The use of lightweight structures and optimization methods – a need for a more effective engineering

Habilitation Thesis

Assoc. Prof. Dr. Eng. Marian Nicolae VELEA

Mechanical Engineering Department
marian.velea@unitbv.ro

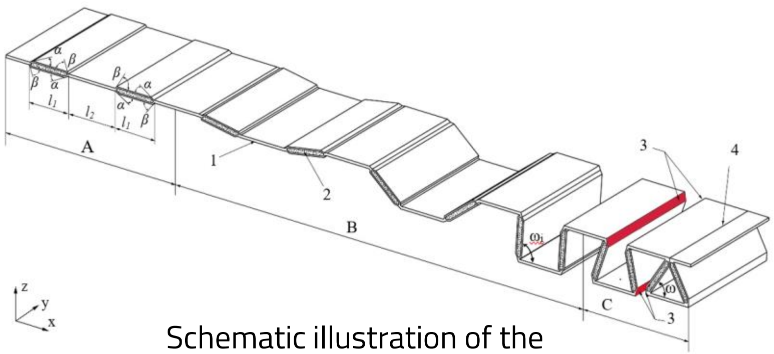
Universitatea Transilvania din Brașov
FACULTATEA DE INGINERIE MECANICĂ

1. **Scientific and professional achievements (2012 – up to date)**
    - Hierarchical sandwich structures
    - Hybrid structures
    - Parametric optimization
    - Non-parametric optimization
    - Multi-objective optimization

2. **The evolution and development plans for career development**

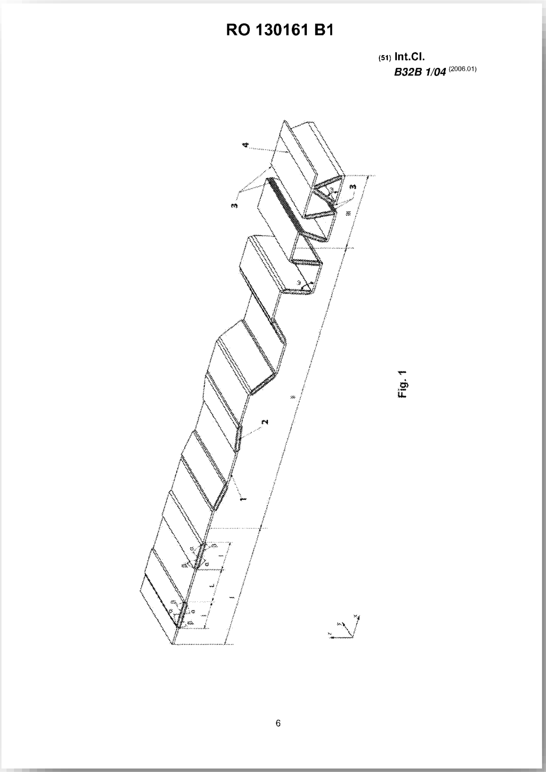
Hierarchical sandwich structures

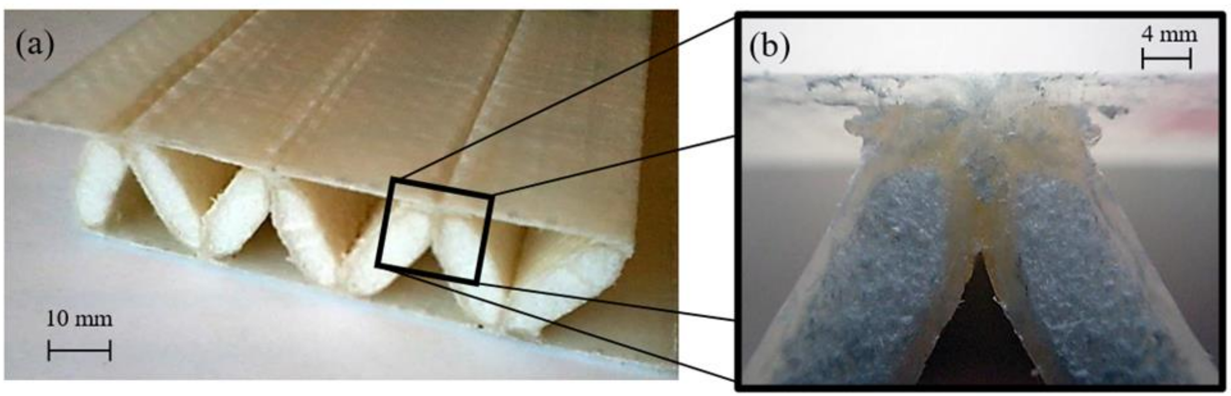
Trifold – hierarchical sandwich structure



Schematic illustration of the manufacturing principle

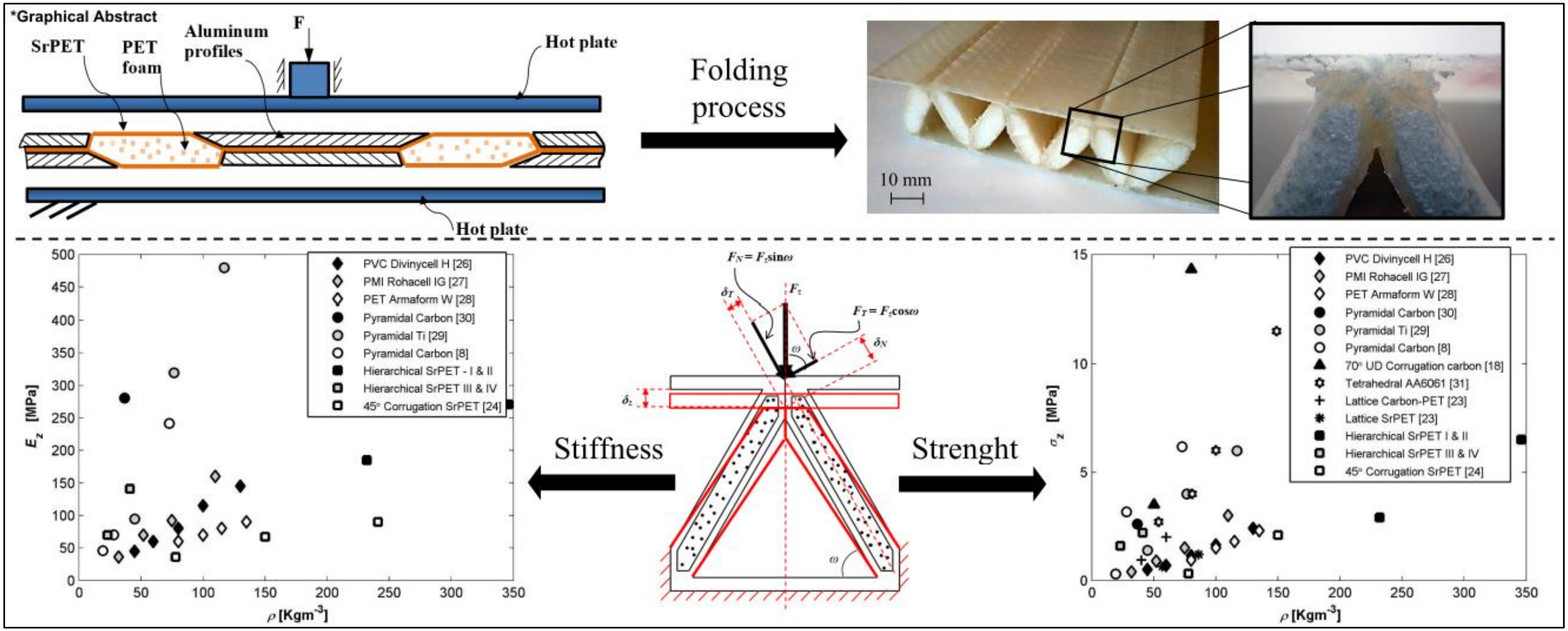
Granted patent





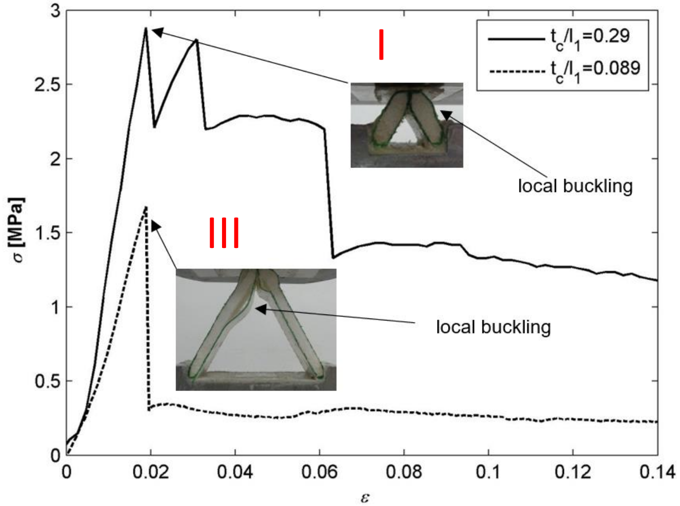
(a) The resulted hierarchical sandwich structure
(b) Cross section within the joining area

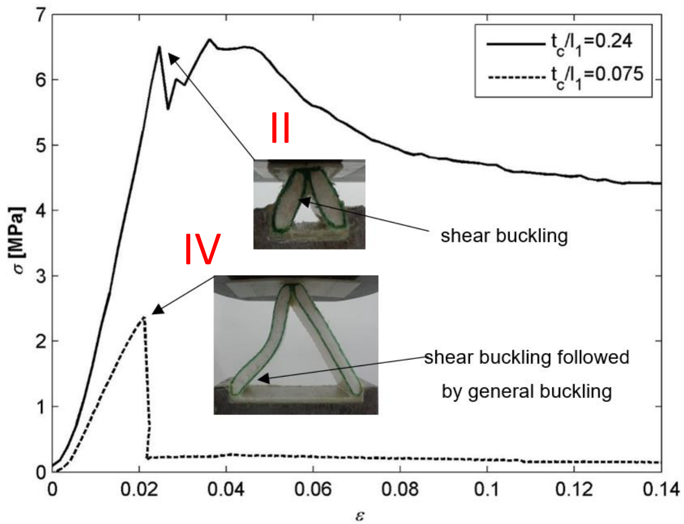
Trifold – hierarchical sandwich structure



