Digital 3D printing of concrete structures using FEM

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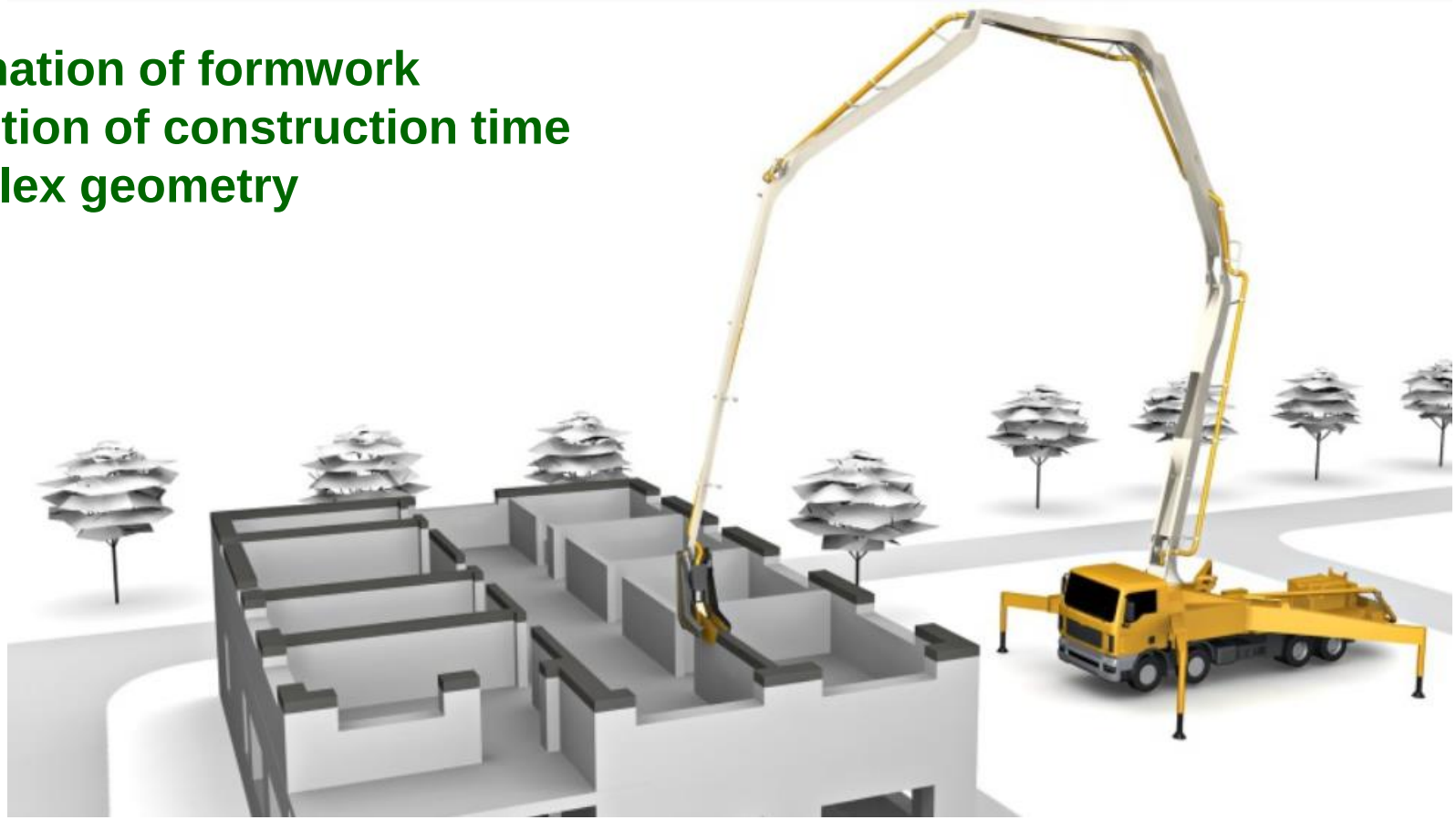
Content:

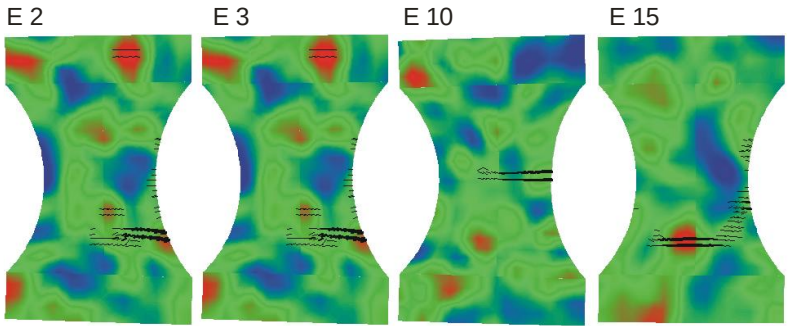
Digital printing of concrete
Implementation in ATENA
Material model for concrete
Validation
Sample analysis

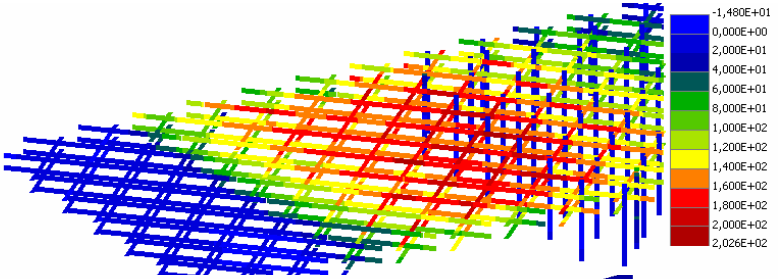
Digital printing of concrete

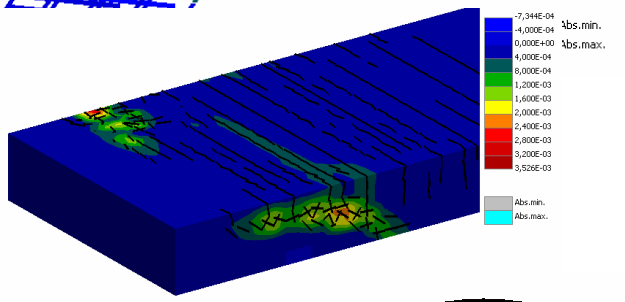
- elimination of formwork
- reduction of construction time
- complex geometry

