FUNDING APPLICATION

Project Title:

Manufacturing of sandwich panels with metamaterial cores using conventional fabrication technologies for large scale production opportunities

Universitatea Politehnica Timișoara

Project Director: **Dr. Ing. Dan-Andrei ȘERBAN**

B. Project Proposal

B.2 Scientific description.

B. 2.1 Project Scope and Objectives

Metamaterials are a class of tessellated cellular structures with engineered geometries (that have no equivalence in Nature, Figure 1) [1, 2], which present mechanical properties that tend to be higher than those of technologically generated cellular structures (polymeric, metallic or ceramic foams) of similar densities [1, 3, 4] (due to the regularity of the pattern as opposed to the random cell sizes and the occurrence of defects, as observed in regular foams [5, 6], Figure 2). Currently, the manufacturing of metamaterial structures is limited to rapid prototyping (RP) [1, 2, 7], which represents a serious hindrance in the wide spread application of these superior structures, due to the various constraints of the RP technologies (the main being the high cost of the base materials, long manufacturing times and limited volume, according to each prototyping machine).

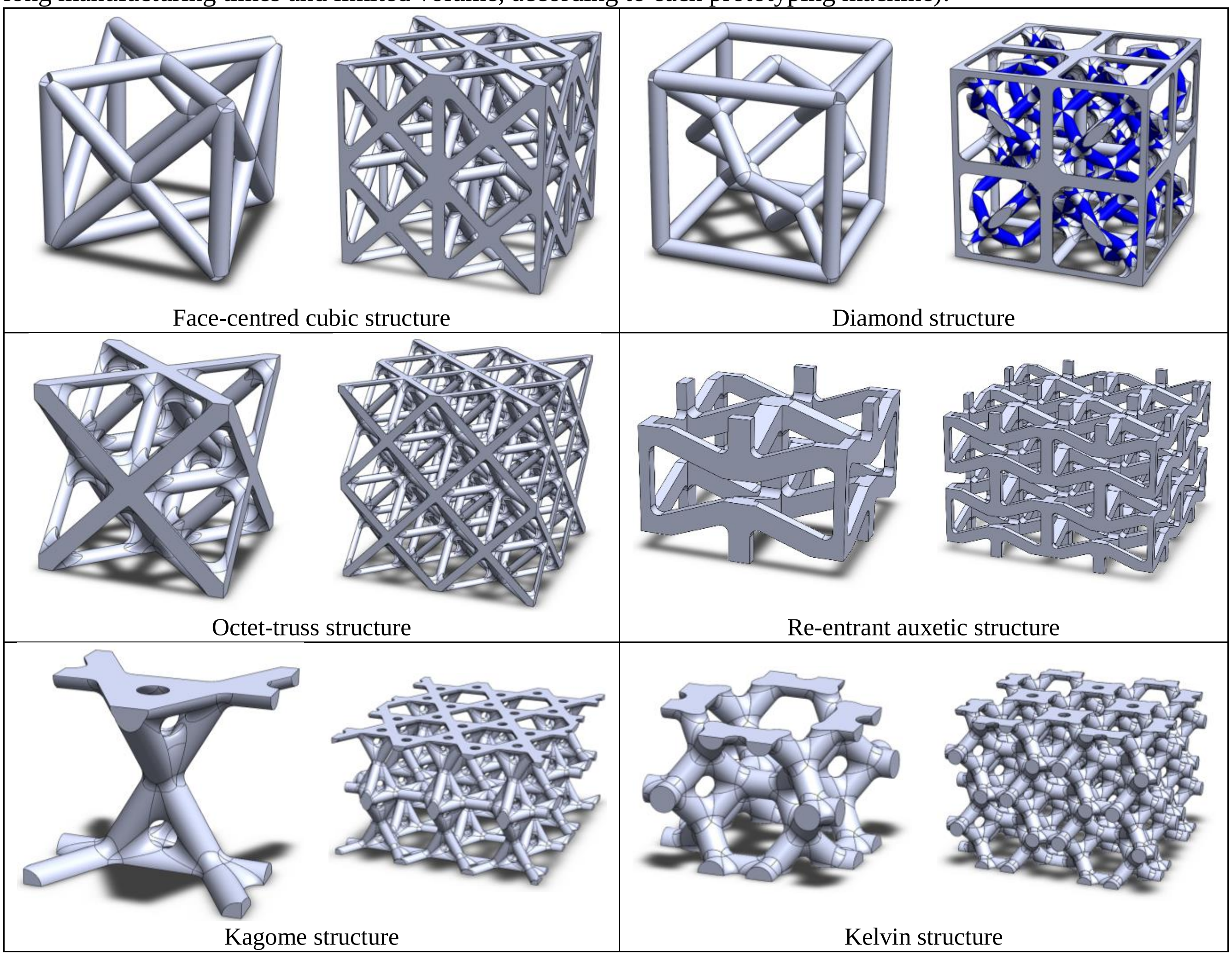
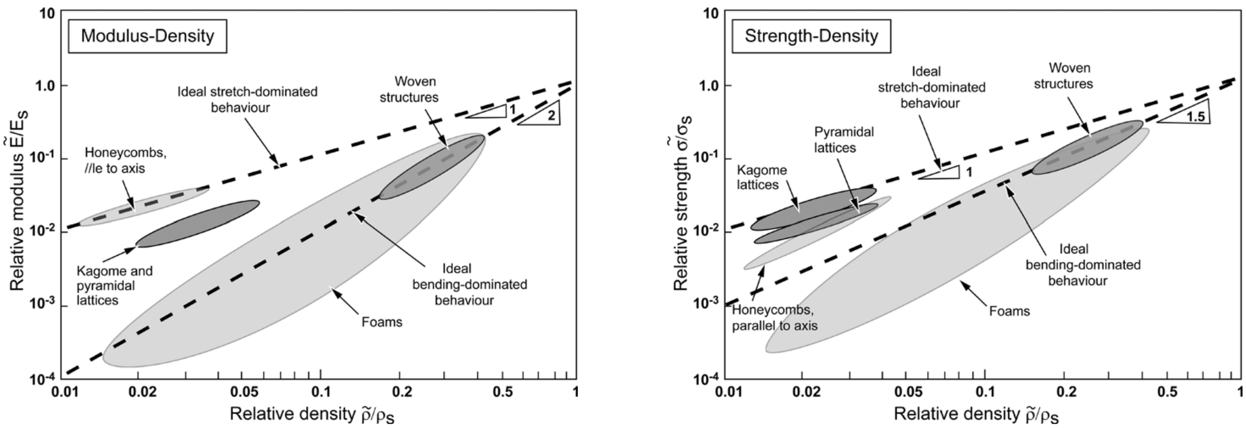