Analytical models for stiffness and strength evaluation in out-of plane compression

Analytical results vs. Experiments in quasi-static out-of-plane compression

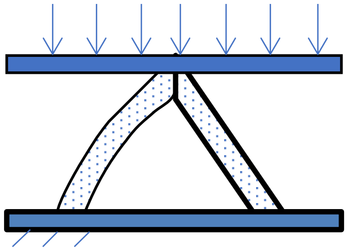




Config	Experimental results				Analytical predictions	
	E_z [MPa]	σ_z [MPa] / Failure mode	E_z/ρ [MPa / kg m^{-3}]	σ_z/ρ [MPa / kg m^{-3}]	E_z [MPa]	σ_z [MPa] / Failure mode
I	185	2.9 / Local buckling	0.79	0.012	236.9	6.2 / Local buckling 419/ General buckling 10.3 / Shear buckling 24.6 / Core shear
II	271	6.5 / Shear buckling	0.78	0.019	455	11.4 / Local buckling 336/ General buckling 8.3 / Shear buckling 20 / Core shear
III	70	1.6 / Local buckling	3.02	0.069	73	1.9 / Local buckling 11.8/ General buckling 3.1 / Shear buckling 7.5 / Core shear
IV	141	2.2 / Shear buckling	3.42	0.054	142	3.7 / Local buckling 11/ General buckling 2.6 / Shear buckling 6.4/ Core shear

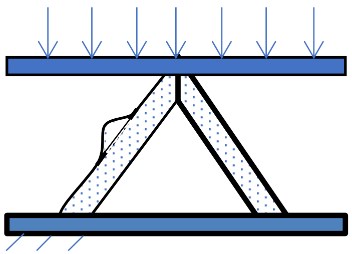
Failure modes

General Buckling



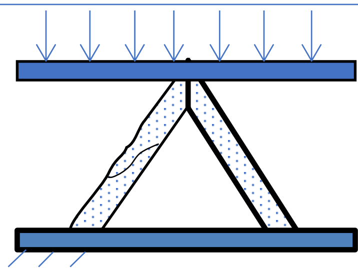
$$\sigma_z = \frac{F_z}{A} = \frac{2E_f\pi^2 t_f \sin\omega\,(t_c+t_f)^2\left(\dfrac{\cos\omega^2}{\dfrac{l_1^2\sin\omega^2}{3(t_c+t_f)^2}+\dfrac{t_c}{G_c(t_c+t_f)^2}}+1\right)}{l_1^2\cos\omega\,(l_1+2t_f)}\ .$$

Local Buckling



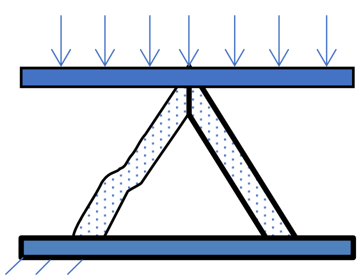
$$\sigma_z = \frac{F_z}{A} = \frac{\sqrt[3]{E_f E_c G_c}\,t_f \sin\omega\left(\dfrac{\cos\omega^2}{\dfrac{l_1^2\sin\omega^2}{3(t_c+t_f)^2}+\dfrac{t_c}{G_c(t_c+t_f)^2}}+1\right)}{\cos\omega\,(l_1+2t_f)}\ .$$

Shear Buckling



$$\sigma_z = \frac{F_z}{A} = \frac{G_c t_c \tan\omega\left(\dfrac{\cos\omega^2}{\dfrac{l_1^2\sin\omega^2}{3(t_c+t_f)^2}+\dfrac{t_c}{G_c(t_c+t_f)^2}}+1\right)}{l_1+2t_f}\ .$$

Core Shear Failure



$$\sigma_z = \frac{F_z}{A} = \frac{\tau_c t_c\left(t_c-\dfrac{\dfrac{G_c l_1^2(\cos\omega^2-1)}{3}}{G_c\cos\omega^2\,(t_c+t_f)^2}+1\right)}{l_1+2t_f}\ .$$

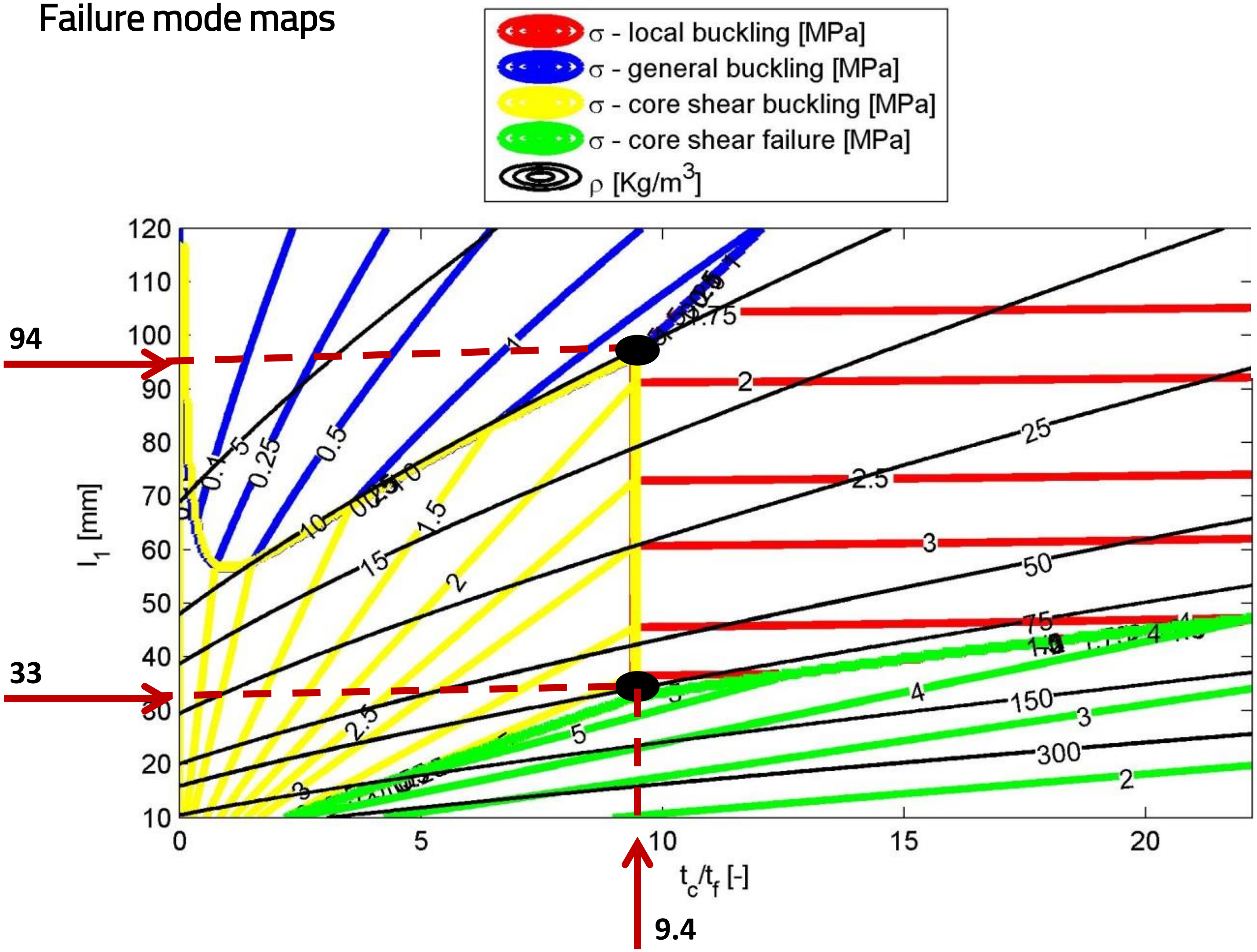
Failure modes

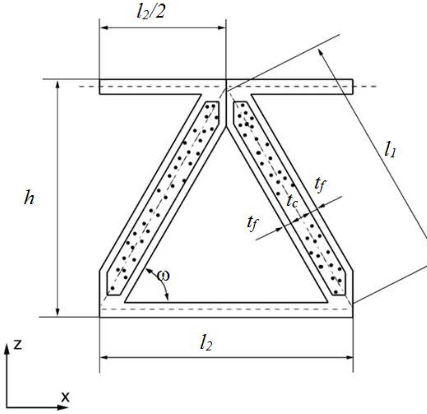
- Maps are generated by using MATLAB scripts
- The strength values are calculated based on the equations of the considered failure modes.
- The lowest calculated value for peak strength give the failure mode.