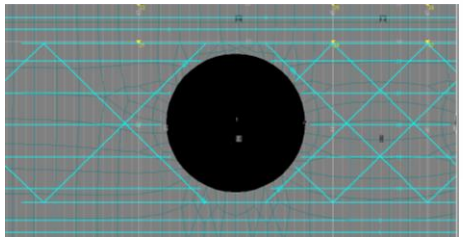


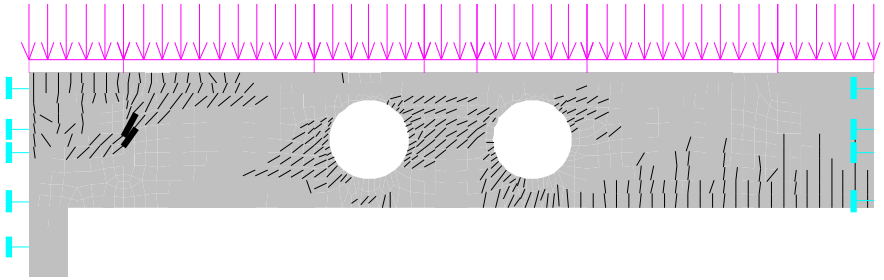
Nonlinear simulation of reinforced concrete structures

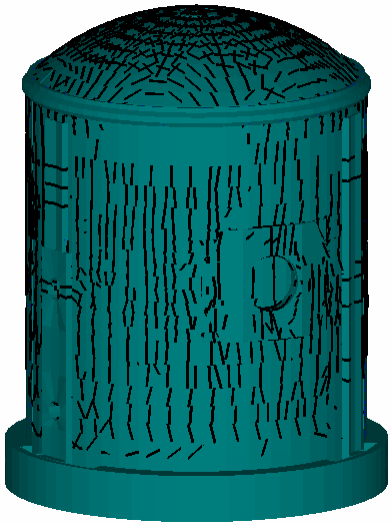












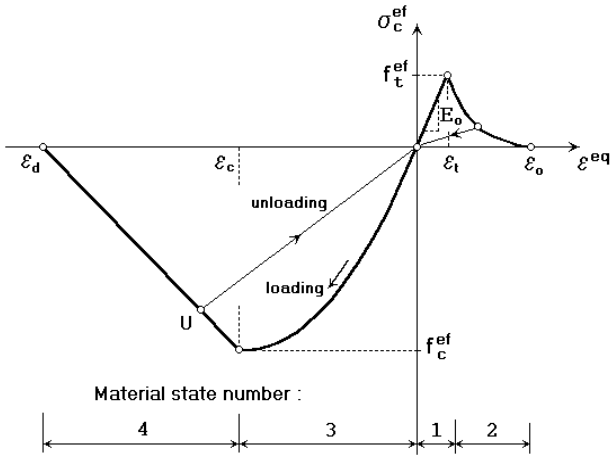
ATENA modelling of digital printing of concrete

- material model developing in time
- construction process for model
- time effect on load: self weight, shrinkage
- visualization while running

