CAPS COMPUTER AIDED PLASTIC SURGERY

IMETUM Zentralinstitut für Medizintechnik

Technische Universität München

Planning of Breast Reconstruction Surgery Using Autologous Tissue Based on Finite Element Modeling

(Finite Elemente Modellierung zur Planung von Brustrekonstruktionen nach Tumorentfernungen mit körpereigenen Weichgewebstransplantaten)

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Funded by: Federal Ministry of Economics and Technology

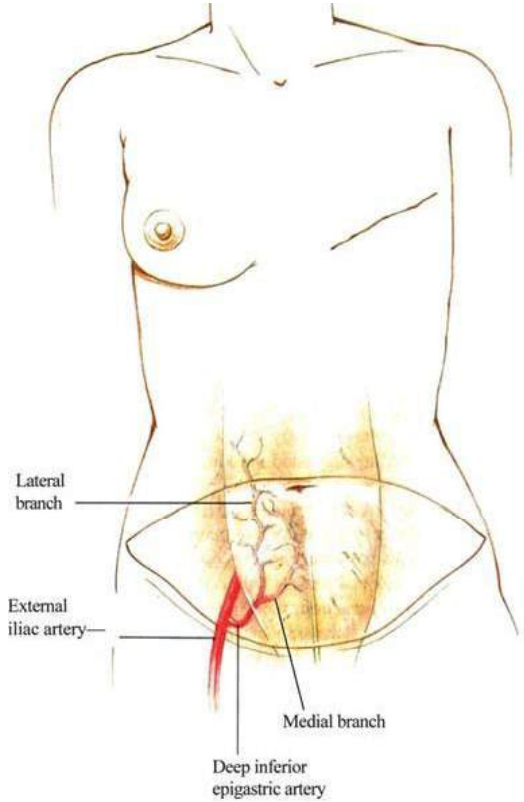
ANSYS Conference & 31th CADFEM Users' Meeting 2013
Juni 19-21, 2013 – Rosengarten Mannheim

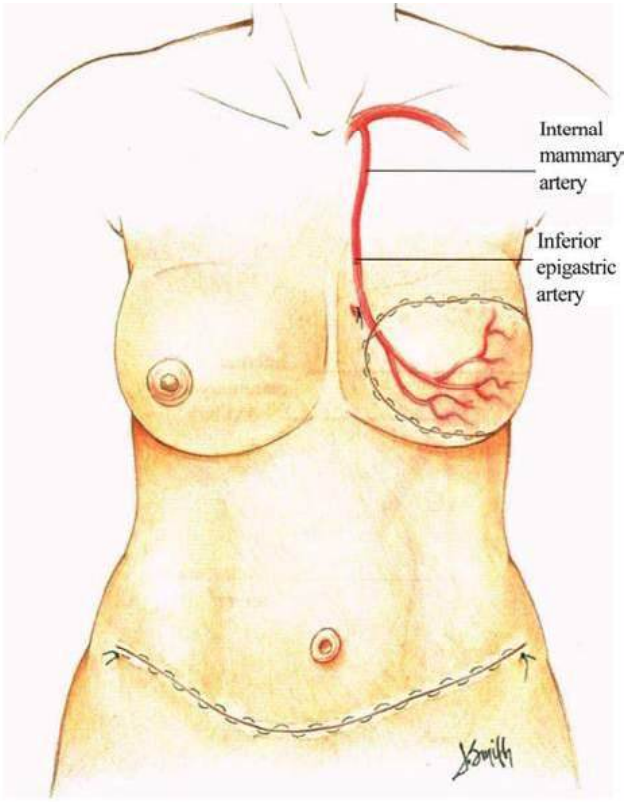
Motivation

Breast cancer is the most common cancer in women

Goal of project: planning aids for the surgeons to rebuild the natural shape of the breast mound in order to regain symmetry after mastectomy

Breast reconstruction surgery using autologous tissue

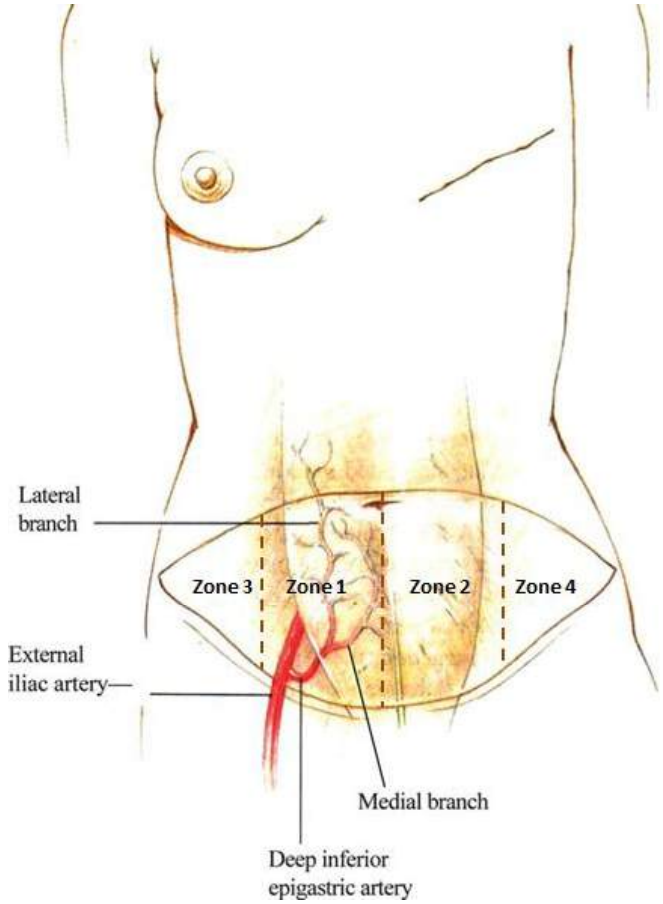




One of the most popular methods is using the soft tissue flap from the abdominal region such as deep inferior epigastric artery perforator flap (DIEP).

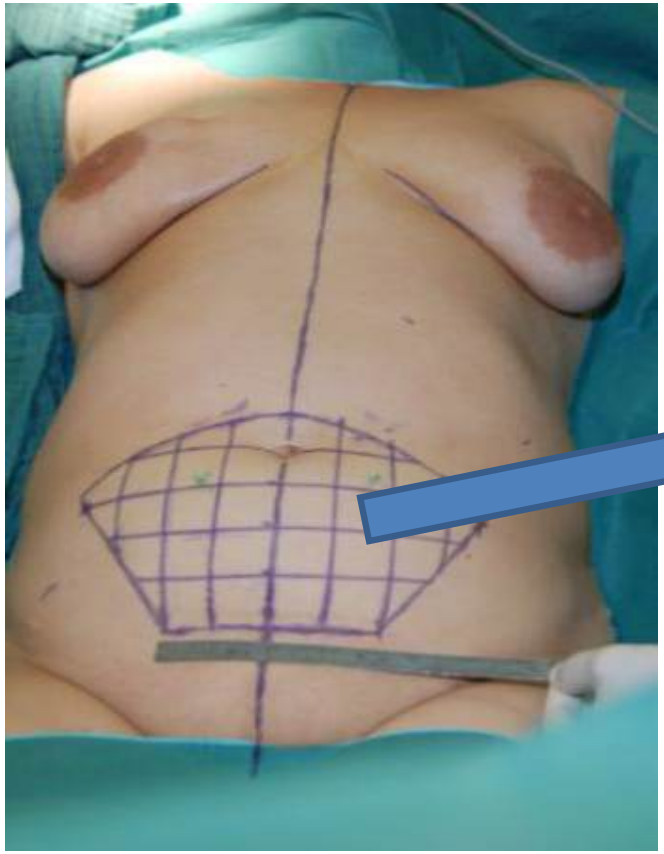
Granzow J. W. et al., (2006): "Breast reconstruction with the deep inferior epigastric perforator flap: history and an update on current technique", J Plast Reconstr Aesthet Surg., Vlo.59, No.6, pp.571-579.

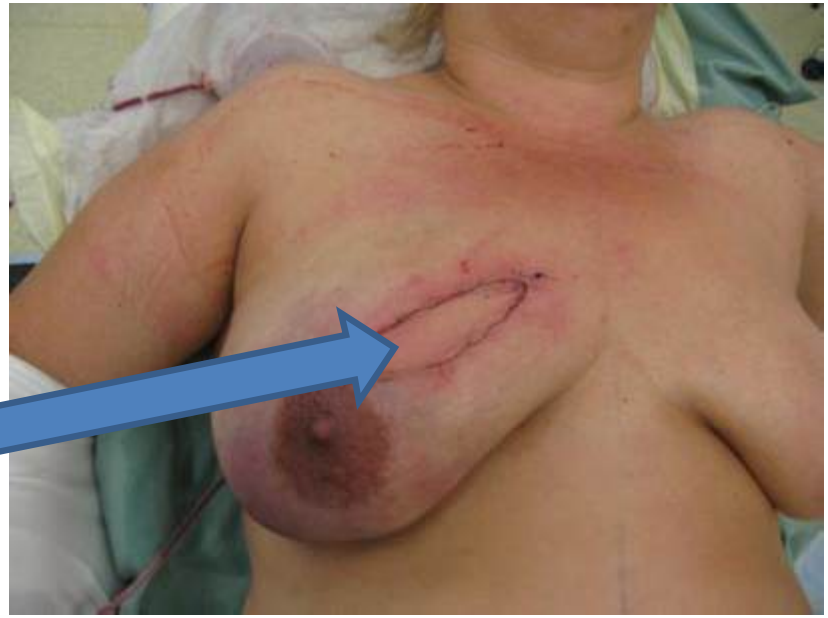
Breast reconstruction surgery using autologous tissue



Different zones on Flap area. The best parts of free flap for reconstructing the breast is Zone 1 and worth part is zone 4 (far from artery).

Breast reconstruction surgery using autologous tissue -primary breast reconstruction

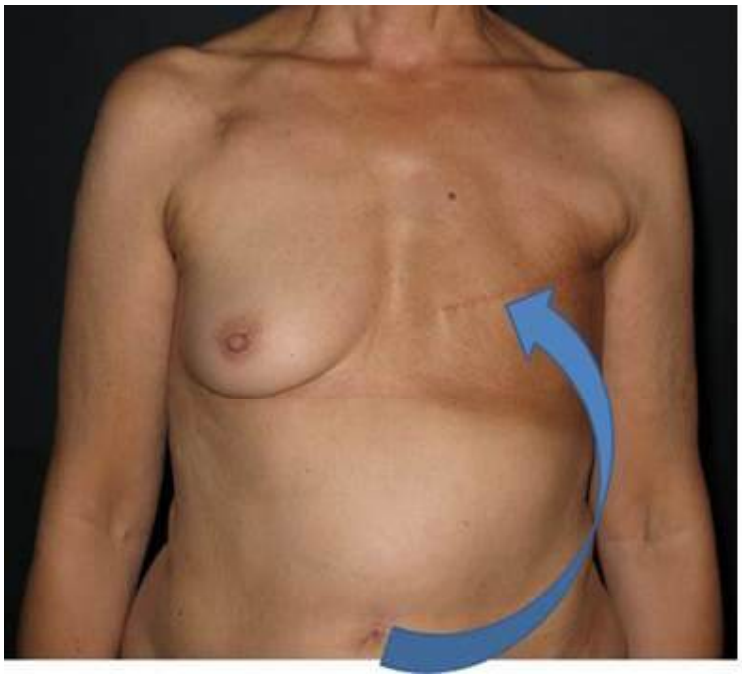




Harvested flap (DIEP) transplanted to chest (the skin is healthy)

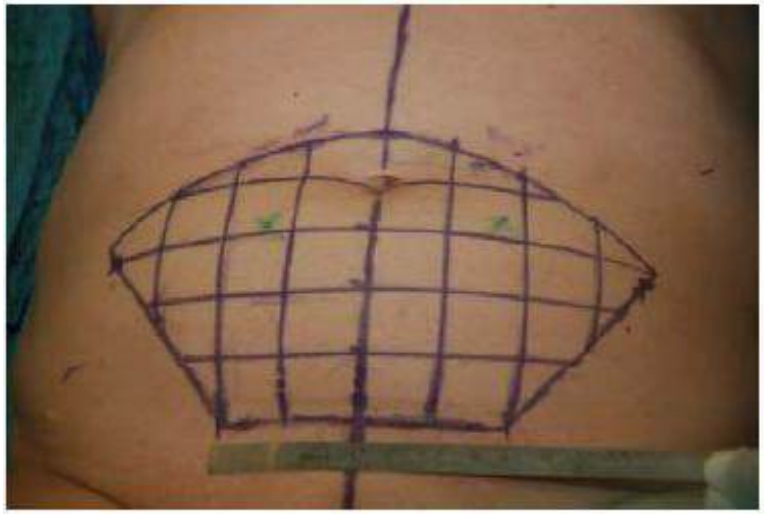
Primary or immediately breast reconstruction
Mastectomy and reconstructing the breast is at the same time

