ParisTech
INSTITUT DES SCIENCES ET TECHNOLOGIES
PARIS INSTITUTE OF TECHNOLOGY

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and

Dottore di Ricerca della Università degli Studi di Genova

Specialità "Meccanica e Costruzione delle Macchine"

Università degli Studi di Genova

presented and defended publicly by

Ruding LOU

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Modification of semantically enriched FE mesh models

Application to the fast prototyping of alternative solutions in the context of industrial maintenance

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THESIS

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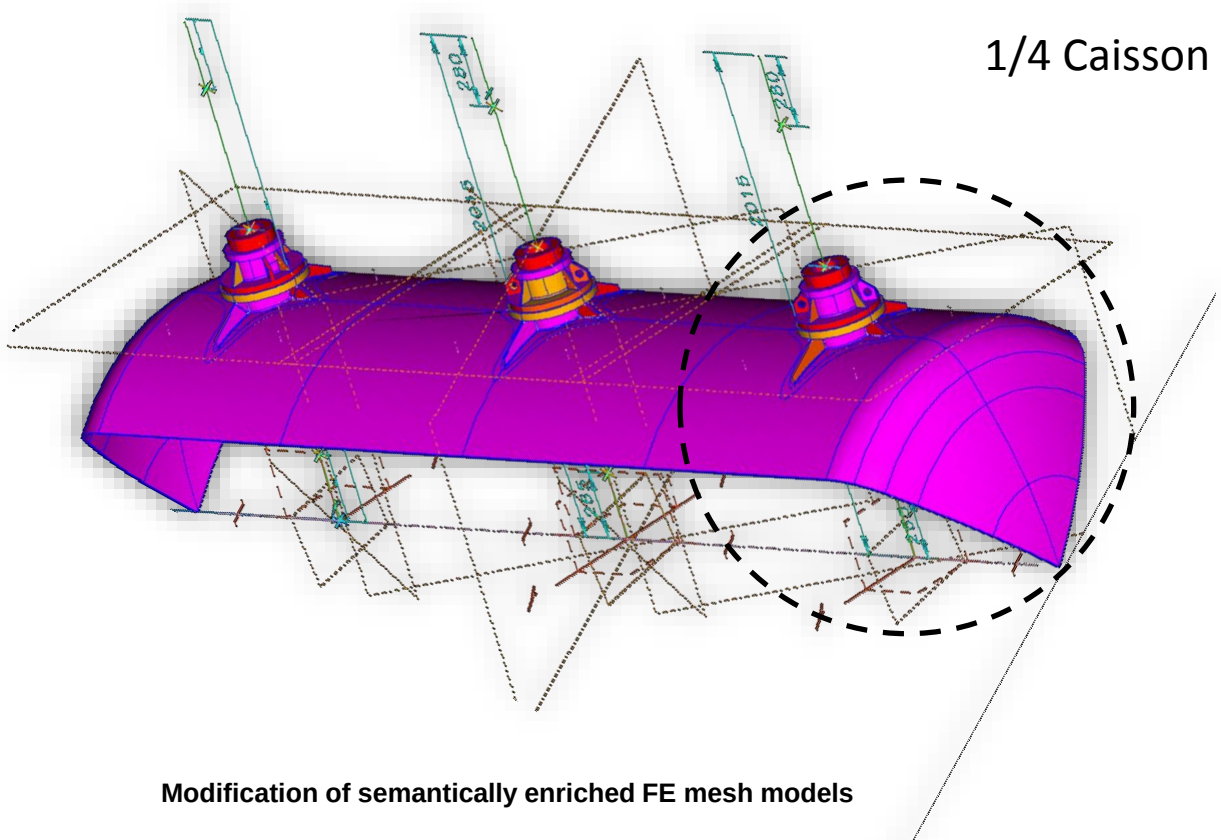
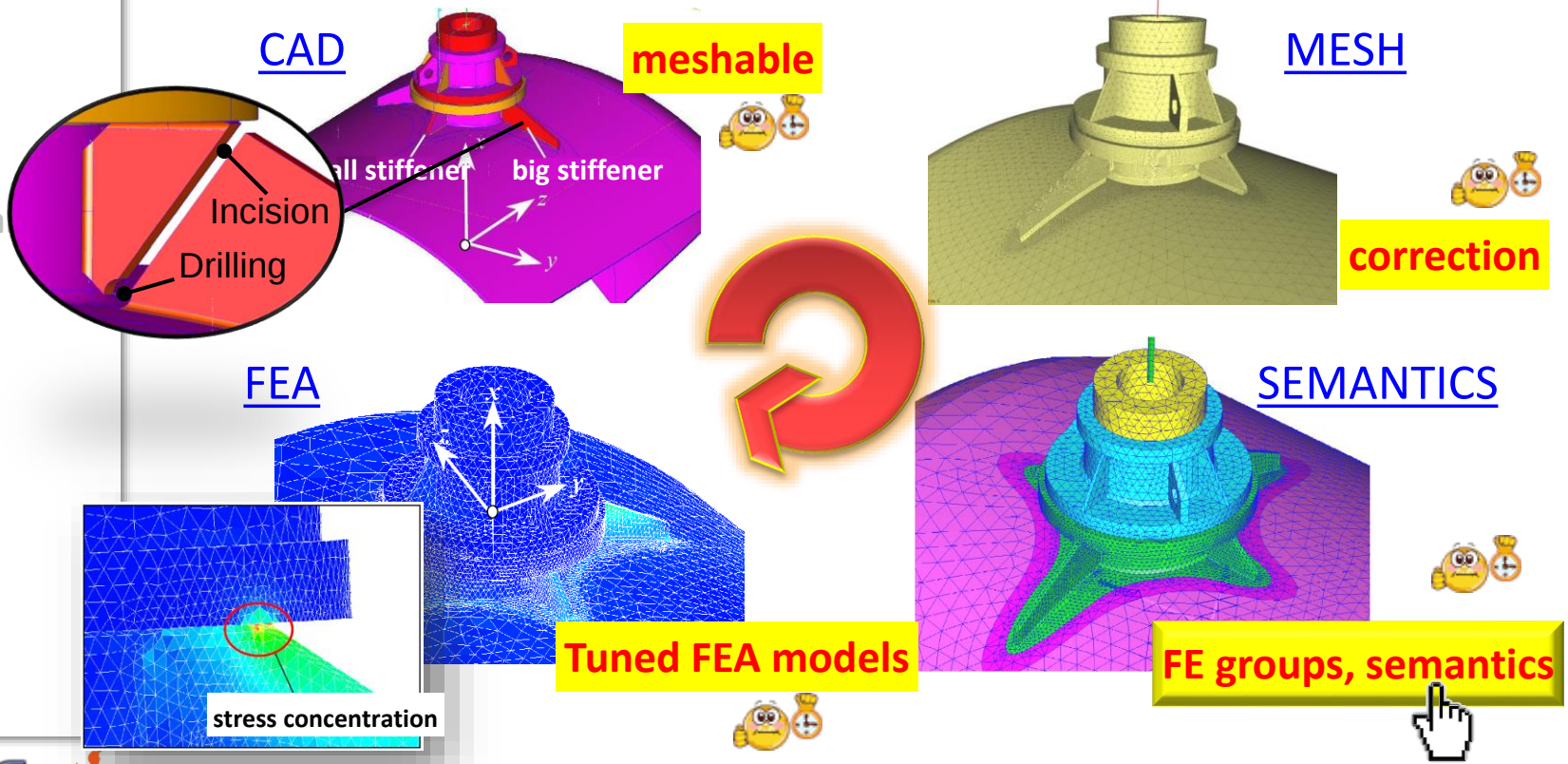
Classical loop for product design optimisation via FEA

- The classical loop consists of four steps
  1. Computer Aided Design (CAD) modelling
  2. Finite Elements (FE) Mesh creation
  3. Simulation semantics definition
  4. Finite Elements Analysis (FEA)
- Study case performed in **E**lectricité **d**e **F**rance (EDF)

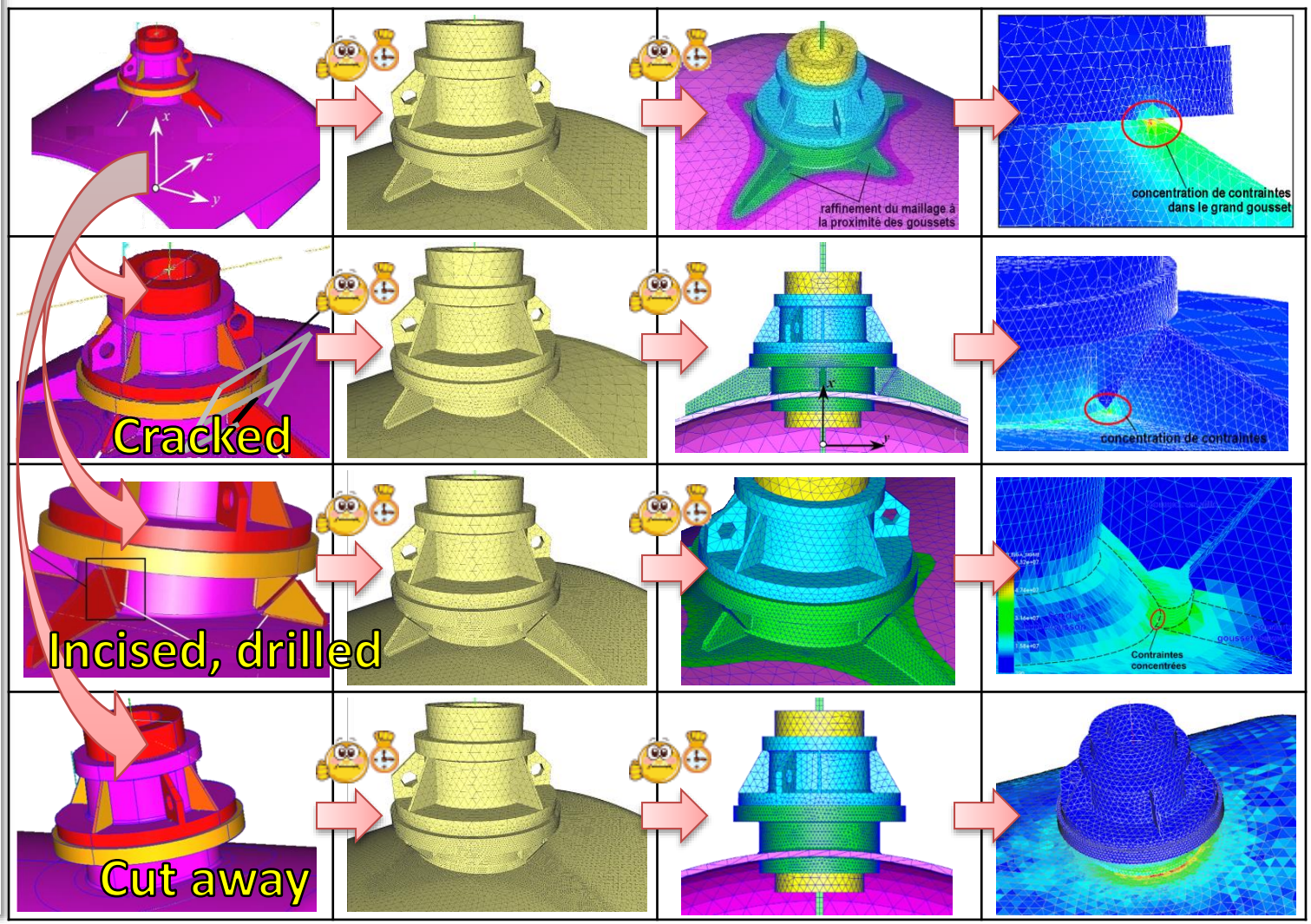


Classical loop for product design optimisation via FEA

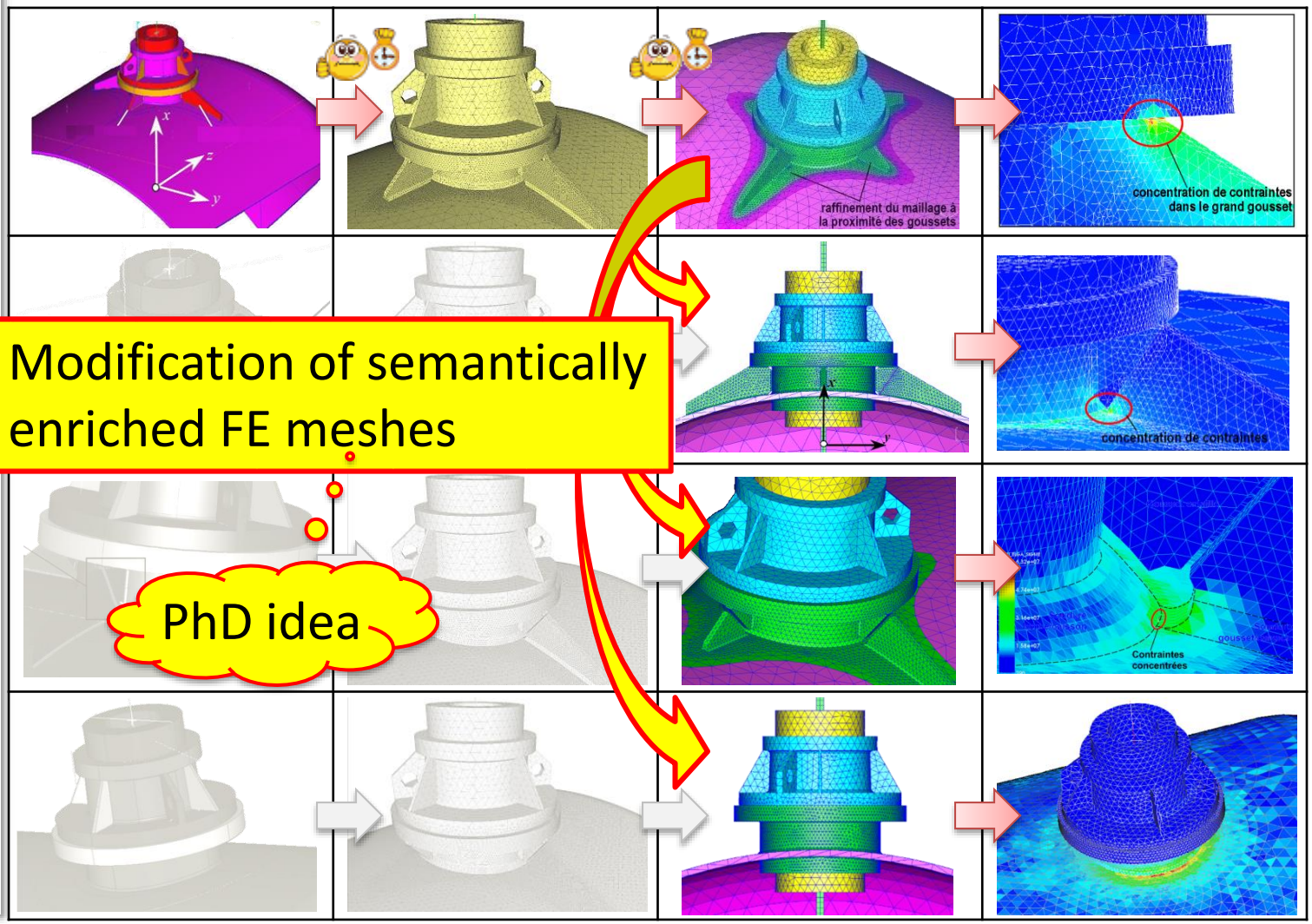
- The classical loop consists of four steps
  1. Computer Aided Design (**CAD**) modelling
  2. Finite Elements (FE) **Mesh** creation
  3. Simulation **semantics** definition
  4. Finite Elements Analysis (**FEA**)
- Study case performed in Electricité de France (EDF) 1/4 Caisson



Classical loop for product design optimisation via FEA



New loop for product design optimisation through FEA



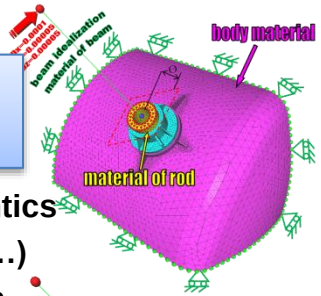
Workflow for FEA model preparation

Today

Tomorrow

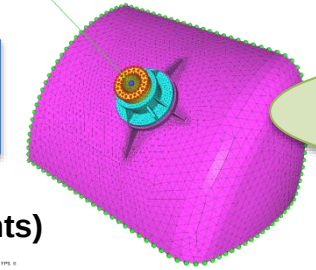
Semantics

FEA / Geometrical Semantics
(Material, BCs, shape …)
associated to groups



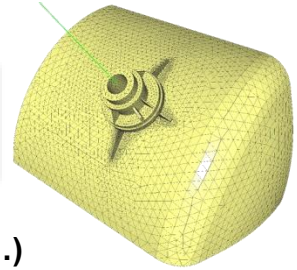
Groups

0D/1D/2D/3D groups
(set of geometric elements)



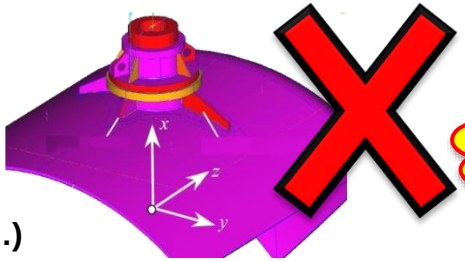
Mesh

0D/1D/2D/3D
meshes (nodes, edges…)



CAD

Parametric geometry
(vector, plane, cylinder, …)