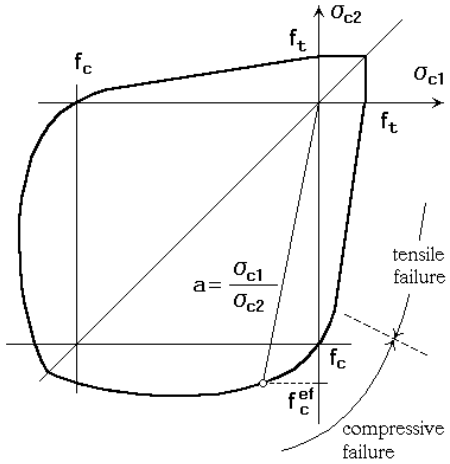
Material model of concrete

- fracture-plastic

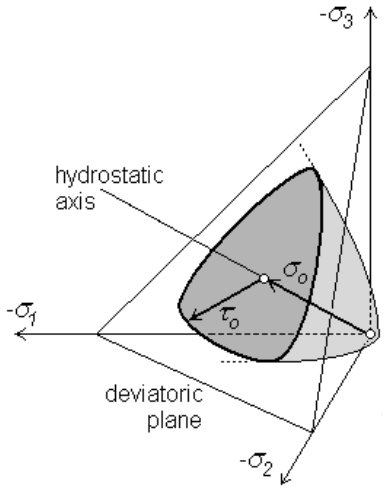
Uniaxial law



Bi-axial criterion



3D failure surface

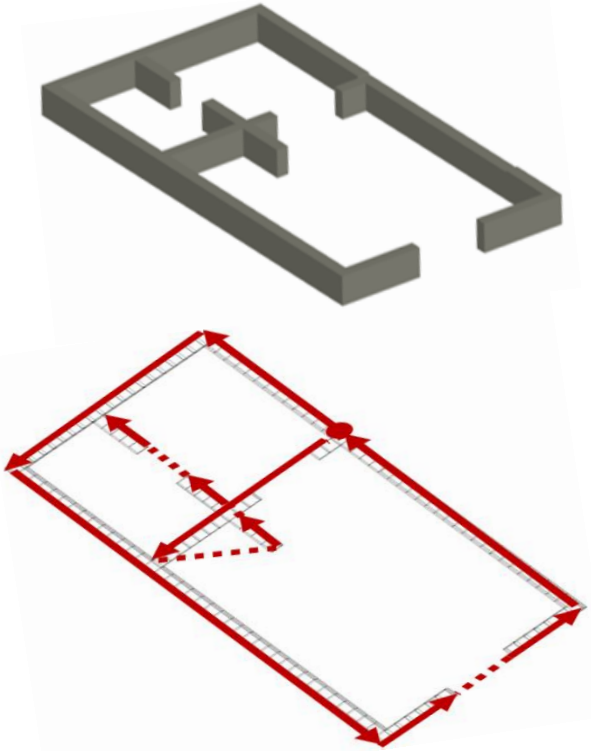


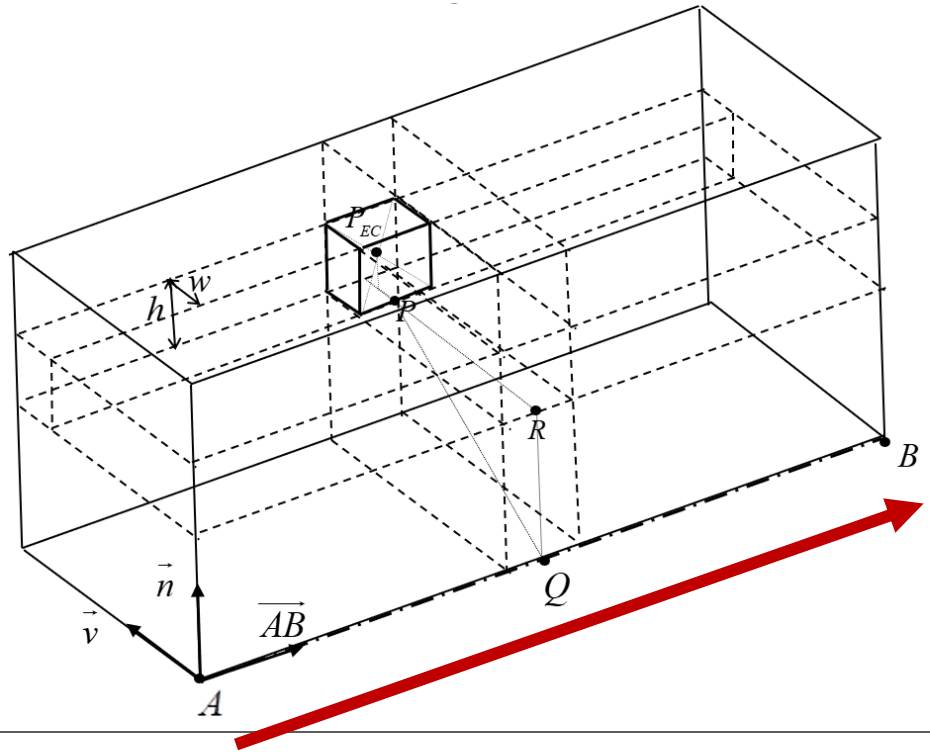
Kupfer 1969

Menetrey Willam, ACI 1995

Construction process

- determination of construction time for each element

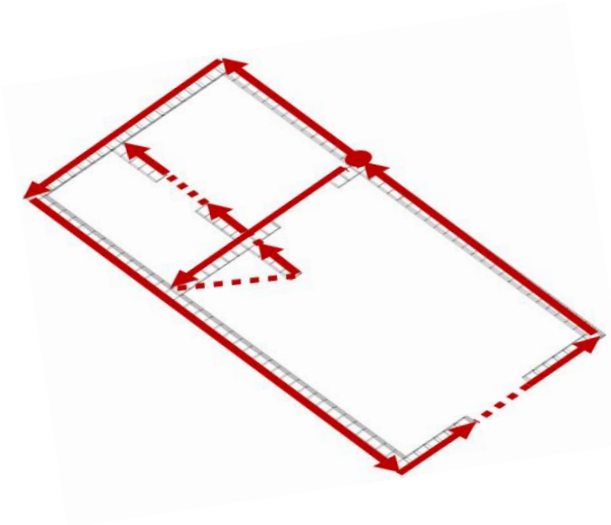


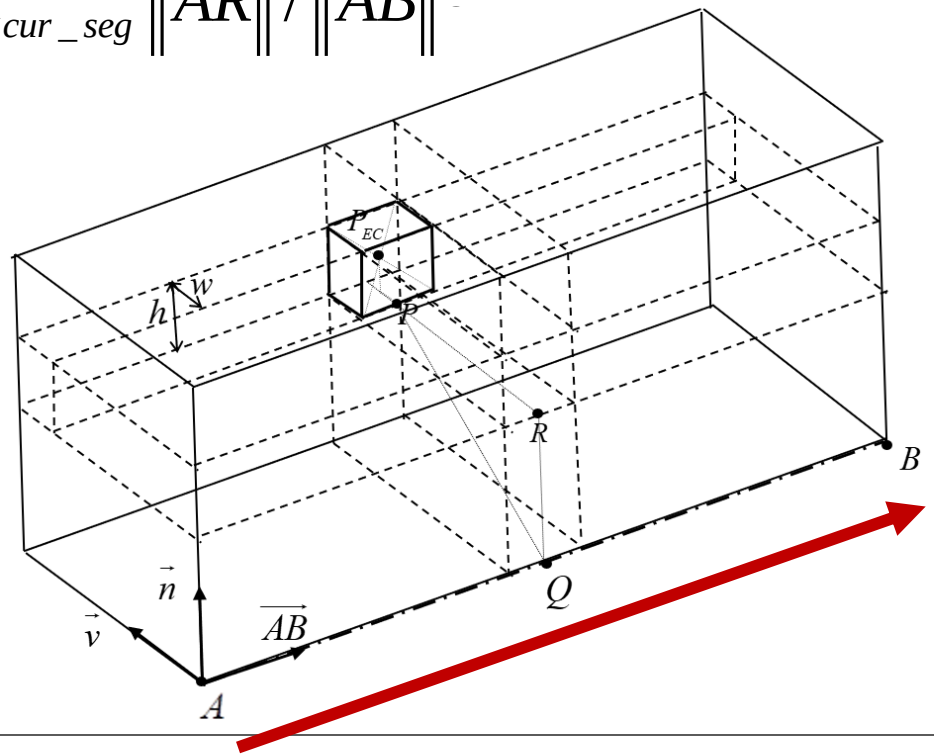


Construction process