Figure 1. Examples of metamaterial unit cells and their corresponding tessellated structures [8]



a) b)

Figure 2. Variation of relative stiffness (a) and relative strength (b) with relative density for various classes of materials [4]

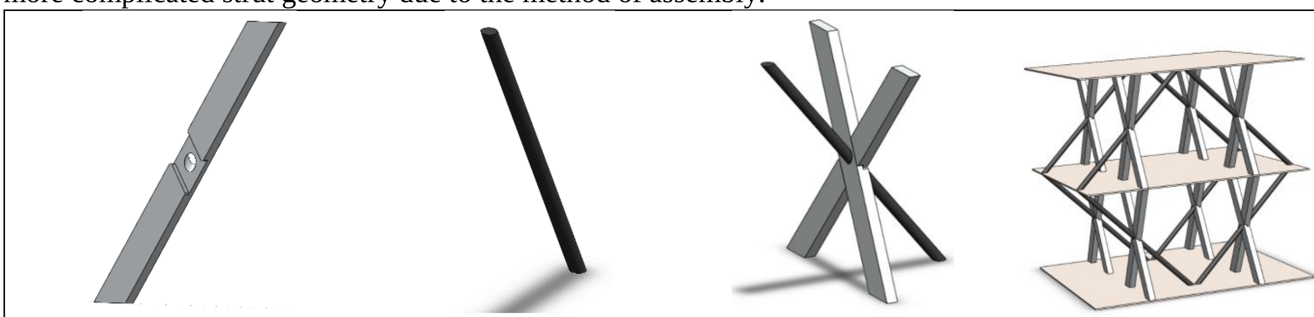
The aim of this project is the development of manufacturing protocols for sandwich panels with metamaterial structures using conventional materials and technologies, in order to reduce the costs and fabrication time and remove the size constraints of such structures, resulting in relatively cheap components with better mechanical properties than the sandwich structures used today.

This concept implies the simplification of the ideal geometries and splitting them into individual members than can be manufactured through conventional technologies (cutting, machining, casting etc.). In consequence, the newly designed unit cells will have relatively simple geometries and will be manufactured from relatively cheap materials, such as carbon steel or aluminium. The implementation of superior materials (alloy steel, titanium alloys or even fibre reinforced polymers) can be considered for high-end applications.

A very important aspect of the new structures is the adequate design of the members, so that they can be easily joined, either through mechanical means (shape joining through slots or orifices, riveting etc.) or through welding or brazing.