Semantics transfer

Group preservation

FEA semantics enriched mesh modification

Local mesh modification

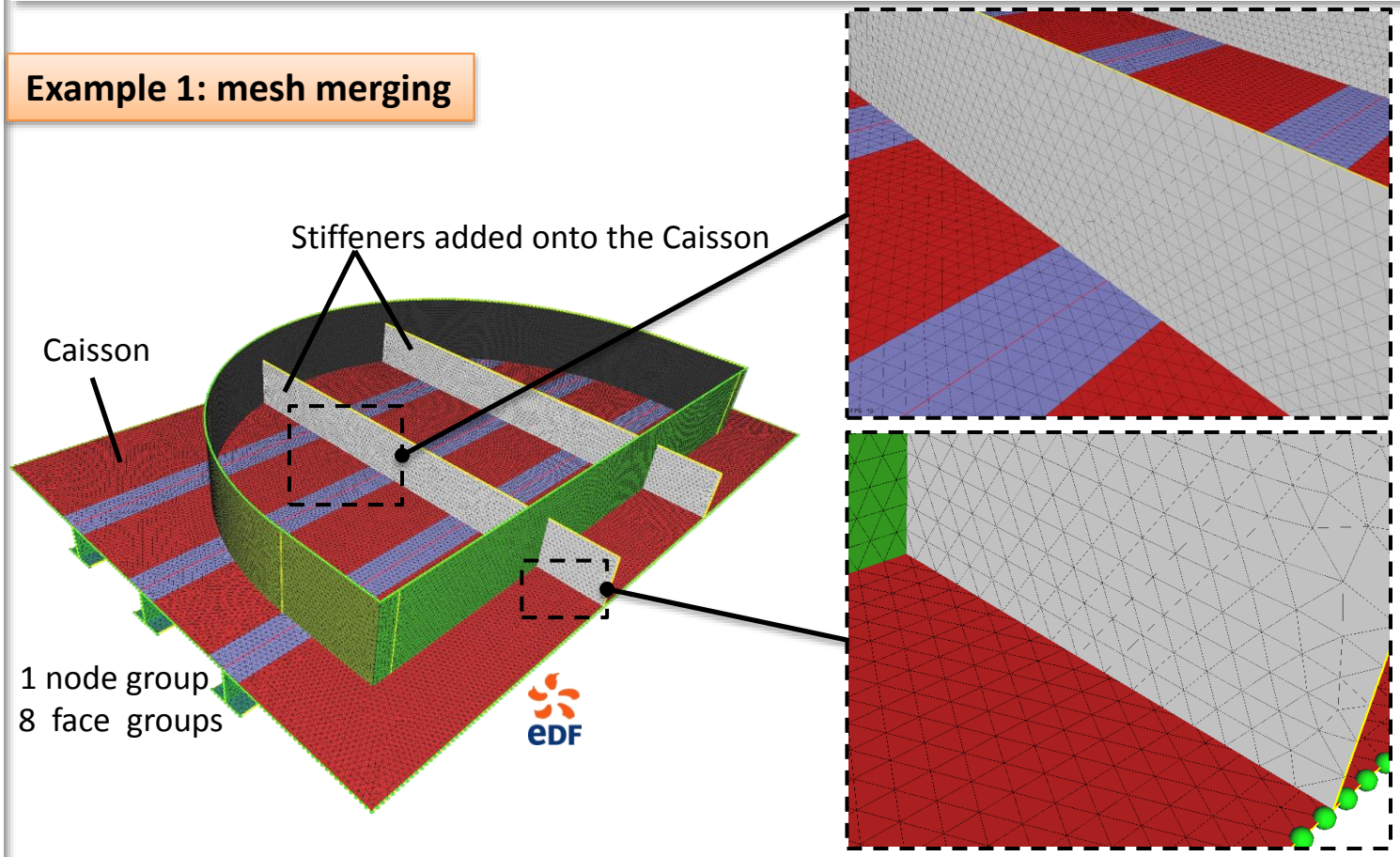
CAD modifications

PhD idea

Modification of semantically enriched FE mesh models

Scientific challenge to overcome

Example 1: mesh merging

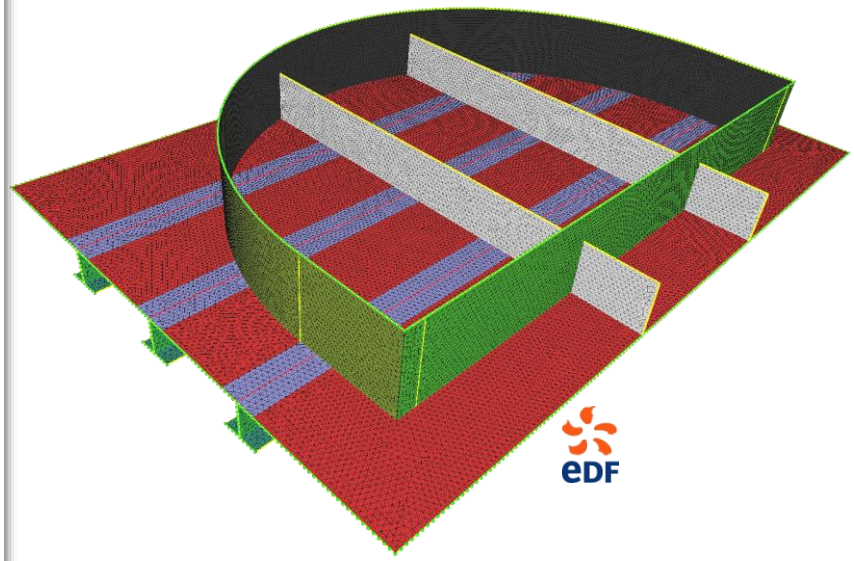


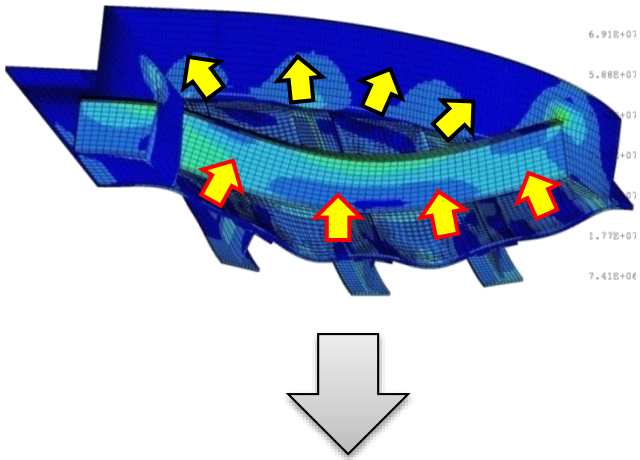
- Modify **locally** the mesh
- Produce good **quality** of mesh
- Avoid the **self-intersection**
- Preserve the **shape of the model**

- Preserve the face **groups** definition
- Preserve the node **group** definition

Scientific challenge to overcome

Example 1: mesh merging





- Fluid pressure defined on the caisson ⇧
- Different materials,
- Different boundary conditions (ex. fixation)

Fluid pressure **propagated** on to the stiffener ⇧

They must be **preserved** during the modification

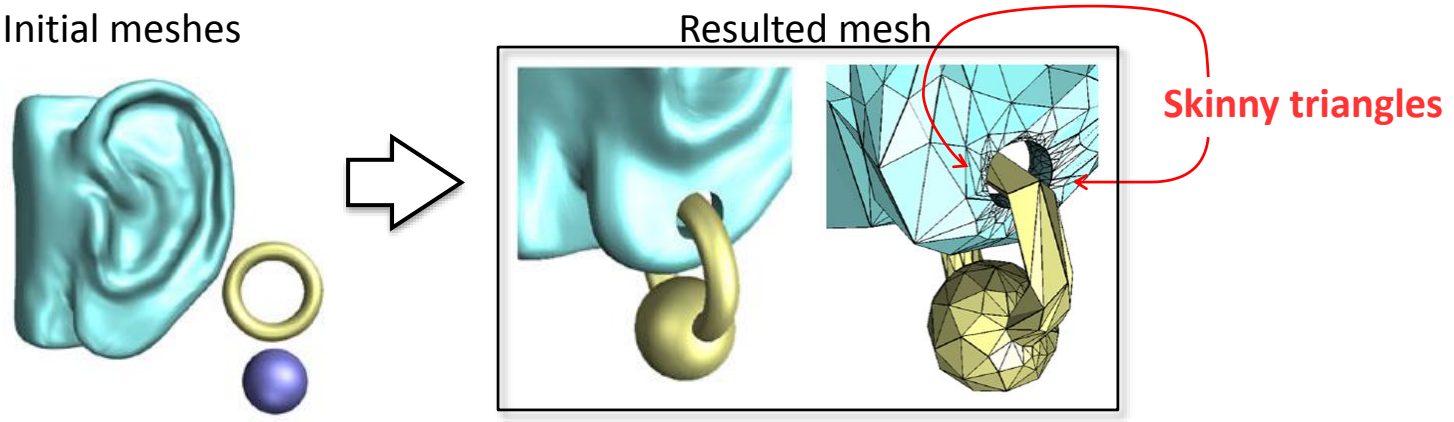
Criteria in context of FEA for analysing bibliography

- **Criteria in terms of geometry**
  - Local modification
    - The modification zone should be as small as possible
  - Initial shape of the model
    - The initial shape of the model should be preserved as much as possible
  - Quality of the mesh elements
    - The average aspect ratio of modified mesh elements should be maximised
  - Self-intersecting elements
    - All self-intersecting elements should be avoided
  - Shape of the modification tool
    - The shape of the modified part on mesh should match as much as possible the tool geometry

- **Criteria in terms of semantics**
  - Maintenance of groups
    - The shape of the groups and the content should be close to the initial ones
  - Maintenance of semantics
    - The semantics should be preserved and updated according to different geometric modification

Representative works (1/7) – mesh Boolean operation

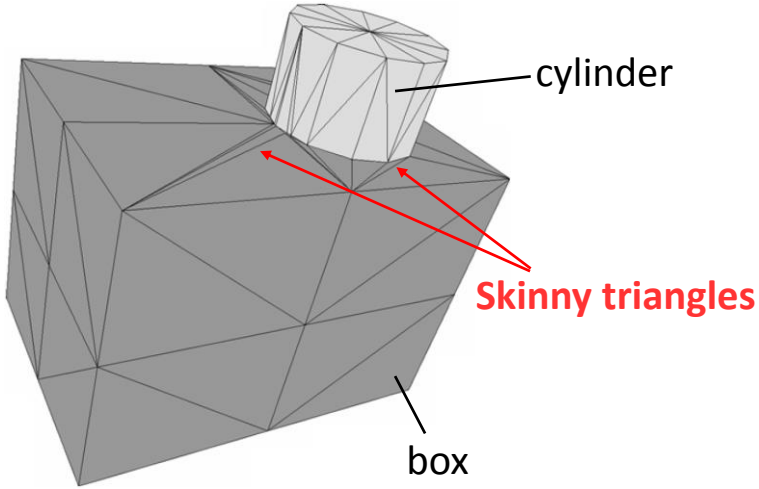
- Criteria in terms of geometry
  - Local modification
  - Initial shape of the model ⊕
  - Quality of the mesh elements ⊖
  - Self-intersecting elements
  - Shape of the modification tool
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Biermann et al. 2001*] Approximate Boolean Operations on free-form triangle meshes

Representative works (2/7) – mesh intersection

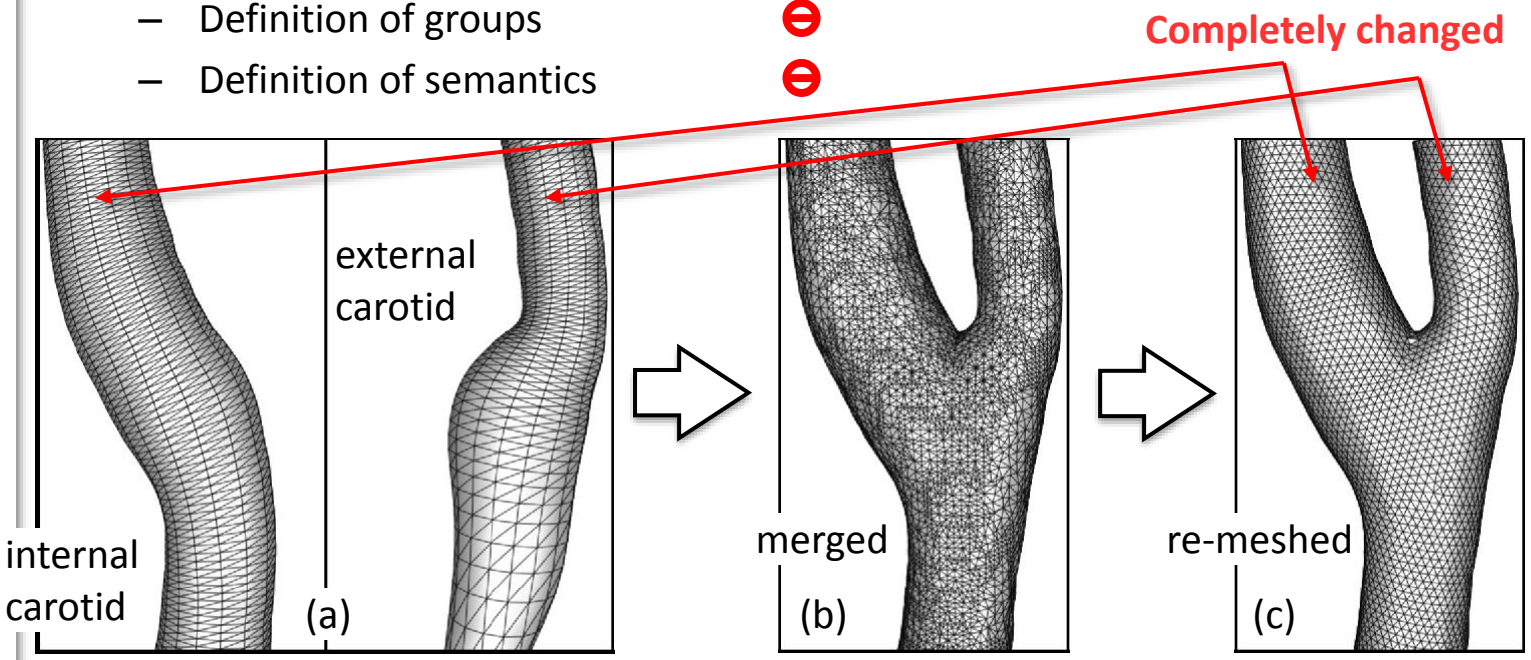
- Criteria in terms of geometry
  - Local modification ⊕
  - Initial shape of the model ⊕
  - Quality of the mesh elements ⊖
  - Self-intersecting elements
  - Shape of the modification tool
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Chouadria et al. 2006*] Contact interface re-meshing in context of assembly collision detection

Representative works (3/7) – mesh merging

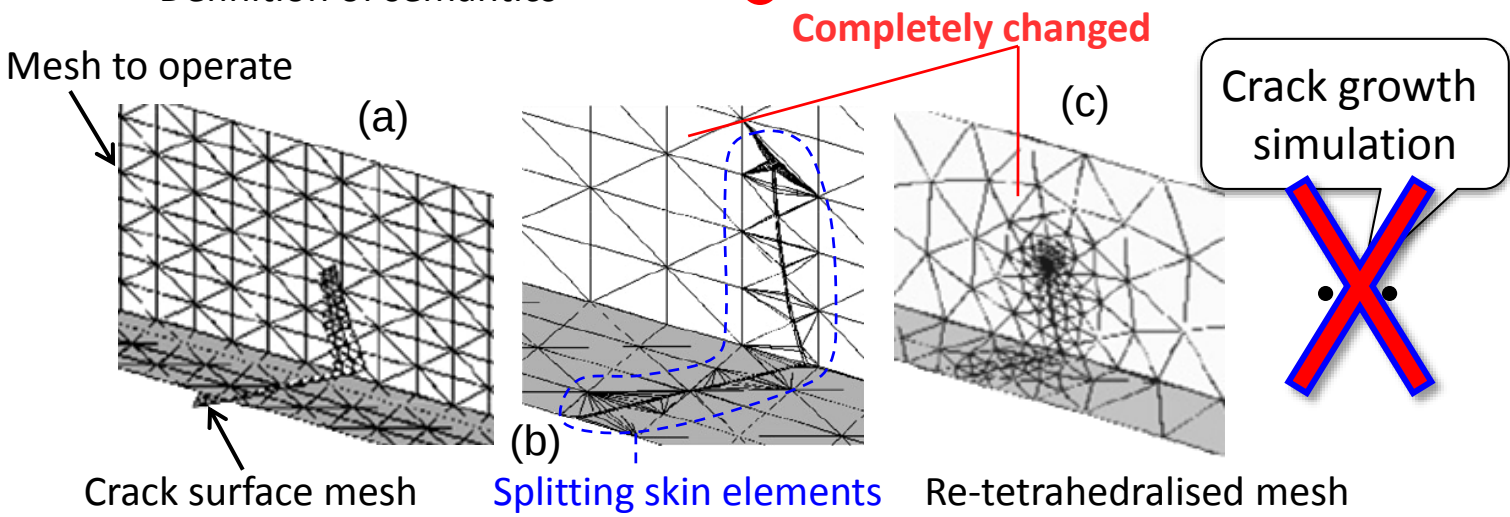
- Criteria in terms of geometry
  - Local modification ⊖
  - Initial shape of the model
  - Quality of the mesh elements ⊕
  - Self-intersecting elements
  - Shape of the modification tool
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Cebral et al. 2001*] Merging of intersecting triangulations for finite element modeling

Representative works (4/7) – mesh cracking

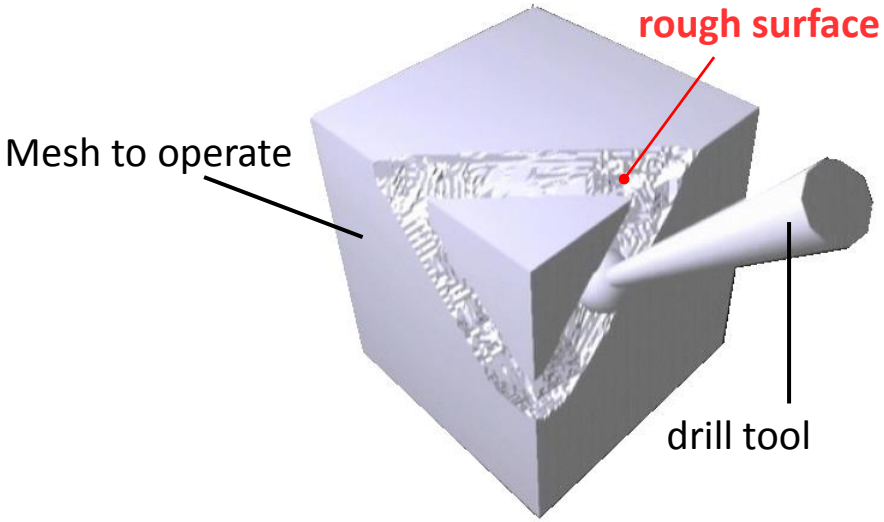
- Criteria in terms of geometry
  - Local modification ⊖
  - Initial shape of the model ⊕
  - Quality of the mesh elements ⊕
  - Self-intersecting elements
  - Shape of the modification tool ⊕
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Bremberg et al. 2008*] Automatic crack-insertion for arbitrary crack growth

Representative works (5/7) – mesh cutting

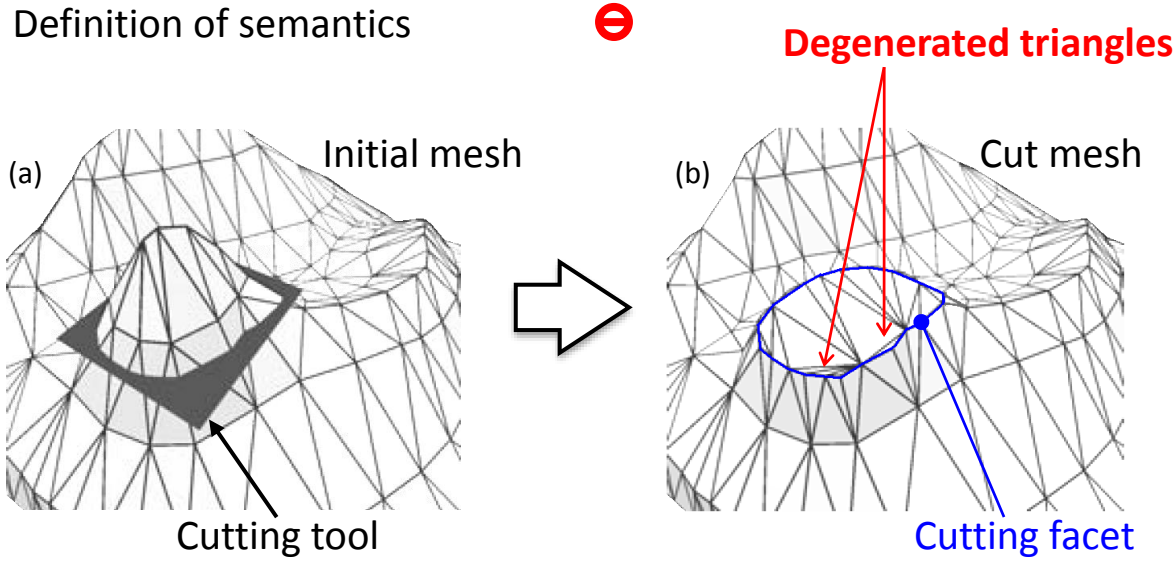
- Criteria in terms of geometry
  - Local modification ⊕
  - Initial shape of the model ⊕
  - Quality of the mesh elements
  - Self-intersecting elements
  - Shape of the modification tool ⊖
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Turini et al. 2006*] Simulating Drilling on Tetrahedral Meshes

Representative works (6/7) – mesh cutting

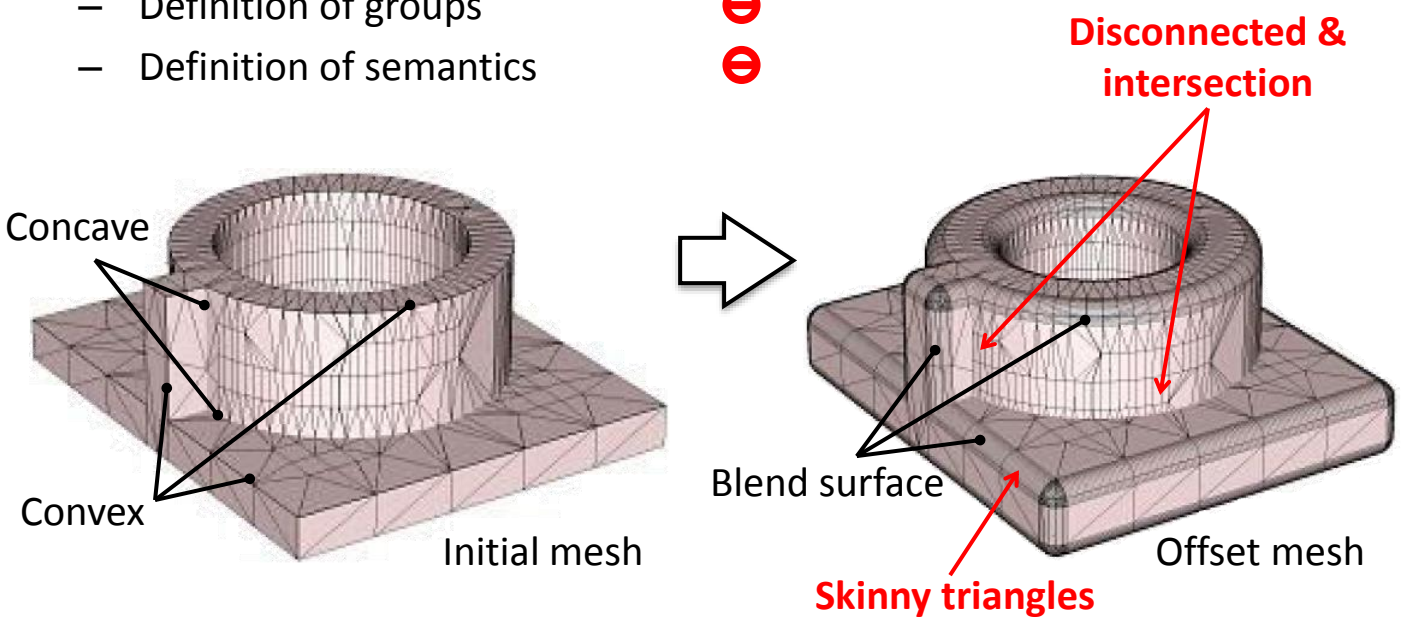
- Criteria in terms of geometry
  - Local modification ⊕
  - Initial shape of the model ⊕
  - Quality of the mesh elements ⊖
  - Self-intersecting elements
  - Shape of the modification tool ⊕
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Dakowicz et al. 2005*] Interactive TIN modification with a cutting tool

