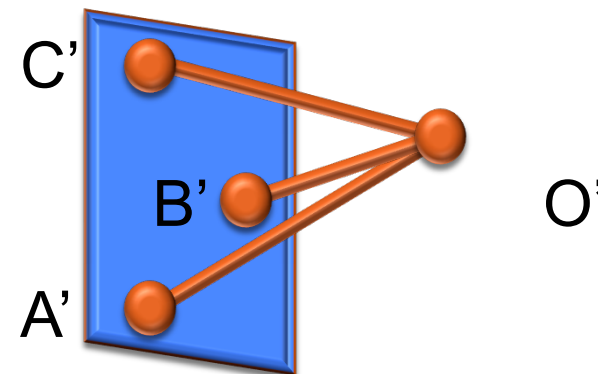


- Mathematical representation

Gi	OA	OB	OC	AB	AC	BC
OA						
OB						
OC						
AB						
AC						
BC						

Known

- Final configuration

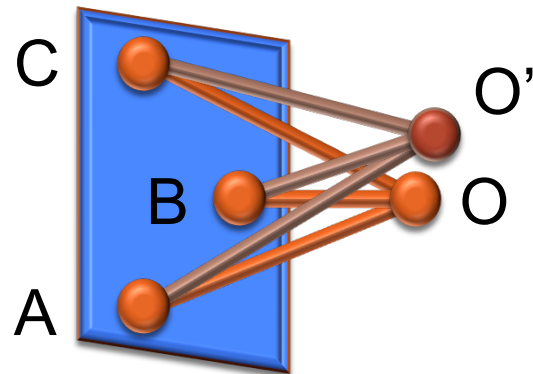


- Mathematical representation

Gf	O'A'	O'B'	O'C'	A'B'	A'C'	B'C'
O'A'						
O'B'						
O'C'						
A'B'						
A'C'						
B'C'						

Calculated with
theoretical
formulations

Method for 3D calculation :



Calculation of the Gif tensor :

- Vectorial association :
Cholesky factorization
- Affine association :
coincidence of 2 points
- Calculation of deviations

$$G = \begin{bmatrix} G_i & G_{if} \\ G_{if}^T & G_f \end{bmatrix}$$

Conclusion

- Use of a parametrical representation based on vectors for the mechanism.
- Use of theoretical (or FEA) techniques for the calculation of part deformation.
- Original idea of representing the mechanism at each stage of its life cycle with a specific set of parameters.
- Possibility to model structures and mobile mechanisms.
- Method available at early design phases.

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Method for 3D calculation 1/2

- Vectorization of the model is not detailed here. (obvious)

Set of vectors : $\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}, \overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{BC}$

- Calculation of the metric tensor of the initial configuration.

$$Gi = \left(\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}, \overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{BC} \right)^T \otimes \left(\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}, \overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{BC} \right)$$

- Calculation of thermal expansion :

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T$$

- Deduction of the metric tensor of the final configuration

$$Gf = \left(\overrightarrow{O'A'}, \overrightarrow{O'B'}, \overrightarrow{O'C'}, \overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{B'C'} \right)^T \otimes \left(\overrightarrow{O'A'}, \overrightarrow{O'B'}, \overrightarrow{O'C'}, \overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{B'C'} \right)$$

Method for 3D calculation

2/2

- Vectorial association between initial and final configuration :

Use of a Cholesky factorisation.

- Choice of 3 independent vectors : \overrightarrow{AB} , \overrightarrow{AC} , \overrightarrow{OA}

$$Gib = \left(\overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{OA} \right)^T \otimes \left(\overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{OA} \right) = (Gic)^T \otimes (Gic)$$

$$Gfb = \left(\overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{O'A'} \right)^T \otimes \left(\overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{O'A'} \right) = (Gfc)^T \otimes (Gfc)$$

- Calculation of the relation between initial and final configuration:

$$Gifb = \left(\overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{OA} \right)^T \otimes \left(\overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{O'A'} \right) = (Gic)^T \otimes (Gfc)$$

- Deduction of :