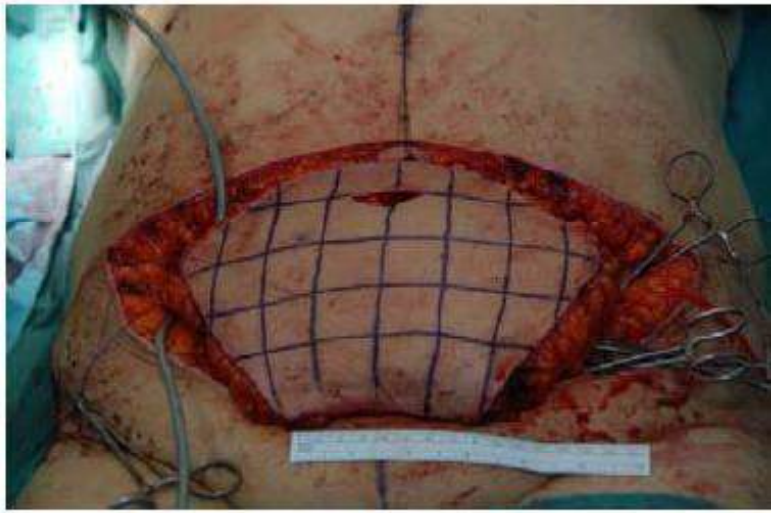
Breast reconstruction surgery using autologous tissue -secondary breast reconstruction

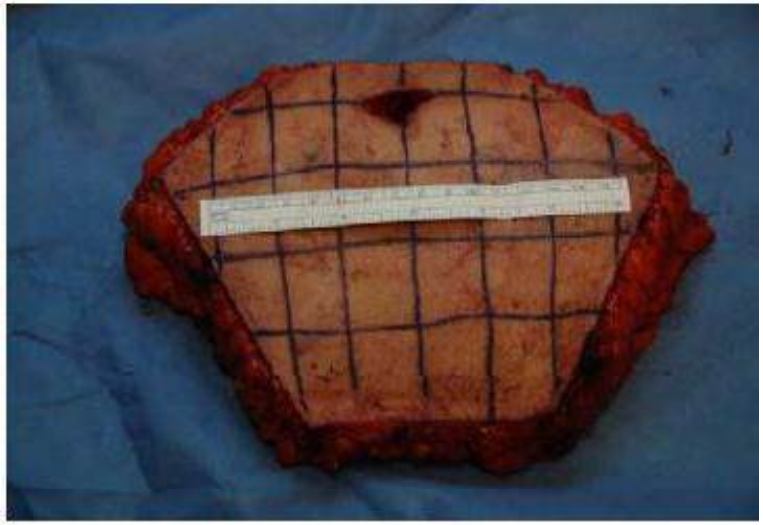


Secondary or delayed breast reconstruction
Mastectomy and reconstructing the breast is not at the same time
We concentrate on this type of breast reconstruction

Breast reconstruction surgery using autologous tissue

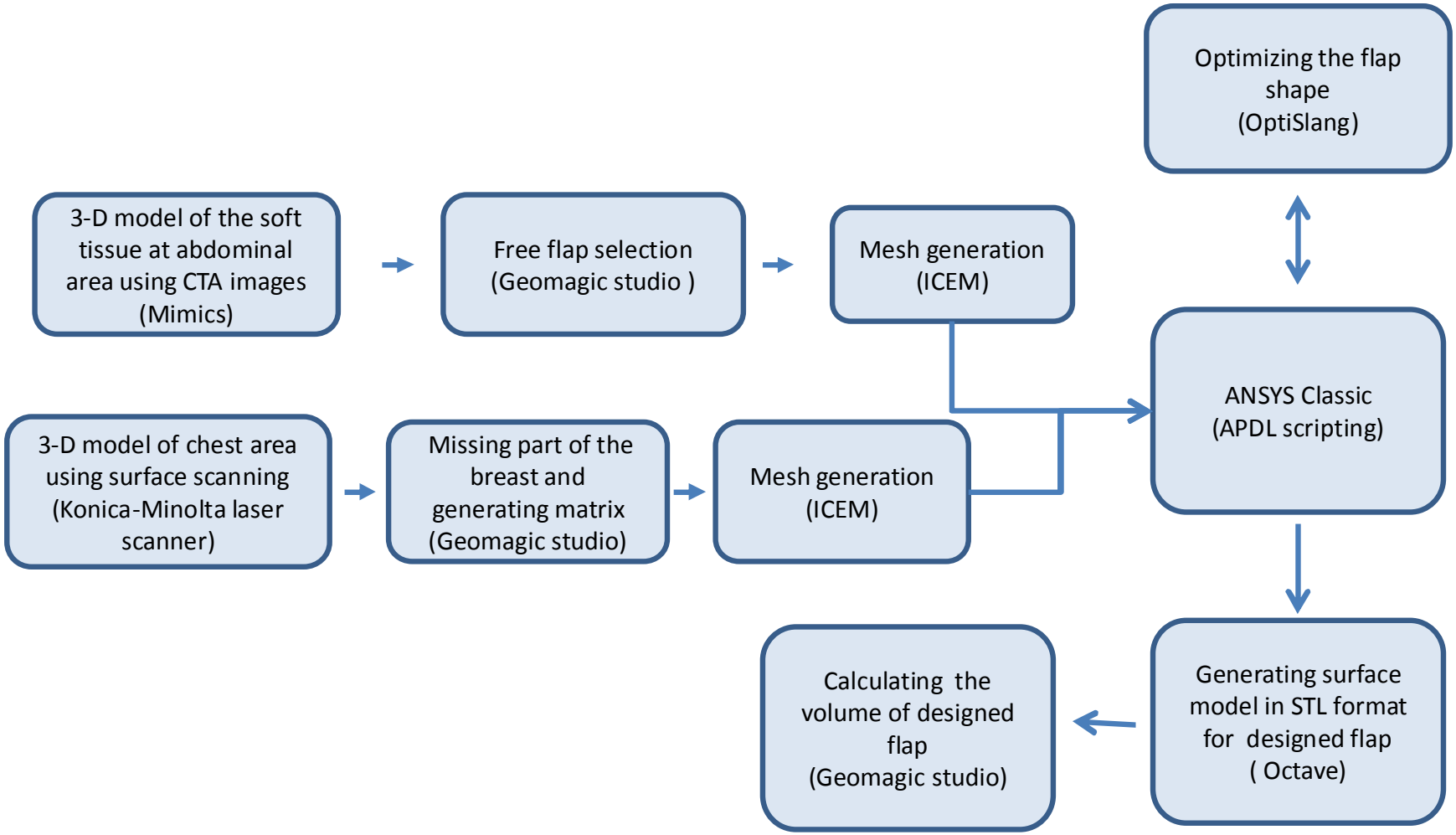




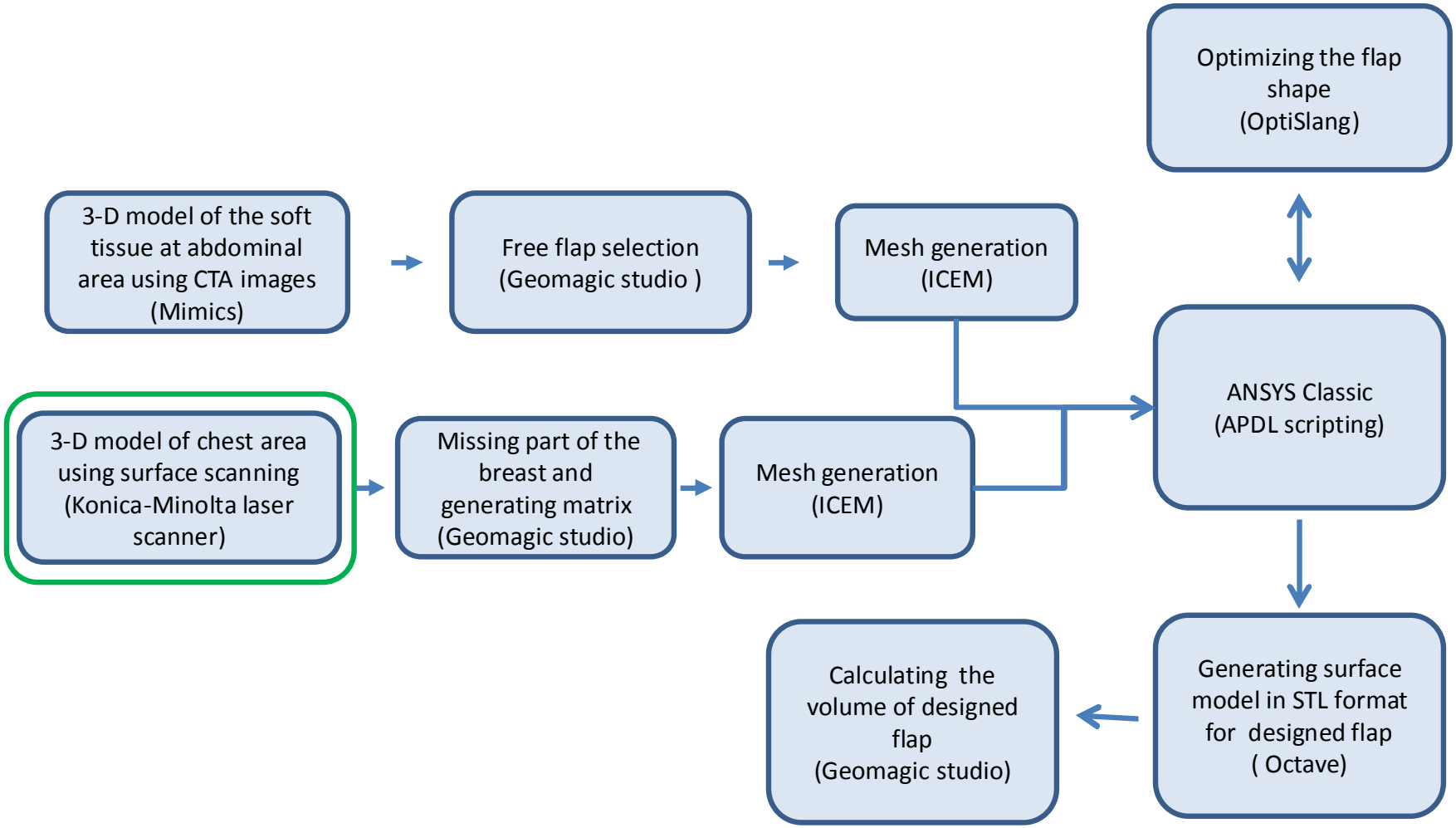


The shape and size of the transplanted flap is a challenge for surgeons.

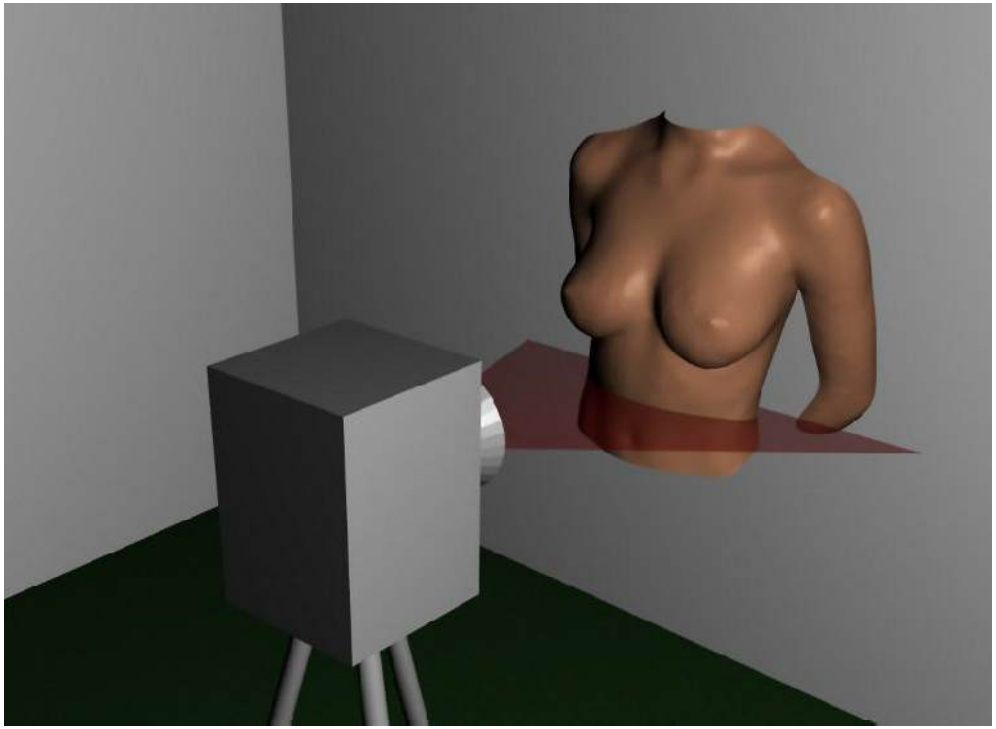
Planning of breast reconstruction surgery using autologous tissue based on finite element modeling

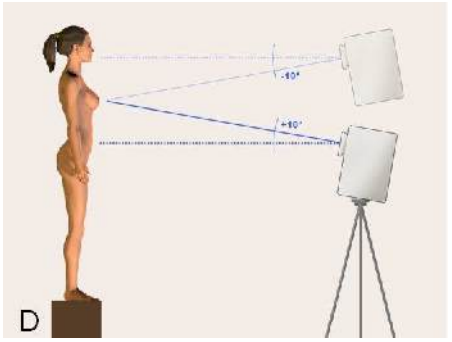


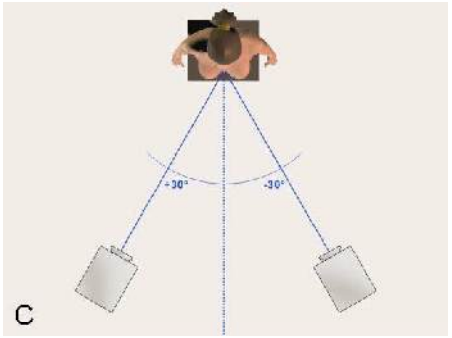
Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



Planning of breast reconstruction based on FE modeling -surface scanning of chest area