Representative works (7/7) – mesh filleting

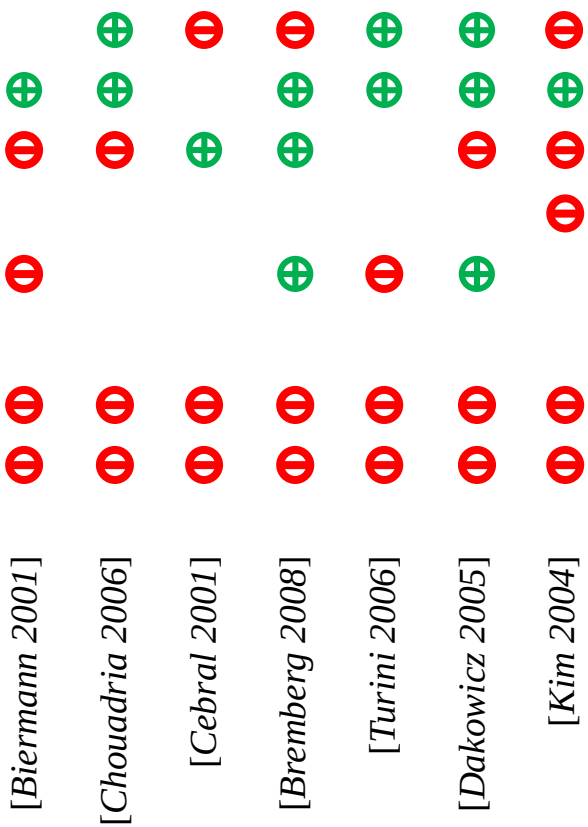
- Criteria in terms of geometry
  - Local modification ⊖
  - Initial shape of the model ⊕
  - Quality of the mesh elements ⊖
  - Self-intersecting elements ⊖
  - Shape of the modification tool
- Criteria in terms of semantics
  - Definition of groups ⊖
  - Definition of semantics ⊖



[*Kim et al. 2004*] Offset triangular mesh using the multiple normal vectors of a vertex

State of the art – Conclusion

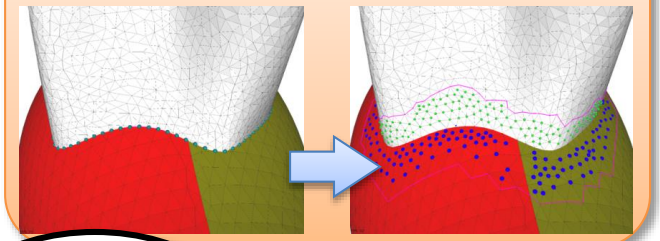
- Criteria in terms of geometry
  - Local modification
  - Initial shape of the model
  - Quality of the mesh elements
  - Self-intersecting elements
  - Shape of the modification tool
- Criteria in terms of semantics
  - Definition of groups
  - Definition of semantics



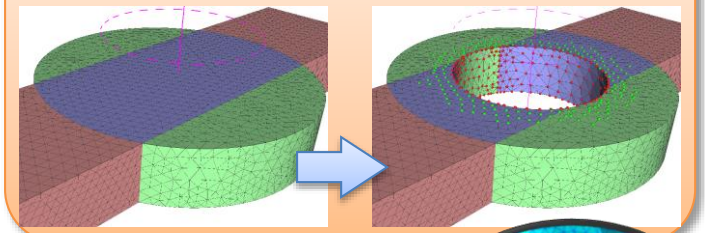
- Conclusion
  - Few works cover all geometric criteria important for FEA context
  - None of them takes into account any semantic criteria
  - Few works act on tetrahedral meshes

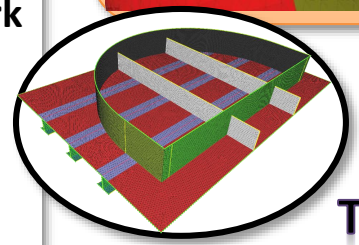
What do we need ?

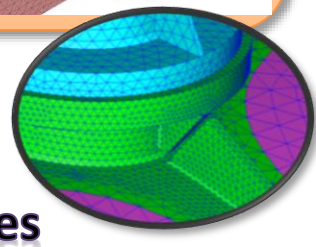
Merge meshes



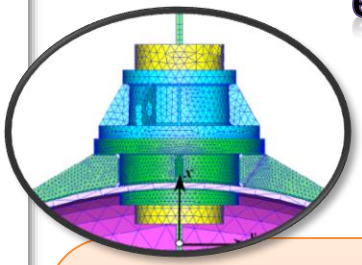
Remove material from meshes







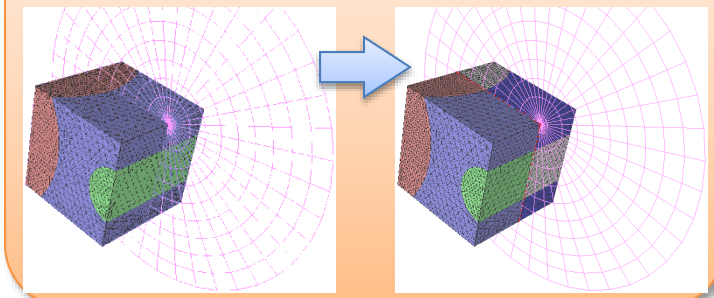
To work on triangle and tetrahedral meshes enriched by groups supporting semantics



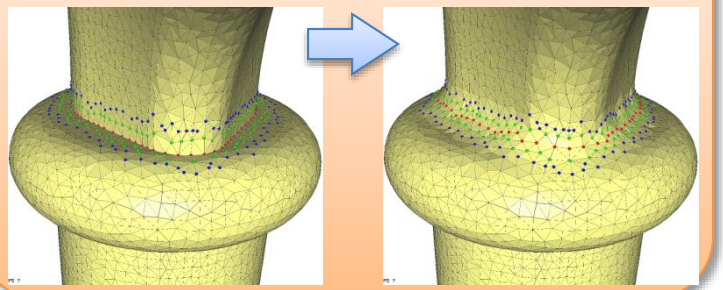
Why these operators ?

-> frequent operations in maintenance context

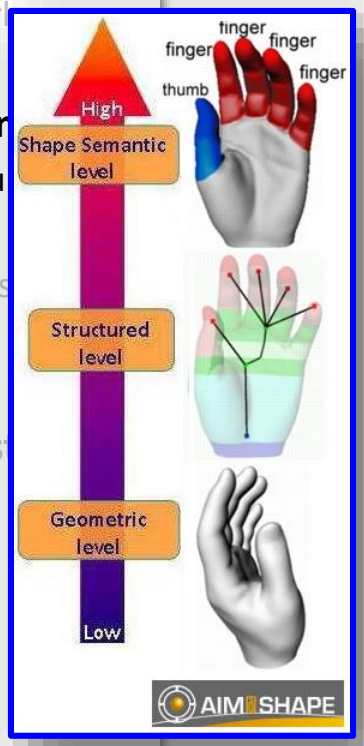
Insert discontinuities in meshes



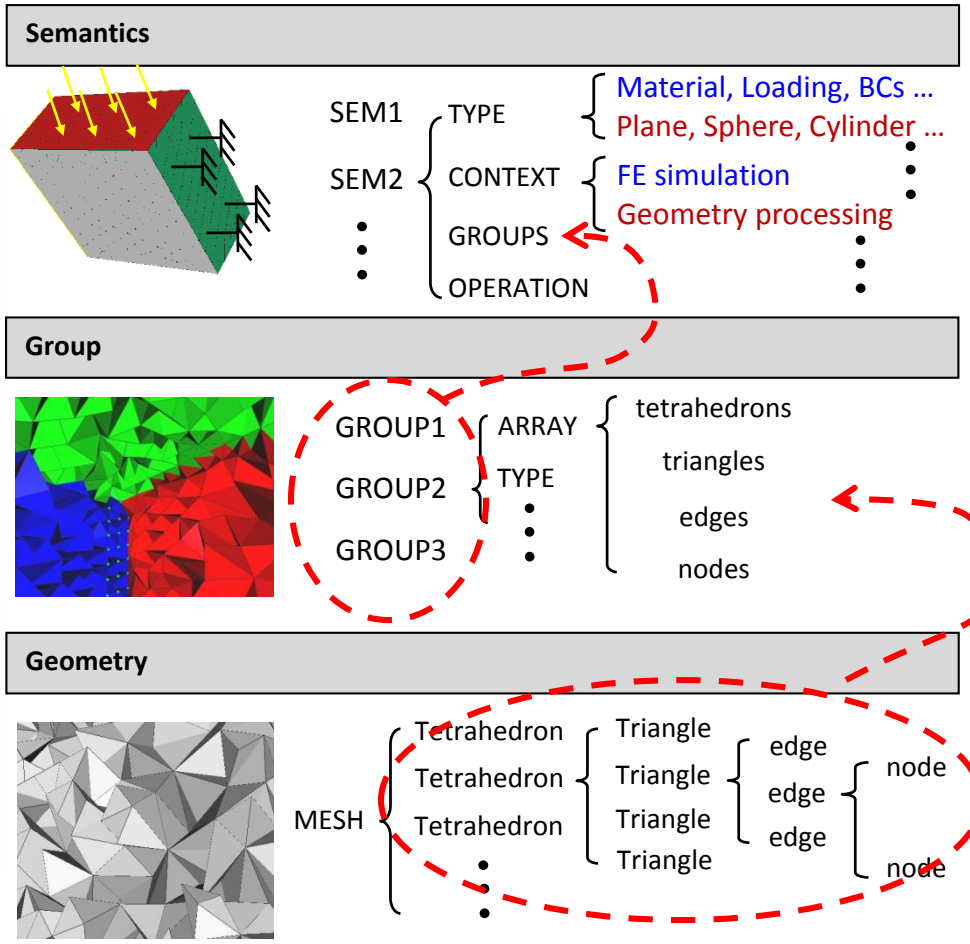
Round/deform meshes



The proposed approach: data structure



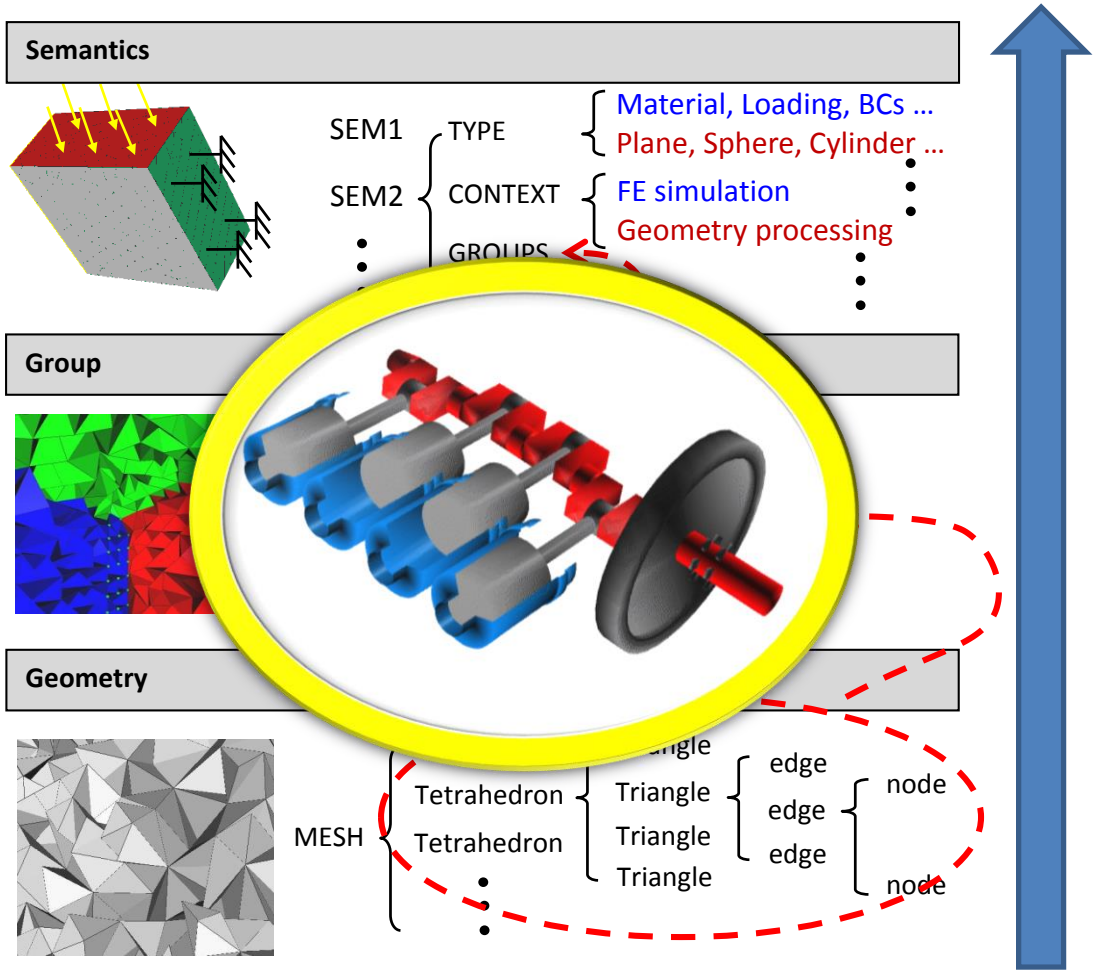
What are the kinds of information should be dealt with ?



Data structure inspired from the "AIM@SHAPE" project approach and adapted to FEA context

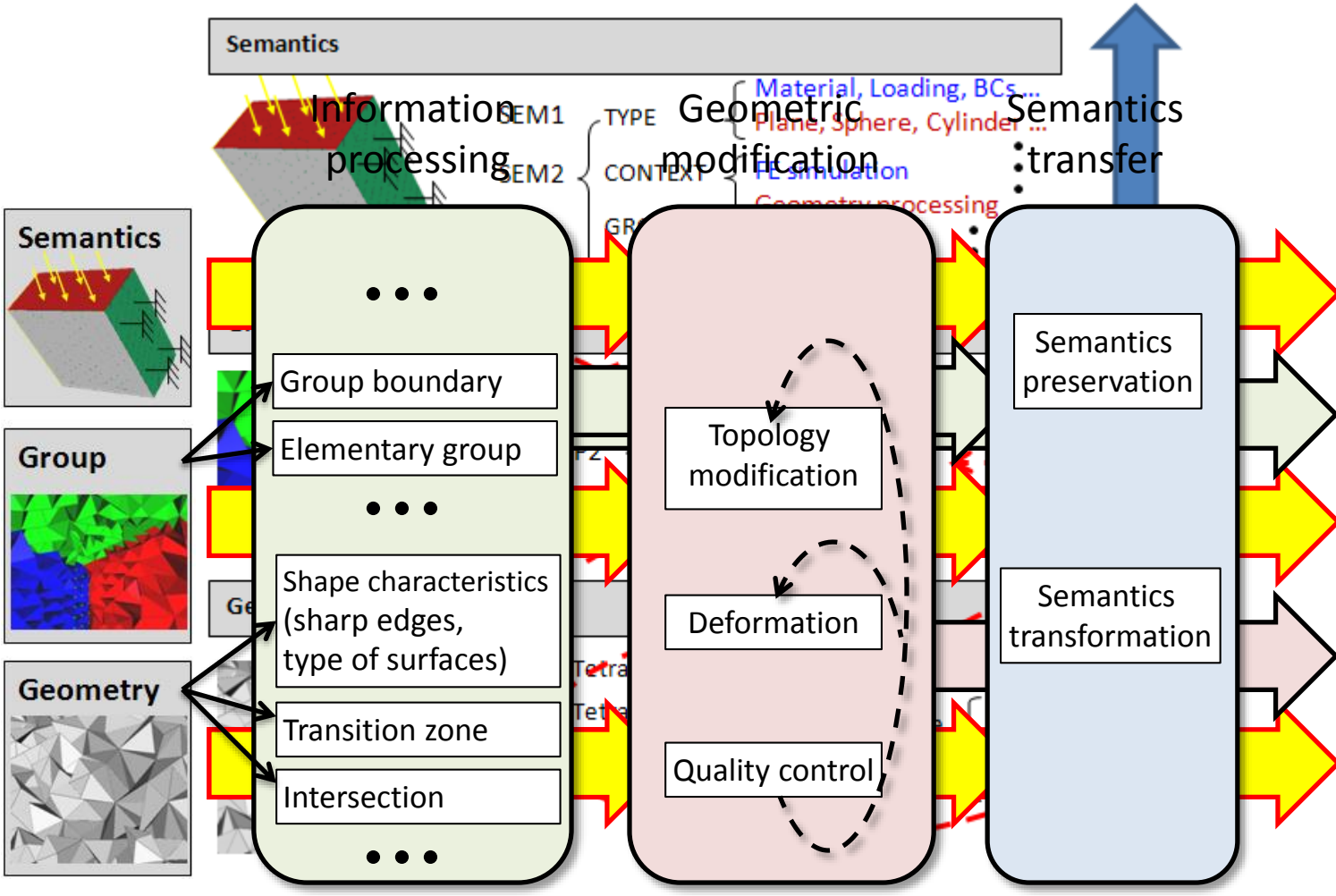
The proposed approach : CAD-less framework

An **operator** able to manipulate this data structure



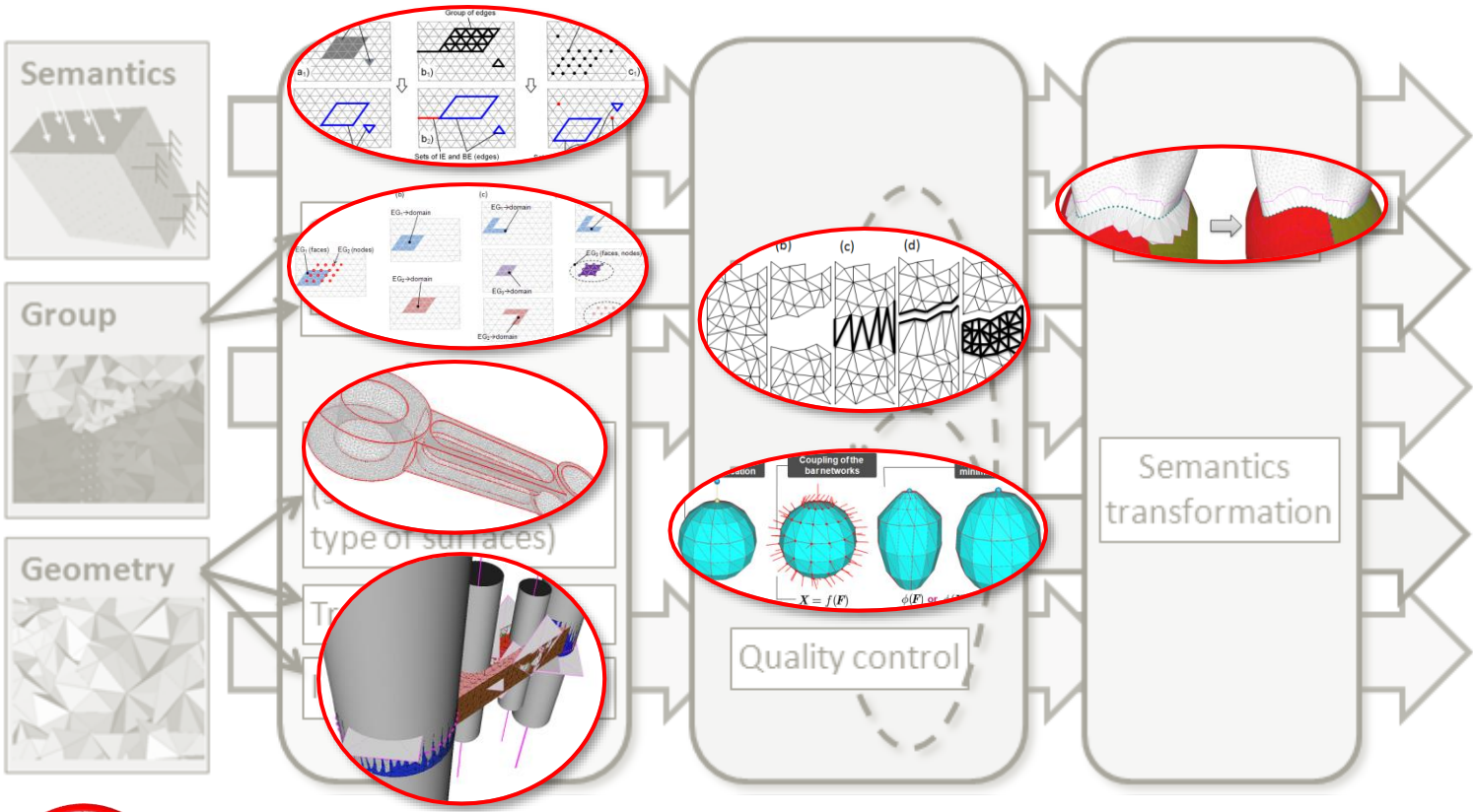
The proposed approach : CAD-less framework