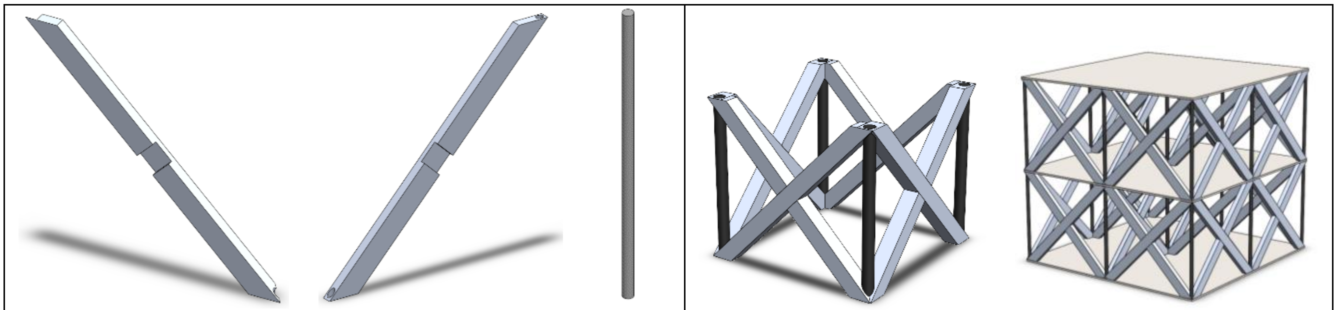
A couple of examples for this approach are presented in Figure 3. In the first case, the Kagome unit cell was split into three members: two identical ones, consisting of struts with rectangular cross section (than can be manufactured through a combination of processes such as cutting and milling, cutting and forging etc., Figure 3 a) and a strut with a circular cross section (that can be manufactured through the cutting of round bars or wires, depending on the required size, Figure 3 b). The unit cell is geometrically joined through the slots and angled orifices in the flat struts (Figure 3 d). The assembly can be further strengthen through the welding or brazing of the joining region, if required. For this example, the horizontal struts form the ideal geometry were replaced with sheet metal, that will provide load bearing if the structure is subjected to axial forces and also act as a faces for the sandwich structure. The Kagome structure will be manufactured through the tessellation of the unit cell in accordance with the ideal geometry (Figure 3 d), a simple solution for consolidation being through the welding of the unit cells to the sheet metal.

A similar approach is considered for the body cubic centred structure presented in Figure 3 e)-l), with a more complicated strut geometry due to the method of assembly.



a) b) c) d)

Kagome unit cell components — Assembled unit cell and tesselated structure



e) f) g) BCC structure unit cell components

h) l) Assembled unit cell and tesselated structure

Fig.3. Examples of joined metamaterial structures

Novelty. The potential applications of such sandwich structures can be very wide, ranging from aerospace, automotive, rail or naval industries (by replacing conventional sandwich panels that are currently in use) to civil engineering (beams or load bearing platforms). Considering the manufacturing technologies and the materials used, this concept can be applied to either small-scale production (automated fabrication of components and manual assembly) or to large-scale production (through the use of robotics). This can lead to the fabrication of high-performance load bearing structures at a reduce cost and result in considerable improvements to the aforementioned domains. In addition, no similar approach of manufacturing metamaterial structures has been found in literature, at the time of the project submission.

The design of the production line is not the scope of this research, but may constitute the theme of a future project, if the results of this study are promising.

The objectives of this project are:

O1. Design study for assembled metamaterial structures. In this objective, several metamaterial structures will be investigated and new designs based on assembled components with similar geometries to the original structures will be proposed.

O2. Design optimization. In order to reduce the mass of the assemblies, finite element analysis will be performed on the newly designed unit cells in order to obtain a more homogenous stress distribution (as the joining regions act as stress concentrators). Topological optimization procedures will also be considered.

O3. Manufacturing of prototypes. The components of the unit cells that were designed and optimized will be manufactured using the available infrastructure and manually joined (positioned, riveted and welded). The optimal joining parameters (i.e. for welding) will also be investigated.

O4. Testing, evaluation and validation of the new structures. The manufactured structures will be subjected to various mechanical tests (compression, bending, impact etc.) and the results will be compared to conventional sandwich structures with similar sizes. Small optimizations will also be considered.

O5. Dissemination of results. The activities of this objective will be associated with the elaboration of patent(s) application(s), investigations regarding the possible transfer of knowledge to economic agents and the elaboration of a final workshop, where the results of the project will be presented to the academic and economic communities.