The 3-D surface scanning of the patient in standing position from 3 different angles (+30, 0 and -30 degrees relative to the lens)

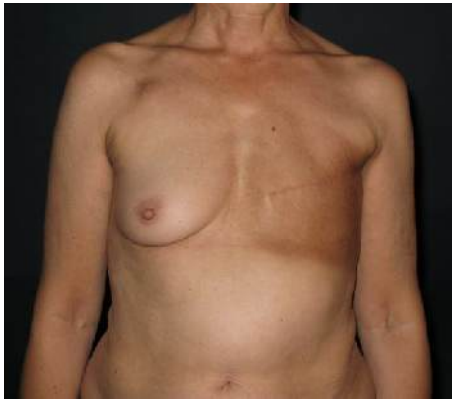
Kovacs L. et al., (2006): "Optimisation of the three-dimensional imaging of the breast region with 3D laser scanners", Ann Plast Surg., Vol56, pp.229 –236

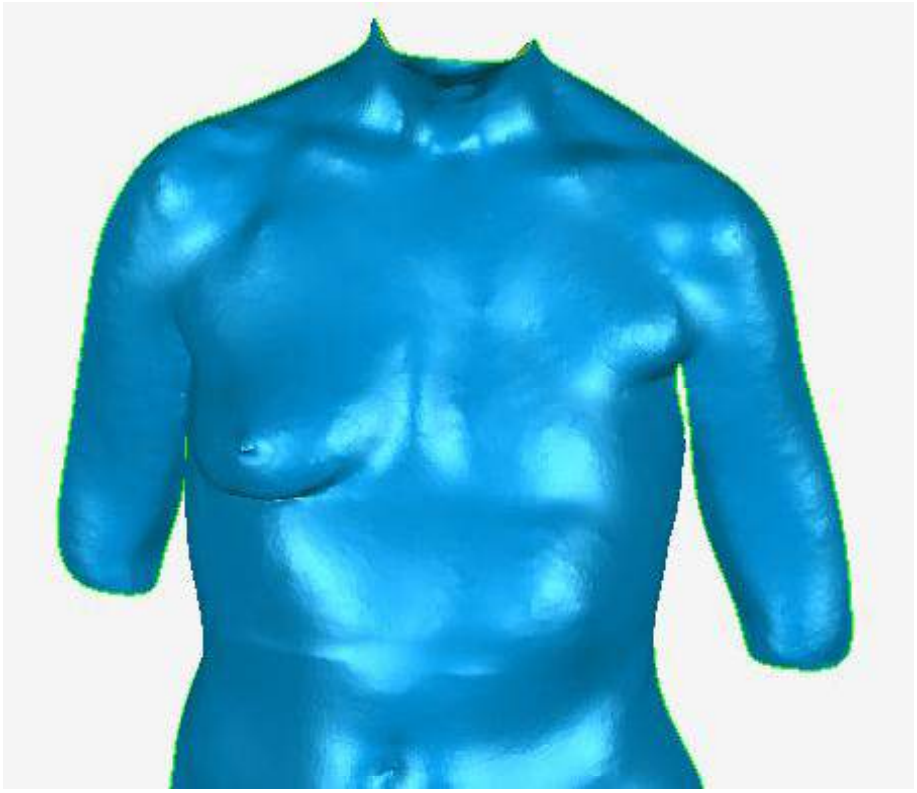
Planning of breast reconstruction based on FE modeling -surface scanning of chest area

The single shots from different angles

The acquired single shots from different angles will be converted into virtual 3-D models using appropriate software tools (Geomagic Studio 12®, Raindrop Geomagic, Inc., NC, USA)

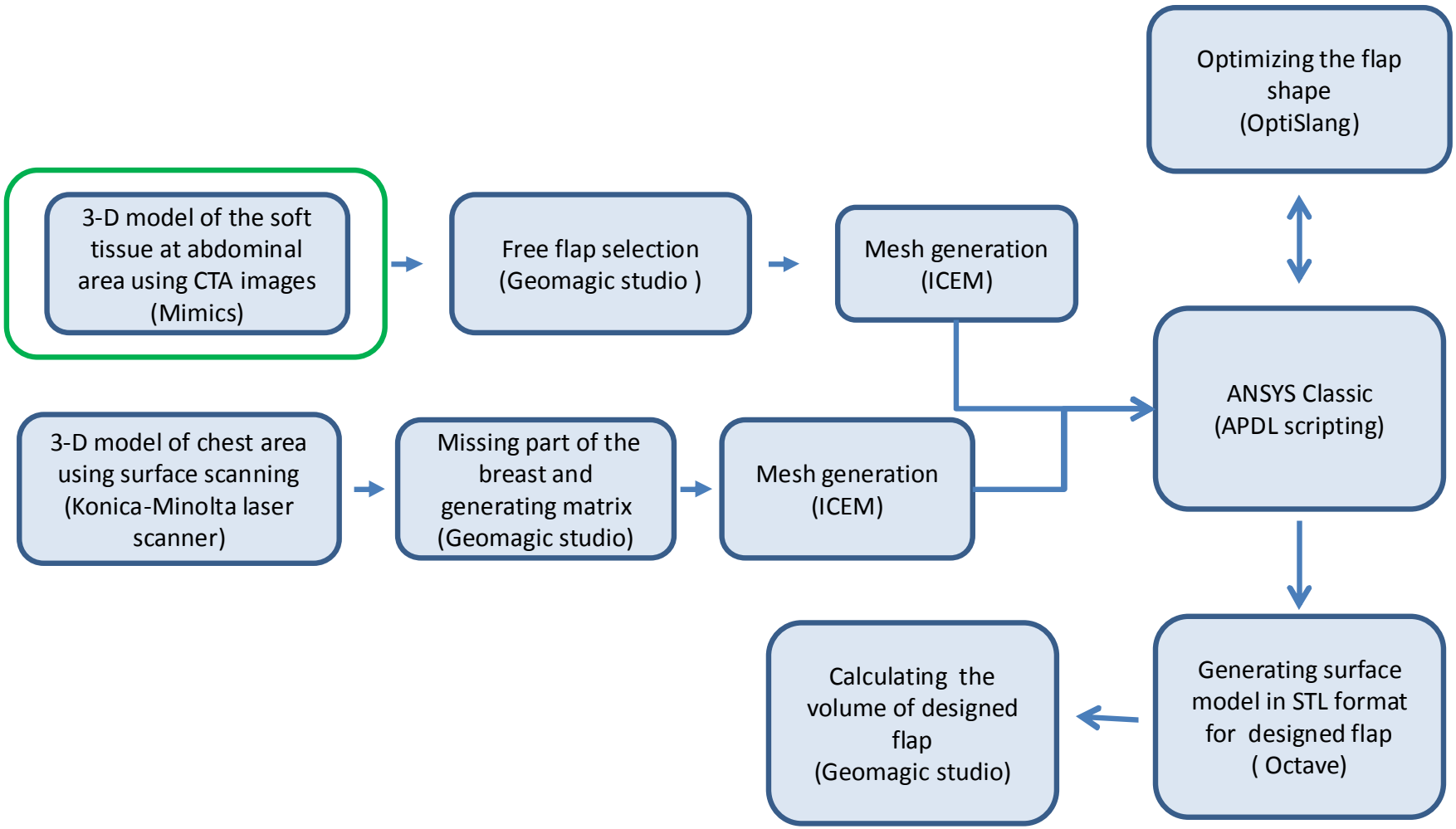
Planning of breast reconstruction based on FE modeling -surface scanning of chest area



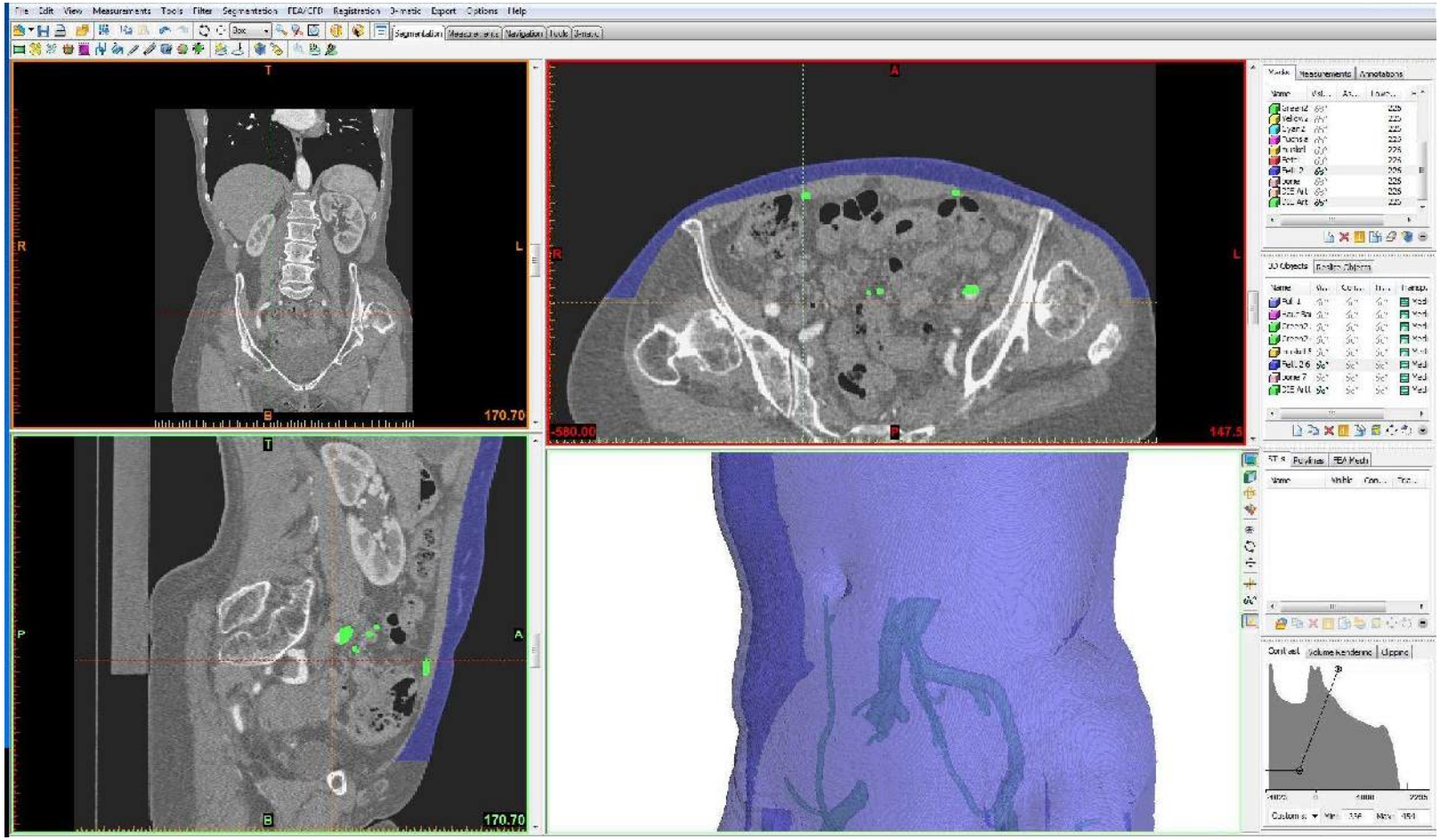


Polygonal 3-D model of the patient's chest after merging

Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



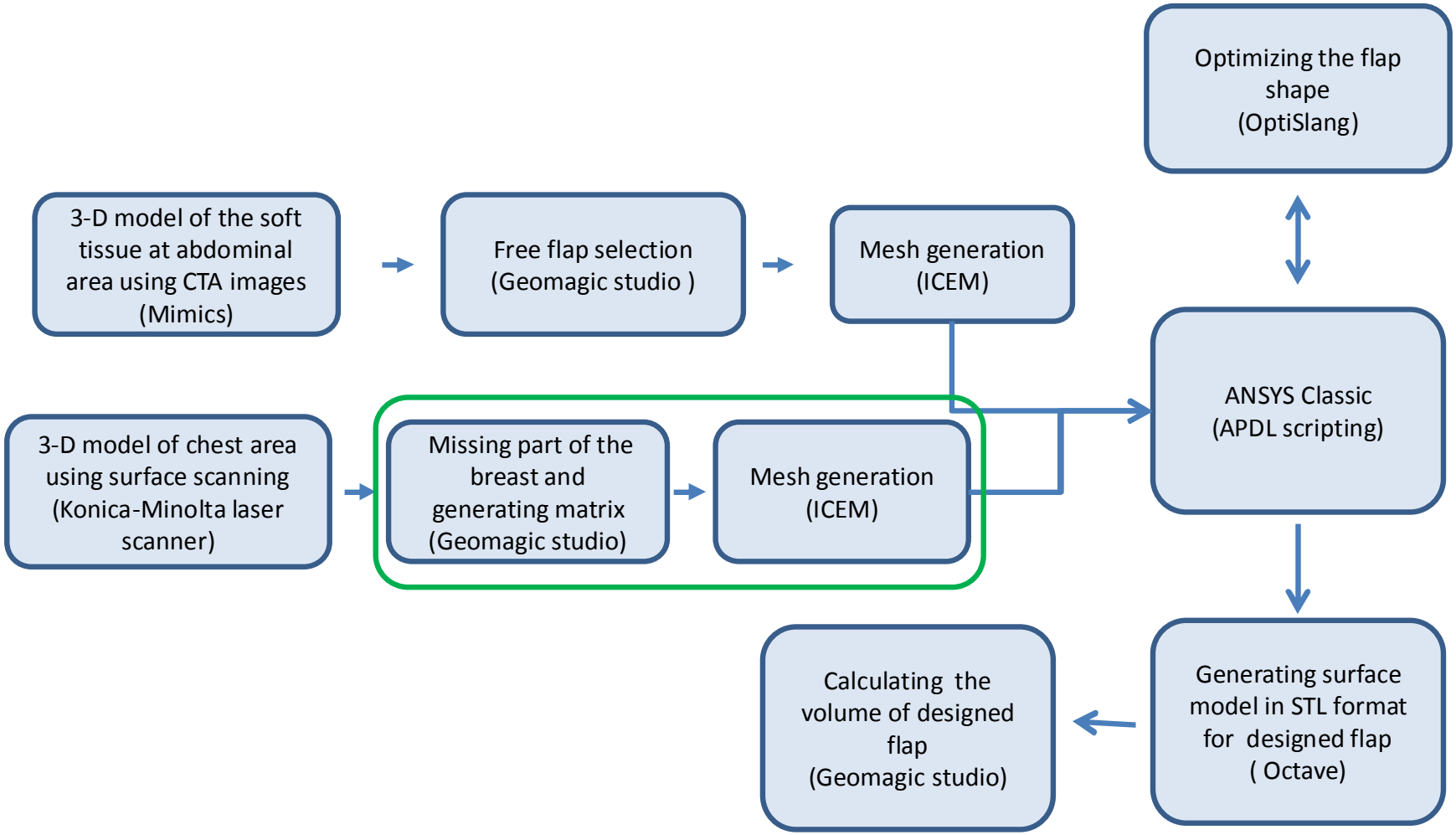
Planning of breast reconstruction based on FE modeling - volume model of the soft tissue using CTA images