An **operator** able to manipulate this data structure : CAD-less operator

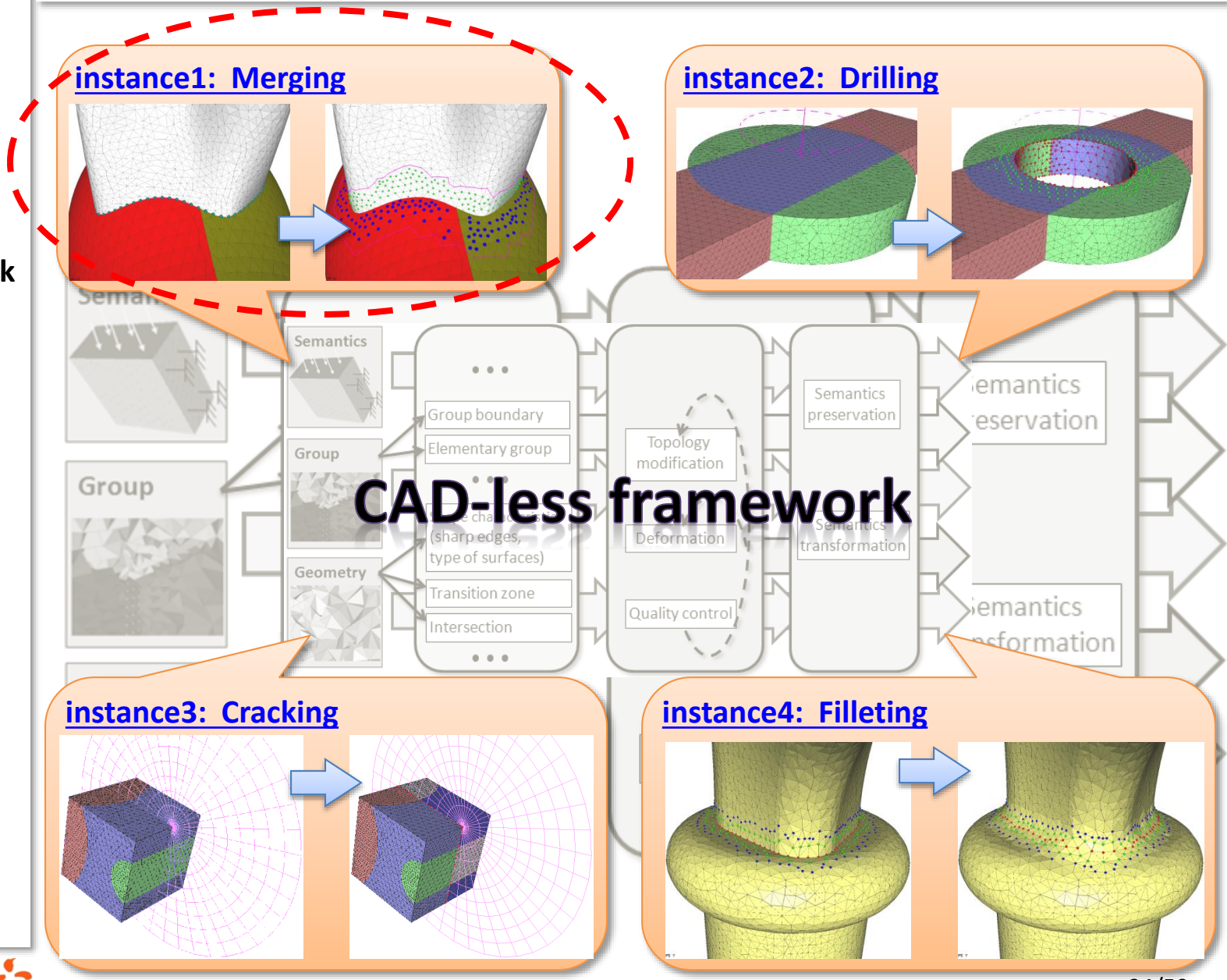


CAD-less framework components

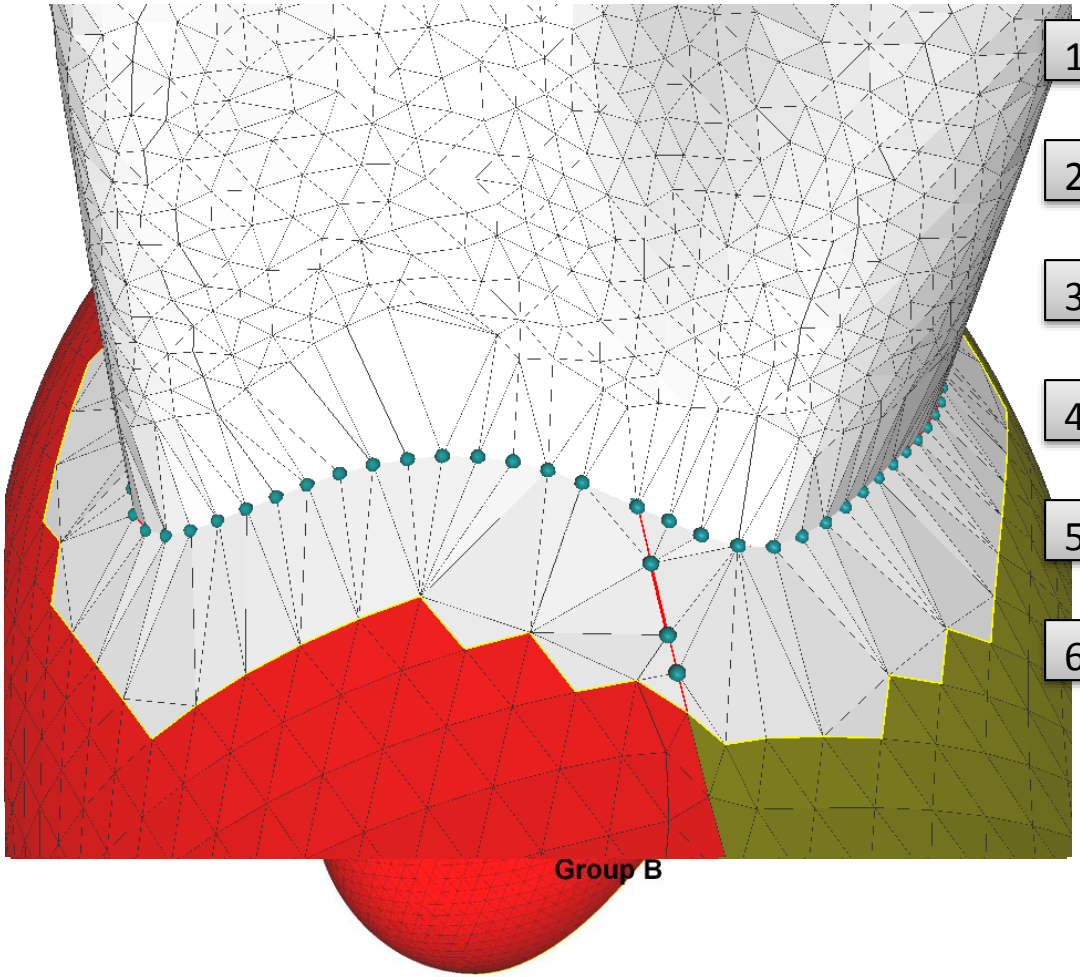
- Components in different aspects for achieving different phases
- Components substitutable



CAD-less framework : prototyped instances



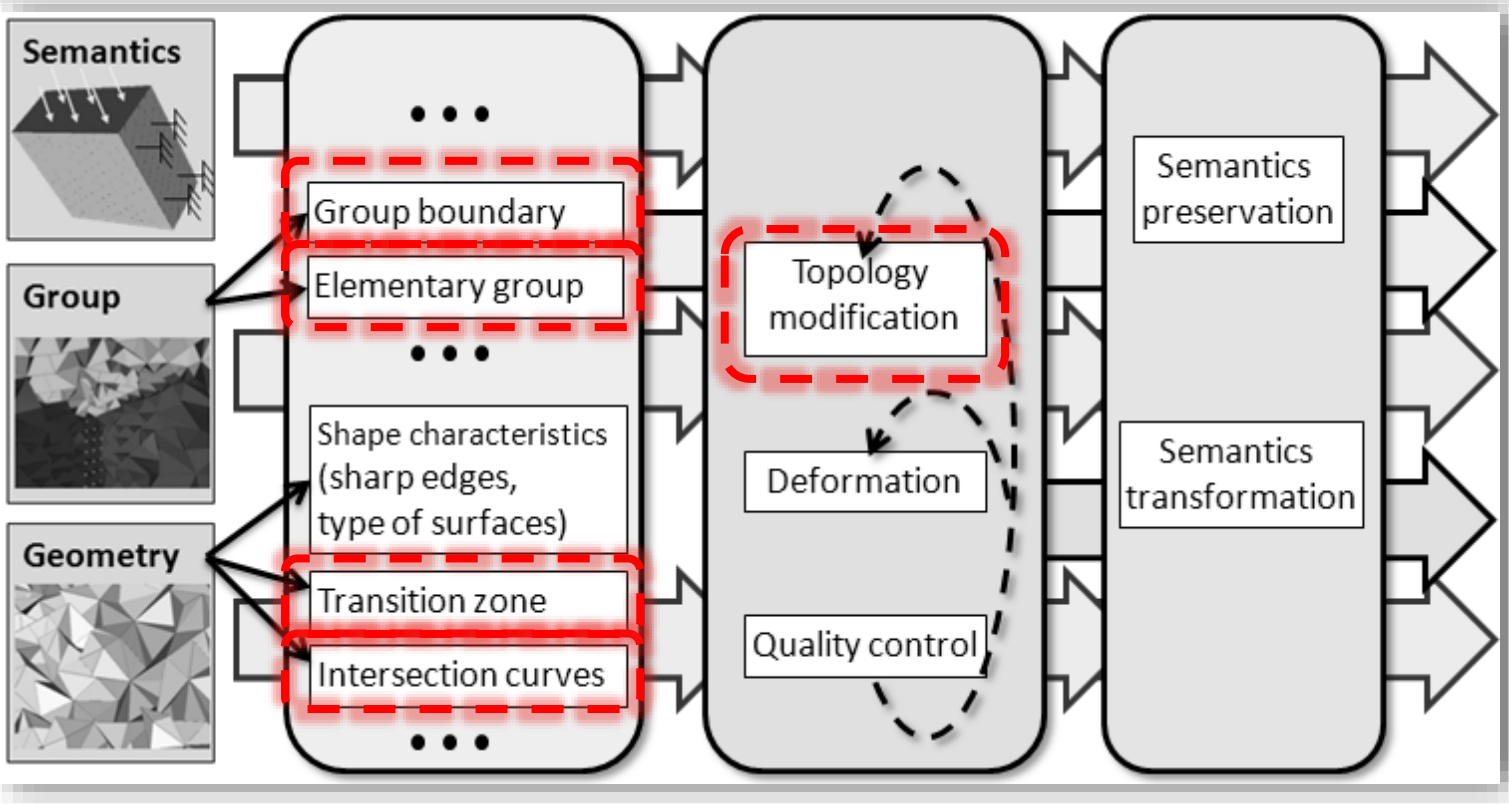
CAD-less framework instance: mesh merging

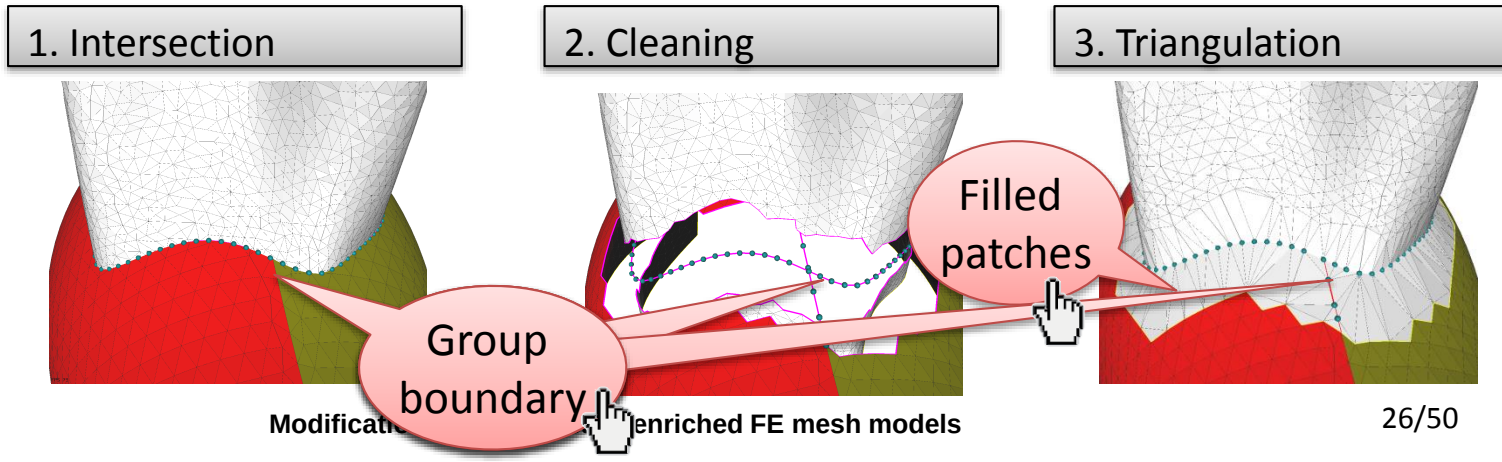


1. Intersection
2. Cleaning
3. Triangulation
4. Group reassignment
5. Insertion of nodes
6. Relaxation

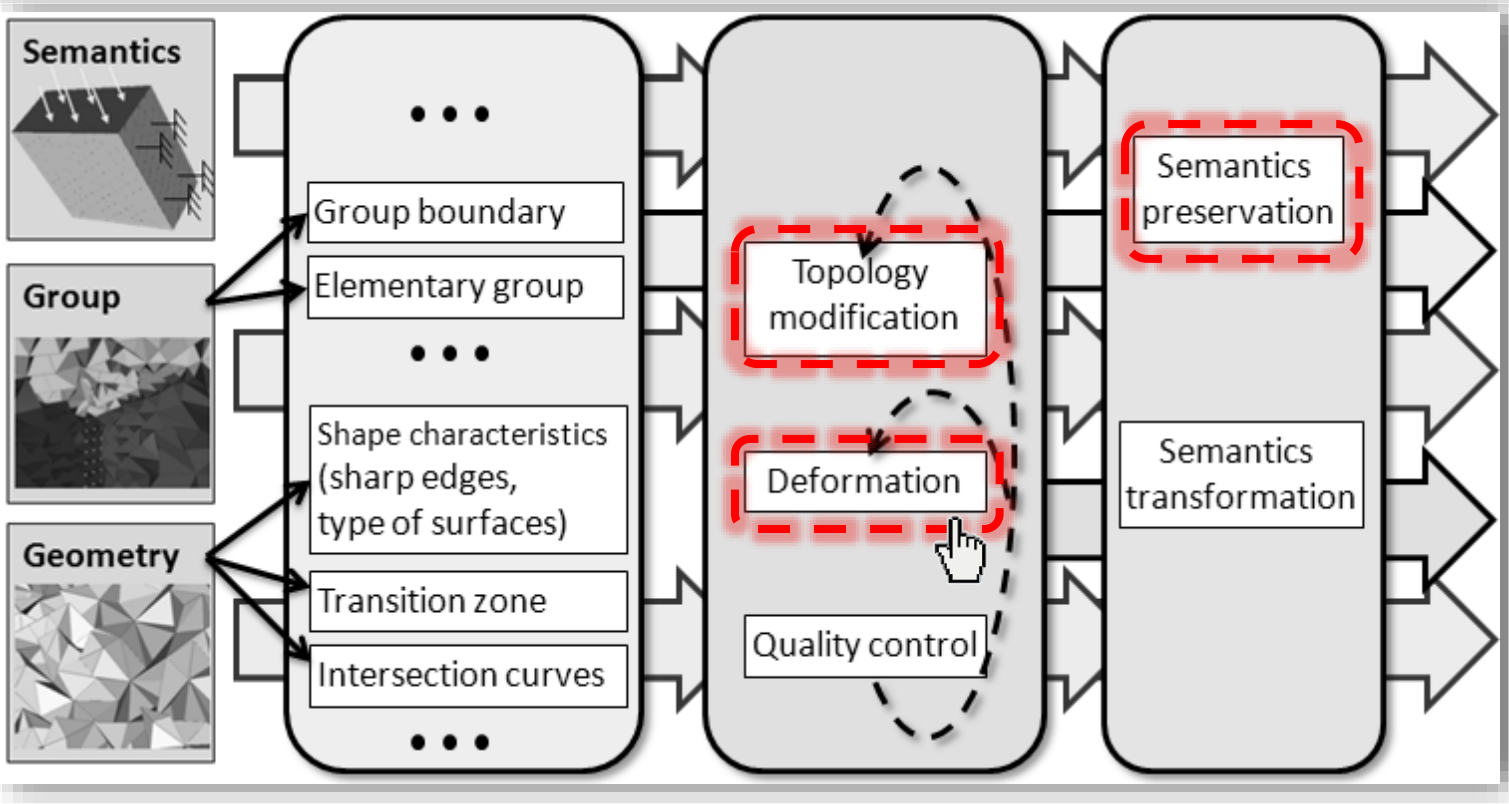
[*Lou et al. 2010*] *Merging enriched Finite Element triangle meshes for fast prototyping of alternate solutions in the context of industrial maintenance* **CAD Journal**

Basic tools and methods for mesh merging

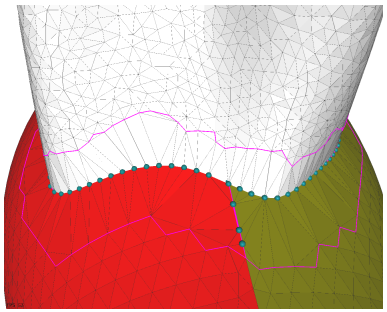




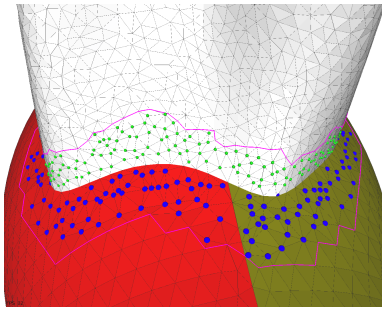
Basic tools and methods for mesh merging