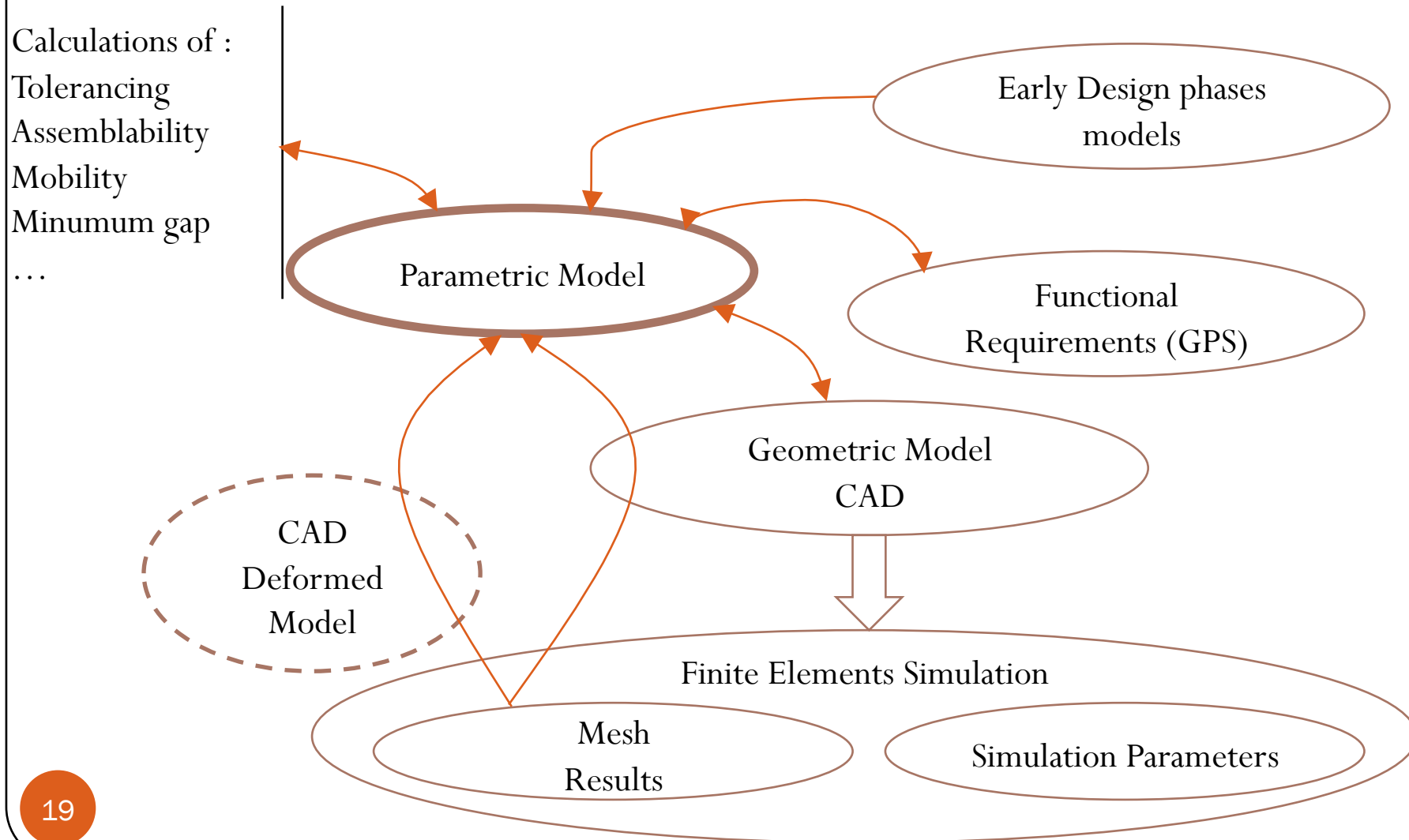
$$Gif = \left(\overrightarrow{O'A'}, \overrightarrow{O'B'}, \overrightarrow{O'C'}, \overrightarrow{A'B'}, \overrightarrow{A'C'}, \overrightarrow{B'C'} \right)^T \otimes \left(\overrightarrow{OA}, \overrightarrow{OB}, \overrightarrow{OC}, \overrightarrow{AB}, \overrightarrow{AC}, \overrightarrow{BC} \right)$$