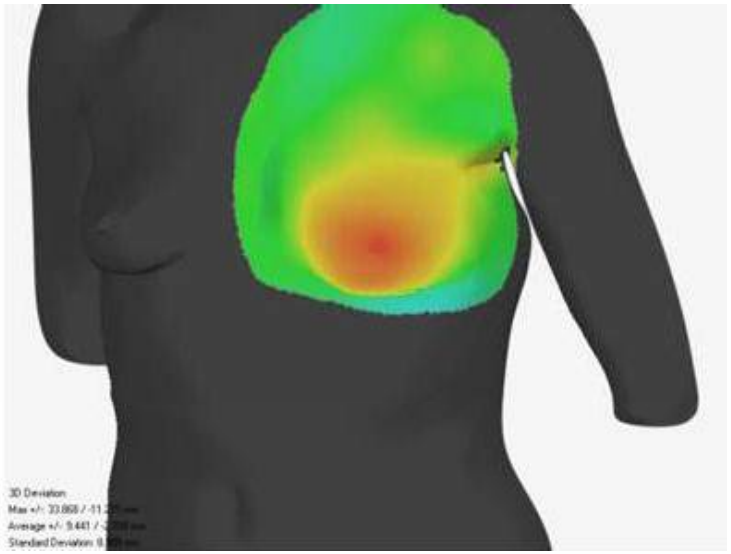
Segmentation and triangulation of the soft tissue material using CTA images

The soft tissues material were semi-automatically segmented and triangulated using the Mimics® 14.0 software (Materialise Inc., Leuven, Belgium)

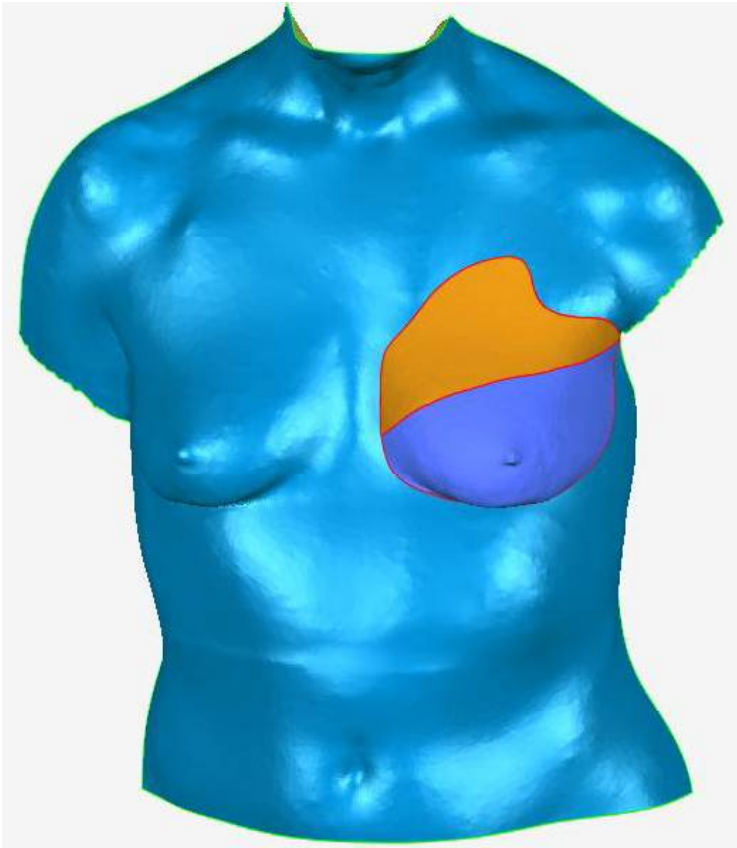
Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



Planning of breast reconstruction based on FE modeling -generating a model for missing part of the breast

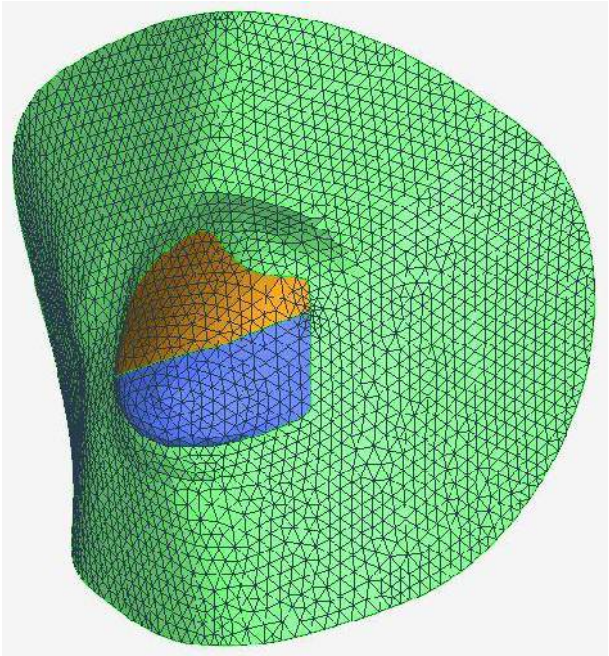


3-D comparison between the healthy and the missing breast



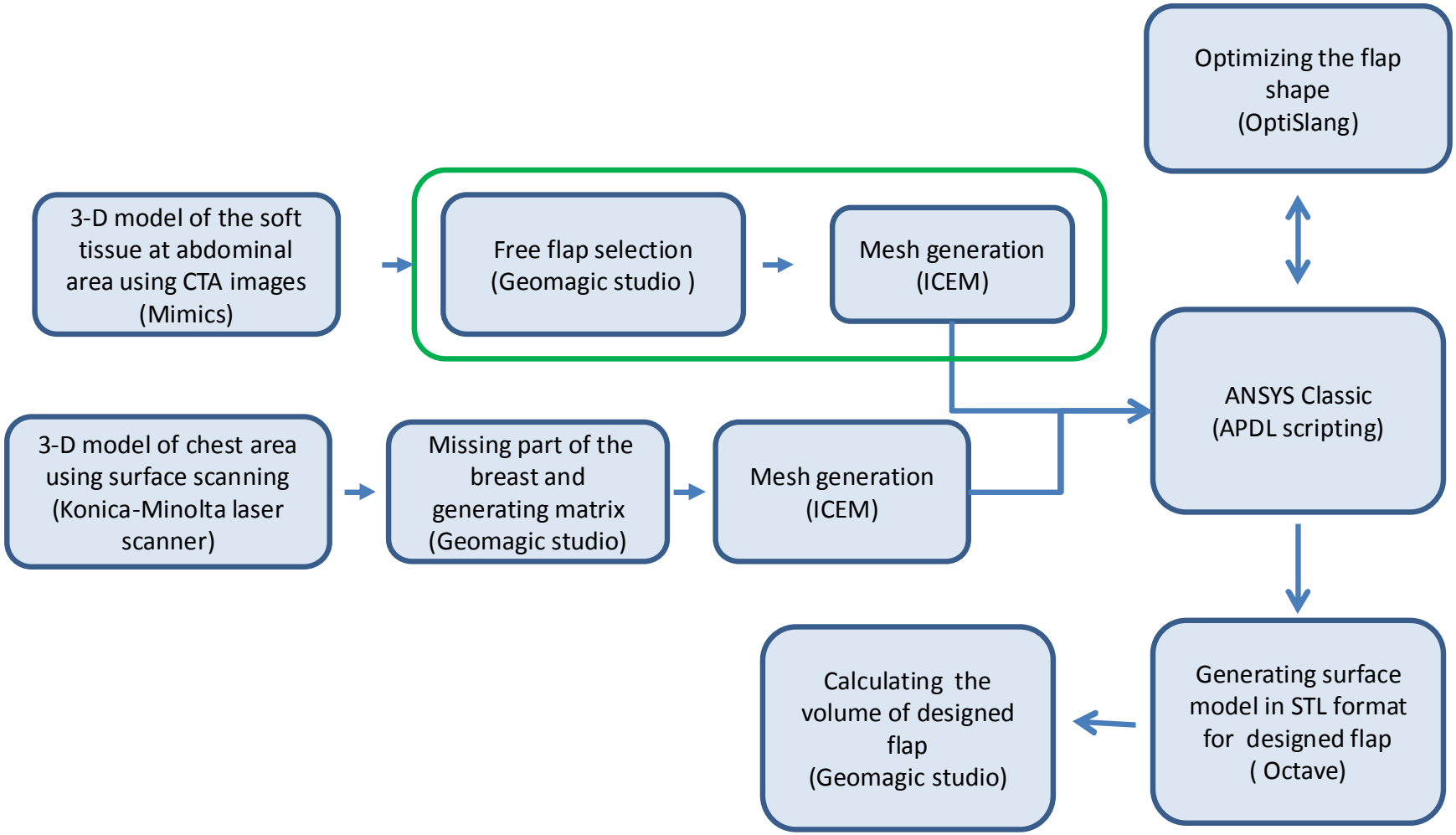
volume the missing part of breast= 214.6 cm^3
with skin =159.8 cm^3
without skin = 54.8 cm^3

Planning of breast reconstruction based on FE modeling -generating a matrix from missing part of the breast

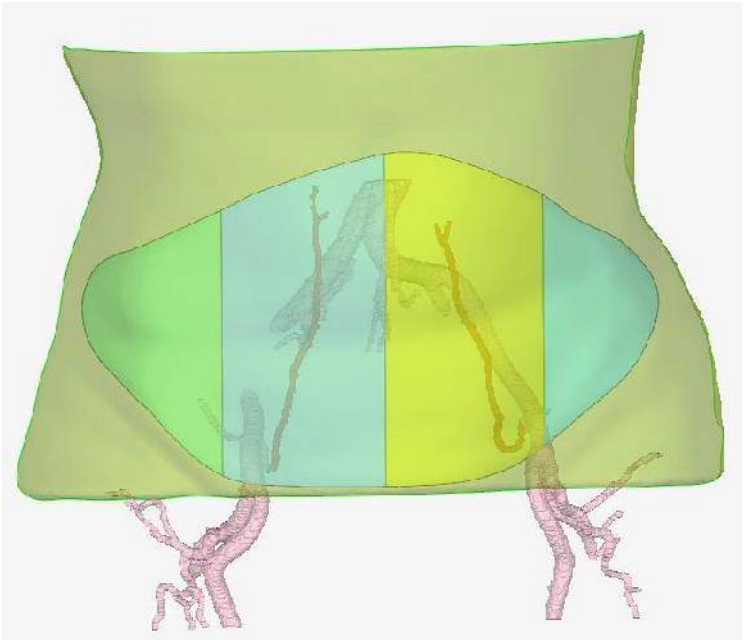


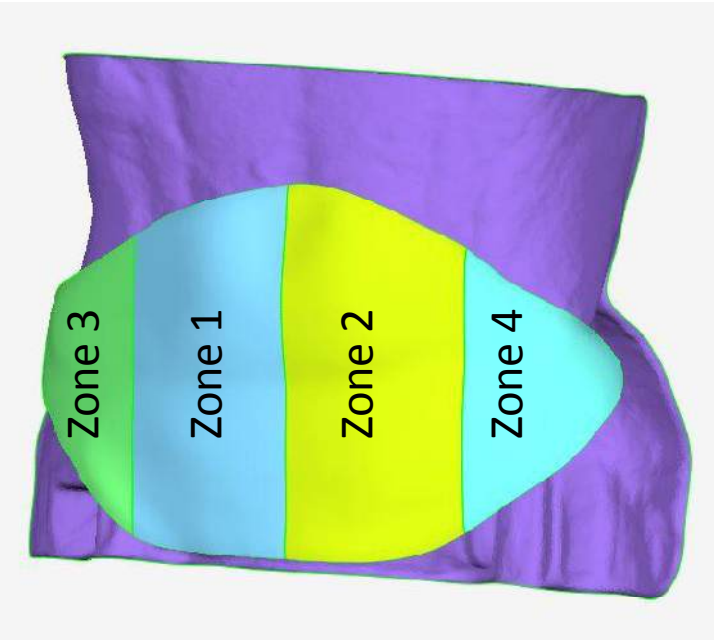
A matrix from missing part of the breast
with 3-D surface elements

Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



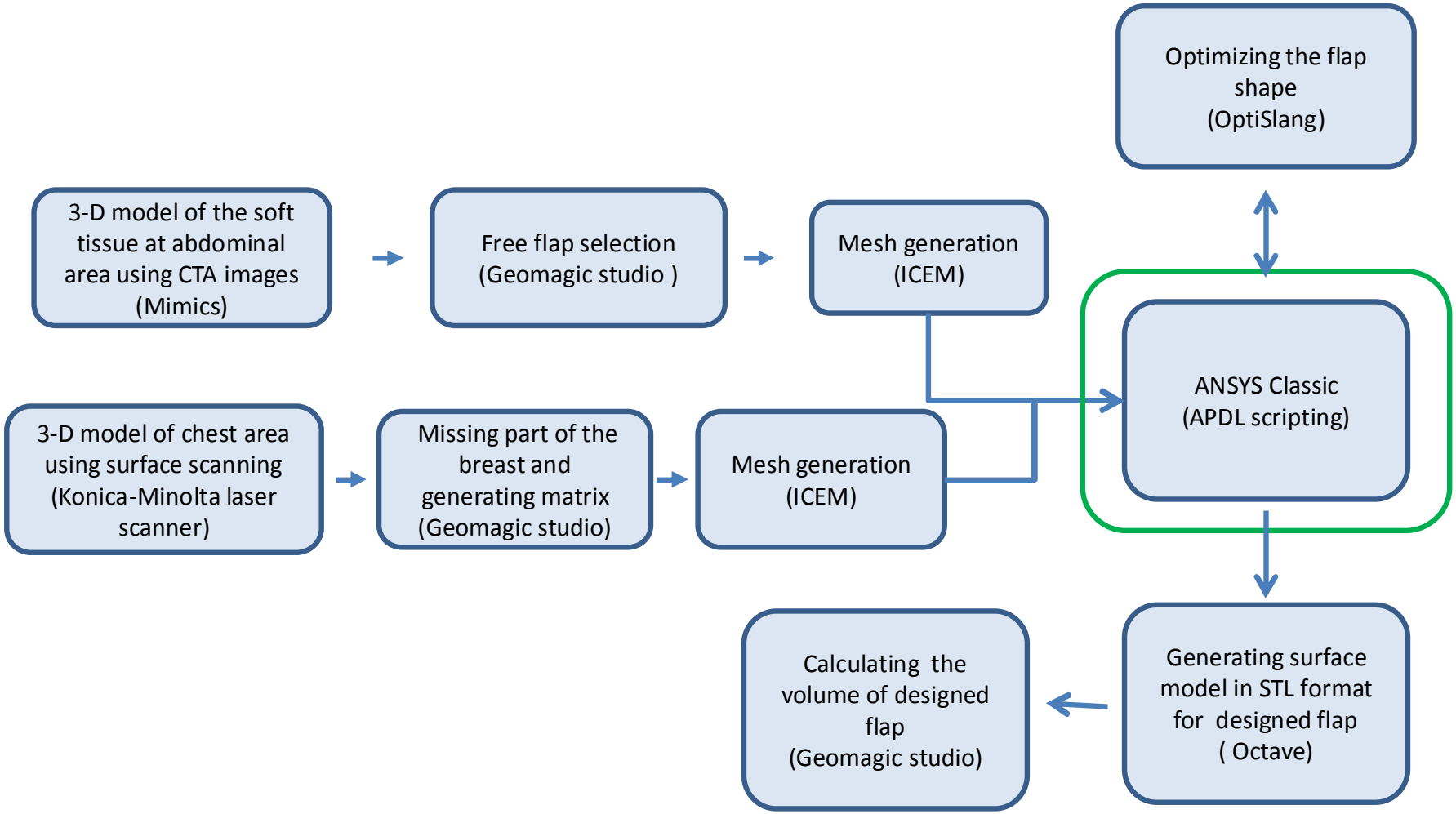
Planning of breast reconstruction based on FE modeling -polygonal 3-D model of the abdominal free flap



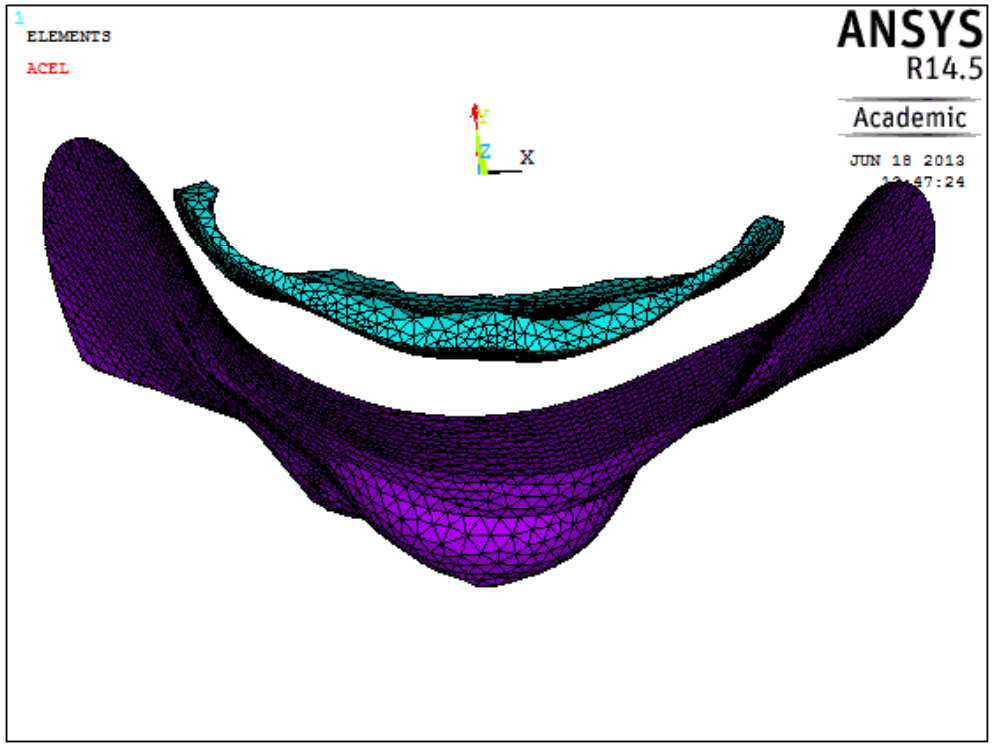


Polygonal 3-D model of the maximum available free flap due to anatomical limitation and its different zones.

Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



Planning of breast reconstruction based on FE modeling -shaping the free flap to missing breast using FE modeling



3-D FE model of missing part of the breast and harvested free flap

Planning of breast reconstruction based on FE modeling -shaping the free flap to missing breast using FE modeling

Flap

Element type: solid 285 (3-D 4-Node Tetrahedral Structural Solid with Nodal Pressures)
(3217 nodes & 15216 elements)

Neo-Hookean Hyperelastic Material model:
Initial shear modulus: 0.00026 MPa
Incompressible material

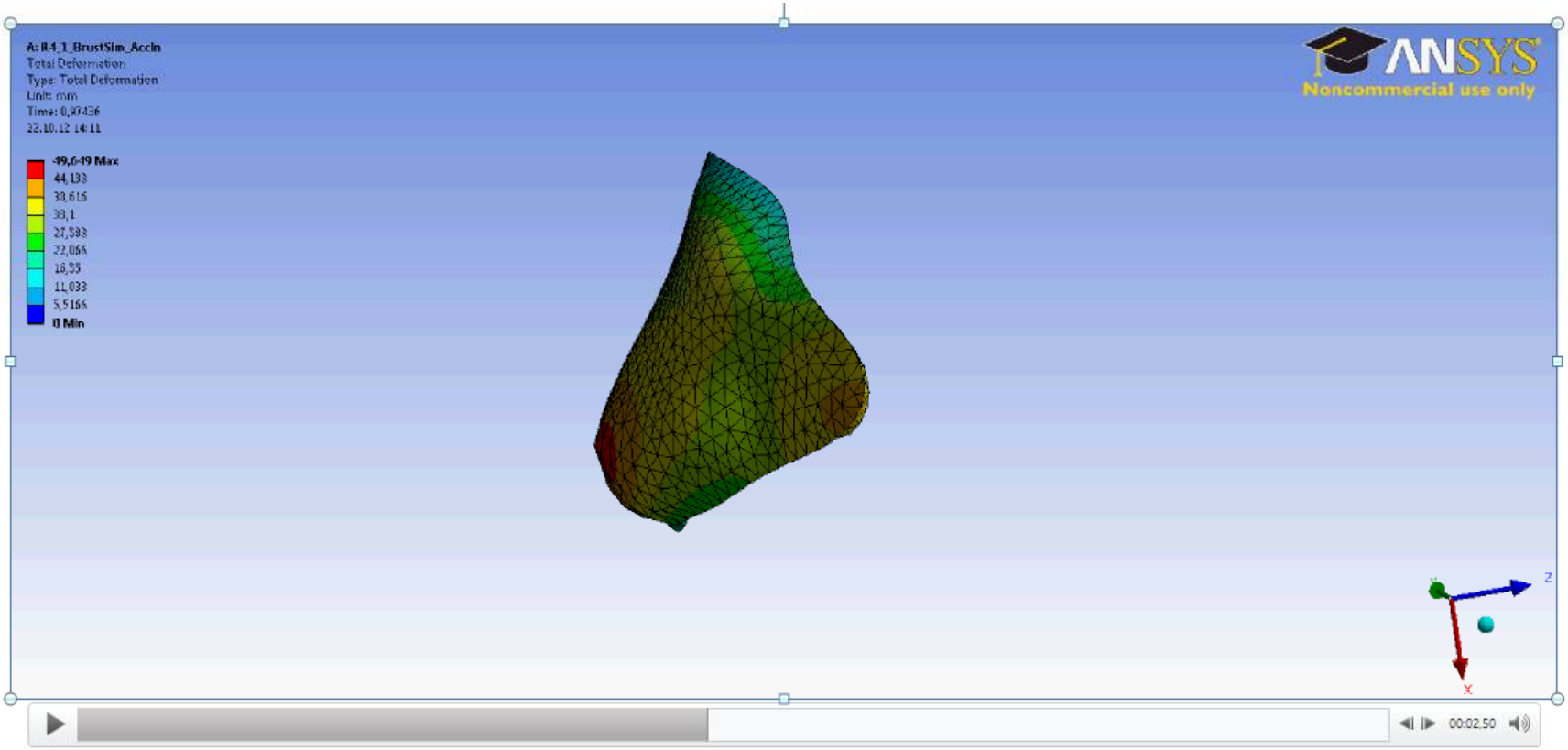
Surface to surface contact definition

Contact element: conta174 on the flap surface
Target element : targ170 on the matrix surface

Frictional contact:
very low friction coefficient between flap and matrix : 0.05

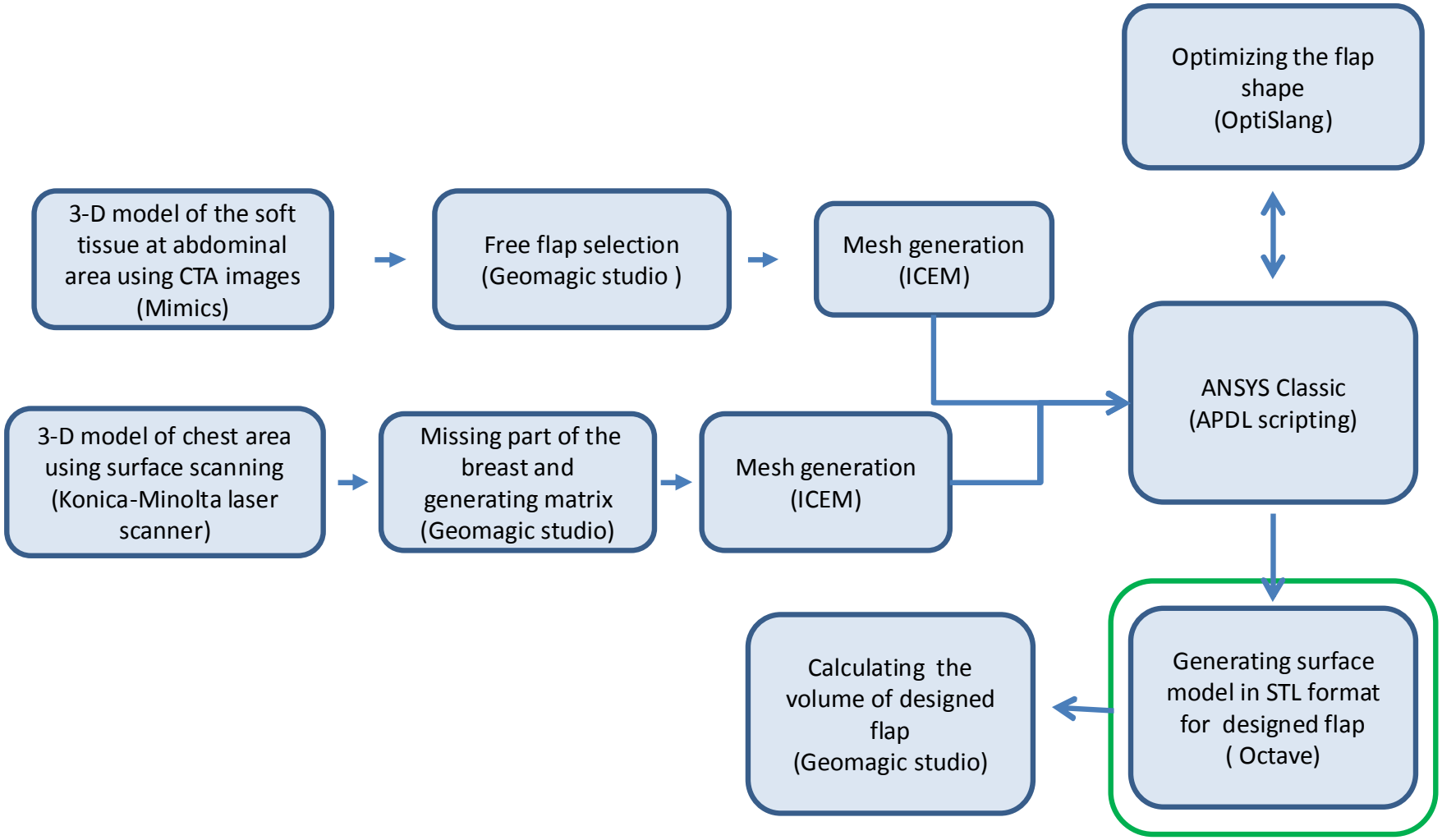
Required analysis time: less than 5 min

Planning of breast reconstruction based on FE modeling -shaping the free flap to missing breast using FE modeling