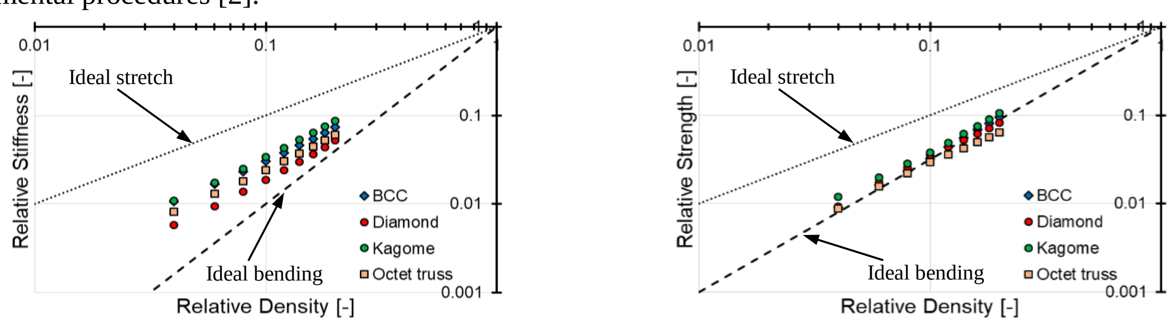
Technology Readiness Level. This project will consider the transition from TRL2 to TRL3. The formulated concept (TRL2) is represented by the ideal metamaterial structures, which were proven to present superior properties compared to conventional materials of similar densities. The aim of this study is to develop experimental proofs of concept (TRL3) for metamaterial structures manufactured through component assembly and the evaluation of their mechanical properties, in order to determine their feasibility in practical applications.

B.2.2 Presentation of the concept of technology / product or existing model which constitutes the starting point of the project

Preliminary results. Sandwich panels represent composite structures that are composed from a minimum of three components: two faces that should possess high stiffness and strength (usually steel, aluminium or fibre reinforced plastics) and a low density core with high energy absorption capabilities (polymeric or metallic foams, honeycomb structures, etc.) [9, 10, 11]. Investigations into the mechanical behaviour of sandwich panels have been conducted by the members of the research team (with emphasis on the mechanical behaviour of the core), and the topic was dealt with in four research Grants: UEFISCDI PN-II-ID-PCE-2011-3-0456, Contract No. 172/2011 “Micro-mechanical modelling of cellular materials with refinements on fracture and damage” (Director: Prof. L. Marșavina), UEFISCDI PN-II-PT-PCCA2011-3.2-0068, Contract No. 206/2012 “High performance lightweight panels with a new optimized design for advanced aircraft” (Partner coordinator: R. Negru), UEFISCDI PN-III-P1-1.2-PCCDI-2017-0391, Contract no. 30PCCDI/2018 “Smart buildings adaptable to the climate change effects” (Partner coordinator: L. Marșavina) and GNaC ARUT 2017, Contract No. 16178/2017 “Mechanical characterization of advanced composite structures with aluminum foam core”, (Director: E. Linul).

The improvement of sandwich structures can be achieved by the implementation of cores that present better mechanical properties than conventional ones (at similar densities). A class of structures that were considered for this purpose is represented by metamaterials, due to their promising mechanical characteristics. Because of their relative complex shapes, metamaterials have been predominantly investigated using numerical analyses [12, 13, 14], the experimental procedures used to validate the models being rather limited, due to their high manufacturing costs [1, 2, 7]. The design, manufacturing and testing of metamaterial structures was the main topic of the Grant UEFISCDI PN-III-P1-1.1-PD-2016-0445, No. 13/2018 “Development of polymer-based metamaterial structures for safety equipment applications” (Director: Dan-Andrei Șerban). One objective of the Grant was the design of several types of parametric metamaterial structures: Body-centered cubic (BCC), Face-centered cubic (FCC), Diamond, Octet-truss, re-entrant auxetic, Kagome and Kelvin (Figure 1). The design implied the generation of a wireframe of the model and the sweeping of cross sections along the paths. All designed structures had three variable parameters: the strut length, the strut thickness (or diameter) and the fillet radius (applied in order to reduce stress concentration in the joints). The determination of the variation of their relative density with structural parameters (strut thickness, strut length and fillet radius) was performed using the CAD software and various equations were fitted in order to obtain the required structural parameters for a given relative volume (density). As the fillet radius increases, so does the relative density. Subsequent studies showed that inclusion of a fillet radius followed by a decrease in strut thickness (considering the strut length constant) in order to maintain identical relative volumes has a positive effect on the mechanical properties. In consequence, the variation of the maximal value for the fillet radius allowed by each geometry, with the strut thickness to length ratio were determined.