- Affine association : Calculation of the deviation of points. $A \equiv A'$

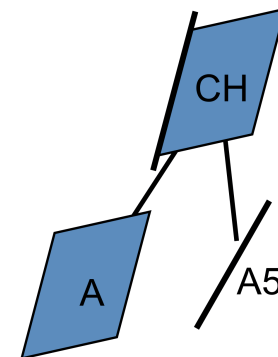
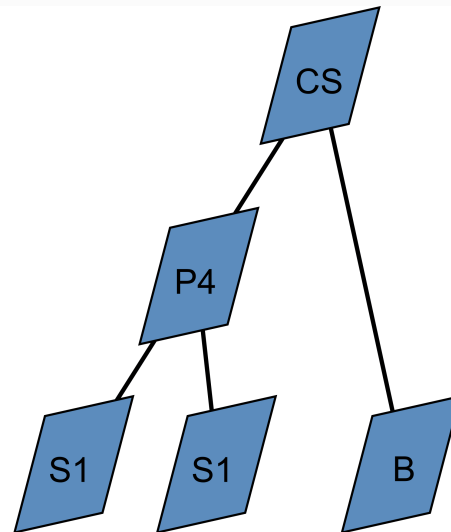
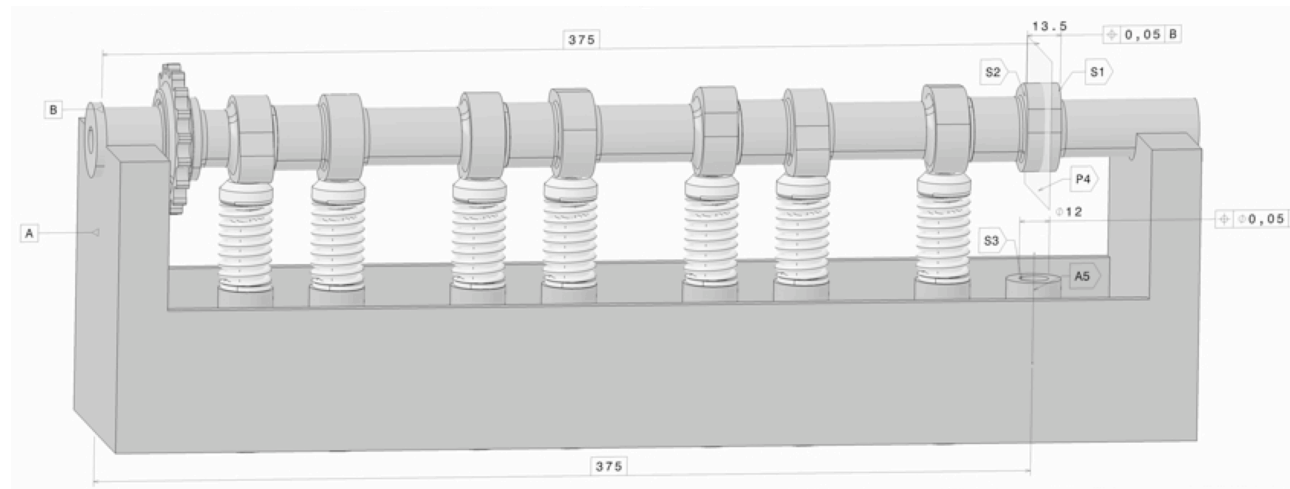
Here we have : $\overrightarrow{AA'} = \overrightarrow{BB'} = \overrightarrow{CC'} = \vec{0}$ $\overrightarrow{OO'} \neq \vec{0}$

Product Structure :