Calculation sequence

```
for omega=15:0.5:75;
    j=j+1;
    i=0;
    for tc=0:0.05:10;
        i=i+1;
Dsand=(Ef.*tf.*(tf+tc).^2.*b)./2;  % the bending stiffness of sandwich elements
Ssand=(Gc.*(tf+tc).^2.*b)./tc;     % the shear stiffness of sandwich elements
Asand=2.*Ef.*tf.*b;                % the compressive stiffness of foam core
% Constants
RR=1 + (cosd(omega)^2) ./ (sind(omega)^2.*Asand * (l1.^2./(12.*Dsand)) +1./Ssand);
TT=1 + (sind(omega)^2.*Asand * (l1.^2./(12.*Dsand)) +1./Ssand) ./ (cosd(omega)^2) ;
%...
%Face Wrinkling (local buckling)
Fa_wrinkling=(Ef*Ec*Gc)^(1/3).*b.*tf;
sigma_wrinkling=((Fa_wrinkling.*sind(omega))./A).*RR;
%...
        if sigma_wrinkling<sigma_euler & sigma_wrinkling<sigma_shear_foam & sigma_wrinkling<sigma_core_shear_buckling;
            failuremode=1;
            generalbuckling(i,j)=0;
            core_shear_failure(i,j)=0;
            lokalbuckling(i,j)=sigma_wrinkling;
            core_shear_buckling(i,j)=0;
        end
%...
    end
end
```

Failure mode maps

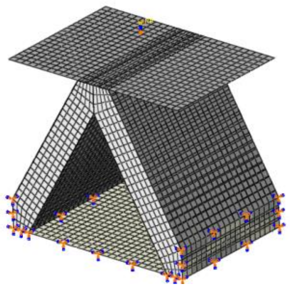


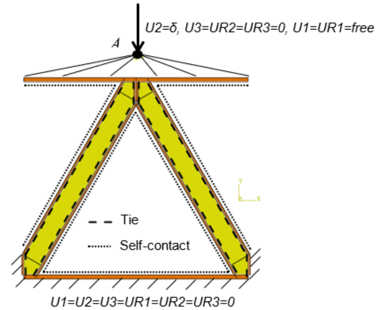


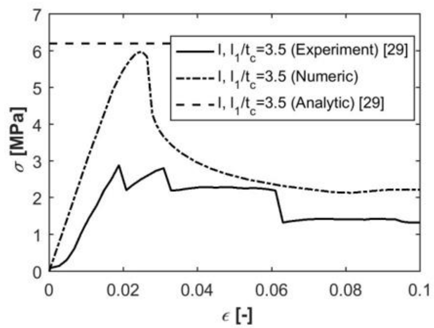
ω=60°

Failure modes maps for the investigated 2nd order hierarchical sandwich structure made from SrPET material and PET foam by assuming ω=60°

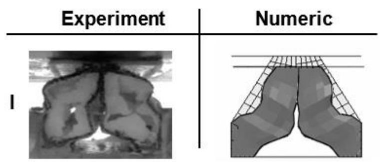
Energy absorption capacity under quasi-static loading conditions (numerical investigation)

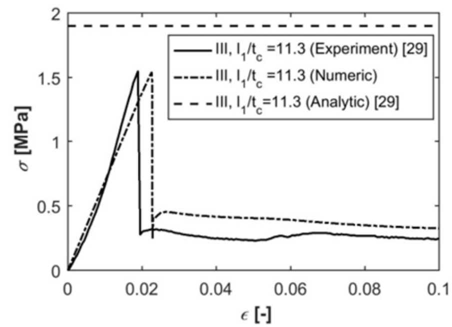




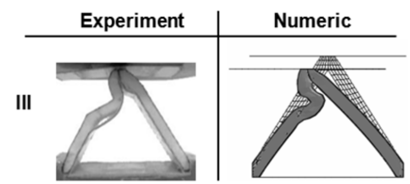


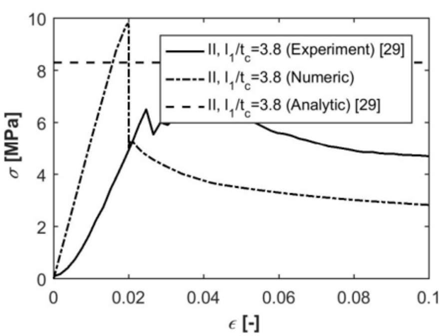
I



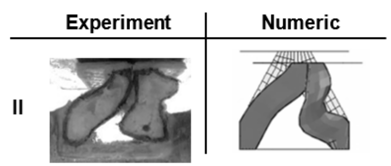


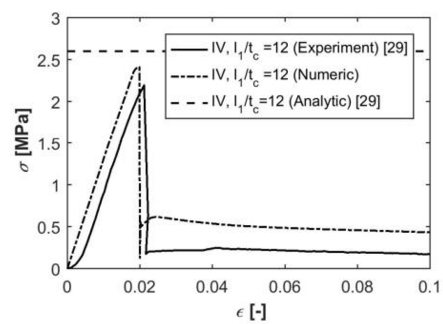
III



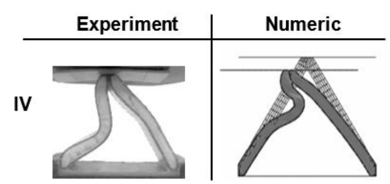


II



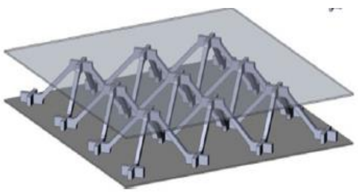


IV

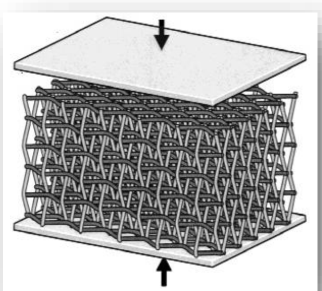


Energy absorption capacity under quasi-static loading conditions

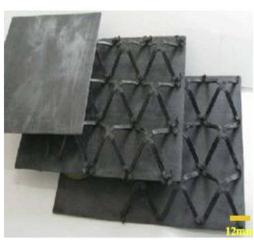
$$E_m = SEA = \frac{E_{abs}}{m}, \qquad \text{where} \qquad E_{abs} = \int_0^{\delta_{max}} F(\delta)\, d\delta,$$



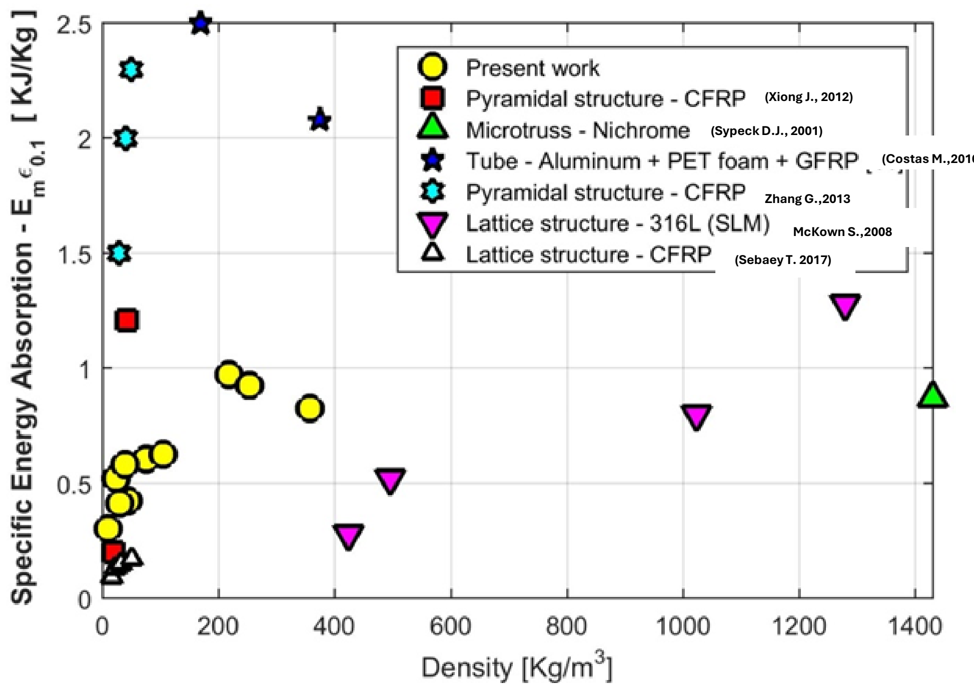
(Zhang G., 2013)



(Sypeck D.J., 2001)

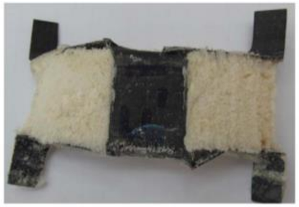


(Xiong J., 2012)



Comparison of the specific energy absorption for different proposed cellular structures for ε = 0.1

(Costas M., 2016)



(Sebaey T., 2017)

(McKown S., 2008)