- determination of construction time for each element

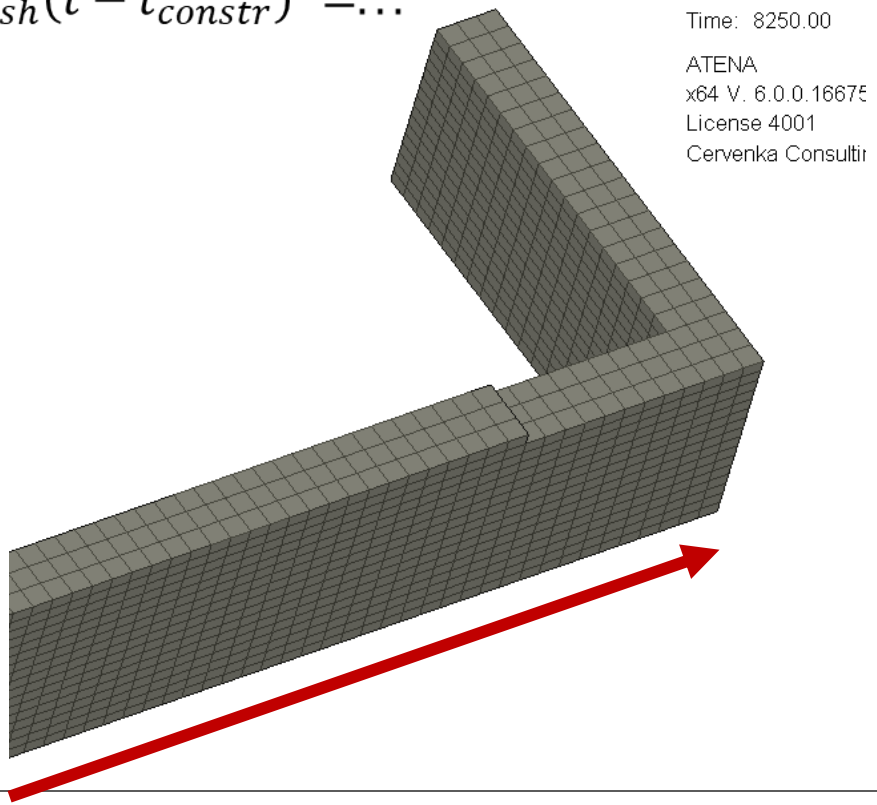
$$t_i^{constr} = \left(l_{id} - 1\right) t_{layer} + t_{prev\_segs} + t_{cur\_seg} \left\|\overrightarrow{AR}\right\| / \left\|\overrightarrow{AB}\right\|$$



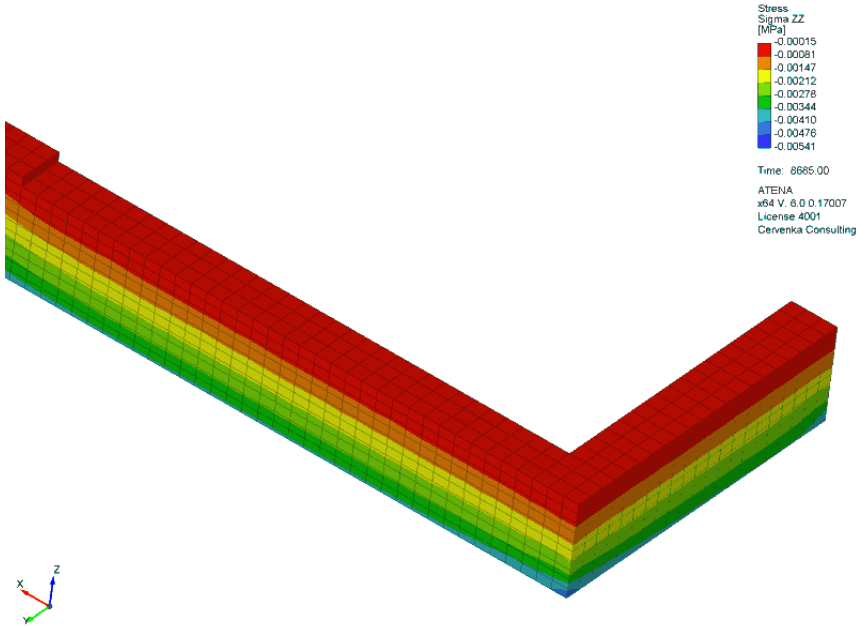


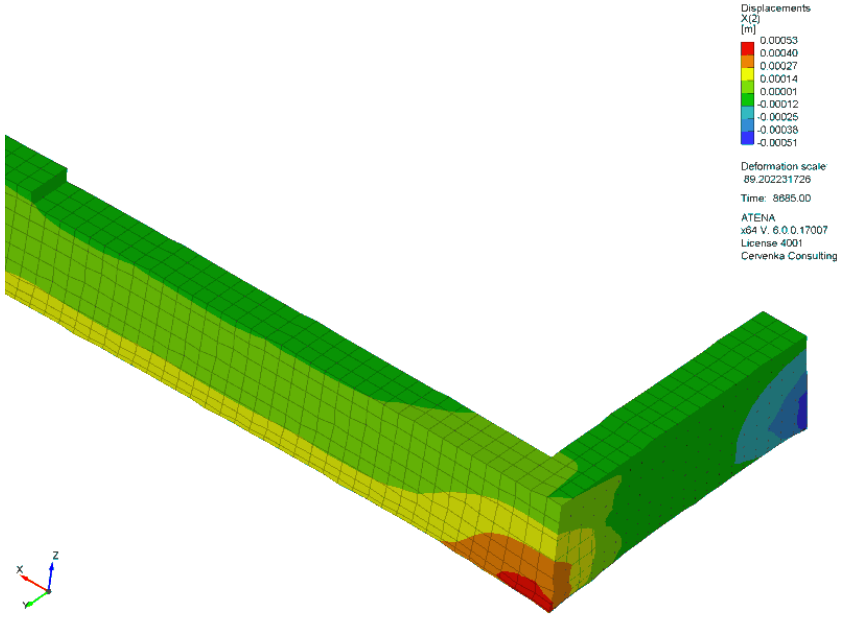
Time effect on load

- self weight body load is applied while printing
- shrinkage element load $\varepsilon_{sh}(t - t_{constr}) = \ldots$