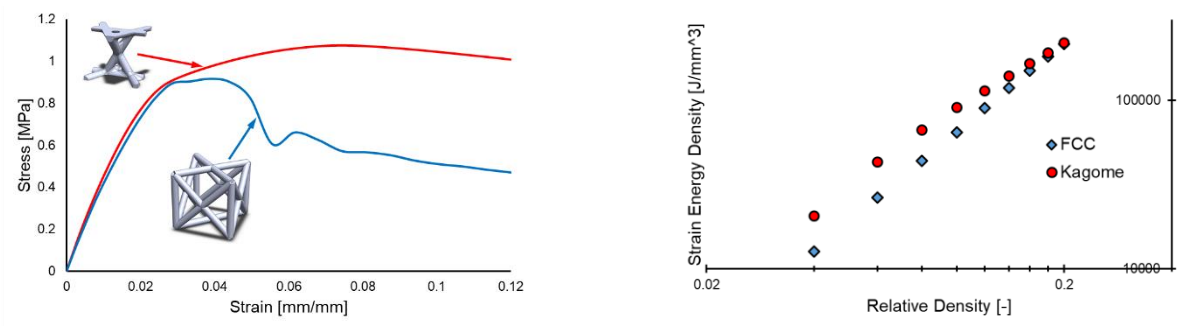
Another objective of the project dealt with the numerical evaluation of the variation of the relative stiffness and strength of each structure with their relative density (Figure 4). Metamaterial structures were generated for set values of relative densities (using the aforementioned fitted equations) and finite element analyses were performed in compression in order to determine the mechanical properties. In the numerical analyses, a material model for isotropic linear elasticity with multi-layer hardening plasticity was implemented and non-linear procedures were employed in order to account for bucking and large scale deformations. The numerical results were validated with experimental procedures [2].



a) b)

Figure 4. Variation of relative stiffness (a) and relative strength (b) with relative density for several structures [8]

Apart from the evaluation of the mechanical properties (stiffness and strength), the energy absorption capabilities of each structure was investigated, as the post yielding/buckling behaviour of each structure is different, and the stiffness and strength may become less relevant. Figure 5 a) presents the stress-strain curves of a Kagome structure (red line) and a FCC structure (blue line) at the same relative density (0.1) showing that, even though the stiffness and yield points are similar for each structure, their energy absorption capabilities differ substantially (for example, the strain energy density for the Kagome structure at $0.1\ mm/mm$ deformation is $90.15 \cdot 10^3\ J/m^3$ while for the FCC structure is $60.2 \cdot 10^3\ J/m^3$) due to the buckling of the struts of the FCC structure. However, for larger relative densities (where the strut length to thickness ratio decreases), the effects of buckling decreases and the strain energy density values become closer for the considered structures (Figure 5 b).



a) b)

Figure 4. Comparison between the Kagome and the FCC structures: stress-strain curve for 0.1 relative density (a) and the variation of the strain energy density at 0.1 mm/mm deformation with relative density (b)

The results of this study consisted in the determination of the optimal structures in terms of stiffness, strength and energy absorption for various relative densities (some structures, like the Octet-truss perform better at low relative densities while other structures, such as the Kelvin tessellations, perform better at higher relative densities).

For the proposed project, the lattices developed and analysed in the Grant 13/2018 will become the basis of the proposed assembled structures. In consequence, this research can be considered a continuation of the aforementioned project, with the scope of developing similar structures which can be easily manufactured with reduced costs.

Expertise of the research team. The project manager, **Dr. Eng. Dan-Andrei ȘERBAN**, has experience with the development of metamaterial structures, being the director of one Grant in this field (PD 13/2018) and has published three articles in this topic [2, 13, 14] (some of the results from the Grant PD 13/2018 are yet to be published, with several articles being developed or under review). Dr. Șerban was the director of an additional project (Grant UEFISCDI PN-III-P2-2.1-BG-2016-0125 No. 93BG/2016 “Transfer of knowledge for dashboard and Head-Up Display optimization through testing and modelling of advanced materials” in collaboration with Continental Automotive) and was the partner project leader for an international project (Grant EraNet LAC ELAC2015/T02-0721 No. 18/2017/2017 “Development of ecofriendly composite materials based on geopolymer matrix and reinforced with waste fibers”, coordinated by the Cracow University of Technology). Besides his investigations into metamaterial structures, Dr. Șerban has expertise in material characterization and the calibration/development of constitutive models for finite element analysis.

Prof. Dr. Eng. Liviu MARȘAVINA, Corresponding Member of the Romanian Academy, has more than 25 years of experience in experimental and numerical stress evaluation for various types of materials and has had significant contributions in the fields of fatigue and fracture mechanics. He was the doctoral advisor of Dr. Șerban and Supervised his research into metamaterials. Having a Manufacturing Engineering diploma, his background will aid in the design of the components while considering the manufacturing technologies during Objective O1. His expertise will also prove to be very valuable during the structure optimization phase (Objective O2), for the evaluation of the mechanical properties of the structures (Objective O4) and in the dissemination phase (Objective O5).

Dr. Eng. Radu NEGRU is an experienced researcher in Mechanical Engineering, having 20 years of background in the mechanical characterization and experimental stress analysis of materials. He has had a close collaboration with the Project leader in the field of sandwich structures and metamaterials, co-authoring several articles in these fields [2, 9, 11, 14]. His will lend his expertise for structural optimization (Objective O2) and manufacturing (Objective O3), mechanical characterization (Objective O4) and dissemination (Objective O5).