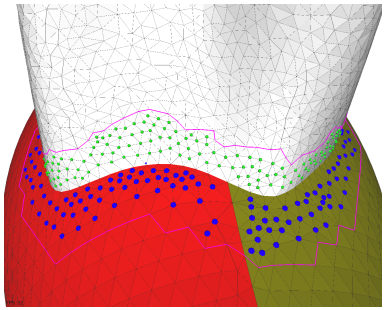
4. Group reassignment



5. Insertion of nodes

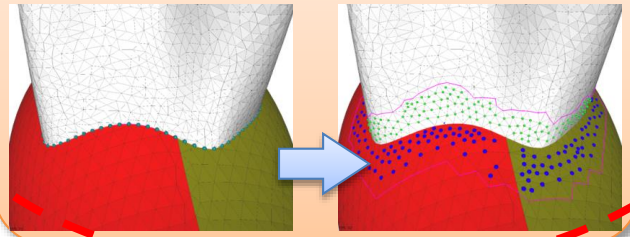


6. Relaxation

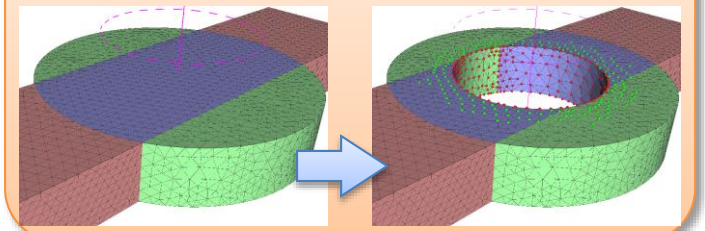


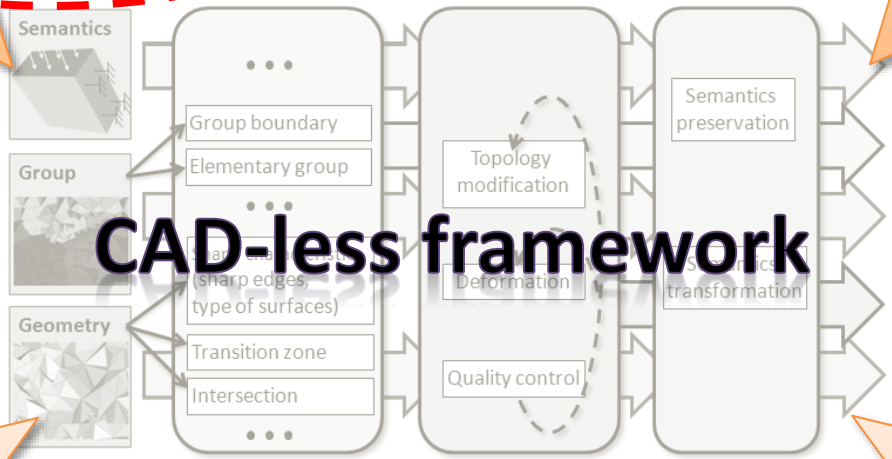
Prototyped instances of CAD-less framework

instance1: Merging

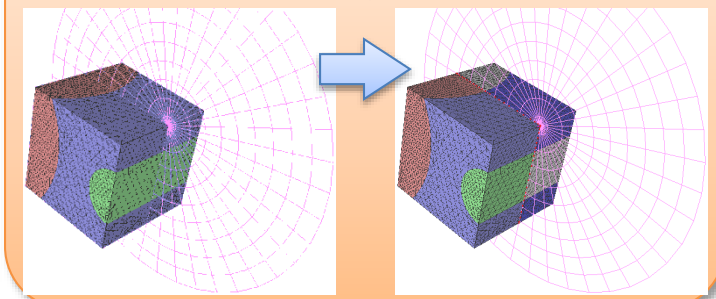


instance2: Drilling

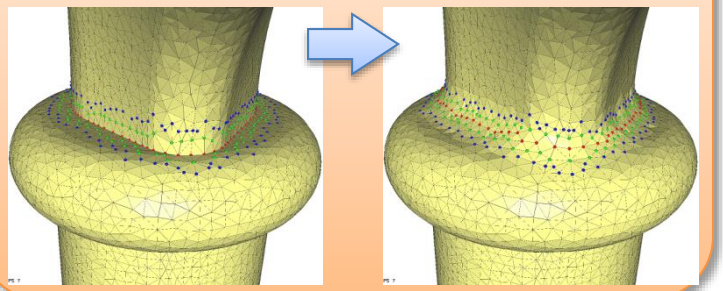




instance3: Cracking

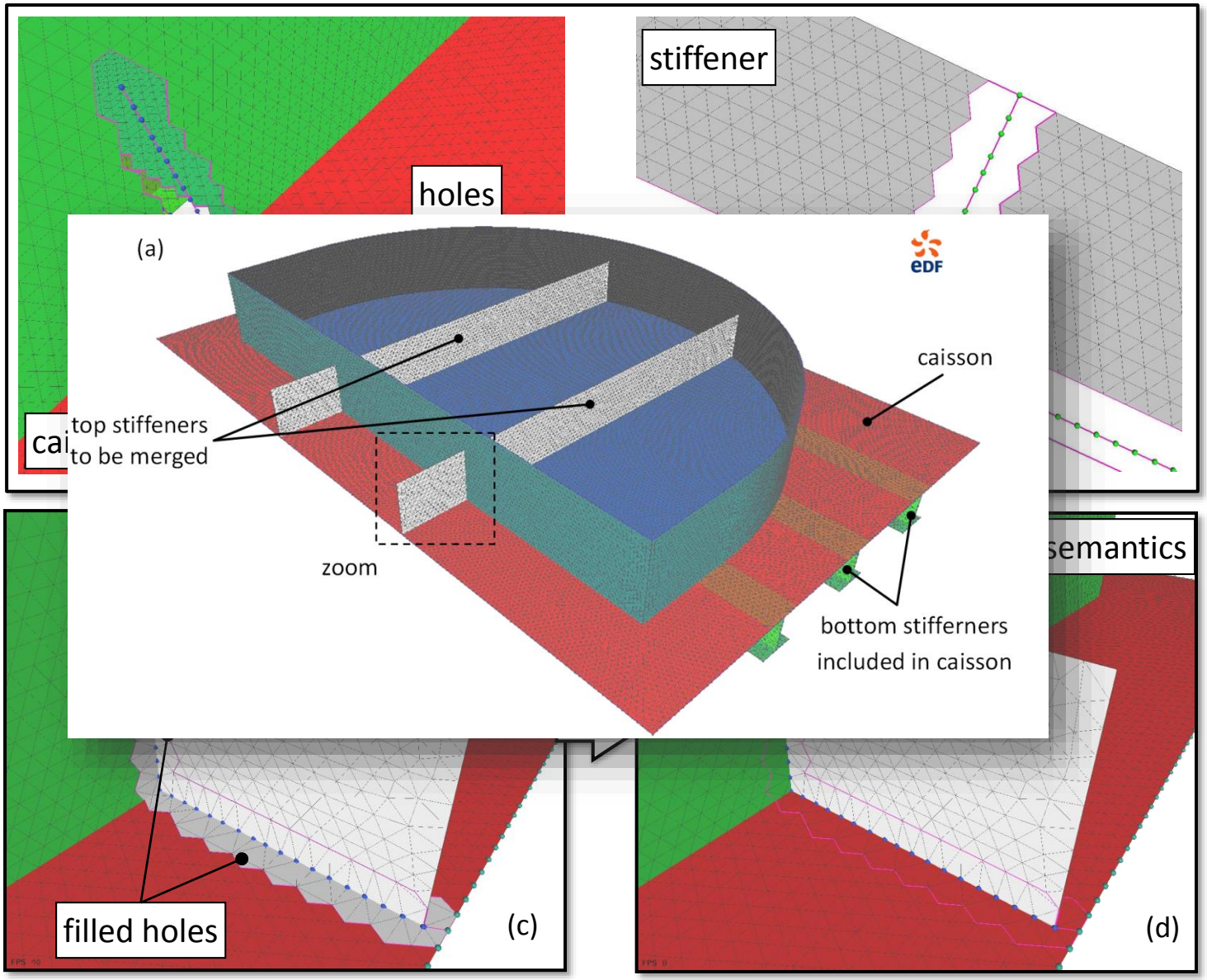


instance4: Filleting



CAD-less framework instance: mesh merging

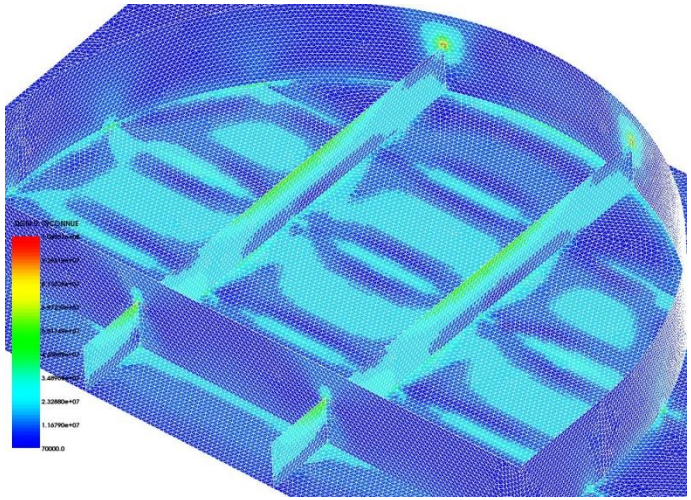
- Industry example



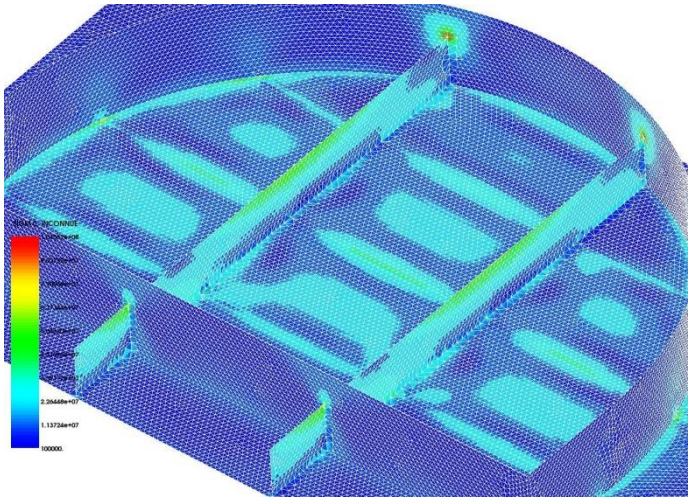
CAD-less framework instance: mesh merging

- Industry example – FEA performed on the CAISSON

Modification using CAD models



Produced by CAD-less approach

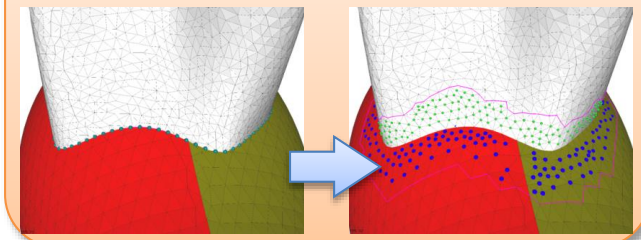


Numerical prototyping methods	Von Mises stress state (MPa)	
	σ_{max} on stiffeners (local stress)	σ_{max} on caisson wall
Using CAD models	137	78
CAD-less approach	127	77

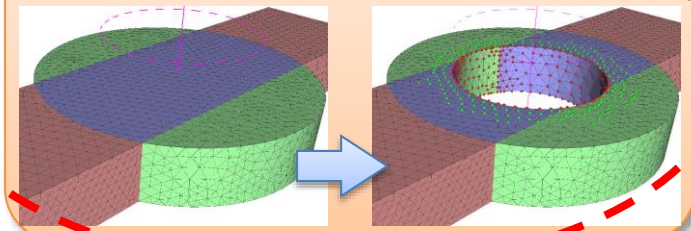
Images and data of SALOME®, courtesy EDF R&D

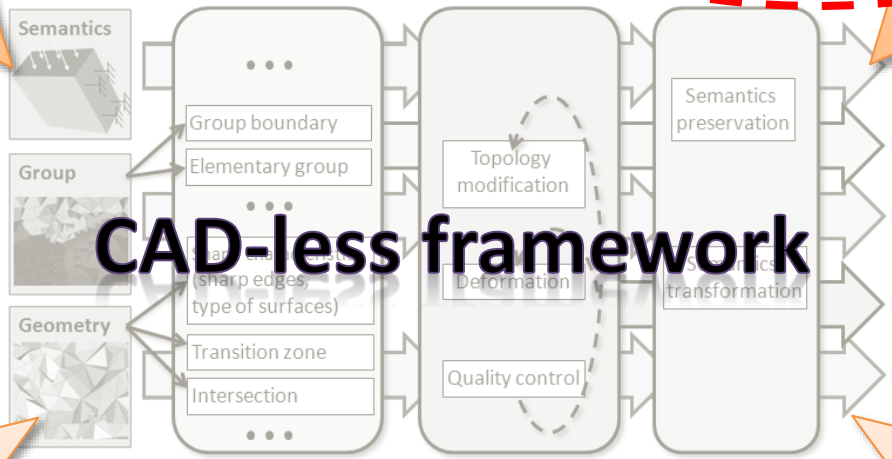
Prototyped instances of CAD-less framework

instance1: Merging

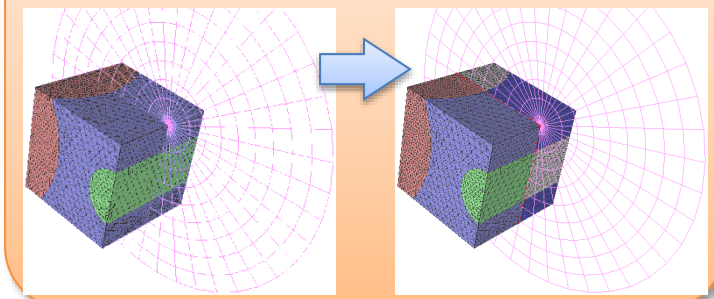


instance2: Drilling

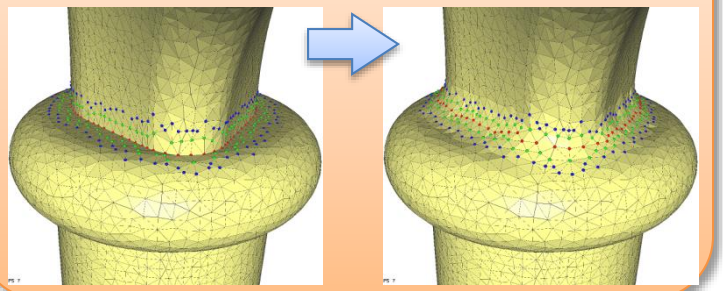




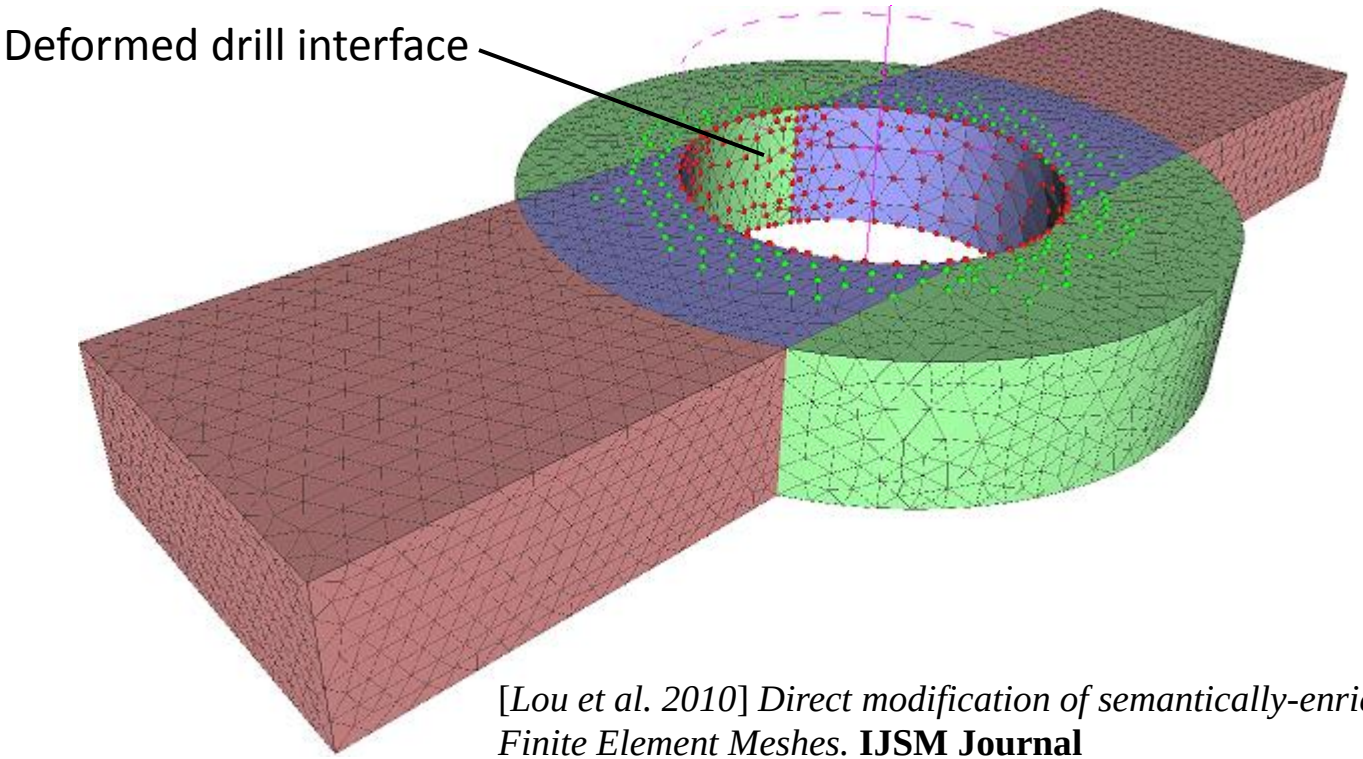
instance3: Cracking



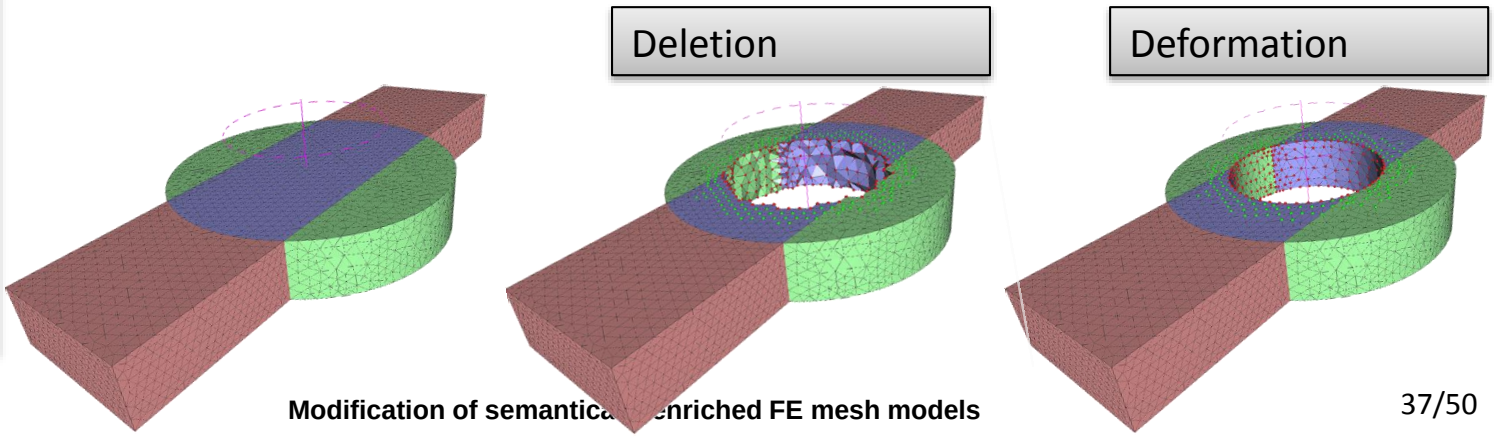
instance4: Filleting



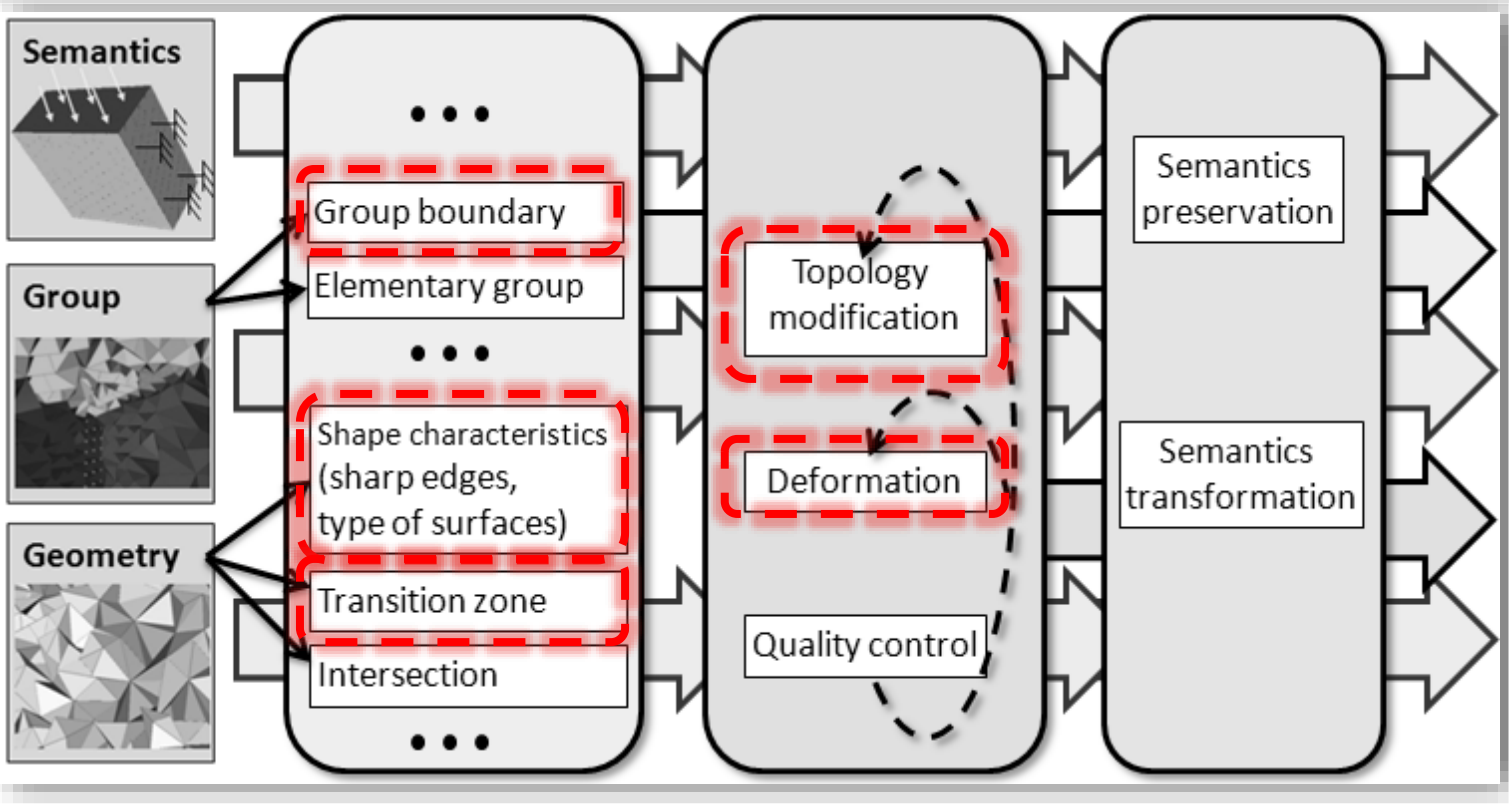
CAD-less framework instance: mesh drilling