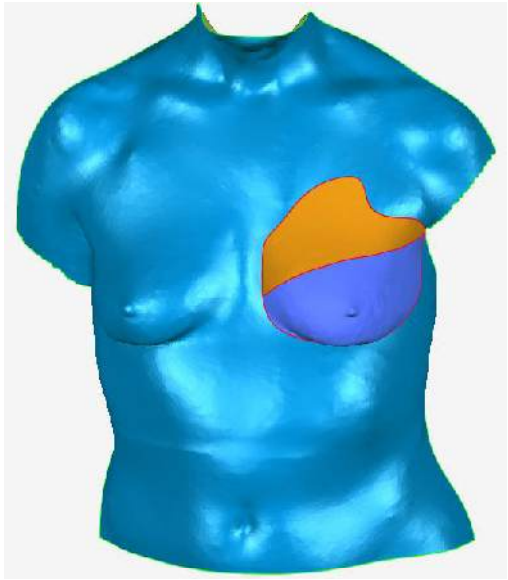


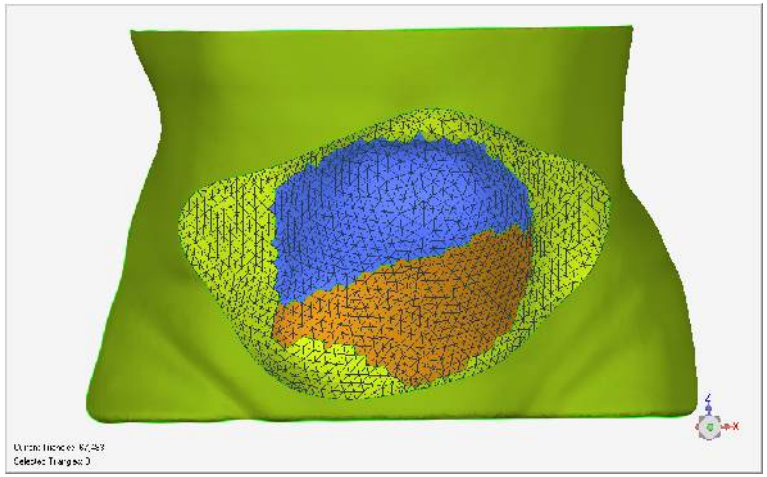
Deformation of the harvested flap while forming it to the shape of the missing breast

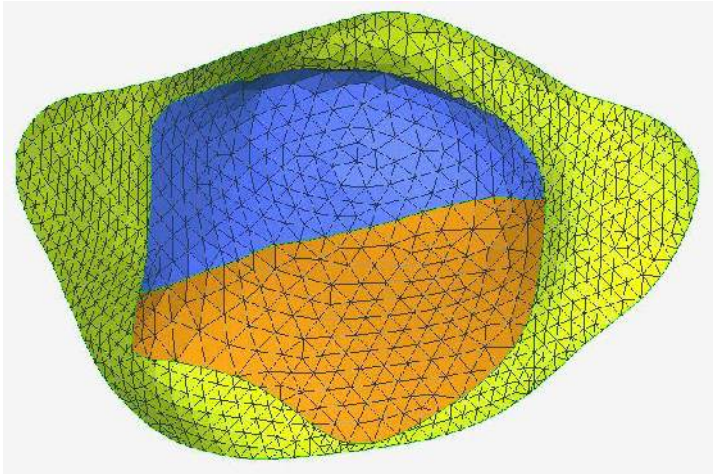
Planning of breast reconstruction surgery using autologous tissue based on finite element modeling

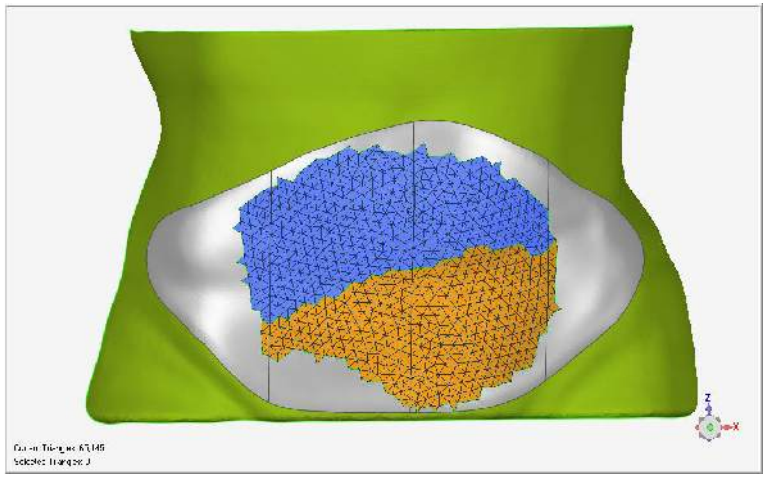


Planning of breast reconstruction based on FE modeling -generating surface model in STL format for designed flap

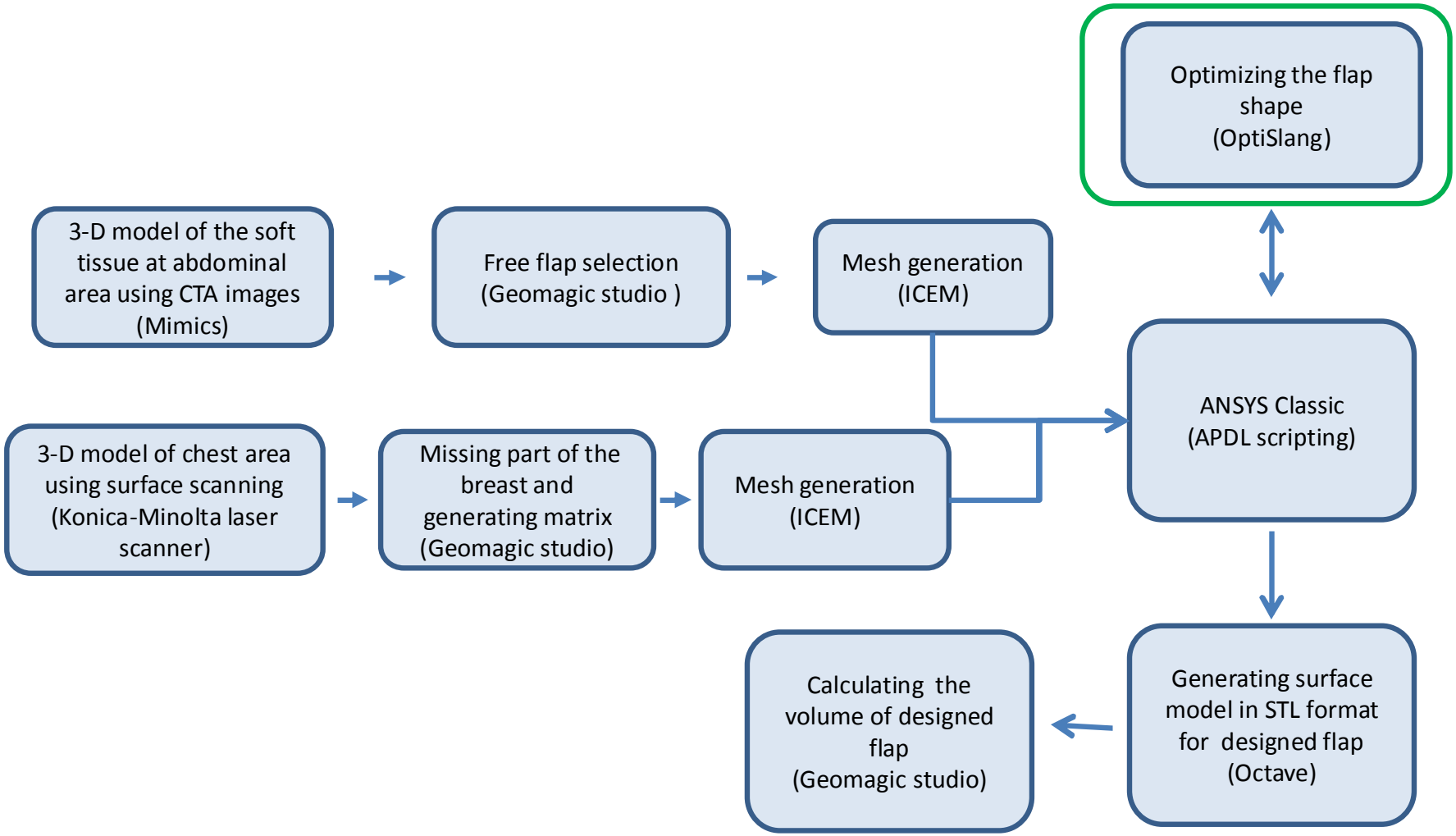








Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



Planning of breast reconstruction based on FE modeling -optimizing the shape of flap

- **Design Parameter**
  we are allowed to change them to find the best design

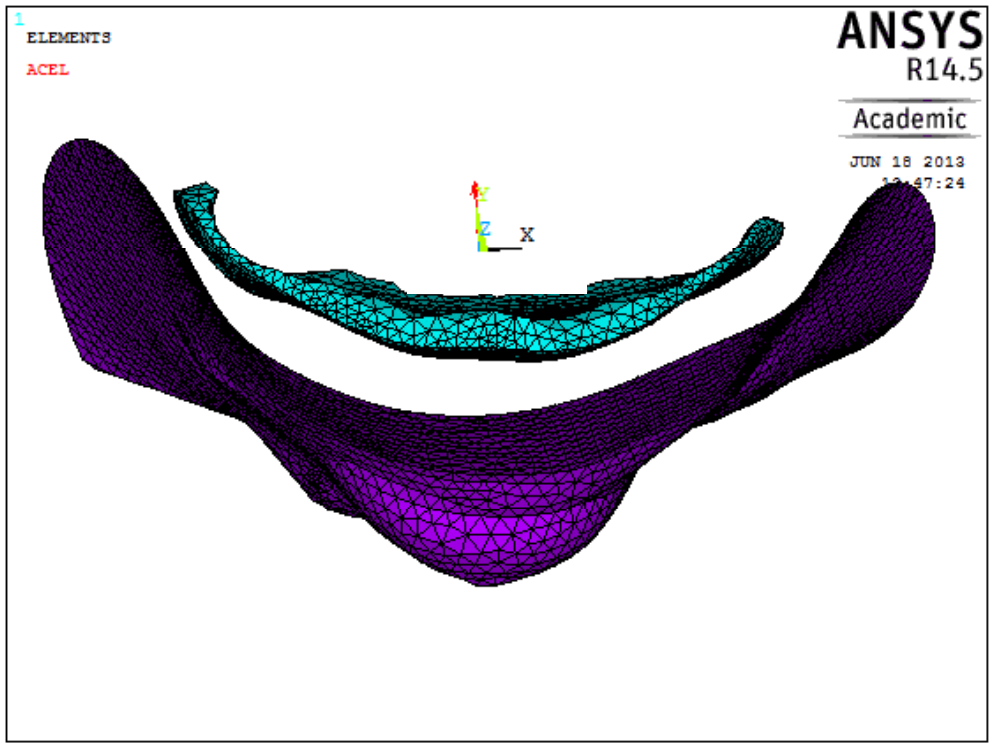
- **Constraint Function:**
  should be fulfilled

- **Objective Function**
  should be minimized

Planning of breast reconstruction based on FE modeling -optimizing the shape of flap

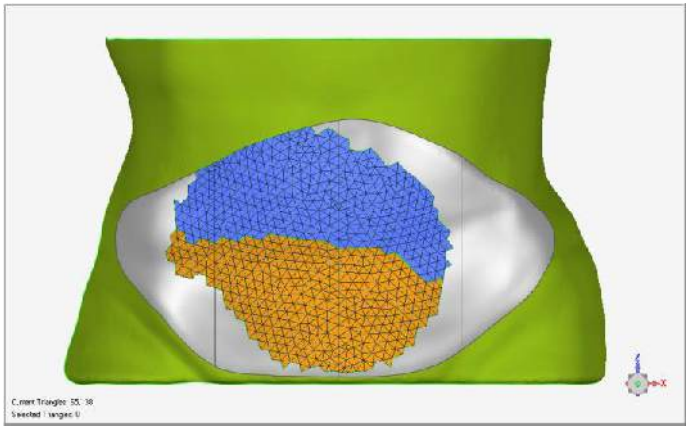
Design Parameter: we are allowed to move and rotate the matrix