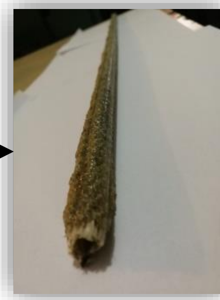
Hybrid Structures

Chassis elements - springs

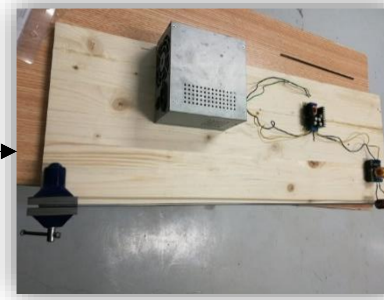
SrPET and CPET weaves

Consolidation under vacuum

SrPET / CPET resulted rod



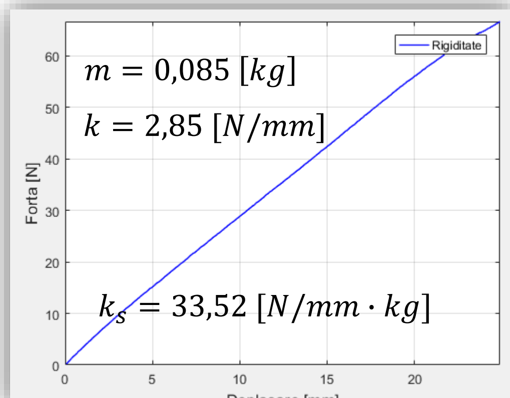
Shape modeling



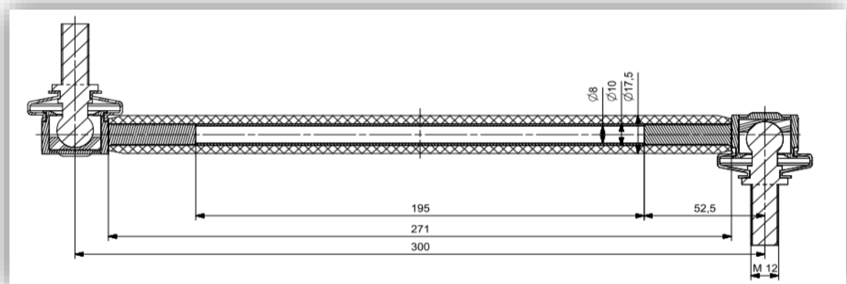
Helicoidal spring SrPET/CPET

Testing

Experimental results



Chassis elements – anti-roll rod



Hybrid concept for an anti-roll rod

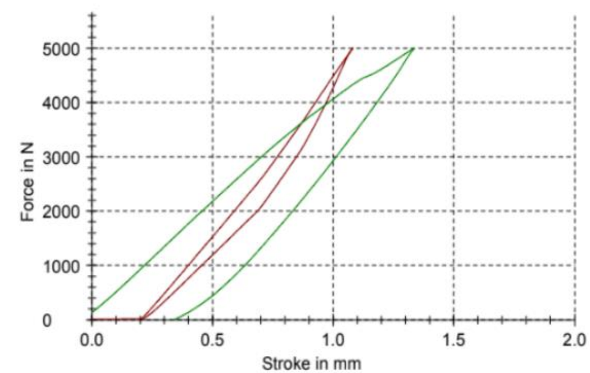
Prototype

Hybrid connecting rod in the vacuum bag prepared for the thermal consolidation process

Results:

	Legends	Nr	Pull out force N
Bieletă oțel		1	5005
Bieltă hibridă		2	5001

Series graph:



Experimental results

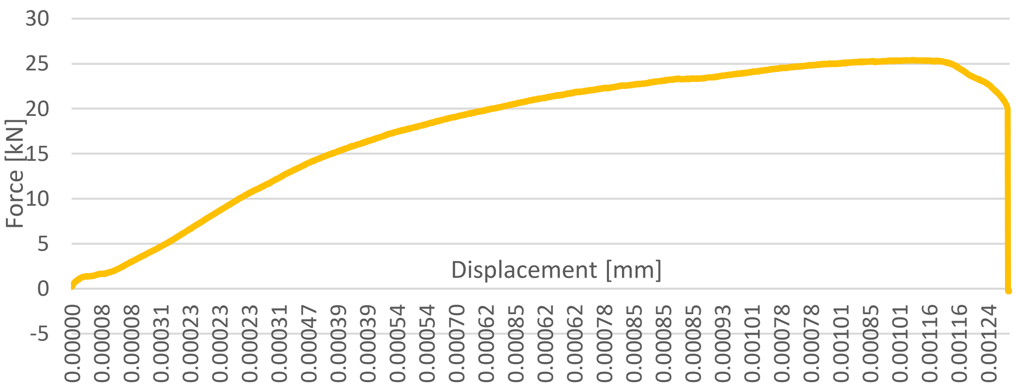
17% mass reduction compared to the steel one, for the same strength

Hybrid joints

Metallic inserts within C/PET weaves

Consolidation under vacuum at 200°C

Resulted hard connection points



Experimental results

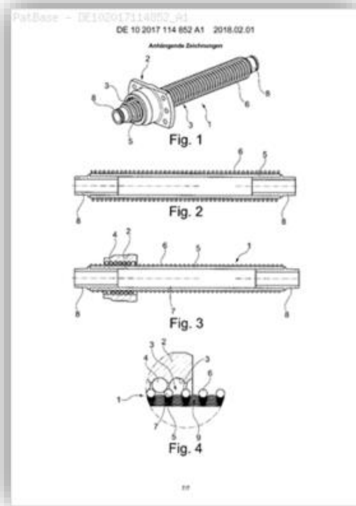
Failure mode

Scientific and professional achievements

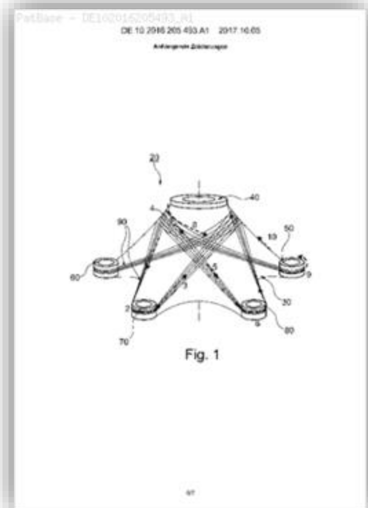
Hybrid structures

Other

Ball screw made from C/PET and steel

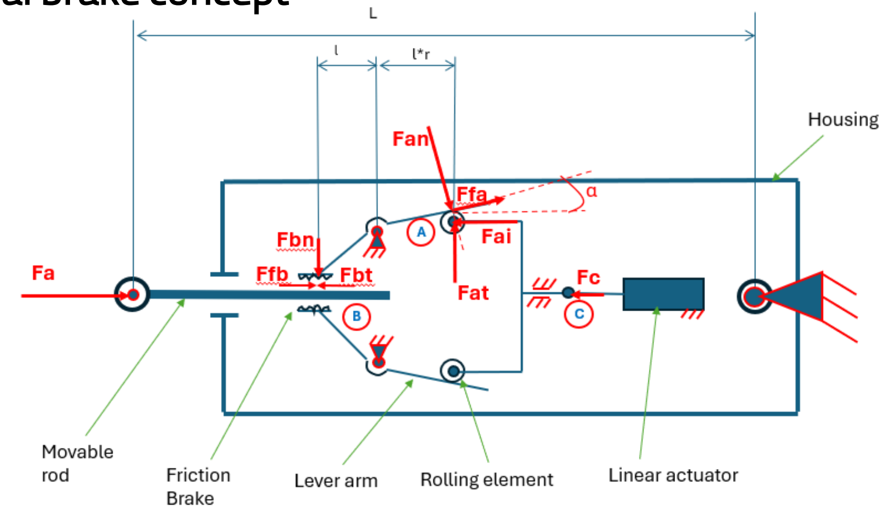


Hybrid flange C/PET and steel



Parametric Optimization

Axial brake concept



Bounds | Modes | Distributions | Links | Constraints

+ Add Input Variable | Remove Input Variable

	Active	Label	Varname	Lower Bound	Nominal	Upper Bound	Comment
1	☑	d	var_1	15.000000	20.000000	30.000000	
2	☑	i_pads	var_2	1.0000000	2.0000000	4.0000000	
3	☑	l_lever	var_3	10.000000	40.000000	50.000000	
4	☑	r_lever	var_4	1.0000000	3.0000000	5.0000000	
5	☑	alpha	var_5	0.5000000	1.8000000	10.000000	
6	☑	mu	var_6	0.3000000	0.5000000	0.5500000	

Define Output Responses | Data Sources | Objectives/Constraints - Goals | Gradients

+ Add Output Response | Remove Output Response | File Assistant | Evaluate from Fit Model

	Active	Label	Varname	Expression	Value	Goals	Evaluate From	Data Type
1	☑	p	r_1	m_1.row_26.col_4.C06_V2	2.3873241	<= 1.0000000	f() Expression	Numeric
2	☑	travel_actuator	r_2	m_1.row_53.col_4.C06_V2	95.461548	Minimize	f() Expression	Numeric
3	☑	Fc - actuator f...	r_3	m_1.row_59.col_4.C06_V2	66.386968	Minimize	f() Expression	Numeric

Movable rod

Inputs			
Geometry			
Diameter	d	29.1142	mm
Loads			
Axial force	Fa	1000.0	N
safety factor	beta	1.5	-
Calculation force	Fa	1500	N

Brake

Inputs			
Geometry			
Friction surfaces (two pair pads)	i_pads	4	-
Friction radius	Rmed	14.5571	mm
Width of the pads	l_pads	40	mm
angle	alpha	90	deg
Friction area	A	3659	mm^2
Distance required to unlock the system	du	1	mm
Friction coefficient	mu	0.55	-
Loads			
Axial Force	Fbt	1500	N
Outputs			
Force needed to brake	Fbn	2727.3	N
Specific pressure	p	0.745	MPa

Lever arm

Inputs			
Geometry			
Length l	l_lever	49.9935	mm
Ratio	r_lever	5	-
Loads			
Force at point B required to lock	Fbn	2727.3	N
Outputs			
displacemnt of point A	delta_A	5	mm
Force at point A required to brake	Fa	545.5	N