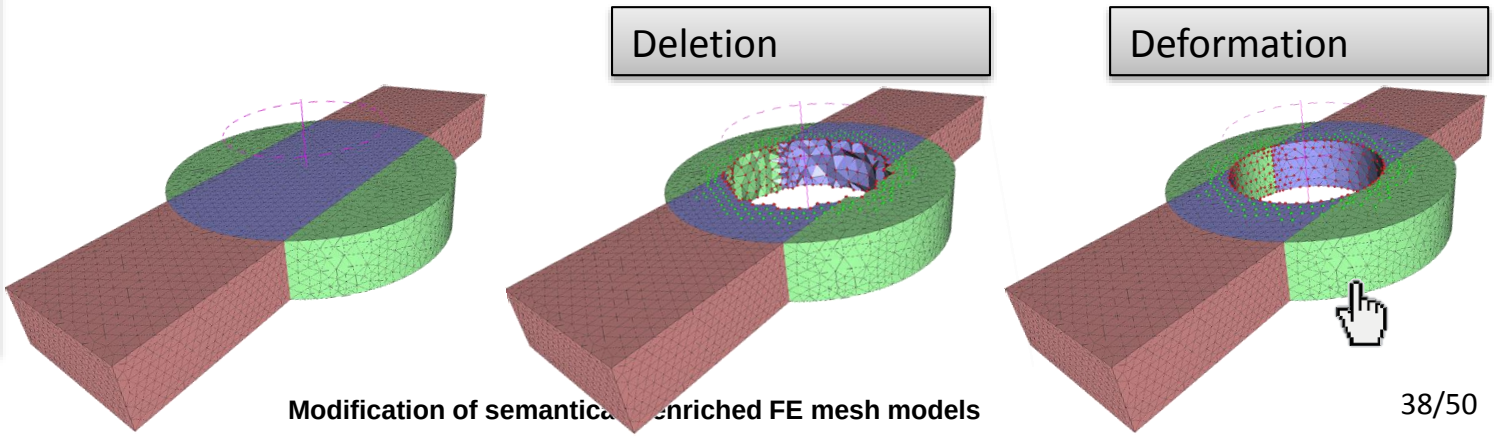


[*Lou et al. 2010*] *Direct modification of semantically-enriched Finite Element Meshes.* **IJSM Journal**



CAD-less framework instance: mesh drilling

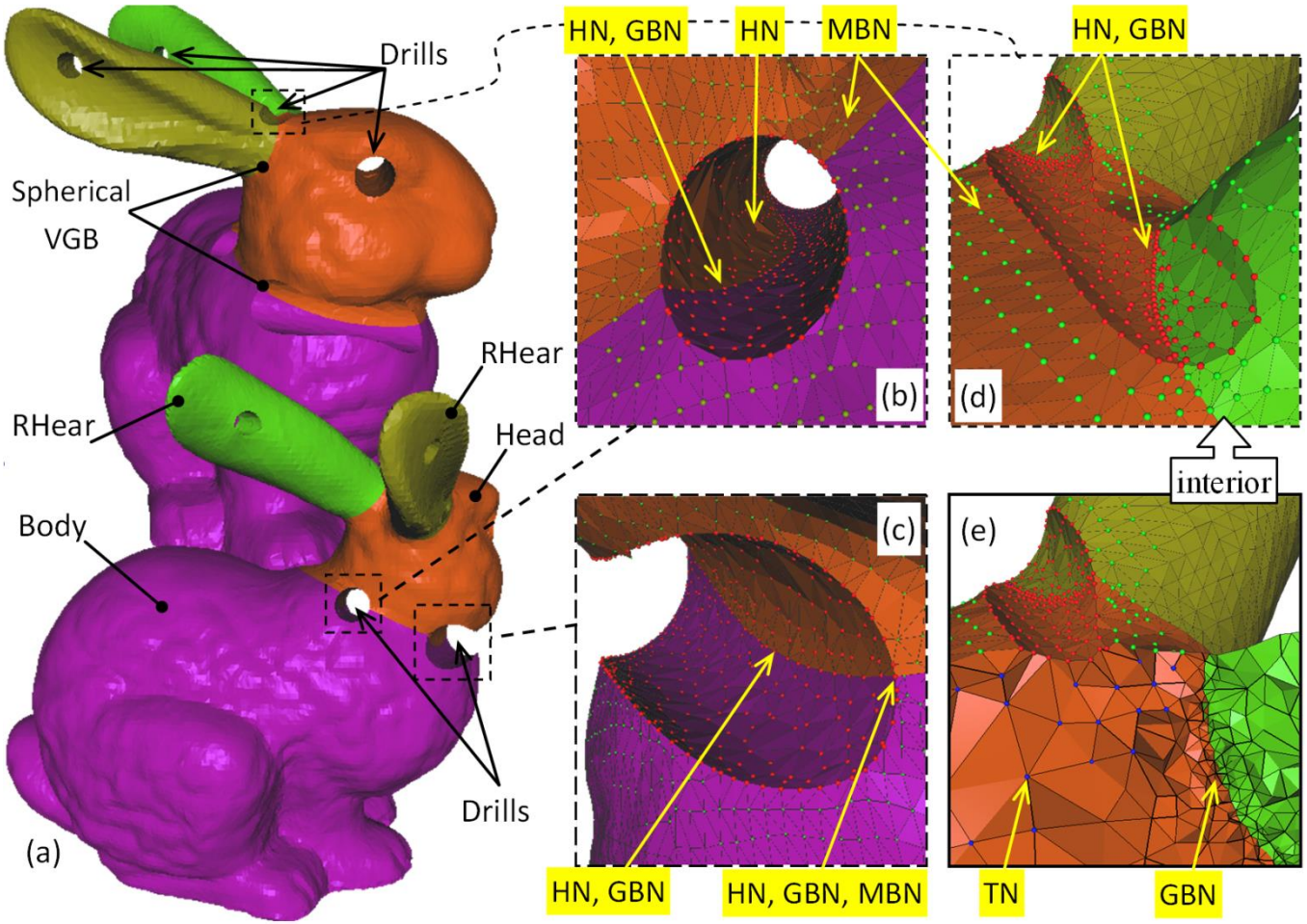




CAD-less framework instance: mesh drilling

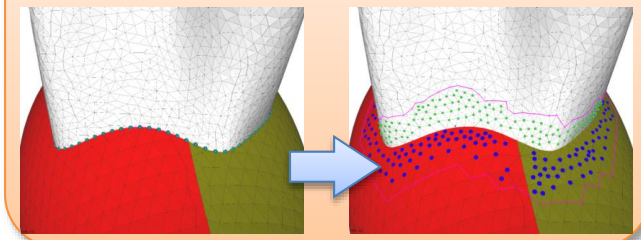
- Other examples

HN: hole node
GBN: group boundary node
MBN: model boundary node

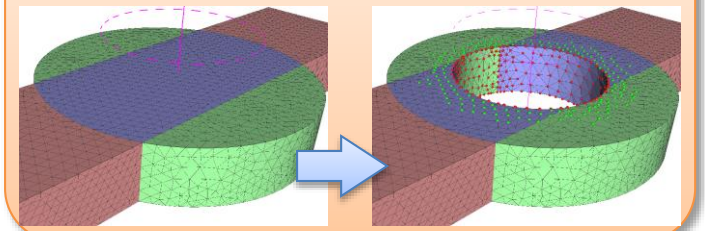


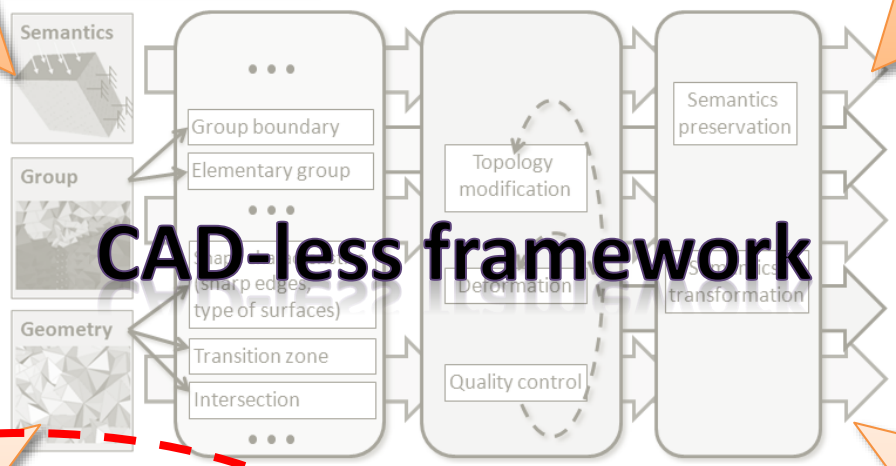
Prototyped instances of CAD-less framework

instance1: Merging



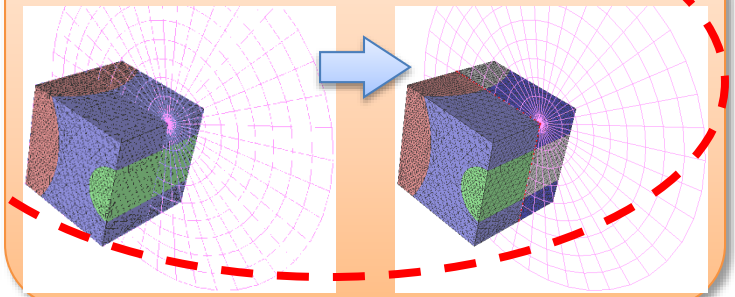
instance2: Drilling



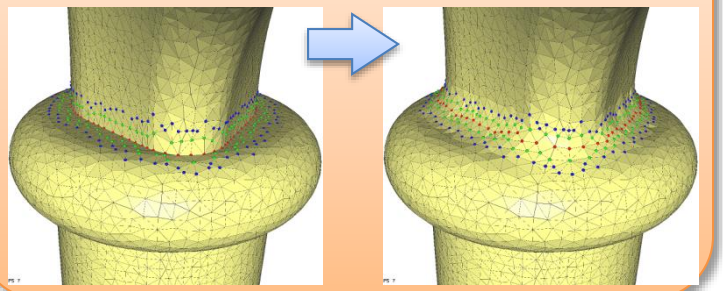


CAD-less framework

instance3: Cracking

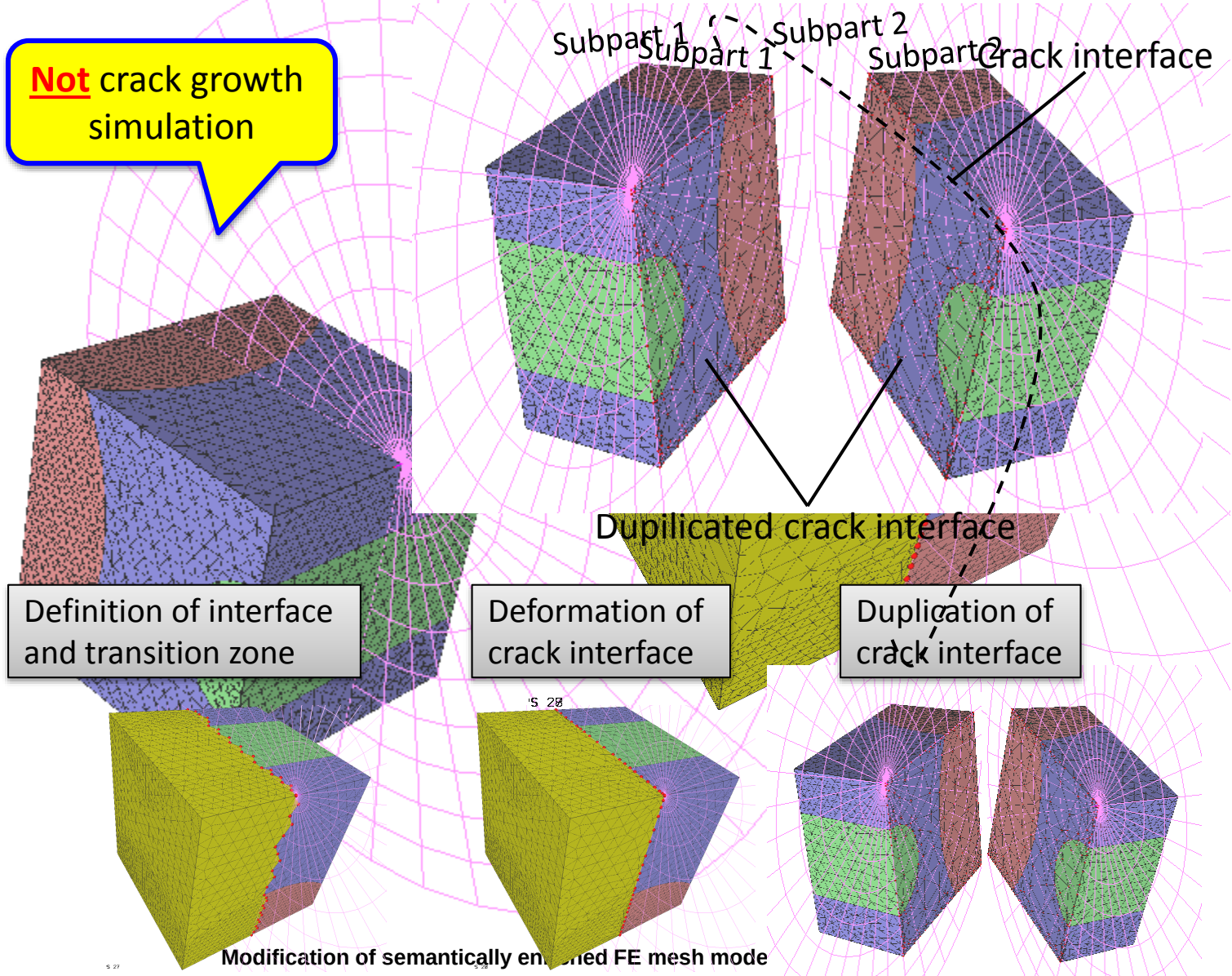


instance4: Filleting

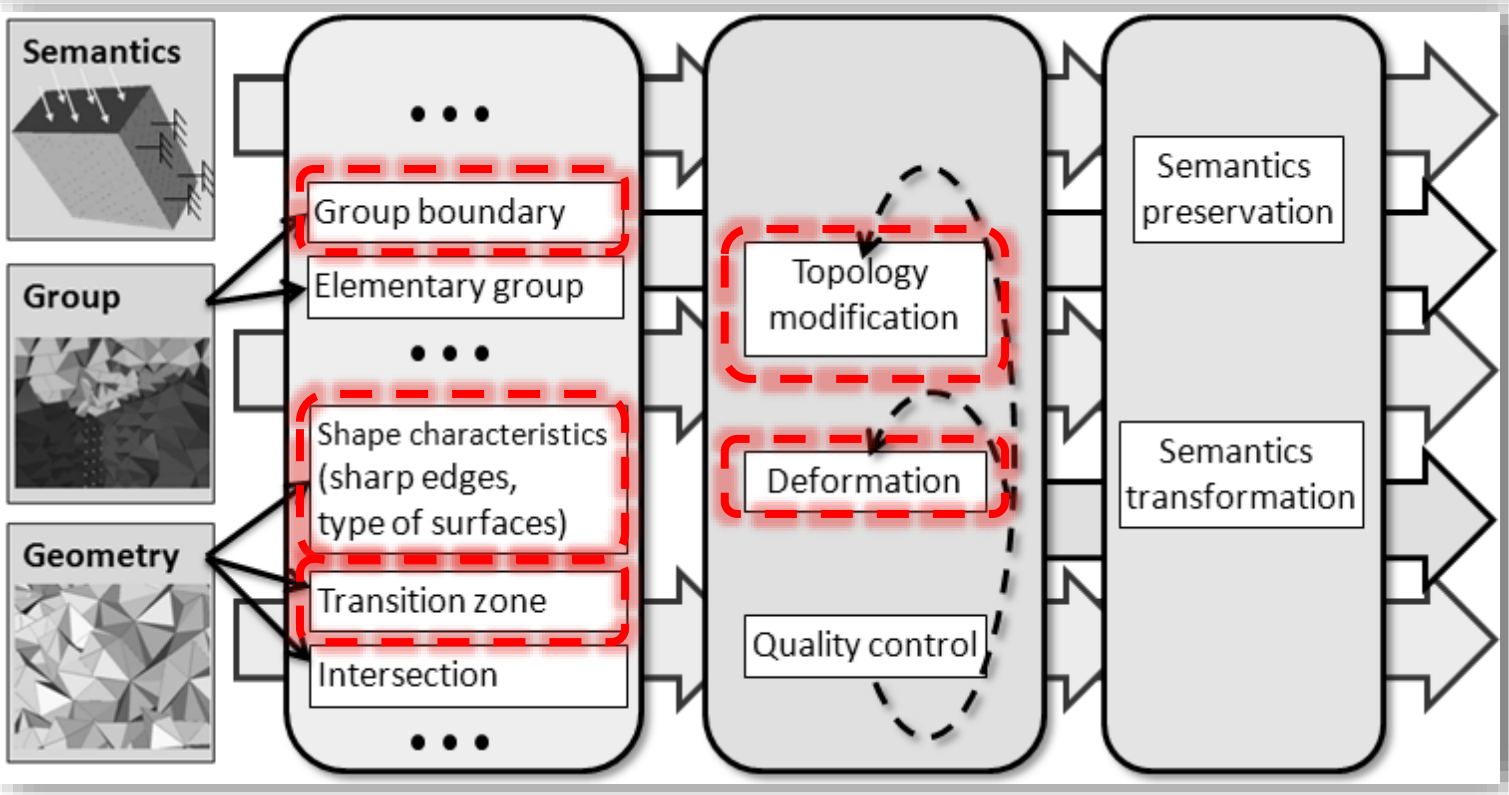


CAD-less framework instance: mesh cracking

[*Lou et al. 2010*] *Direct modification of semantically-enriched Finite Element Meshes.* **IJSM Journal**