Dr. Eng. George BELGIU is an experienced researcher in Manufacturing Engineering. He has expertise in computer aided product design and manufacturing using conventional methods (machining, die cutting, injection moulding) [15, 16, 17] as well as rapid prototyping. He will provide a valuable input in the design stages of the project (Objectives O1 and O2) and will coordinate the manufacturing of the structures (Objective O3).

Dr. Eng. Bogdan RADU is an experienced researcher in Material Science, with a background in welding and brazing [18, 19, 20]. He will provide expertise regarding the suitable welding techniques in the design stage (Objective O1) and will be responsible with the development of the welding protocols for the structure assembly (Objectives O3 and O4).

Dr. Eng. Emanoil LINUL is an experienced researcher in Mechanical Engineering, being specialized in the development and testing of cellular materials and composite structures. He has coordinated and participated in numerous studies regarding the mechanical properties of sandwich structures and the influence of temperature and strain rate [10, 21, 22]. Considering his experience, he will be the coordination of the testing and evaluation stage of the project (Objective O4), and he will also contribute to the optimization of the designed structures (Objective O2), the manufacturing of the panels (Objective O3) and in the dissemination phase (Objective O5).

The research team will also include a vacant position for a postdoctoral researcher with experience in manufacturing and testing that will participate in Objectives O1, O3 and O4. If the project proposal is accepted for financing, the Project leader will enrol a PhD student, whose doctoral theme will be linked to the project.

In order to optimize the project management, each objective will be coordinated by an experienced researcher that will micromanage a team of researchers, according to their experience (Table 1). The project leader together with the coordinators will develop the general outline of each objective and he will take part in the activities of all objectives. His role will vary from supervision (for the activities associated with fields where he has less experience, Objective O3) to active involvement (in his fields of expertise, Objective O1, O2 and O4).

Table 1. Assignment of members for each objective

Objective O1 Design study for assembled structures	**Objective O2** Design optimization	**Objective O3** Manufacturing of prototypes	**Objective O4** Testing, evaluation and validation	**Objective O5** Dissemination of results
Coordinator: Prof. L. Marșavina **Team:** Dr. Eng. G. Belgiu Dr. Eng. B. Radu Postdoc researcher	**Coordinator:** Dr. Eng. R. Negru **Team:** Prof. L. Marșavina Dr. Eng. G. Belgiu Dr. Eng. E. Linul PhD Student	**Coordinator:** Dr. Eng. G. Belgiu **Team:** Dr. Eng. R. Negru Dr. Eng. B. Radu Dr. Eng. E. Linul Postdoc researcher PhD Student	**Coordinator:** Dr. Eng. E. Linul **Team:** Prof. L. Marșavina Dr. Eng. R. Negru Dr. Eng. B. Radu Postdoc researcher PhD Student	**Coordinator:** Prof. L. Marșavina **Team:** Dr. Eng. R. Negru Dr. Eng. E. Linul

B.2.3 METHOD of project implementation

The activities associated with each objective and their corresponding deliverables are presented in Table 2.

Table 2. Activities associated with each objective and corresponding deliverables

Obj.	Title		Deliverable
O1	**Design study for assembled metamaterial structures**		Research report
	A1.1	Preliminary study regarding the development of assembled metamaterial structures based on ideal geometries	
	A1.2	Component design for the assembled metamaterial structures	
	A1.3	Objective management: Elaboration of scientific report	
O2	**Design optimization**		Research report Scientific articles
	A2.1	Preliminary finite element analyses on the assembled structures	
	A2.2	Structure optimization in accordance with the resulting stress distribution	
	A2.3	Structure refinement using topological optimization	
	A2.4	Objective management: Elaboration of scientific report	
O3	**Manufacturing of prototypes**		Research report Scientific articles
	A3.1	Component manufacturing	
	A3.2	Assembly of structures	
	A3.3	Joining parameter optimization	
	A3.4	Objective management: Elaboration of scientific report	
O4	**Testing, evaluation and validation of the new structures**		Research report Scientific articles
	A4.1	Static and dynamic testing of composite structures	
	A4.2	Evaluation of structural design and possible improvements	
	A4.3	Identification of optimal configurations	
	A4.4	Objective management: Elaboration of scientific report	
O5	**Dissemination of results**		Final workshop and report Patent application
	A5.1	Elaboration and submission of patent application(s)	
	A5.2	Evaluation of opportunities for transfer of technology to manufacturers	
	A5.3	Final workshop	

Methods and instruments of investigation. Activity A1.1 will consist in the evaluation of several metamaterial structures in order to determine if the given geometries are suitable for simplification. Based on the wireframe of the unit cells, a number of design choices (number of members, complexity of shape etc.) will be considered and the optimal geometries will be determined for at least three types of metamaterial structures. Structure designs will also be developed, opting for the ideal way of joining the components (which will ultimately influence the geometries of the components). The optimal geometries will be further developed in **Activity A1.2**, where each component of the assembly will be designed in accordance with chosen method of joining and manufacturing.