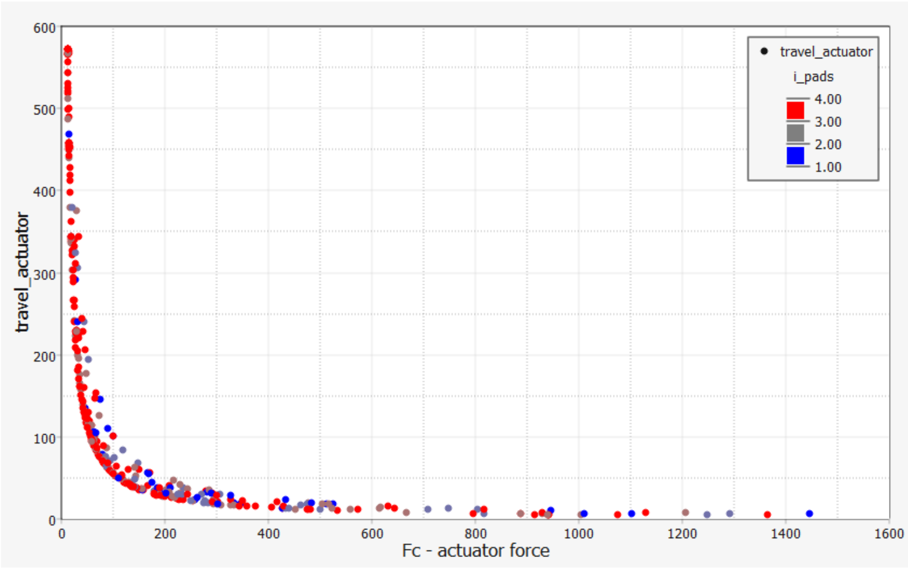
Rolling elements and connical part

Inputs			
Geometry			
Angle	alpha	0.50	deg
Friction coefficient	mu	0.002	-
No of arms - rollers		2	-
Loads			
Force	Fa	545.46	N
Outputs			
Bending force on the arm	Fat	545.409	N
travel distance	travel_actuator	572.943	mm
Required force to brake	Fai	5.74	N

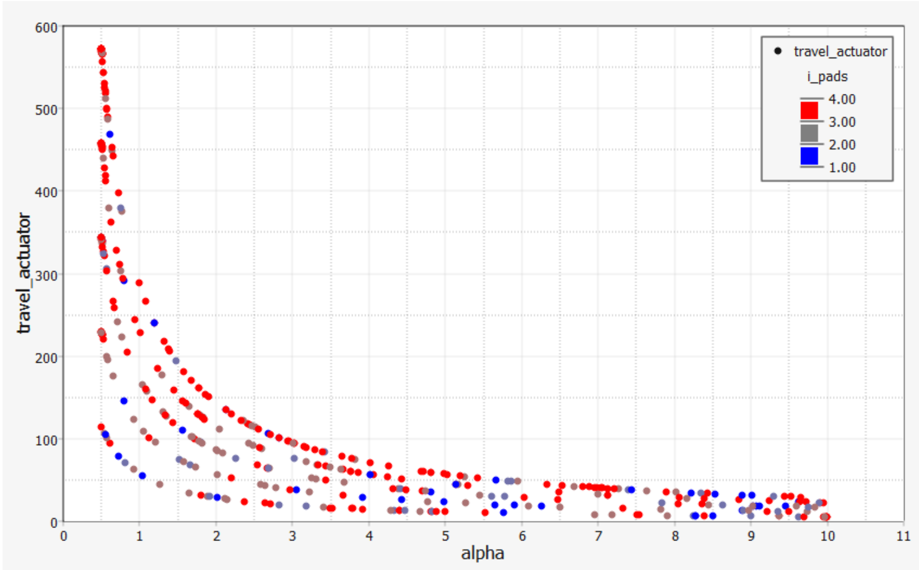
Actuator

Inputs			
Axial force	Fc - actuator force	11.5	N

Axial brake concept



Trade-off between actuator force and the required travel distance while indicating the number of friction pads



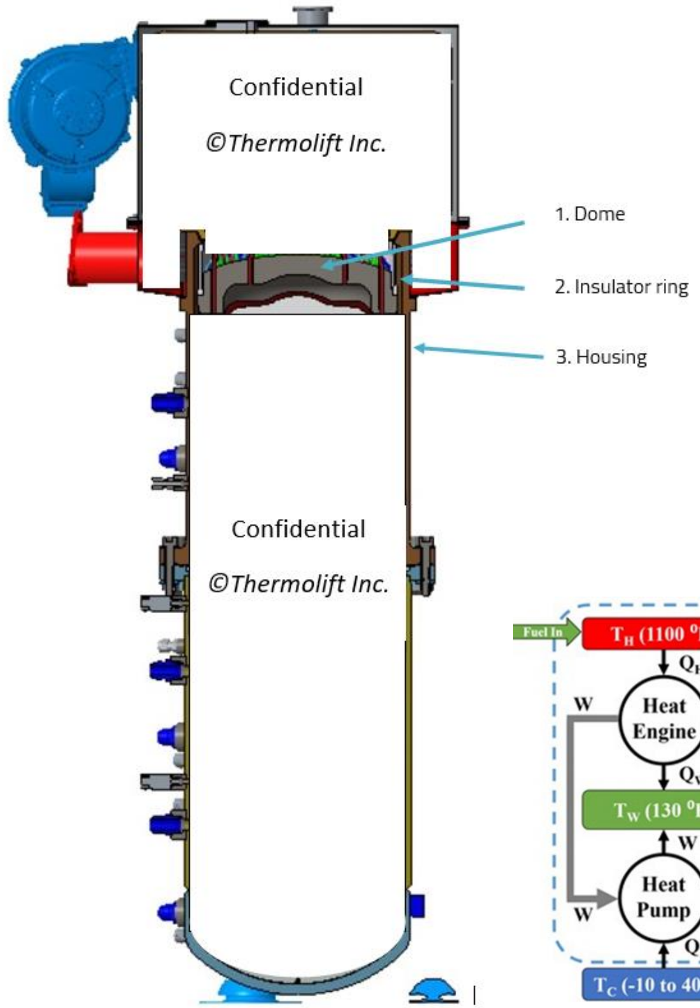
All calculated solutions. Trade-off between alpha and the required travel distance