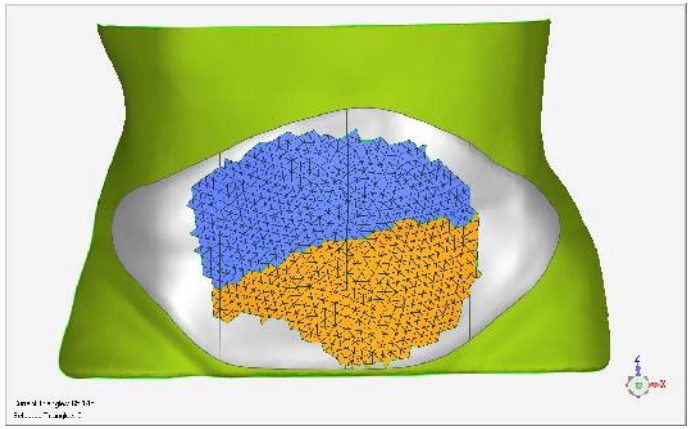
dpxc	Moving the matrix in x direction	-30 to +30 mm
dpzc	Moving the matrix in z direction	-10 to +30 mm
dpthzx	Rotating the matrix in zx plane	-30 to +30 degree

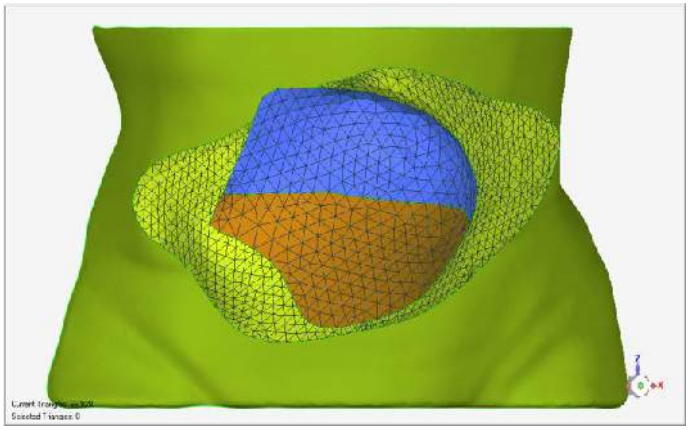


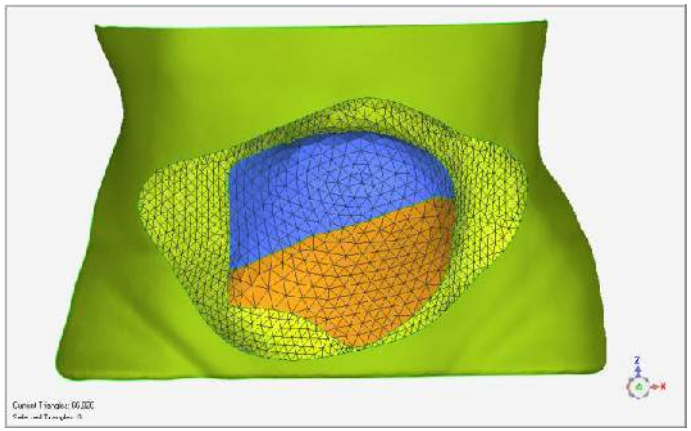
Planning of breast reconstruction based on FE modeling -optimizing the shape of flap

Constraint: the design flap must be located inside the maximum available free flap due to anatomical limitation.









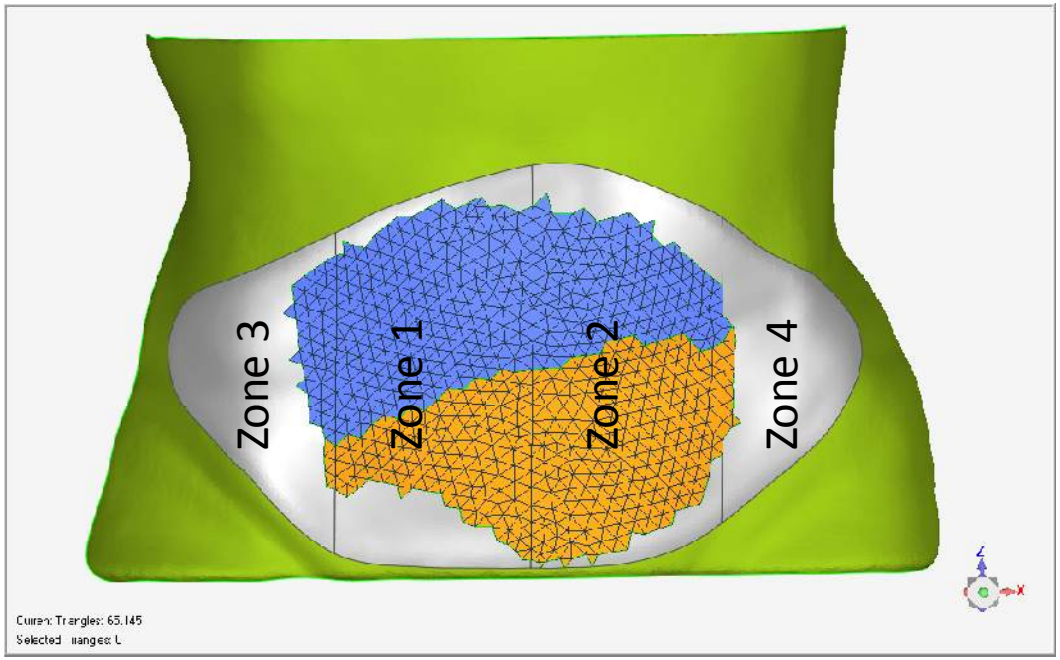
constraint condition is failed

constraint condition is satisfied

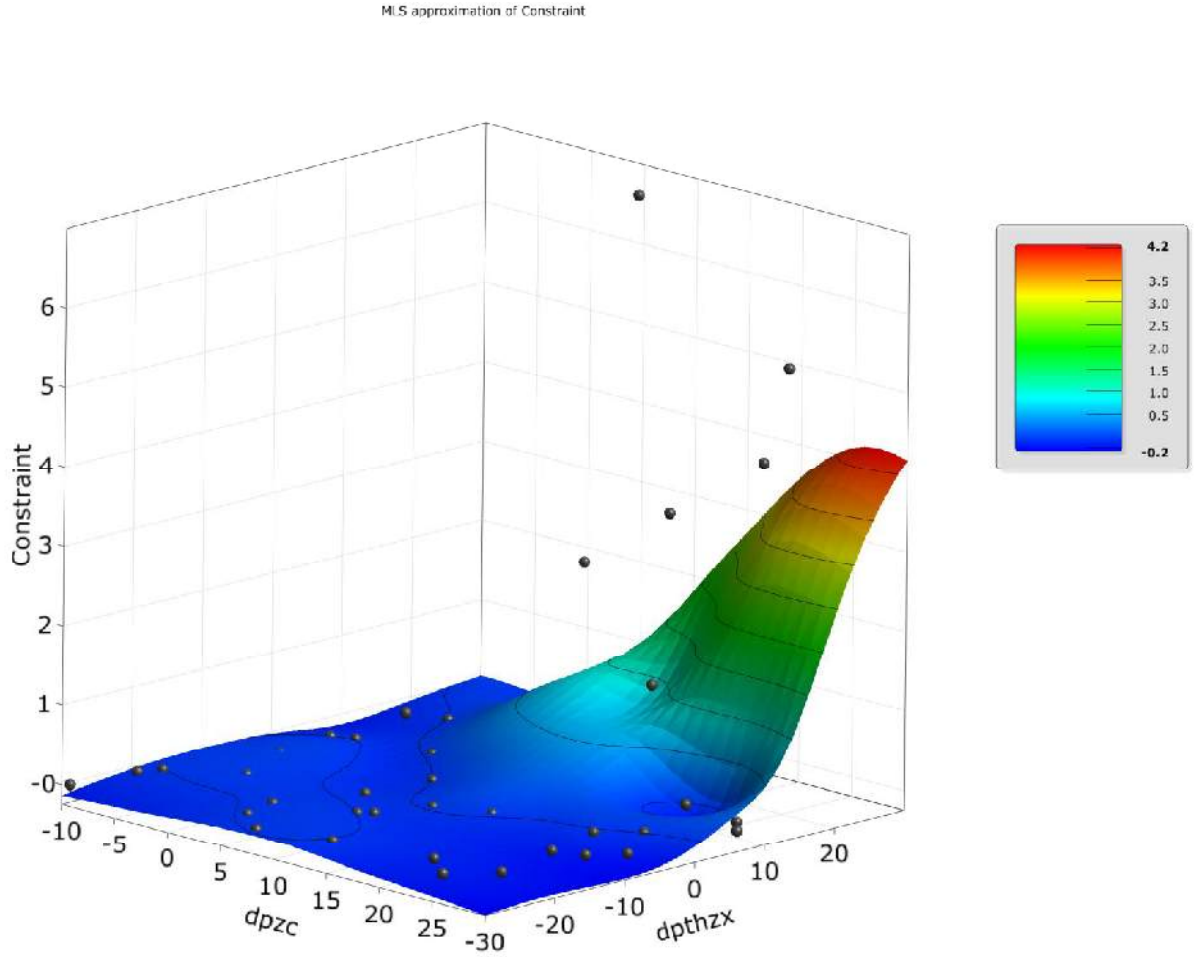
Planning of breast reconstruction based on FE modeling -optimizing the shape of flap

Objective:

Minimize the area of free flap located in zone 4 and 3.

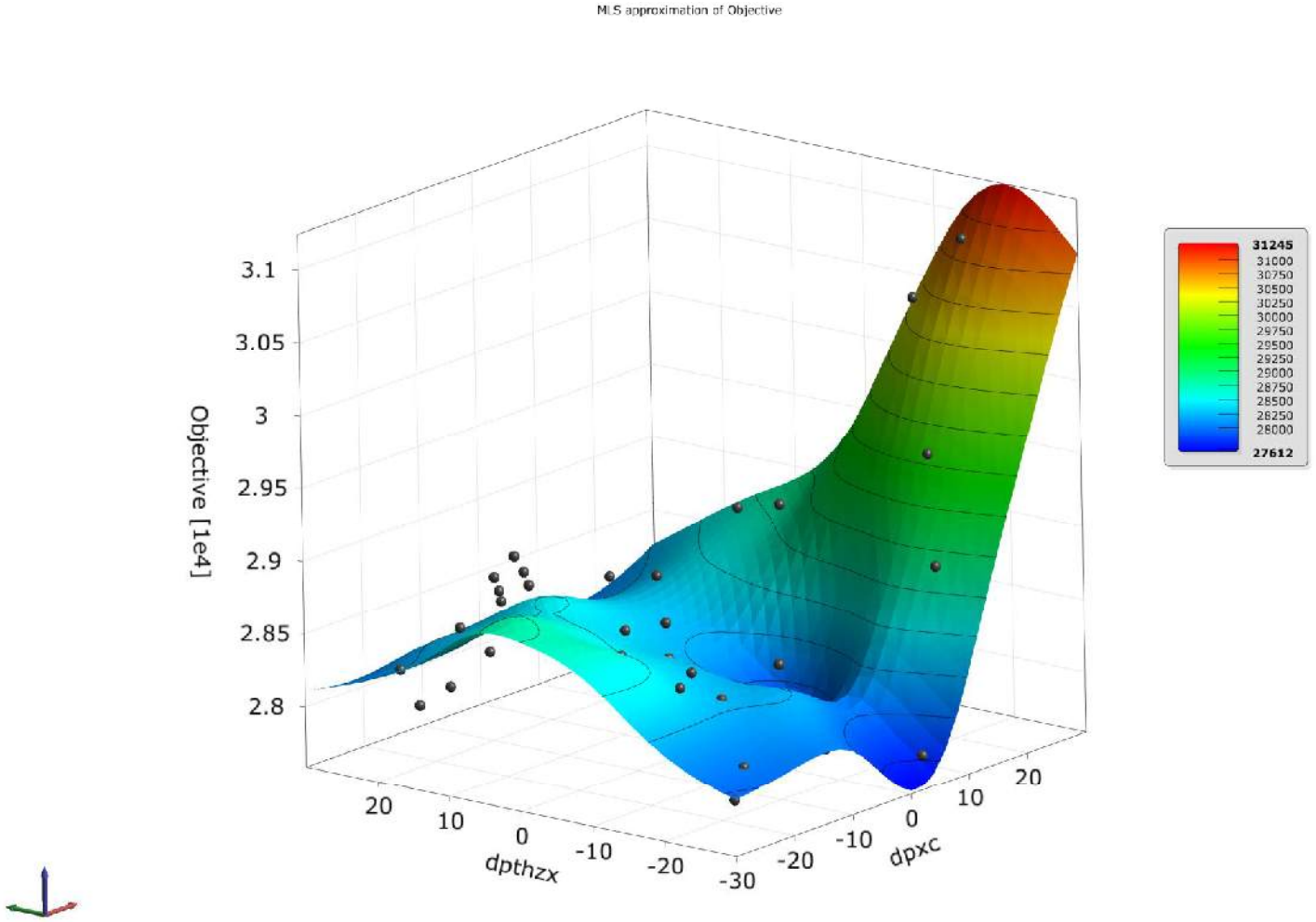


Planning of breast reconstruction based on FE modeling -optimizing the shape of flap