In **Activity A2.1**, the assembled geometries will be subjected to finite element analysis for several loading types (mainly compression and bending) in order to determine the stress distribution. Considering that the joints will act as stress concentrators, in **Activity 2.2**, the components of the structure will be optimized in order to obtain a relatively uniform stress distribution (i.e. thicker cross sections around the joints, reduction of volume for the struts). The optimization will be further developed using topological optimization procedures in **Activity 2.3** (automatic determination of optimal structures in terms of stiffness versus volume, performed by specialized software, such as Abaqus/Tosca).

Activity A3.1 will deal with the manufacturing of the designed components. No specialized tools will be developed for the prototypes (i.e. dies for cutting or forging), as the required geometries will be manufactured through machining (even though other technologies might be more adequate for large-scale production). In **Activity A3.2**, the structures will be manually assembled and joined. In **Activity A3.3**, the structured will then be inspected and, if required, some assembly procedures will be modified, such as weld reinforcement of joints, tuning or replacement of the welding process (i.e. if the weld bead or the thermal influenced zone is too large).

The manufactured structures will be subjected to various types of experimental procedures during **Activity A4.1**, in order to determine their mechanical response. Considering the observed failure mechanism (strut failure through buckling or plastic deformation, component failure in the joint region, weld failure etc.), structural optimizations will be performed in **Activity A4.2**. Following several iterations, the results will be thoroughly analysed and an optimal design for each type of structure will be chosen in **Activity A4.3**.

After the comparison of the test results with benchmark values for conventional sandwich panels of similar sizes and weights, patent applications will be developed for the feasible designs (**Activity 5.1**). In **Activity 5.2**, several companies will be contacted in order to propose future collaboration for the transfer of technology. A final workshop will also be scheduled (**Activity 5.3**), where the results will be presented to both academic and industrial parties.

The **Gantt chart** of the project is presented in Table 3

Table 3. Gantt chart

Obj	Act	Year I												Year II											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
O1	A1.1																								
	A1.2																								
	A1.3																								
O2	A2.1																								
	A2.2																								
	A2.3																								
	A2.6																								
O3	A3.1																								
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	A3.4																								
O4	A4.1																								
	A4.2																								
	A4.3																								
	A4.4																								
O5	A5.1																								
	A5.2																								
	A5.3																								

The main **deliverables** of this project will be at least **three new types of assembled metamaterial structures** that are suitable for large-scale production. Taking into account the performance of the developed structures, at least **one patent application** will be submitted.

The **dissemination of results** will be performed both to the academic and industrial communities. Disseminations to the academic medium will consist in the elaboration of at least four scientific articles for Objectives O2, O3 and O4 (in accordance to Table 2) which will be submitted to prestigious journals, such as *Materials & Design*, *Mechanics of Advanced Materials and Structures* or *Composite Structures* and the participations to international conferences, such as *Advanced Materials and Structures*, *Innovative Technologies for Joining Advanced Materials*, etc.. Regarding the dissemination to the industrial community, the participation to an invention exposition (*Euroinvent*, *International Exhibition of Inventions/Innovations "Traian Vuia"* etc.) will be considered. For the final workshop of Objective O5, representatives for both academic and industrial communities will be invited.

Research team. The structure of the research team, with the associated activities for each member and the allocated budget are presented in Table 4.

Table 4. Structure of the research team

	Name	Role	Activities	Hours/ month	No. months	Allocated budged (gross)
1	Dr. Eng. Dan-Andrei ȘERBAN	Project leader	O1, O2, O3, O4, O5.	12	24	64800
2	Prof. Dr. Eng. Liviu MARȘAVINA	Experienced researcher	O1, O2, O4, O5	10	21	47250
3	Dr. Eng. Radu NEGRU	Experienced researcher	O2, O3, O4, O5	12	20	54000
4	Dr. Eng. George BELGIU	Experienced researcher	O1, O2, O3.	8	18	32400
5	Dr. Eng. Bogdan RADU	Experienced researcher	O1, O3, O4.	8	16	28800
6	Dr. Eng. Emanoil LINUL	Experienced researcher	O2, O3, O4, O5	12	19	51300
7	Vacant	Postdoctoral researcher	O1, O3, O4.	6	18	16200
8	Vacant	PhD Student	O2, O3, O4.	8	17	13600
					TOTAL	308350 Lei

Available infrastructure:

1. Laboratorul Ștefan Nădășan, Politehnica University of Timișoara,
http://erris.gov.ro/St-Nadasan-Research-Laborato

The Ştefan Nădăşan Laboratory for experimental and numerical stress analysis provides the necessary equipment for accomplishment for objectives O1, O2, and O4. The available equipment required for project implementation:

- 5 kN Zwick/Roell Z005 universal testing machine;
- 15 kN walter+bai dynamic/fatigue test system;
- Charpy Impact test equipment: four Charpy hammers (one instrumented) of 5, 30 and 75 kg·m
- Repeated Impacts Testing Equipment;
- CAD/CAM software: Solidworks, PTC Creo; FEA software: ANSYS, ABAQUS, Digimat;
- Instrumented drop tower equipped with a Quantum X data acquisition system;
- Dantec Dynamics Q-400 3D Digital Image Correlation System;
- ISTRA 4D V2.8.6 software for shearographic measurements, testing, analysis and evaluation.

2. Medical Engineering Research Center, Politehnica University of Timișoara,
http://erris.gov.ro/Medical-Engineering-Research

The Medical Engineering Research Center provides additional resources for the objectives O3 and O4. Available equipment required for project implementation:

- 3 axis CNC Milling machine Young Tech YT 800 FM;
- Multiaxial dynamic/fatigue dynamic testing machine INSTRON 8874 equipped with an environmental chamber (-40 °C to 300 °C);

3. ICER - Research Institute for Renewable Energy, Politehnica University of Timișoara,
http://erris.gov.ro/ICER-Research-Institute

The Research Institute for Renewable Energy provides a 5-axis CNC milling machine required in the objective O3, a high-speed camera for recording the deformation of the structures during impact loading (Objective O4). Available equipment required for project implementation:

- CNC Milling machine DOOSAN DNM-650 equipped with Fanuc-OiM-D interface, 4 axes,
- High Speed Camera Photron Fastcam SA3 (60,000 fps)

4. Research Center for Processing and Characterisation of Advanced Materials, Politehnica University of Timișoara
https://eeris.eu/ERIF-2000-000T-1185

The Research Center for Processing and Characterisation of Advanced Materials will provide the welding equipment required for Objective O3. Available equipment required for project implementation:

- ESAB LUC 500 welding power source;
- WIG Inverter MW 300 W Fronius welding equipment;

- REHM SYNERGIC 262 welding equipment;
- ESAB AC MULTITRAC machine;
- MIG/MAG PHOENIX 300 welding equipment;
- MIG/MAG WIG Plasma BUG-O-SYSTEM equipment;

Potential risks in project implementation:

- Financial risks – The project budget might exceed the planned one.
- Risks associated with project deadlines and objectives duration – The project objectives might not be accomplished in time.
- Management risks – the deficient project management that might cumber the project development
- Risks associated with logistics – impact of the current pandemic on shipments and travels
- Quality risks – de delivery of bellow-expectation results.

Minimization of potential risks:

The financial risks are minimized through the fact that the entire required research infrastructure is contained within the laboratories of the host institution. The consumables will be purchased from manufactures with whom the host institution had previous collaborations (thus knowing the approximate pricing). If some expenses exceed their projected budget, they can be covered from the overheads.

Risks associated with project deadlines and objectives duration are minimized through sensible time management and through objective overlapping, in case the duration of some objectives exceeds the anticipated value. In addition, similar testing and manufacturing equipment is available in other laboratories associated with Politehnica University of Timişoara, in case some equipment will be unavailable. In addition, some services can be externalized, if the deadlines are too tight.

The management risks are minimized through the managing experience that the candidate has acquired as project leader and member throughout his scientific career.

The risks associated with logistics due to the current pandemic cannot be controlled by the research team.

The quality risks are minimized by the scientific experience of the research team.

The proposed **budget** is presented in Table 5.

Table 5. Budget

Personnel costs		**Logistics**[1]		**Travel**[2]		**Indirect costs**[3]		**Total**	
Lei	**Euro**	**Lei**	**Euro**	**Lei**	**Euro**	**Lei**	**Euro**	**Lei**	**Euro**
308350	62677	191650	38956	10000	2033	90000	18294	600000	121959

The personnel costs were evaluated in accordance with the total number of hours each team member will put in (Table 4) and with the allowable tariffs per hour, as specified in HG no. 327 from 20 March 2003.

The majority of the logistics costs will be directed towards the purchasing of consumables: semi-finished metal, machining tools, welding consumables etc. Apart from the budget for consumables, 10000 Lei (~2033 €) will be reserved yearly for financial audit services.

The travel expenses will cover the participation of one or more team members at international conferences and invention expositions. Given the current pandemic and the possibility of future travel restrictions, the allocated funds are relatively low.

Overheads represent around 18% of the direct costs.

[1] Subcontracting – no more than 5% of the project's public budget
[2] For institutions under the state aid scheme, costs for travel will be made from their own contribution
[3] Max. 25% of direct costs minus subcontracting and equipment costs.

C. Bibliography

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