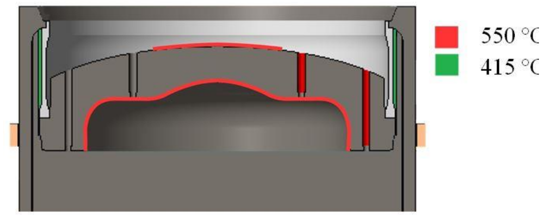
Non-parametric Optimization

Scientific and professional achievements

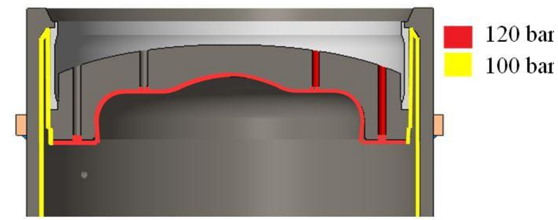
Non-parametric optimization

Thermolift heat pump

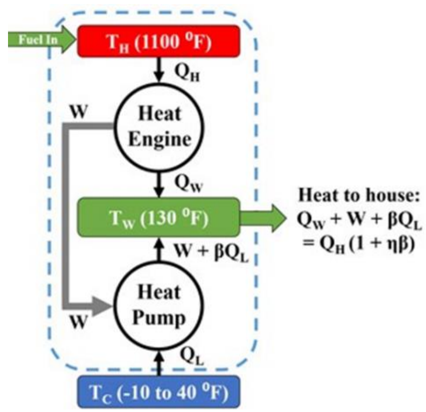




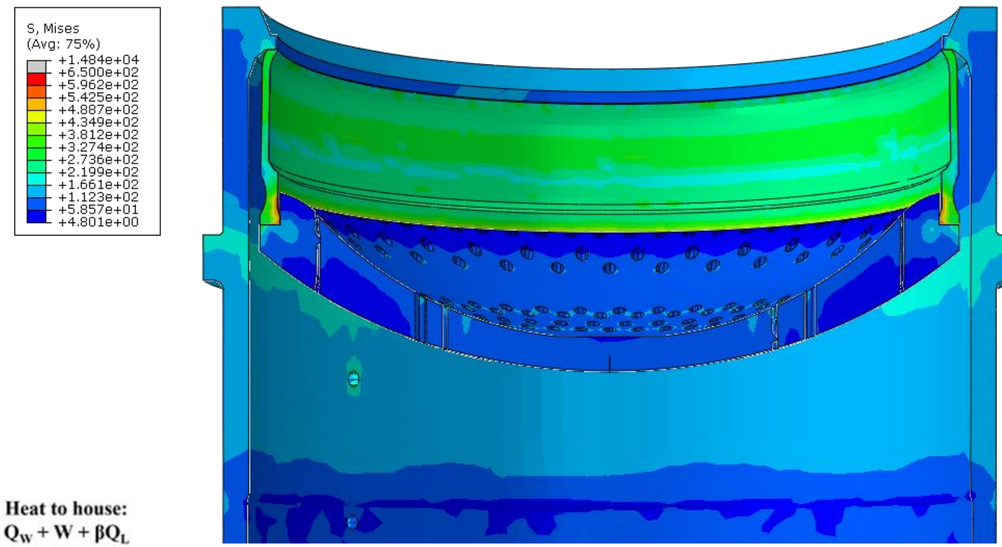
Thermal Loads



Mechanical Loads



Working principle



von Misses stress distribution within dome and insulation ring – optimal shape

- **mass of the dome is reduced by approx. 45 %**

Multi-objective Optimization

Scientific and professional achievements

Multi-objective optimization

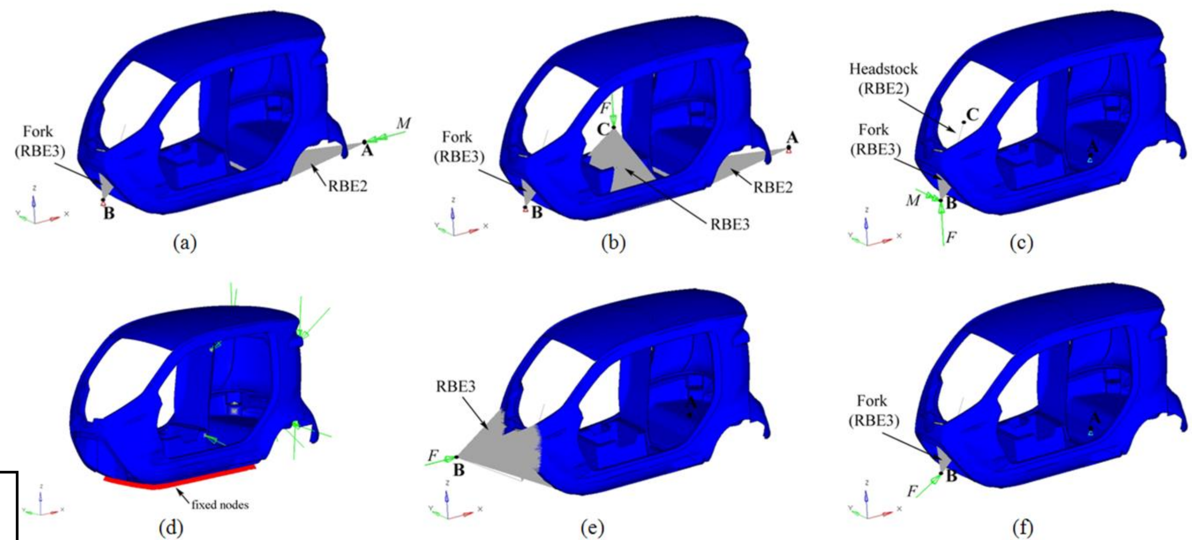
Zbee vehicle

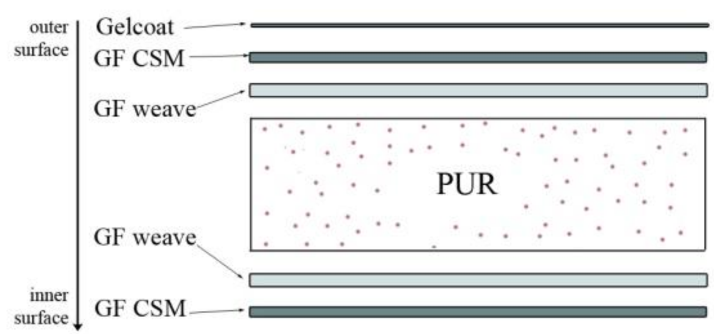
Optimization problem:

Objectives:
- min mass
- min cost
- max torsion stiffness
- max bending stiffness
- min deformation (impact)
- min headstock displacement (curb strike)
- min headstock displacement (front brake)

Constraints:
- Manufacturing constraints
- Hill Failure index < 0.2

The applied loads and constraints

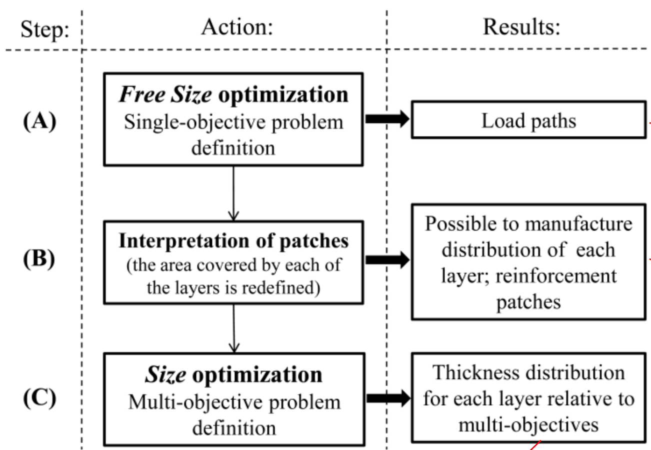


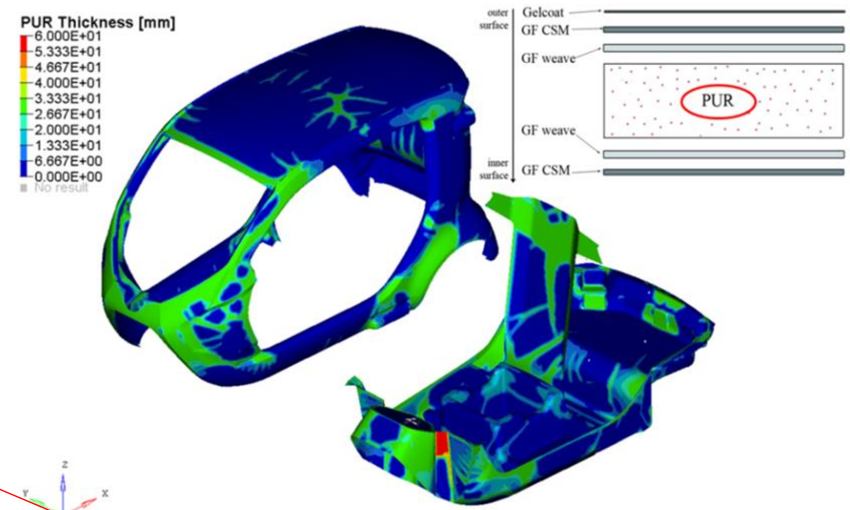


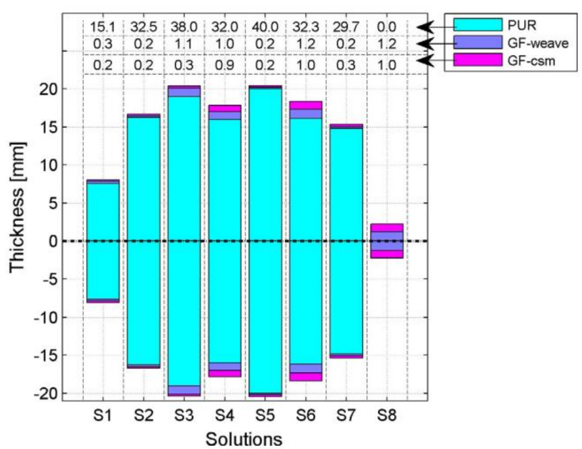
Section within the composite body structure

Zbee vehicle

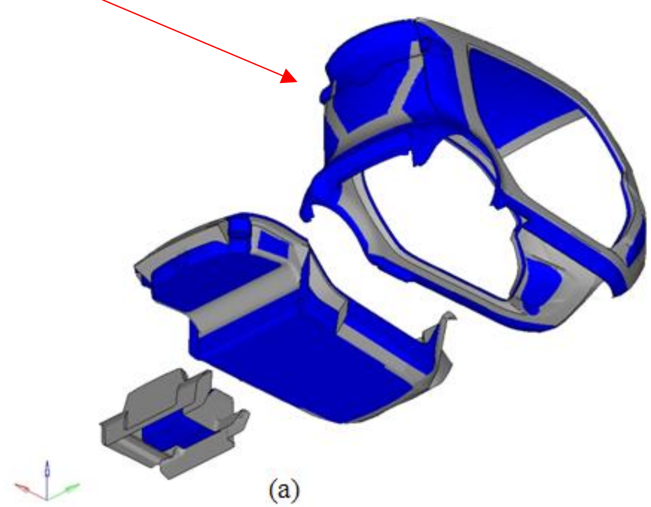
Optimization methodology applied on the composite body