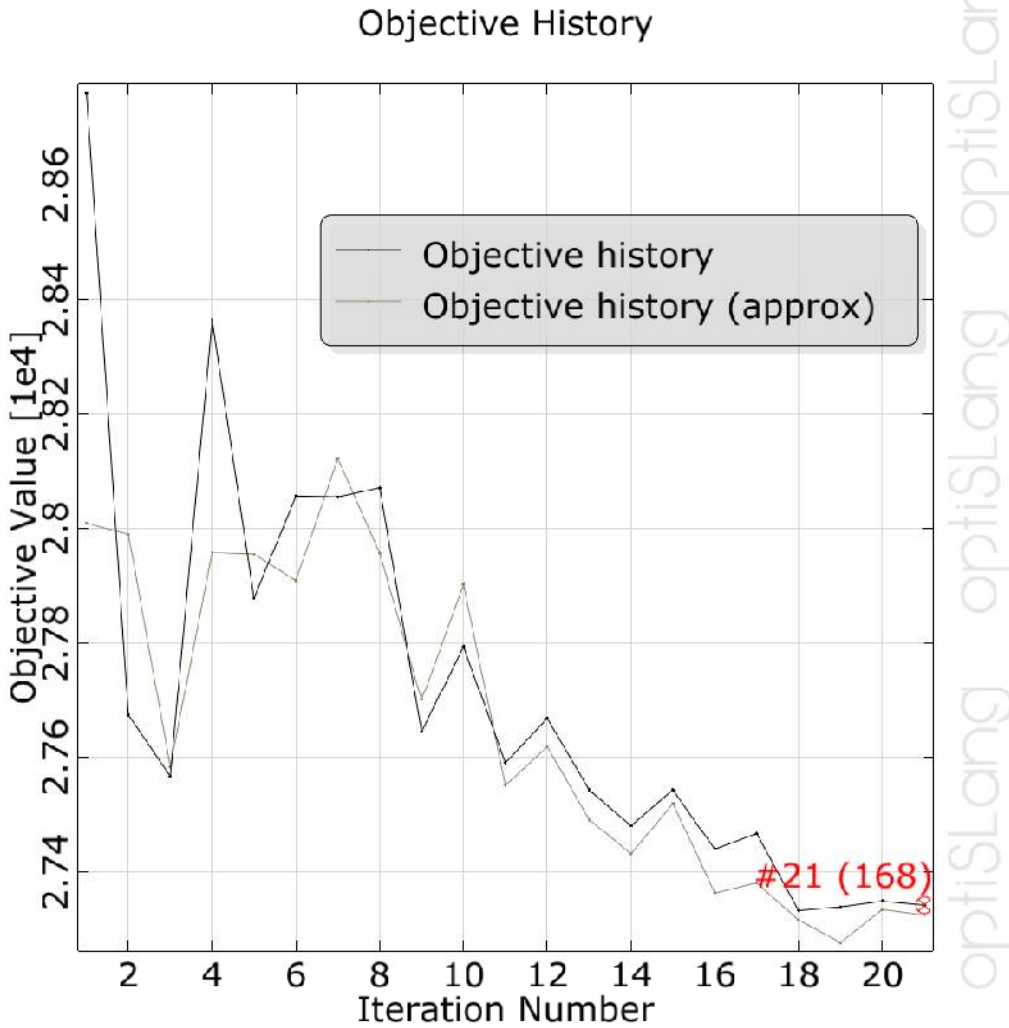
3-D plot of response surface (variables vs. constraint)

Planning of breast reconstruction based on FE modeling -optimizing the shape of flap



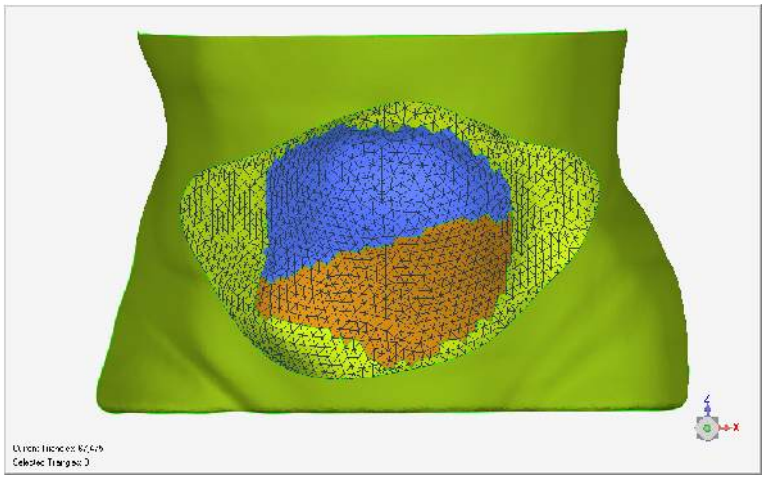
3-D plot of response surface (variables vs. objective)

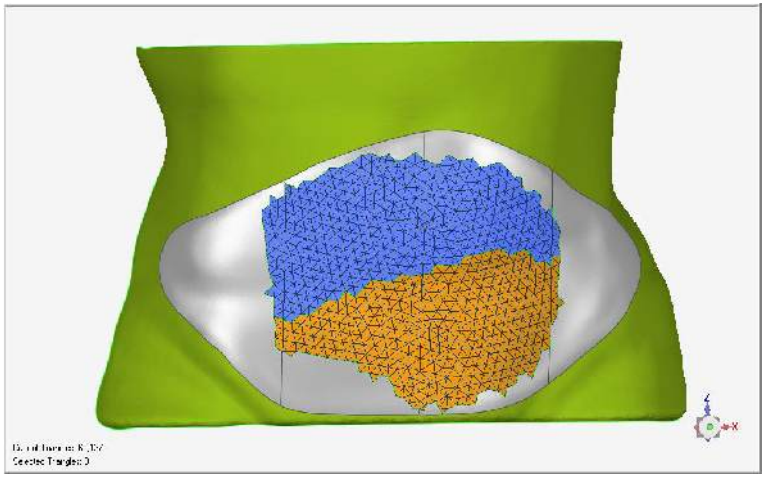
Planning of breast reconstruction based on FE modeling -optimizing the shape of flap



Objective history of best design

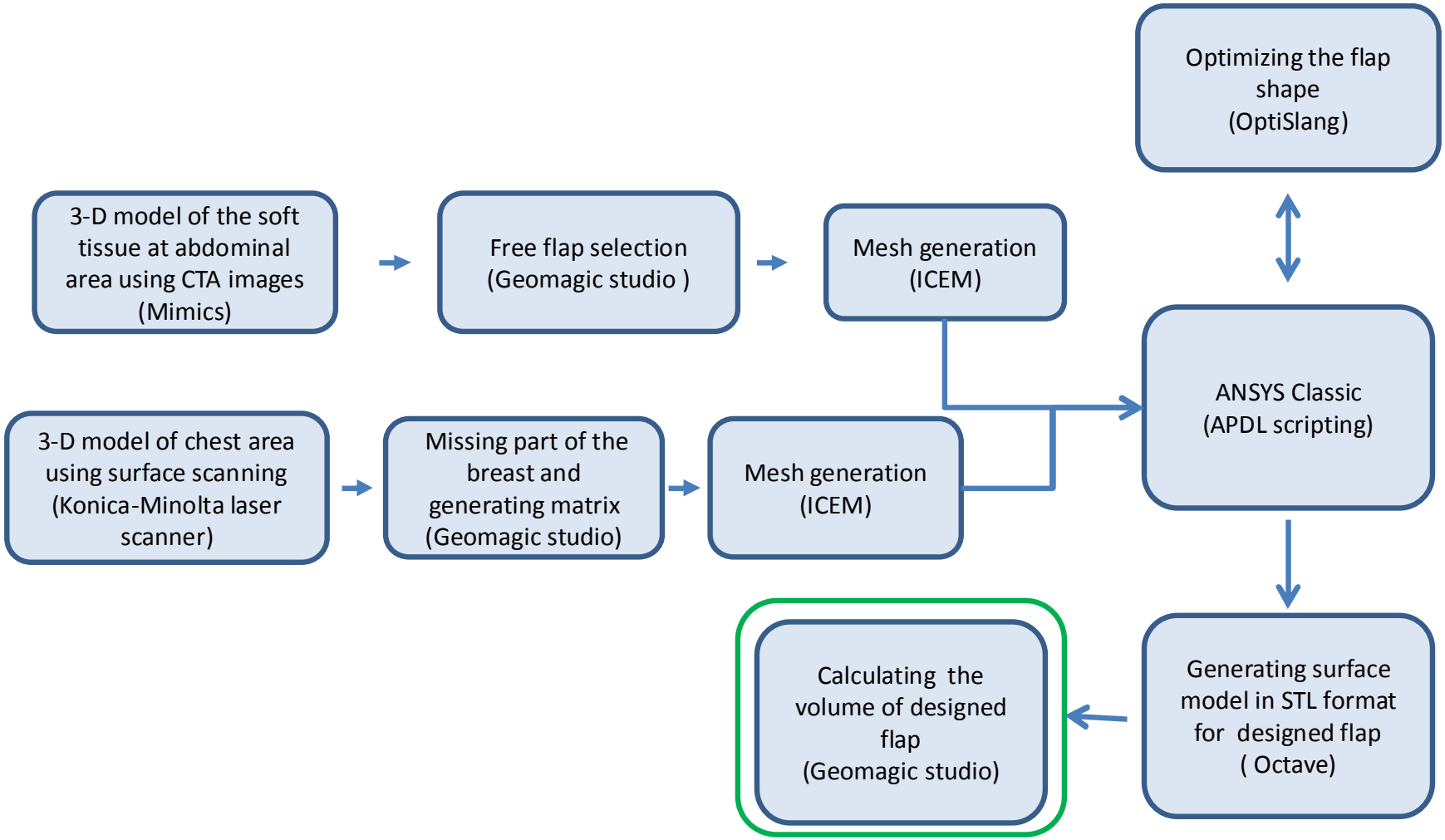
Planning of breast reconstruction based on FE modeling -optimized flap geometry



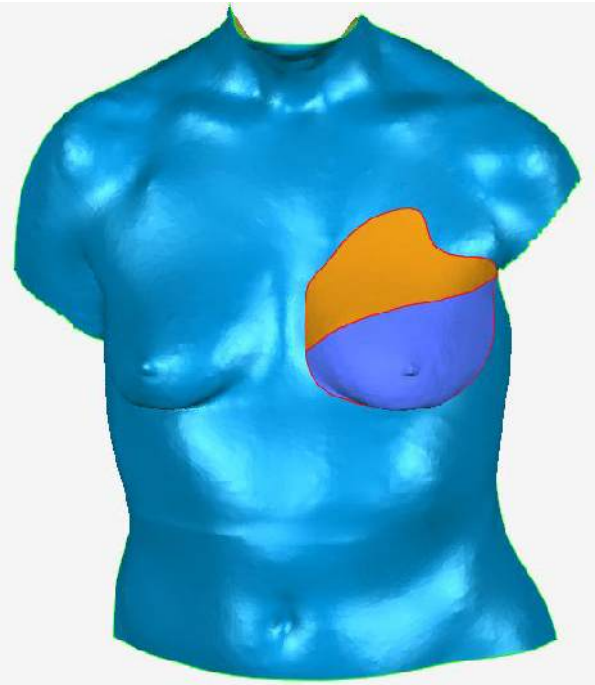


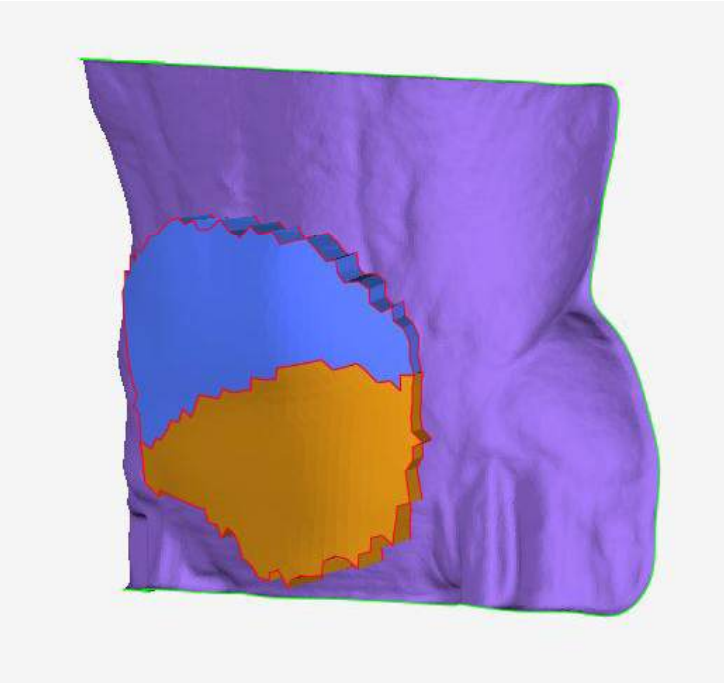
Best design

Planning of breast reconstruction surgery using autologous tissue based on finite element modeling



Planning of breast reconstruction based on FE modeling -calculating the volume of designed flap





volume the missing part of breast= 214.6 cm^3
with skin=159.8 cm^3
without skin= 54.8 cm^3

volume the optimized flap= 271.1 cm^3
optimized flap with skin= 156.4 cm^3
optimized flap without skin= 114.7 cm^3
(volume will decrease after removing the skin)

Planning of breast reconstruction surgery using autologous tissue based on 3-D imaging

Conclusion:

- The presented approach will enable the surgeon to estimate the needed amount of abdominal tissue to reconstruct a symmetric breast matching volume and dimensions.
- The present study shows that modern 3-D imaging techniques may provide essential additional information to the surgeons at the stage of preoperative surgical planning.

Further targets:

- Considering the effect of initial stresses on flap deformation
- Clinical study to determine the accuracy and analyze the clinical benefit compared to other existing planning methods

Planning of breast reconstruction surgery using autologous tissue based on 3-D imaging

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