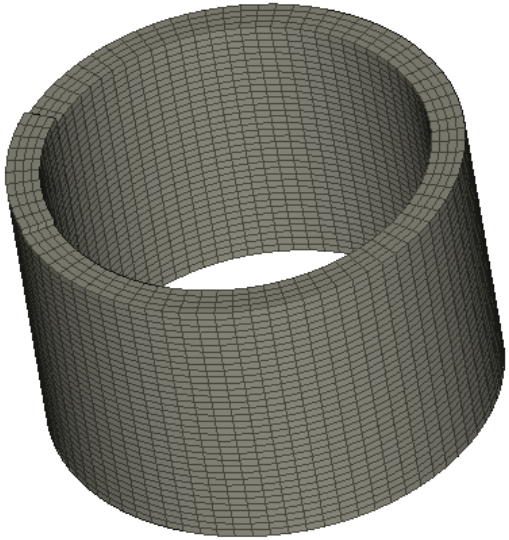
Visualization

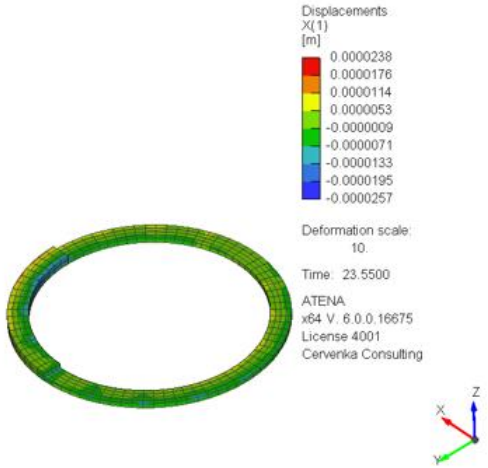


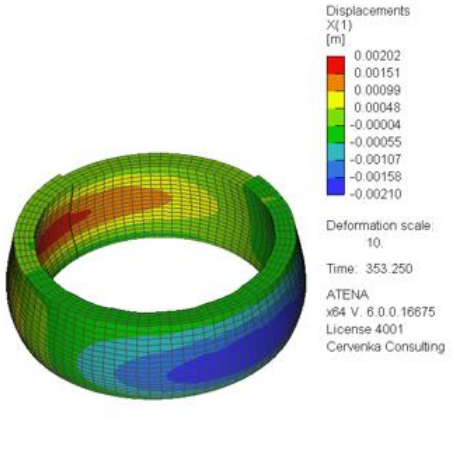


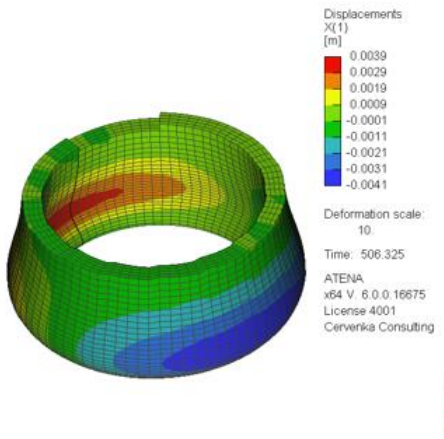
Validation based on literature

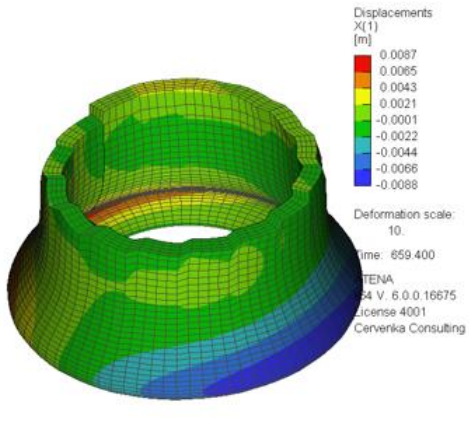
Wolfs at.al. example:







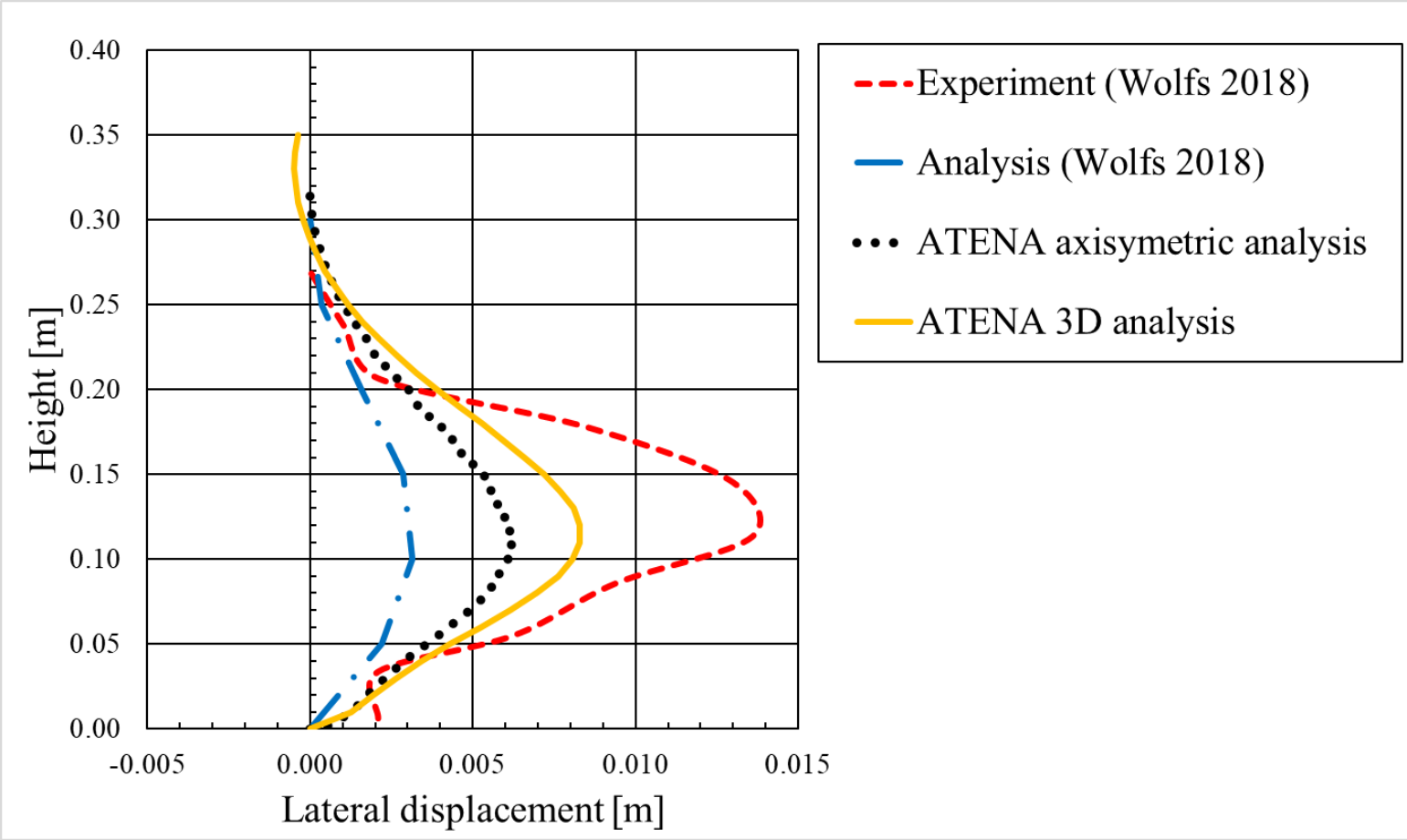




Wolfs at.al. material

Parameter	Name	Unit	Reference
Young modulus	E	MPa	Uniaxial compressive test
Poisson ratio	ν	-	Uniaxial compressive test
Tensile strength	f_t	MPa	Direct shear test
Compressive strength	f_c	MPa	Uniaxial compressive test
Onset of nonlinear behavior in compression	$f_{c,0}$	MPa	Estimated
Specific fracture energy	G_f	kN/m	Model code
Critical compressive displacement	ε_{cp}	m	Uniaxial compressive test (Force vs. displacement plot)
Plastic strain at compressive strength	w_d	-	Uniaxial compressive test (Stress vs. strain plot)
Specific weight	γ	kN/m^3	weighting
Aggregate size	a_g	m	sieving

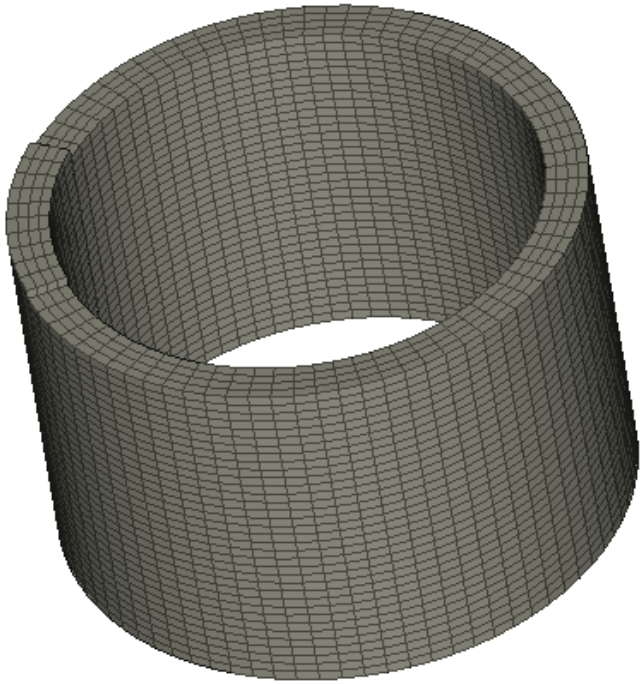
Lateral displacement Experiment vs. Numerical models

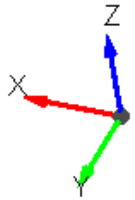


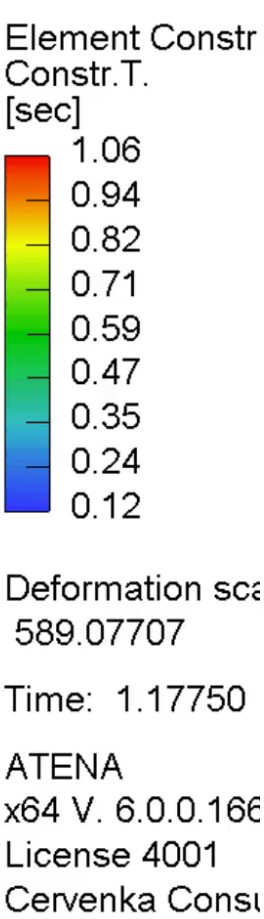
Critical height Experiment vs. Numerical models

Wolfs at.al. example:

-Wolfs 3D experiment	0.29m
-Euler load	0.33m
-Wolfs axisym. (Abacus)	0.46m
-Atena axisym.	0.33m
-Atena 3D model	0.36m






Element Constr
Constr.T.
[sec]
1.06
0.94
0.82
0.71
0.59
0.47
0.35
0.24
0.12
Deformation sca
589.07707
Time: 1.17750
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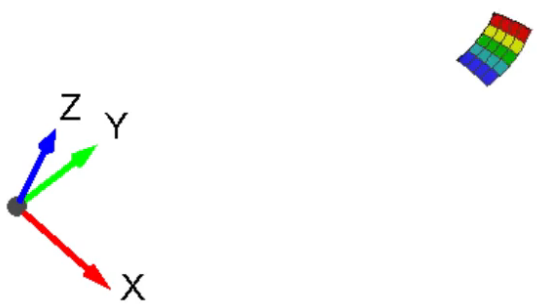
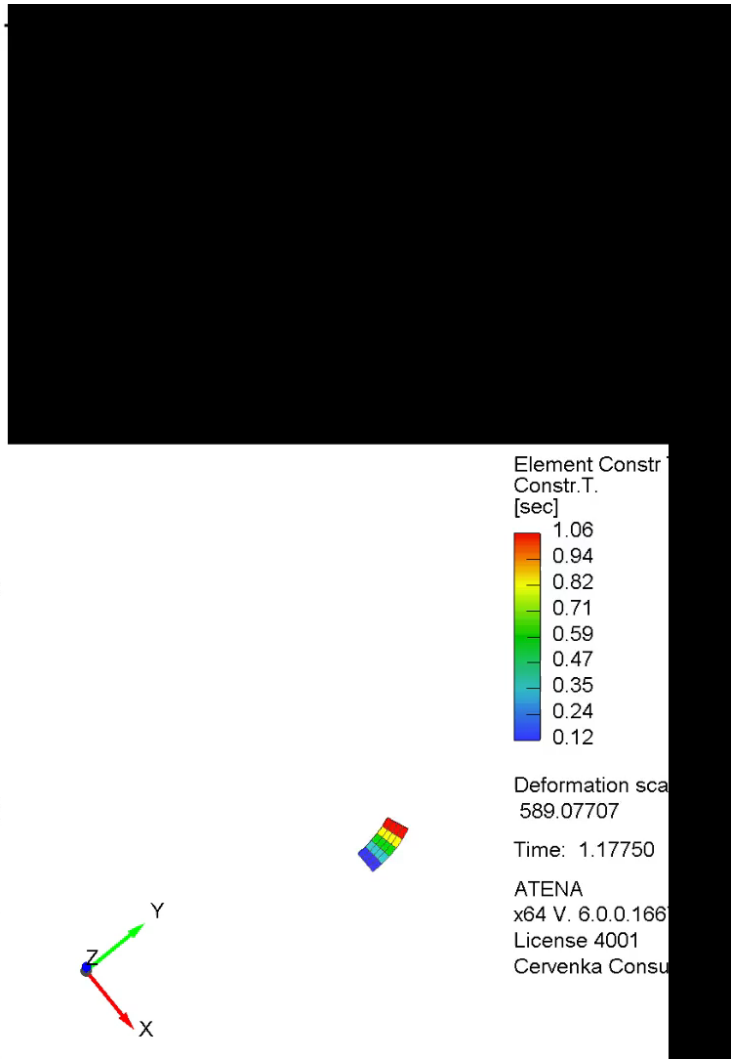