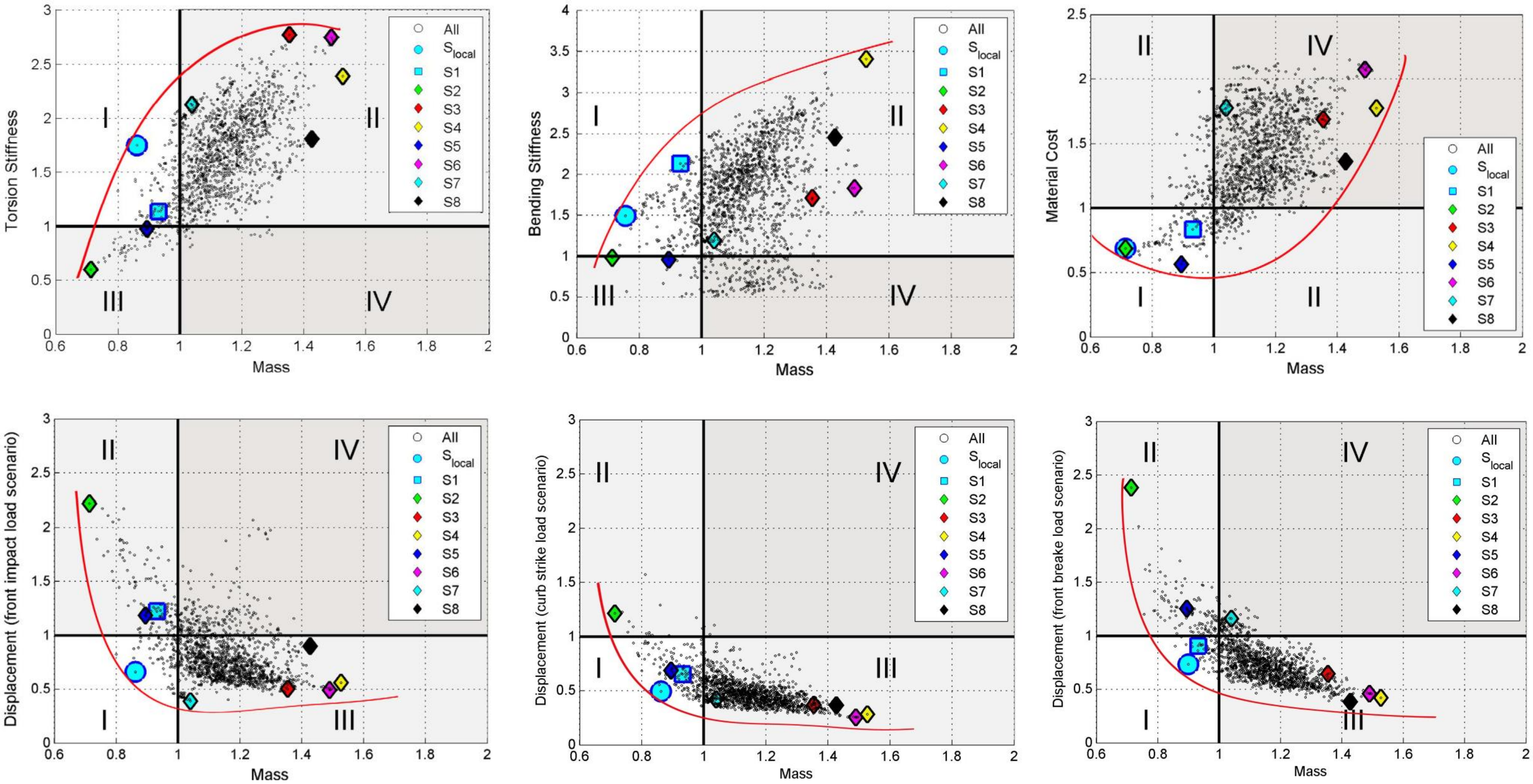


Thickness distribution of the selected patch

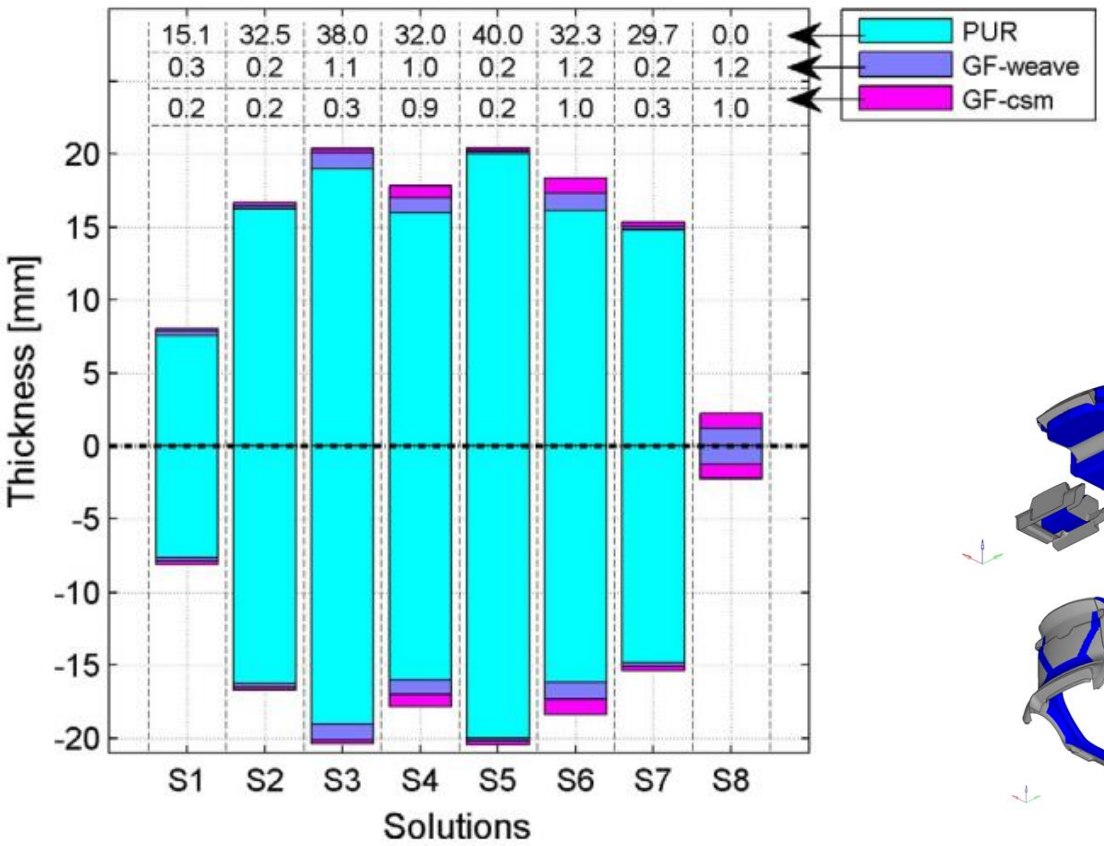


Interpretation of the layers' distribution within the composite body following the free size results

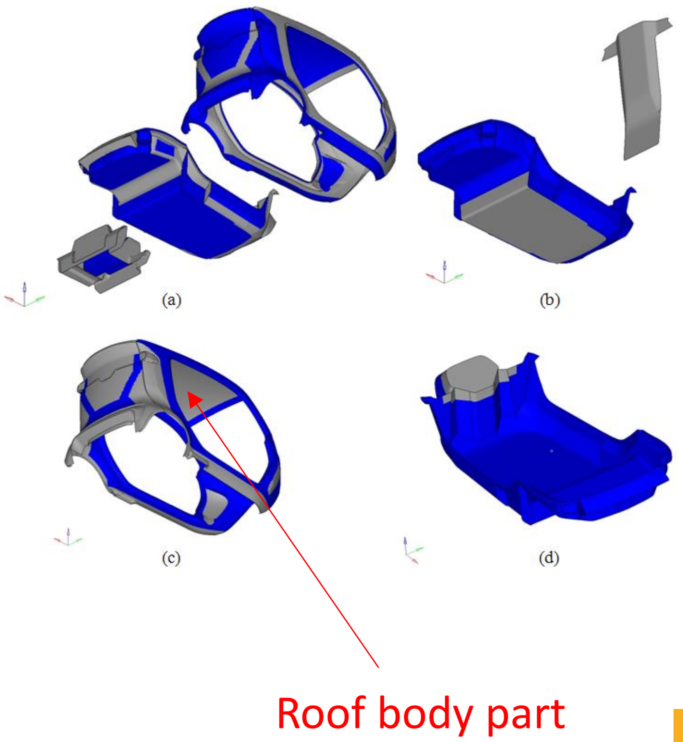
Zbee vehicle



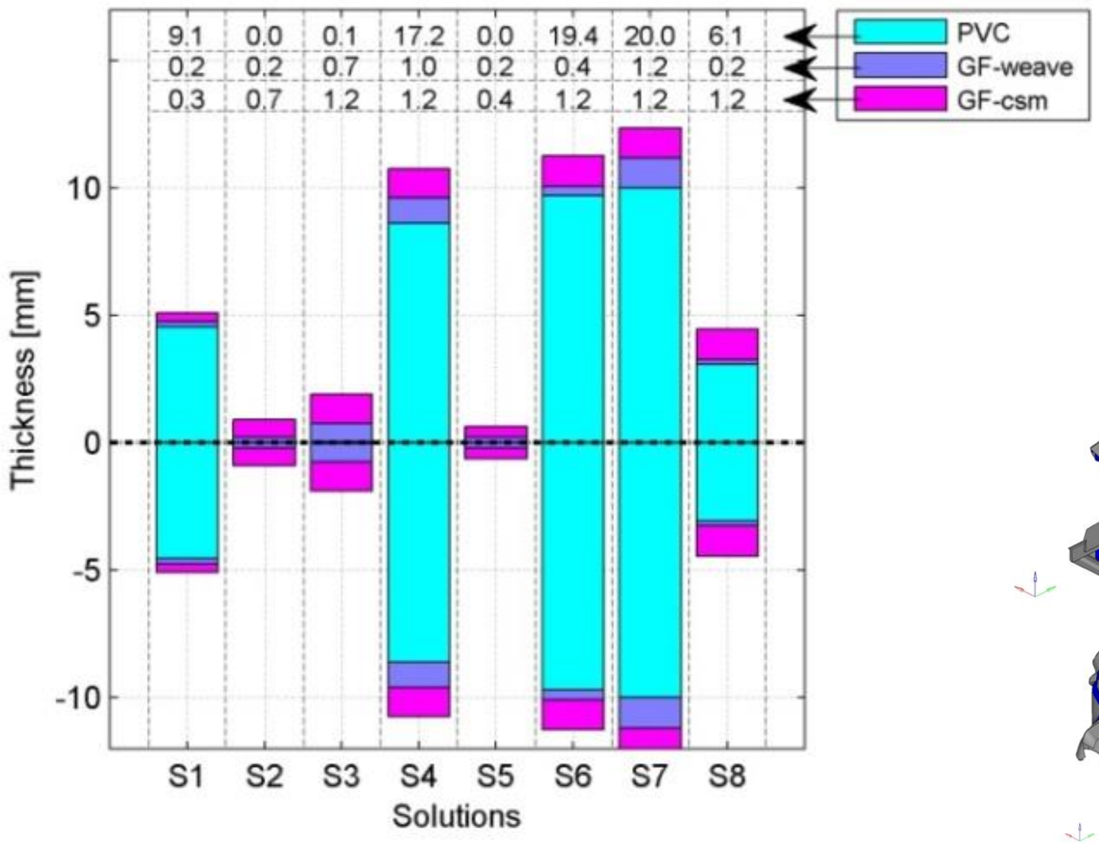
Zbee vehicle



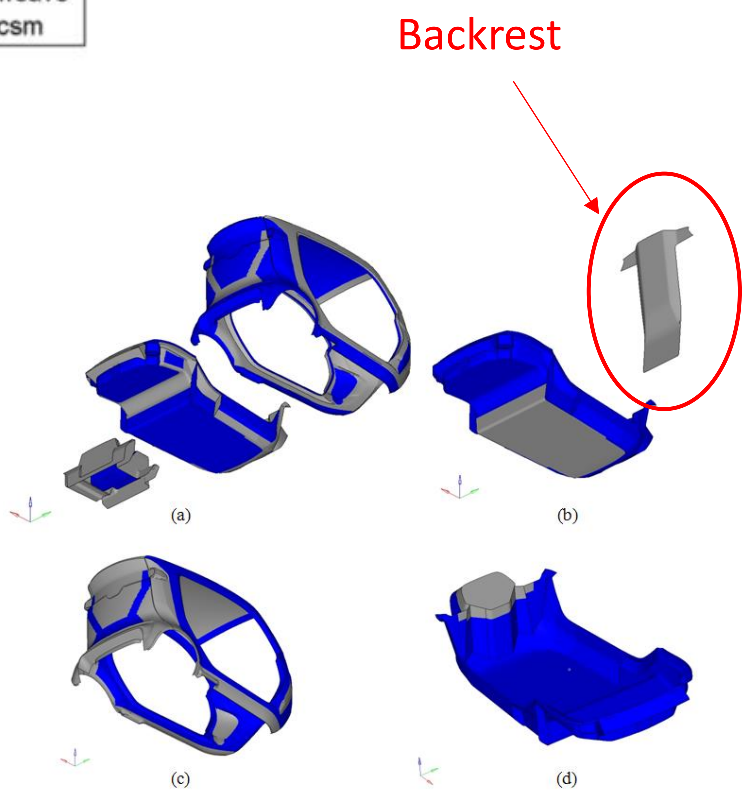
Values of the layers' thicknesses obtained for the Roof body part, for the selected design solutions