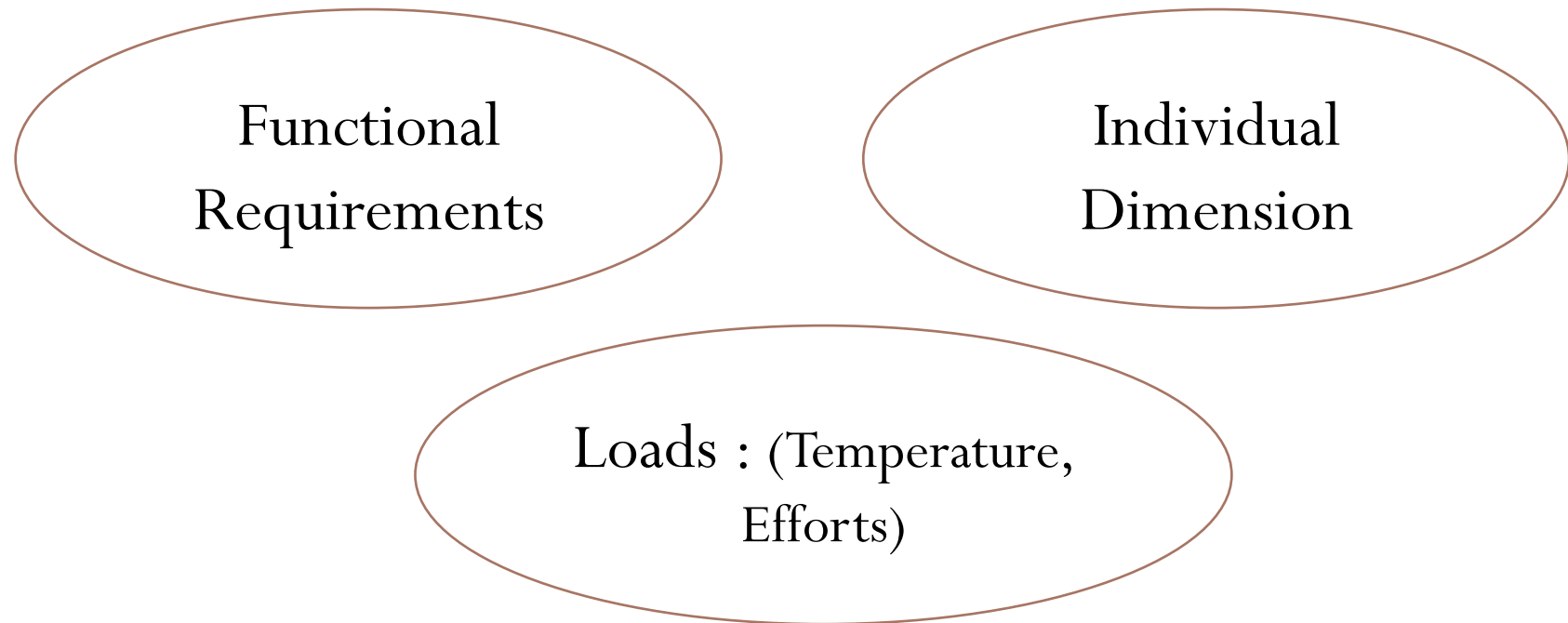
Links and data exchange



Application Case: Parameterization



Design variables and constraints



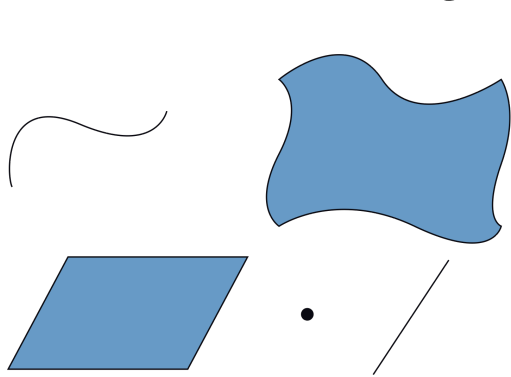
Design paradigm : 2 out of 3 of the above elements must be chosen for a design to be fully constrained.

Introduction

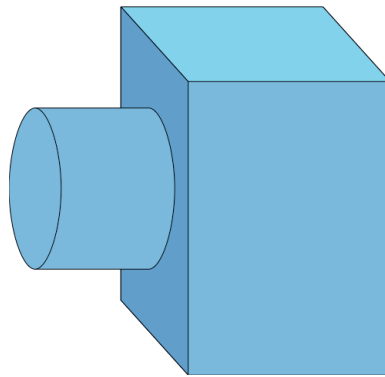
- Currently, the study of the functional requirement (FR) is done on an ideal model of the mechanism

Product Structure : Assembly representations

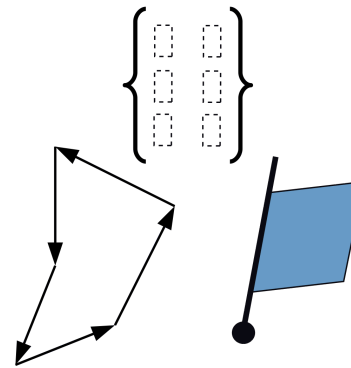
- Each designing task uses a specific assembly representation.
- This framework integrates models related to geometric modelling, tolerance analysis and stress analysis.



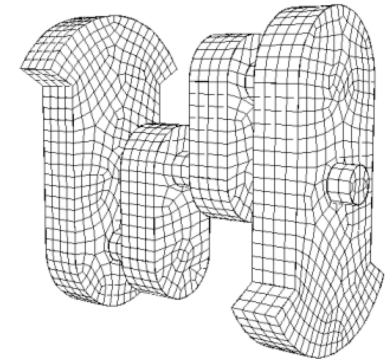
Geometric elements
Points, Lines, Planes,
Curves, Surface, ...



B-Rep, CSG models



TTRS / MGRE
Small displacement Torsor
Loops of vectors



Meshing

- In this work we propose to use vectors and loops of vectors as model for assemblies.

Method for 3D calculation :

	OA	OB	OC	AB	AC	BC	O'A'	O'B'	O'C'	A'B'	A'C'	B'C'
OA												
OB												
OC												
AB												
AC												
BC												
O'A'												
O'B'												
O'C'												
A'B'												
A'C'												
B'C'												