Z
Y
X


Element Constr
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Deformation sca
589.07707
Time: 1.17750
ATENA
x64 V. 6.0.0.166
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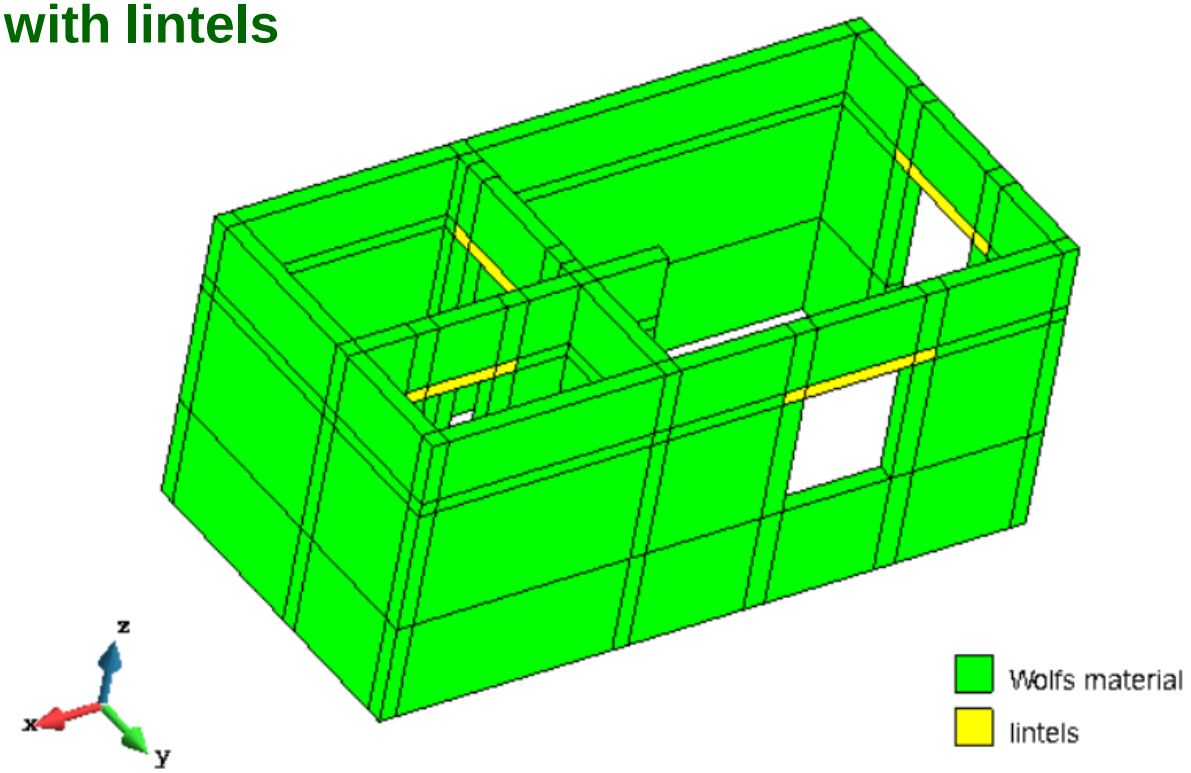
Y
Z
X

Sample analysis

- Simple house with lintels



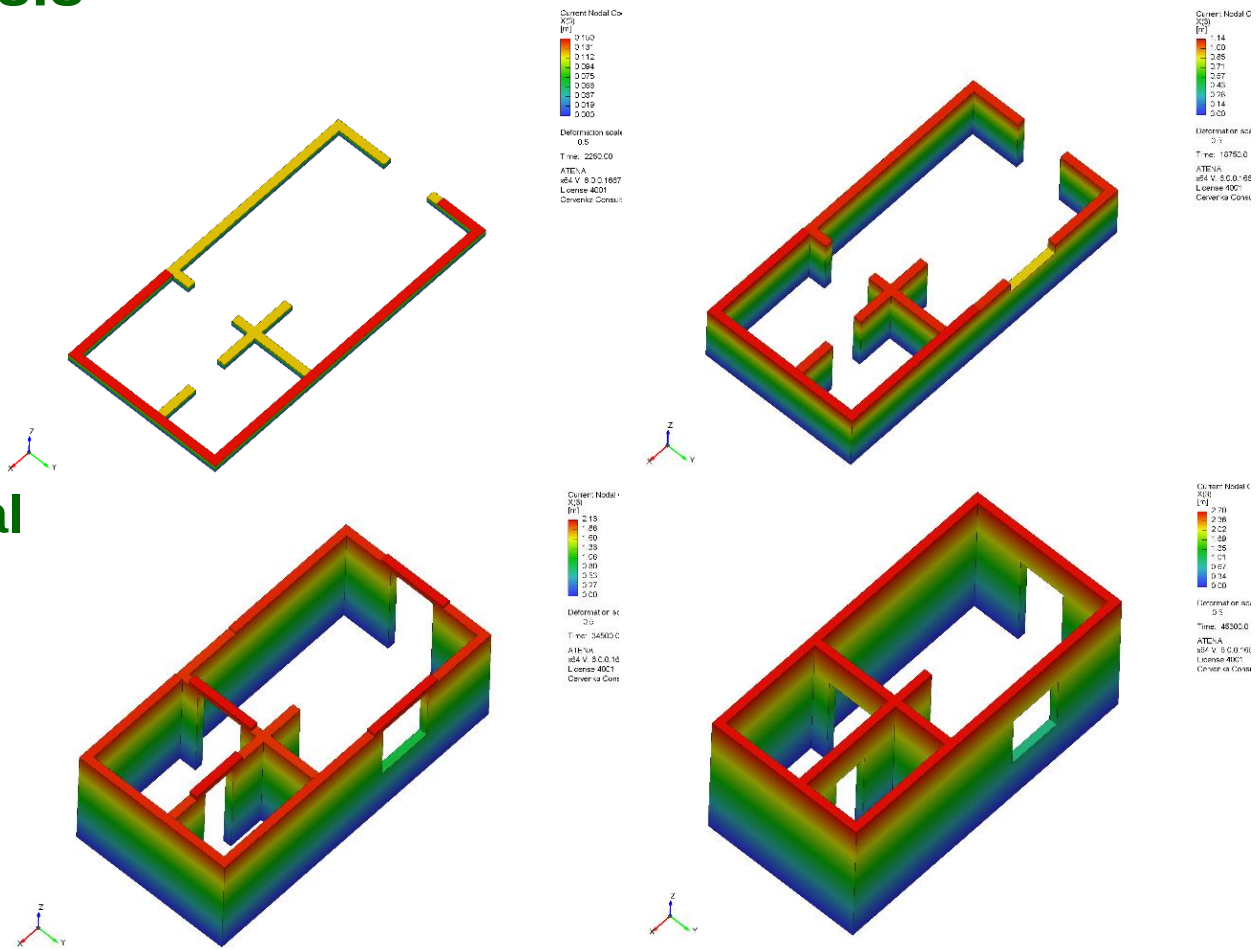
-Project digiCON2 – TU Dresden, Cerion, Cervenka Consulting s.r.o.