Zbee vehicle



Values of the layers' thicknesses obtained for the Backrest body part, for the selected design solutions



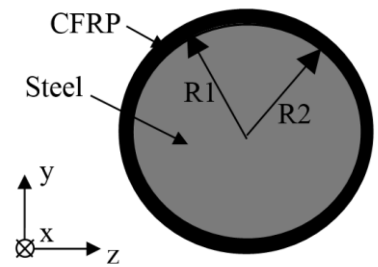
Anti-roll adjusment system

Steel housing and arms

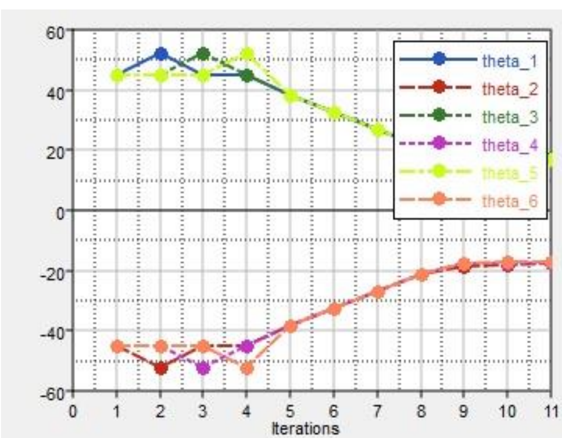
[Schaeffler product]

CFRP body (arms and housing)

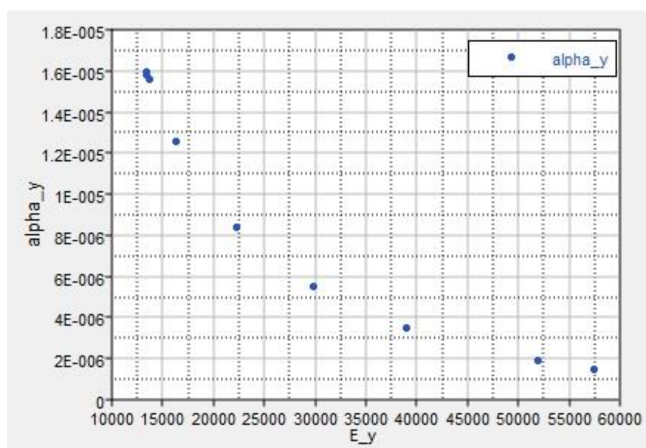
Hybrid steel-composite connection



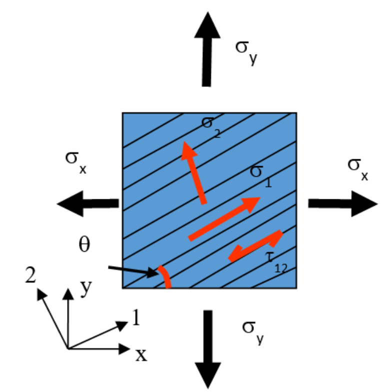
Thermal expansion [1/°C]	Steel	Carbon fiber	Epoxy resin
α_1	16E-6	-0.6E-6	55E-6
α_2	16E-6	8.5E-6	55E-6



Fiber orientation



Pareto front



Local and global coordinates of the lamina

The evolution and development plans for career development

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13 Co-authors

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ftimiciuc, Mihaela A.	3
enkert, Dan	2
chneider, C.	2
azemahvazi, Sohrab	1
Jitarașu, Octavian	1

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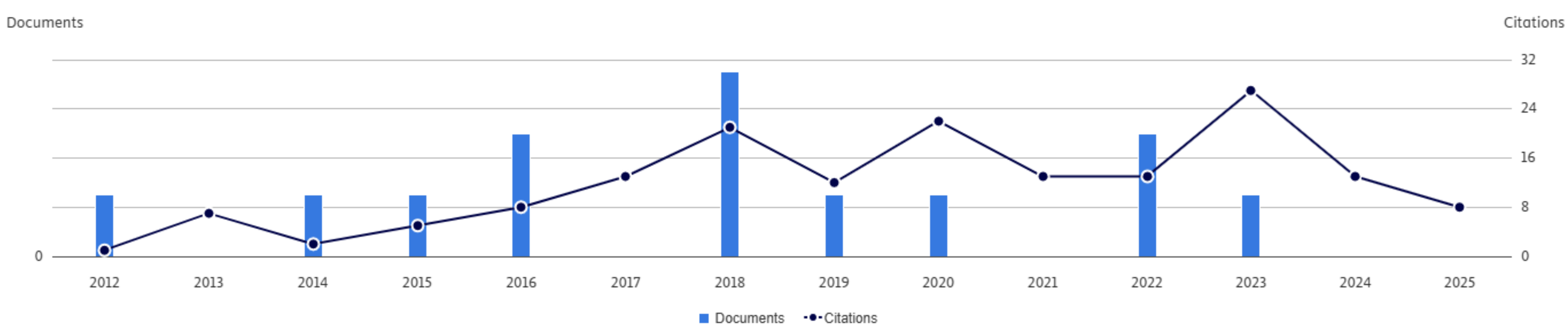

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Marian Nicolae VELEA
Transilvania University of Brașov
Verified email at unitbv.ro - Homepage

Lightweight structures Optimisation Methods Hybrid structures

FOLLOWING

TITLE	CITED BY	YEAR
Compression properties of novel thermoplastic carbon fibre and poly-ethylene terephthalate fibre composite lattice structures C Schneider, MN Velea, S Kazemahvazi, D Zenkert Materials & Design (1980-2015) 65, 1110-1120	66	2015
Multi-objective optimisation of vehicle bodies made of FRP sandwich structures MN Velea, P Wennhage, D Zenkert Composite Structures 111, 75-84	52	2014
Second order hierarchical sandwich structure made of self-reinforced polymers by means of a continuous folding process MN Velea, C Schneider, S Lache Materials & design 102, 313-320	24	2016
In-plane effective elastic properties of a novel cellular core for sandwich structures MN Velea, S Lache Mechanics of Materials 43 (7), 377-388	24	2011
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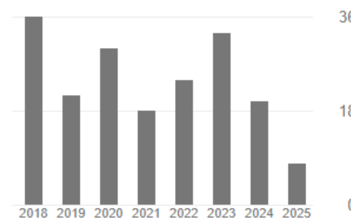

Co-authors EDIT

- Simona Lache — Professor, Transilvania Universit…
- Per Wennhage — KTH Royal Institute of Tehcnology
- Dan Zenkert — KTH
- Sohrab Kazemahvazi — University of Cambridge
- Calin Husar — Siemens Industry Software
- Ioan Calin ROSCA — Professor, Transilvania Universit…
- Marius Cristian Luculescu — Transilvania University of Brasov

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2. **Velea, M.N.,** Lache, S., 2018, Failure mode maps of a hierarchical sandwich structure made of self-reinforced PET, AIP Conference Proceedings 1932, 030022
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1. **Velea, M.N.,** 2022, Matlab – Instrument de calcul în inginerie, Editura Universității Transilvania din Brașov.
2. Dima, G.D., **Velea, M.N.,** 2016, CATIA V5 - Proiectare de Produs, Editura Universității Transilvania din Brașov
3. **Velea, M.N.,** 2011, Structuri celulare uşoare – Concepție, Modelare şi Analiză, Editura Universității Transilvania din Braşov.

Research perspective – intentions for the future would be:

- **to enlarge the existing research group** with scientific interests and objectives in the field of lightweight structures and optimization methods;
- to create and maintain **professional links** with researchers from other European countries; attracting funds from research grants;
- **to collaborate with the economic entities** in order to raise their interests in collaborating with the Romanian academic sphere, and to provide success collaboration stories regarding transfer of knowledge to industry;
- to capitalize the research results by publishing **scientific papers in international journals**;
- to protect and exploit the results of research with economic potential by obtaining **invention patents** and to carry out **technological transfer to the industrial environmen**t.

Didactic perspective – intentions for the near future would be:

- **to affiliate to the doctoral school of Unitbv**
- **to coordinate Ph.D students** in the field of **lightweight structures and optimization techniques**
- to motivate and attract students by **highlighting the practical implications of the taught subjects**;
- to present an **interdisciplinary approach**, facilitating the creation of connections between the knowledge accumulated by students in other disciplines and those to be acquired;
- **to invite external specialists** from the research or industry environment in the course/seminar/laboratory hours to reinforce and demonstrate the use of the concepts presented in the taught subjects, through practical, real examples;

Management perspective

- The **involvement in management activities will be carried on** (currently I am coordinating the master program **Simulation and Testing in Mechanical Engineering**)

- **Other management responsibilities will be assumed if / when those are needed** within the appropriate context.

Thank you!