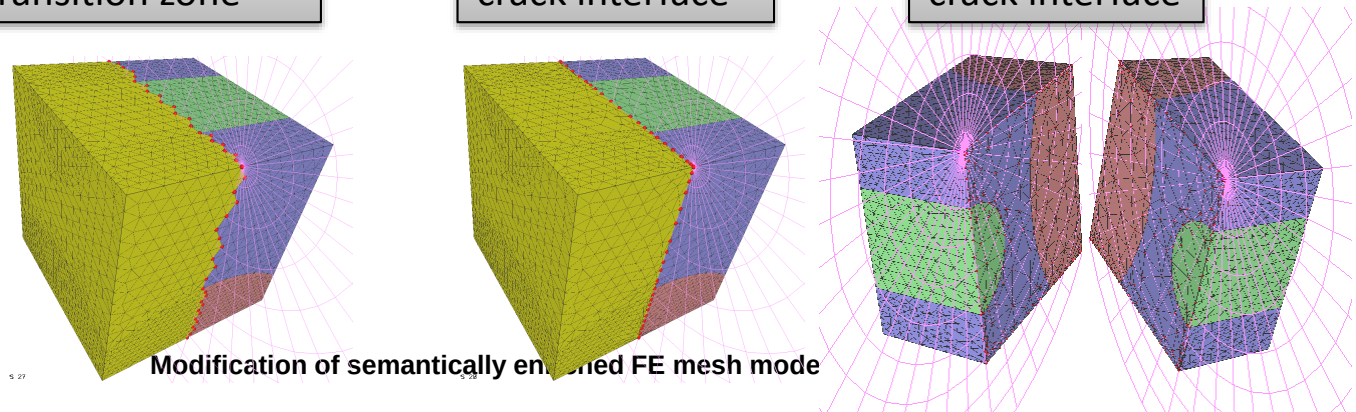
CAD-less framework instance: mesh cracking



Definition of interface and transition zone

Deformation of crack interface

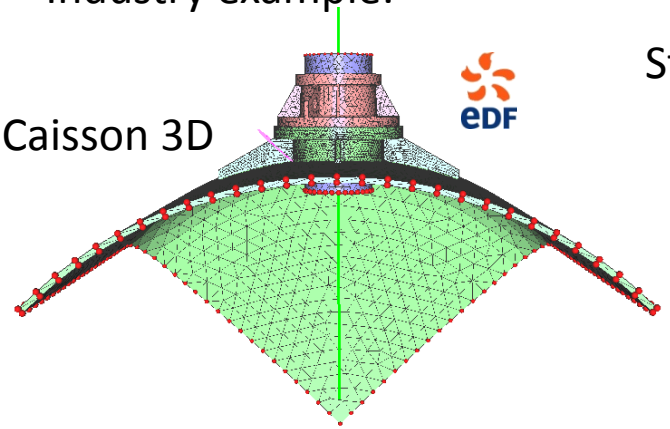
Duplication of crack interface

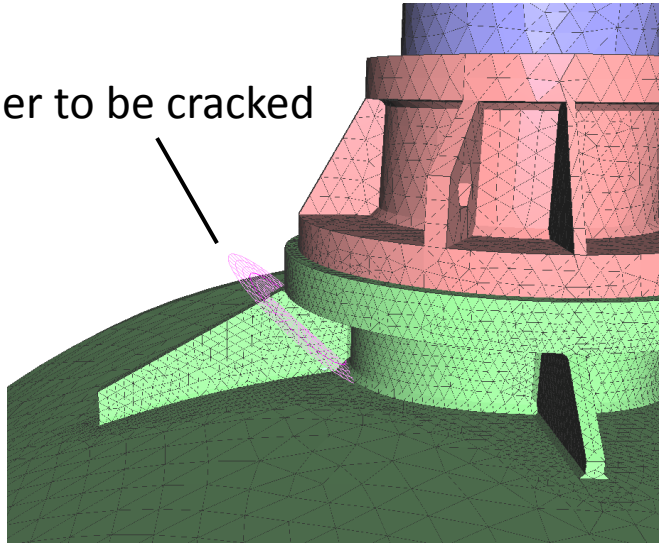


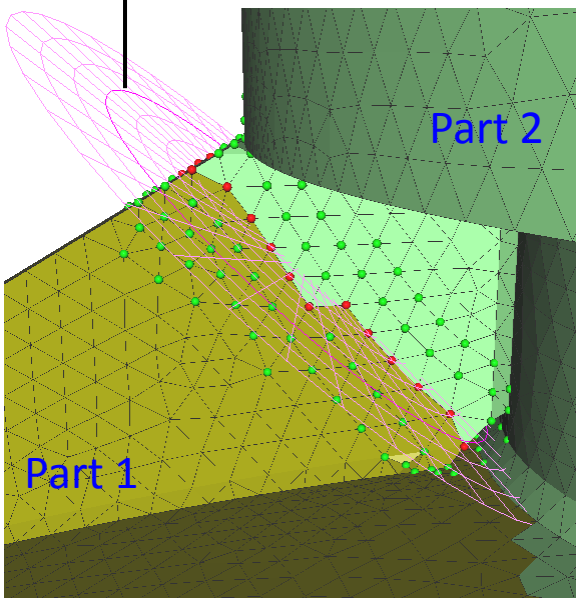
Modification of semantically en[illegible]ned FE mesh mode

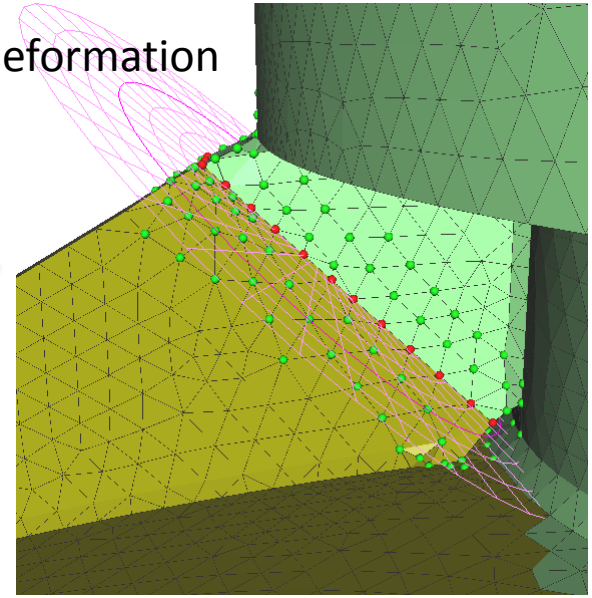
CAD-less framework instance: mesh cracking

- Industry example:



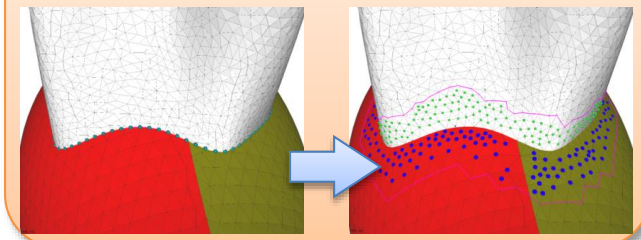




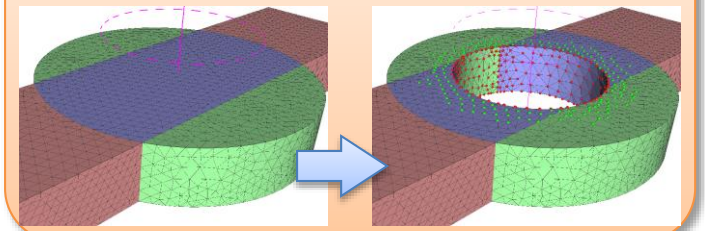


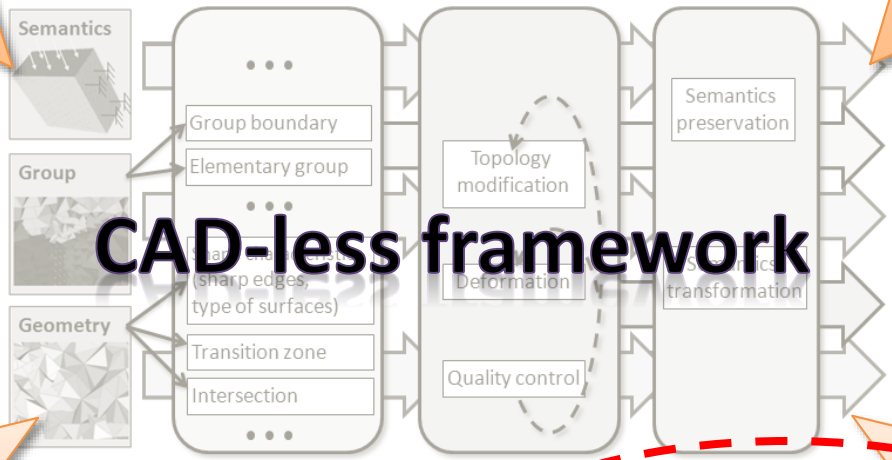
Prototyped instances of CAD-less framework

instance1: Merging

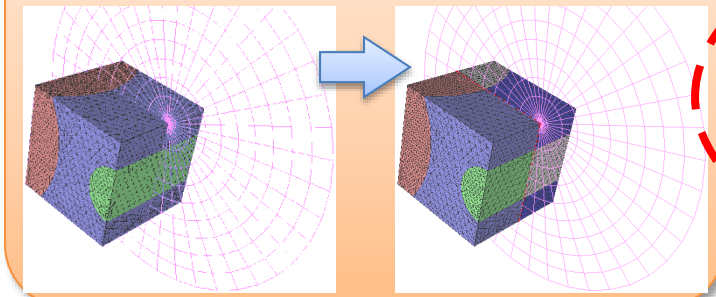


instance2: Drilling

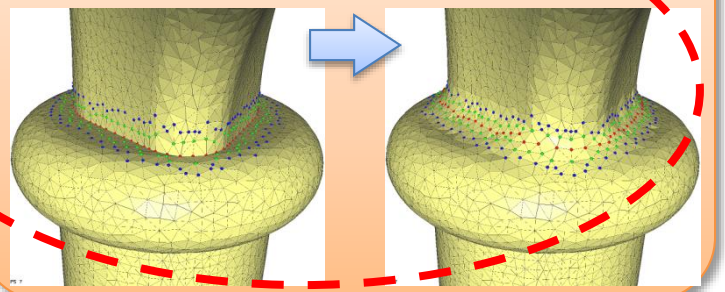




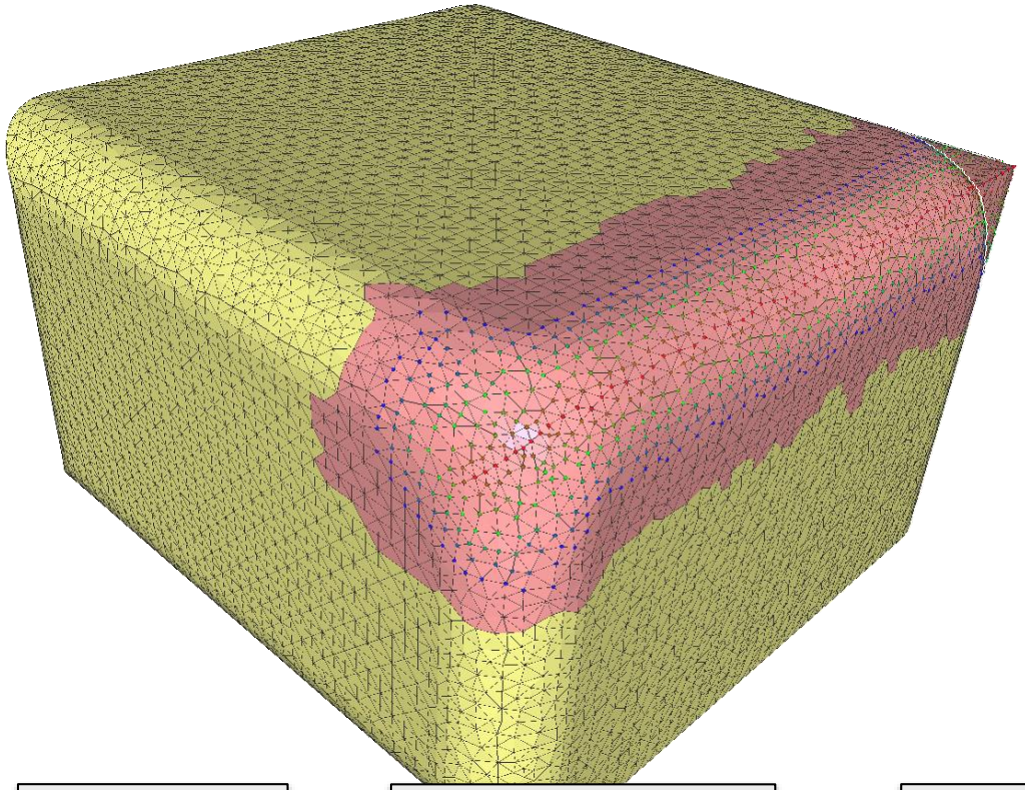
instance3: Cracking



instance4: Filleting



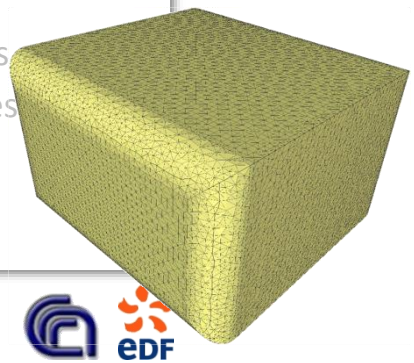
CAD-less framework instance: mesh filleting

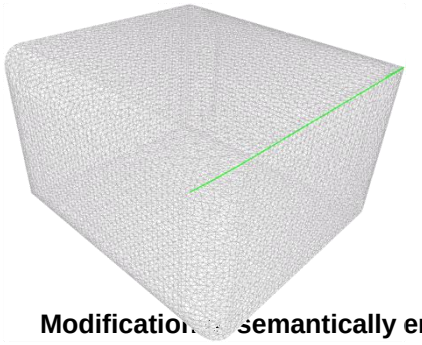


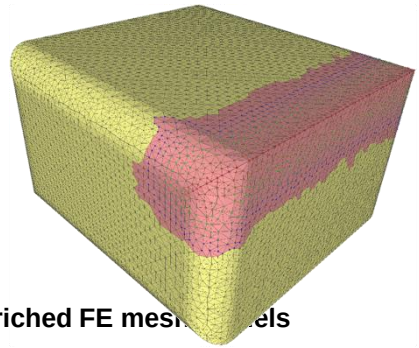
Sharp edges identification

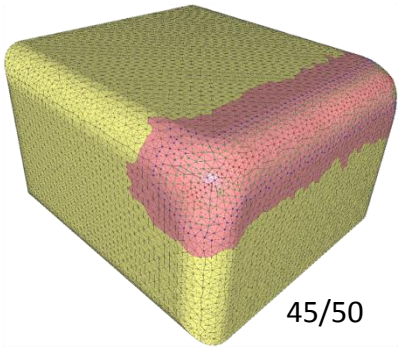
Filleting bandwidth definition

Filleting deformation

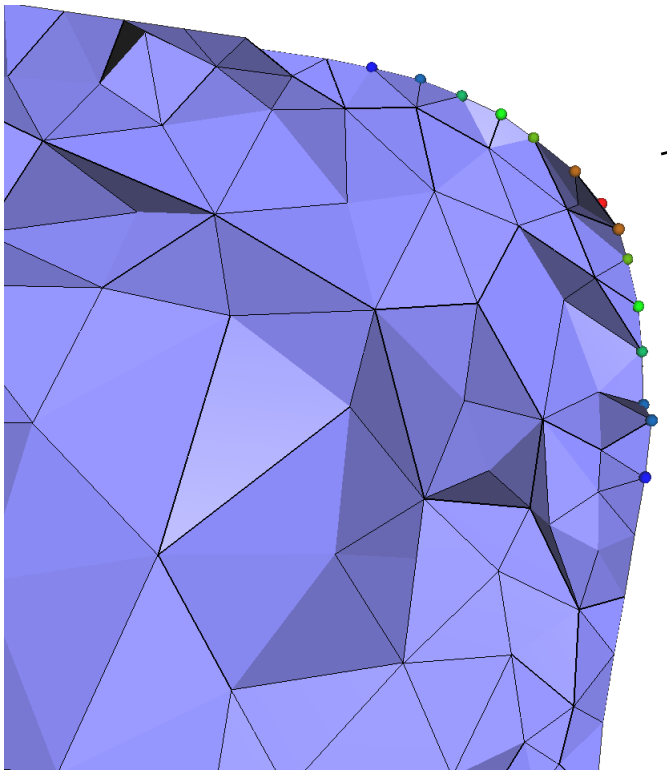








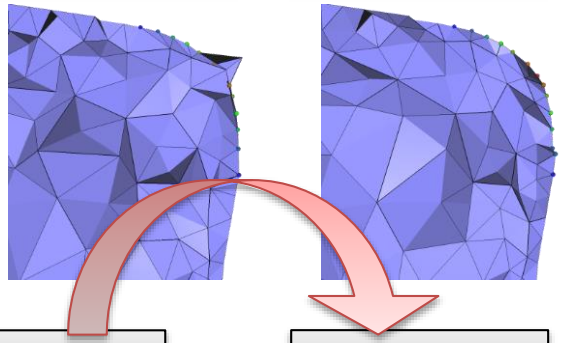
CAD-less framework instance: mesh filleting