Sample analysis

-Printing speed:
5 cm/s

-Printed layer *h*:
3 cm

-Maximum lateral displacement:
4 mm

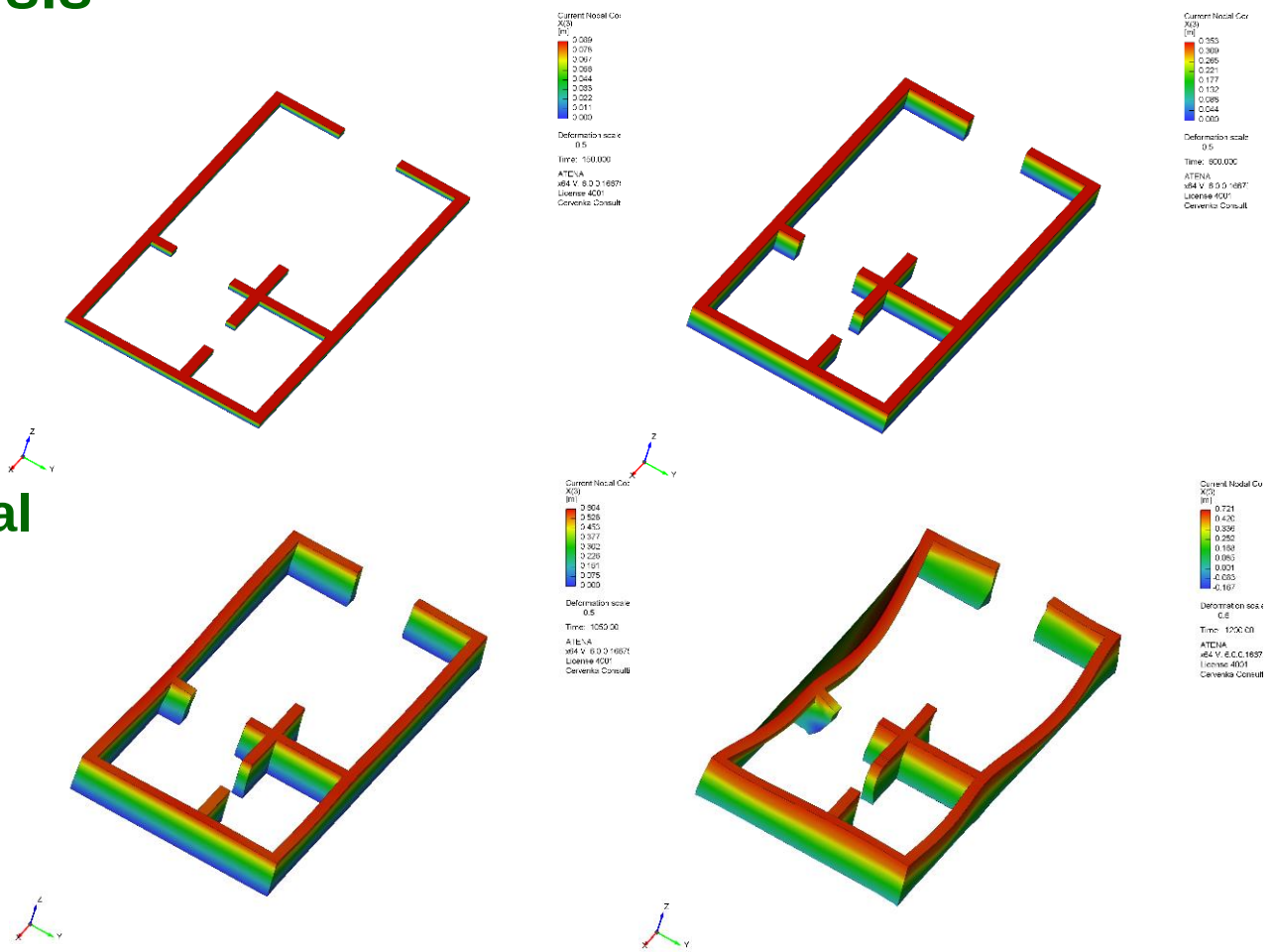


Sample analysis

-Printing speed:
50 cm/s

-Printed layer *h*:
3 cm

-Maximum lateral displacement:
0.9 m



Conclusions

-ATENA module for digital printing of concrete as an extension of standard FEM

-Simple implementation and use

-Available for civil engineering practice

-Good compromise between accuracy, user labor and CPU demands

-Validation analyses – good accuracy

Aknowledgement

TAČR TF04000051 DigiCon2 project "Software for simulation service for digital concrete production„ Technology Agency of Czech Rep.

THANK YOU
FOR YOUR ATTENTION