Inversed internal tetrahedra

Surface deformation

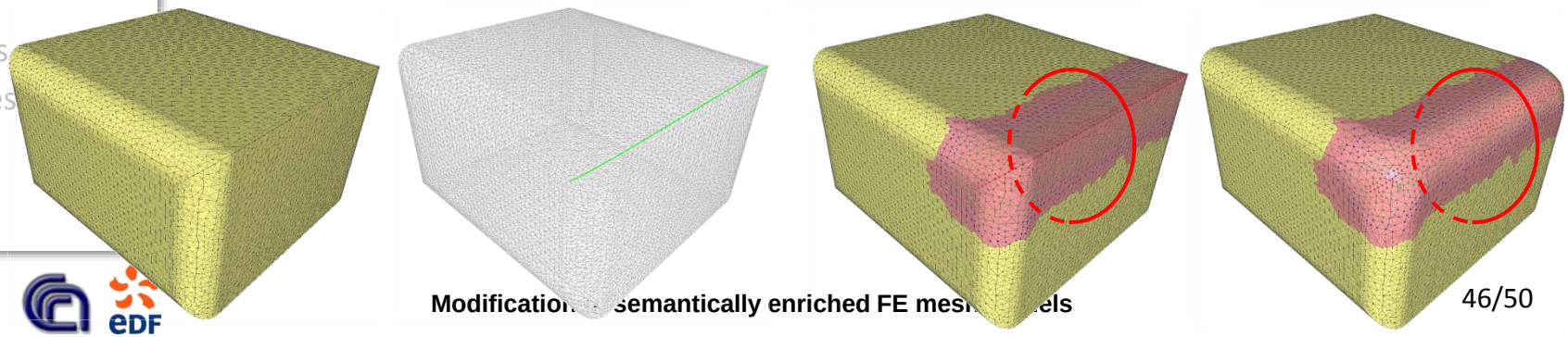
Volume deformation



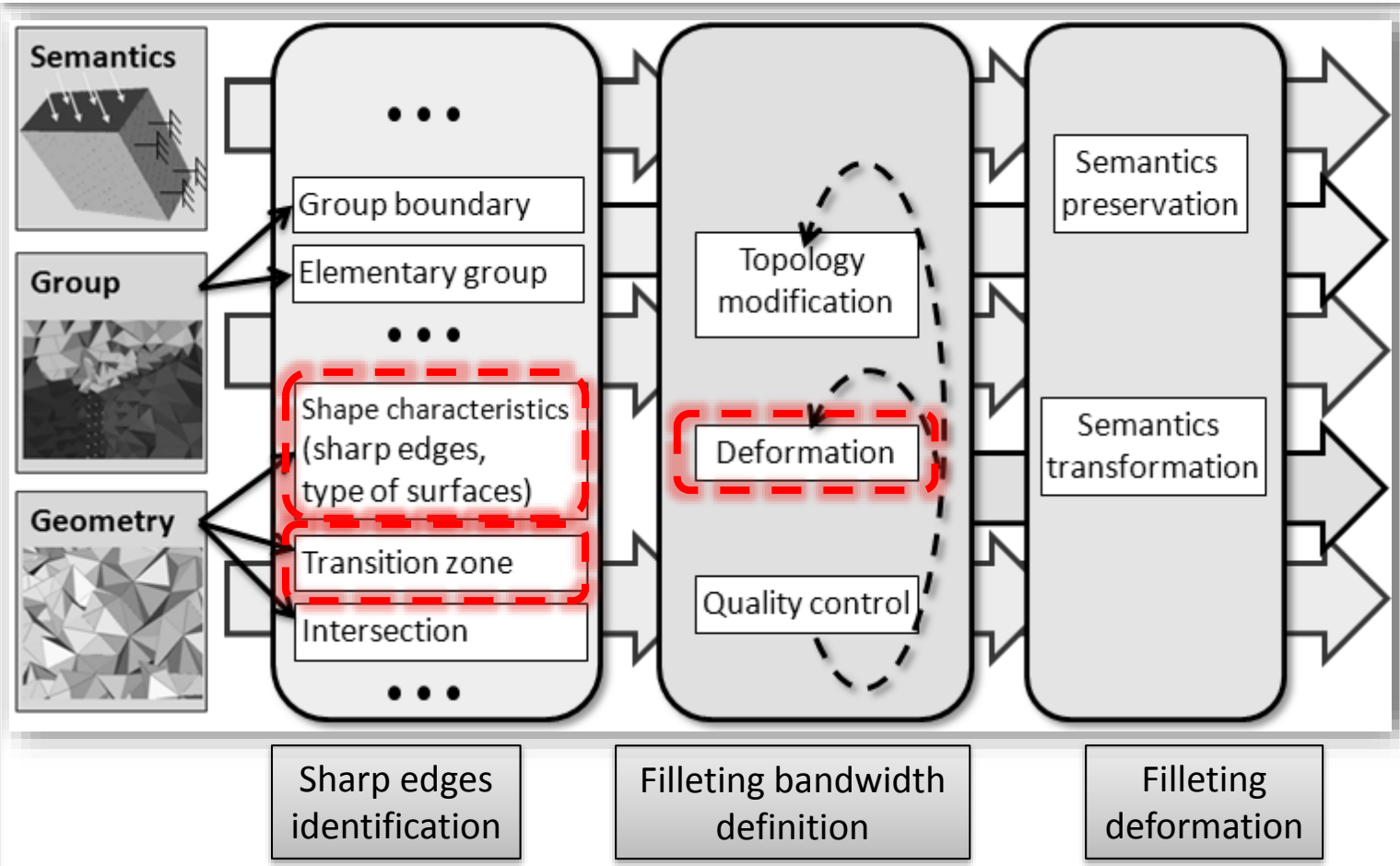
Sharp edges identification

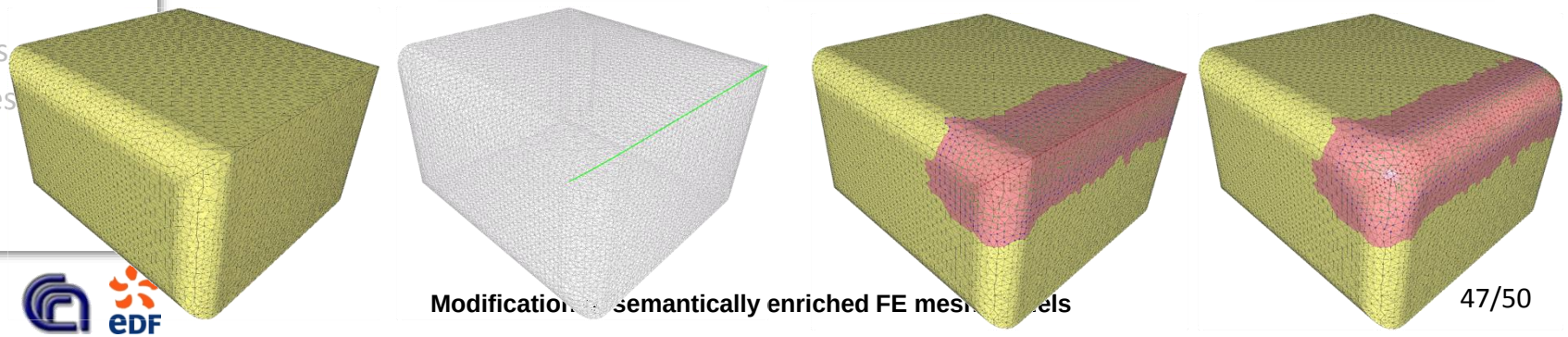
Filleting bandwidth definition

Filleting deformation

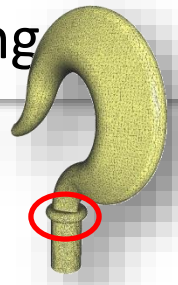


CAD-less framework instance: mesh filleting

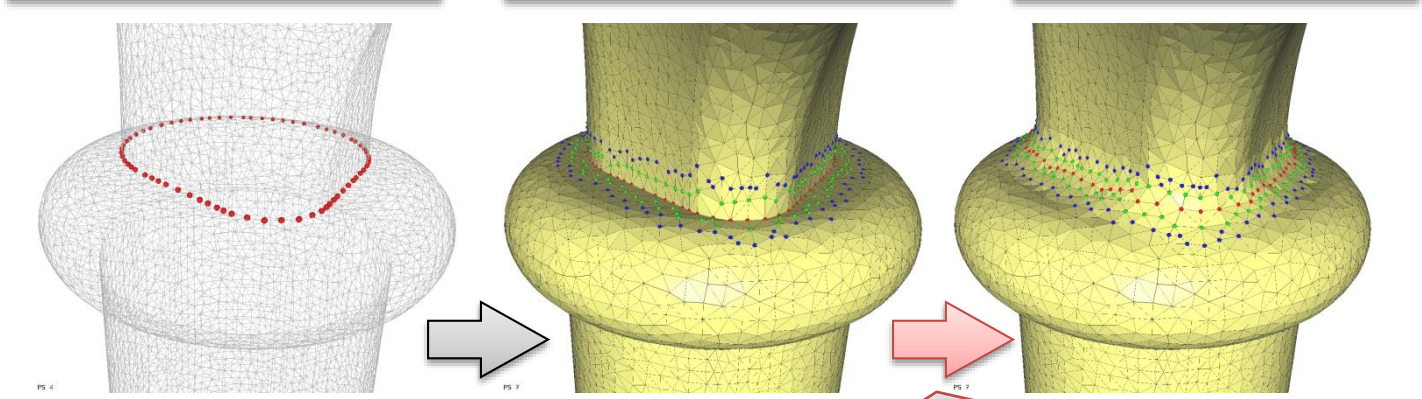


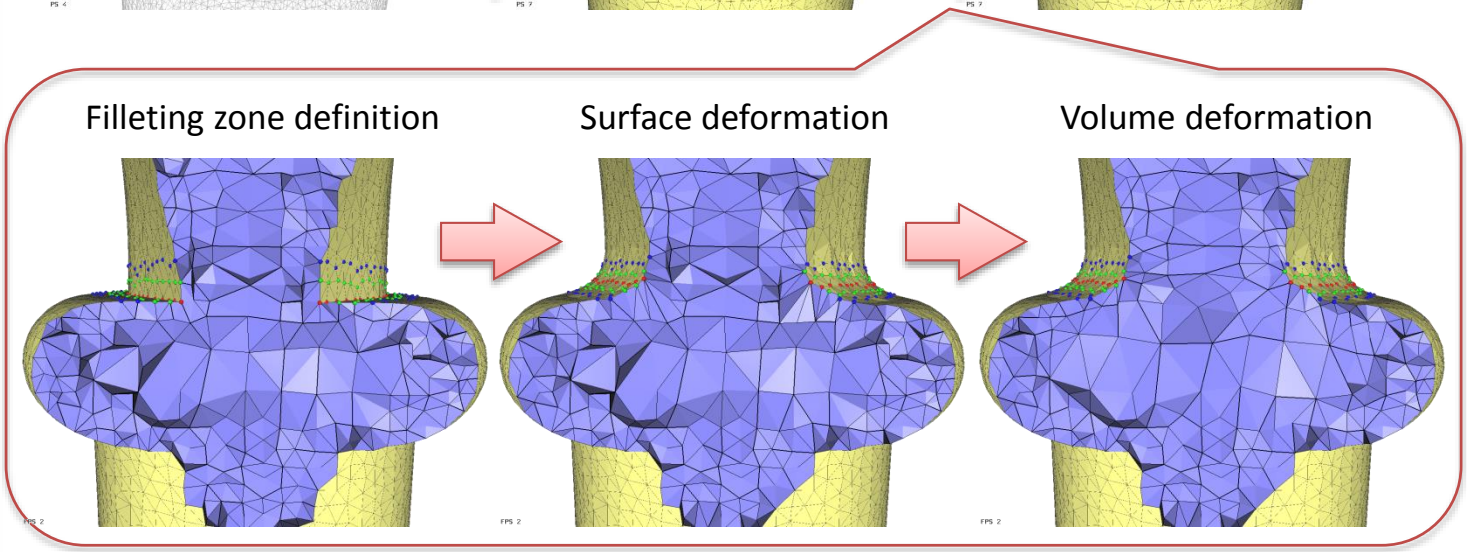


CAD-less framework instance: mesh filleting



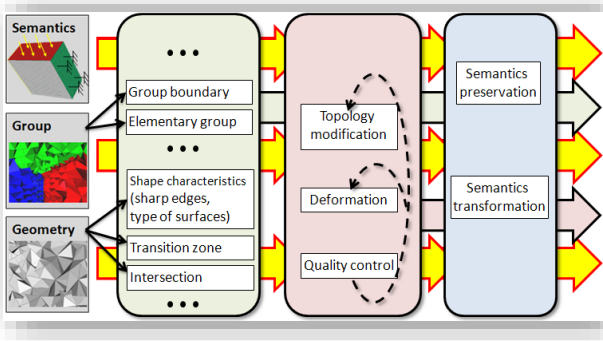
- Other examples of filleting: Hook



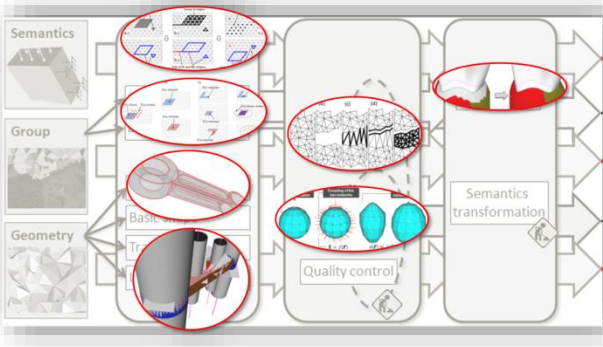


Conclusion of the contribution

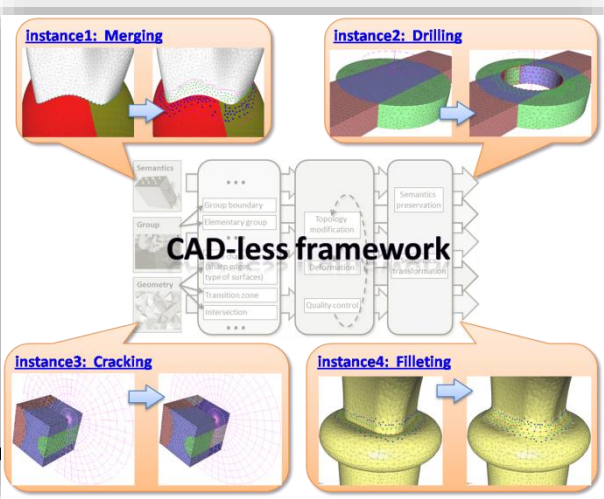
- A general framework of CAD-less operator is proposed in order to accelerate the FEA mesh models preparation.



- The framework is modular which gives a flexibility
- Methods, models and tools have been proposed and improved



- Four instances of the CAD-less operator are defined and prototyped.
- This work opens new research directions of semantically enriched mesh manipulation...



Perspectives and future works

- short-term future works
  - Treat specific configurations producing bad quality elements
- mean-term future works
  - Add new operators (chamfers, extrusion....)
  - Treat over-constrained configurations...
  - Work on the semantics processing, propagation and updating mechanisms...
- long-term future works from the thesis (open perspective)
  - Semantics-driven mesh simplification (Arts & Metiers ParisTech - Cluny)
  - Idealisation of semantically-enriched CAD model (EADS)
  - Images-driven semantically enriched FE mesh modification (from M. Panchetti PhD thesis)

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PARIS INSTITUTE OF TECHNOLOGY
ARTS ET MÉTIERS ParisTech

2011-ENAM-0017

Università degli Studi di Genova

Thanks very much
Questions ?

Ruding LOU

June 21st, 2011

Modification of semantically enriched FE mesh models

Application to the fast prototyping of alternative solutions in the context of industrial maintenance

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Professor, Arts et Métiers ParisTech

M. Jean-Philippe PERNOT
Associate Professor, Arts et Métiers ParisTech

Mme. Bianca FALCIDIENO
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Mme. Franca GIANNINI
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Laboratoire des **S**ciences
De l'**I**nformation et des **S**ystèmes

imati
Istituto di **M**atematica **A**pplicata e
Tecnologie **I**nformatiche di Genova

EDF
Électricité **d**e **F**rance
Recherche & Développement

THESIS

Annexe 1: Semantics enrichment on FE mesh of CAISSON

MESH

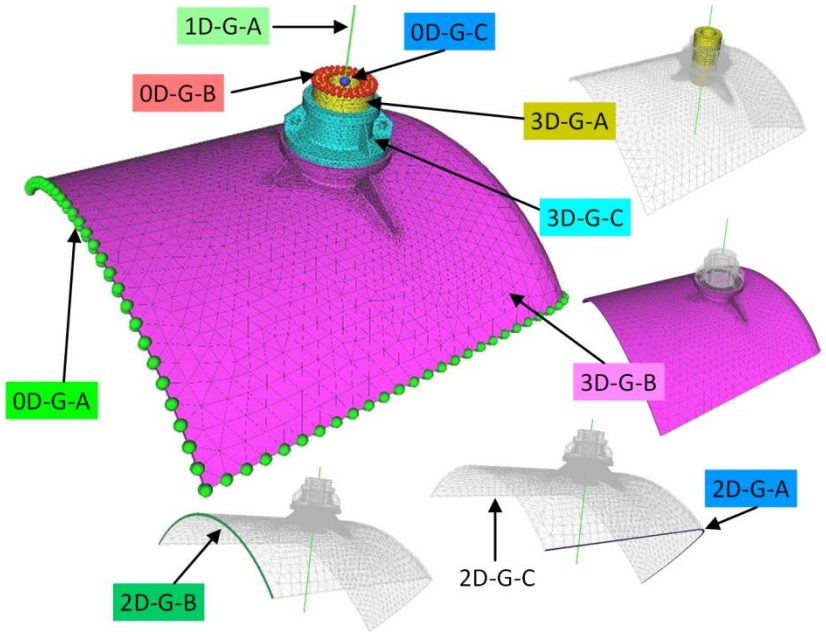
Grouping
mesh elements

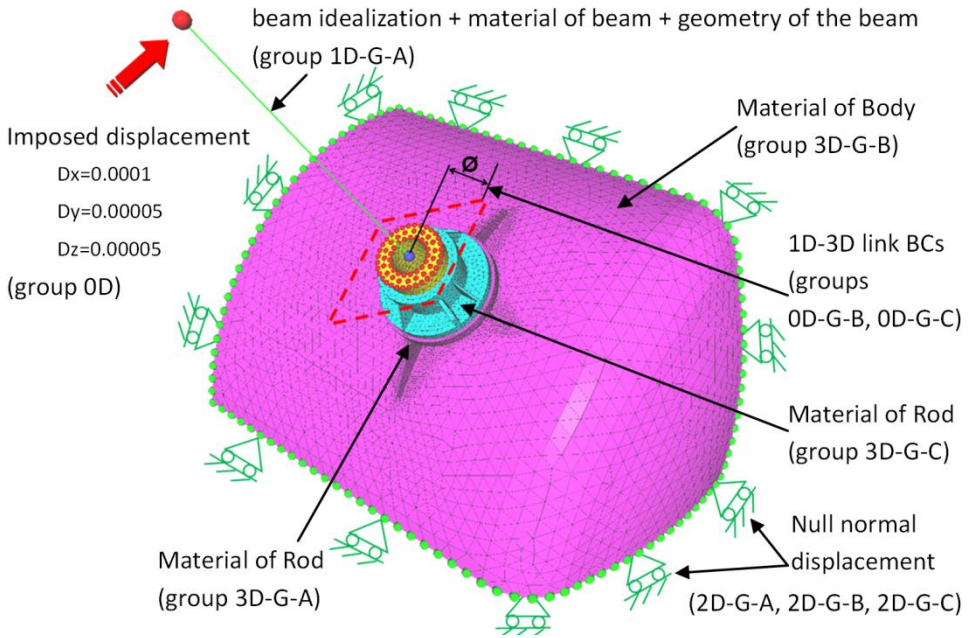
Creating and associating
semantics with groups

FEA

0D/1D/2D/3D **groups**
(set of geometric elements)

Physical / Geometrical **Semantics**
(Material, BCs, shape …)



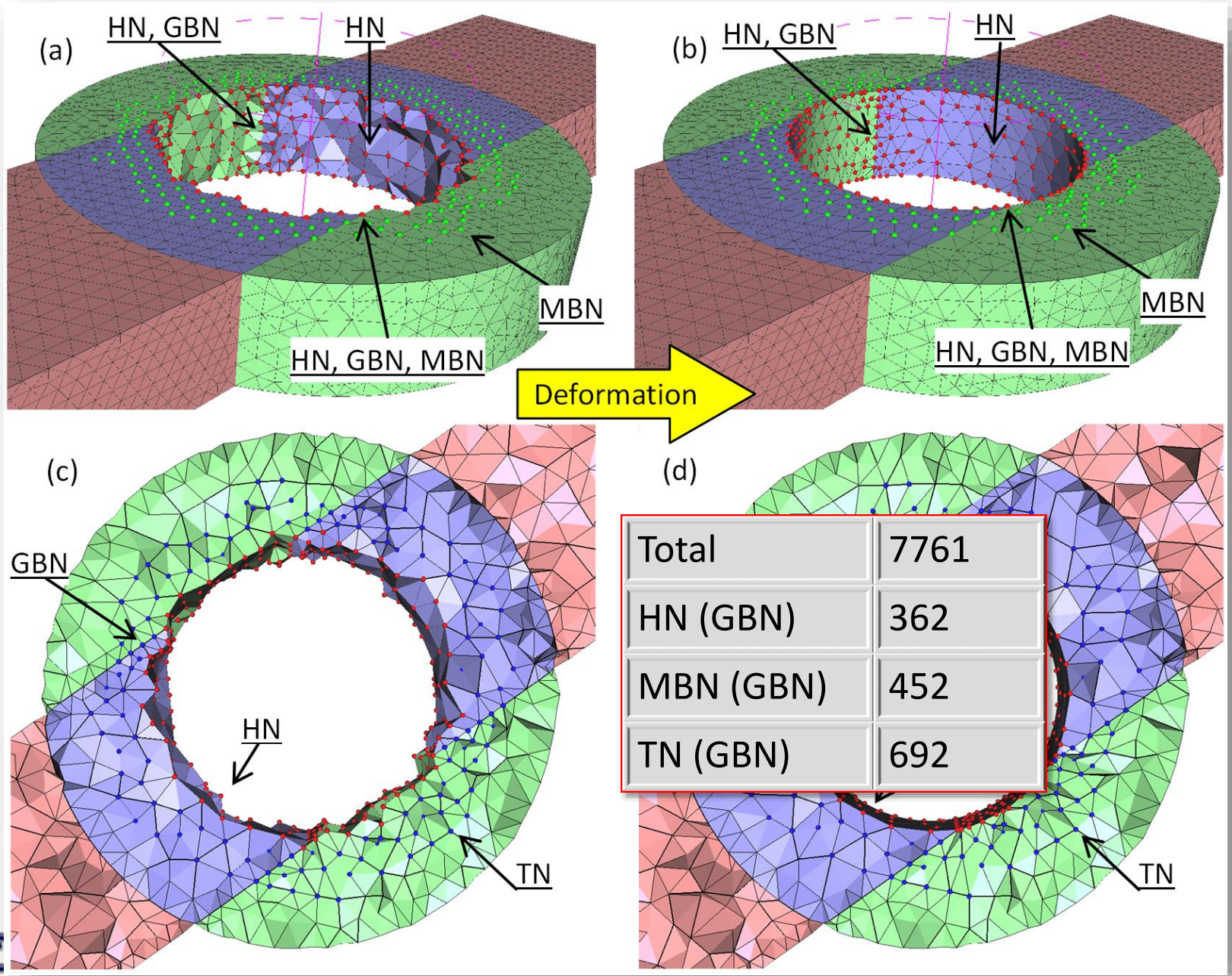


Annexe 2: Deformation constraints definition for mesh drilling

HN:
hole node

GBN:
group boundary node

MBN:
model boundary node



Total	7761
HN (GBN)	362
MBN (GBN)	452
TN (GBN)	692