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ADDITIVE MANUFACTURING ACADEMY
TO BOOST TRAINERS' COMPETENCES IN INDUSTRY

Summary

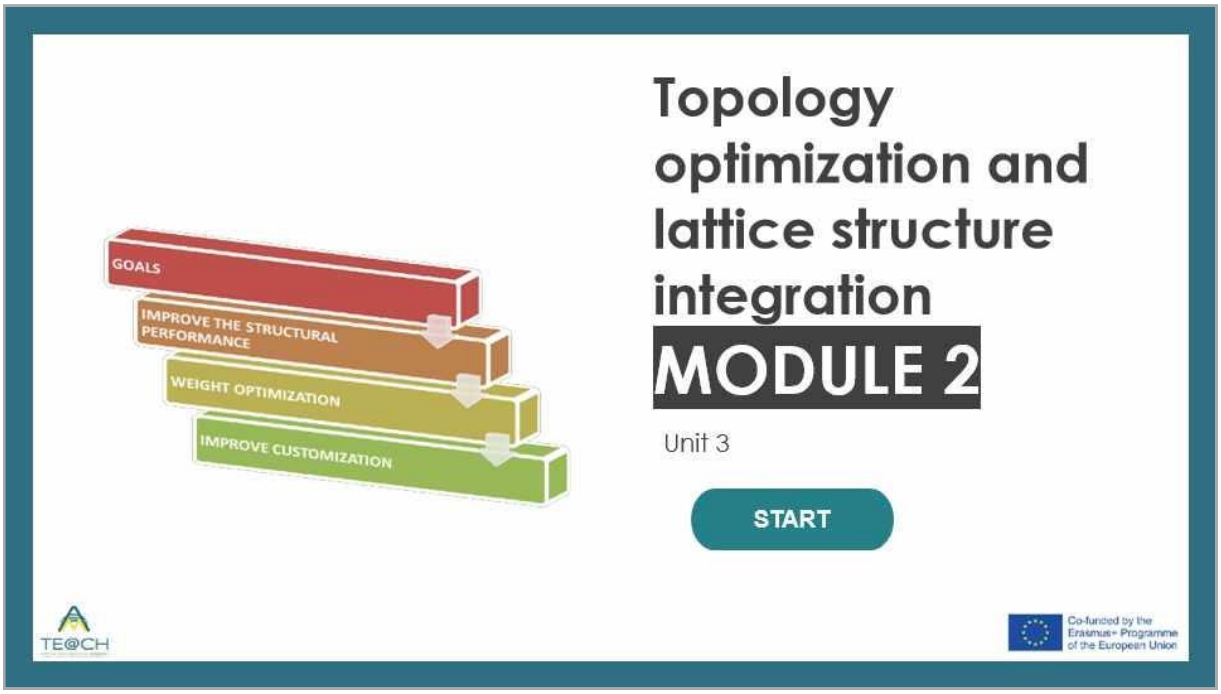
Design for Additive Manufacturing (DfAM)

Project Number: 2021-1-IT01-KA220-VET-000033365

UNIT 3 – TOPOLOGY OPTIMIZATION AND LATTICE STRUCTURE INTEGRATION

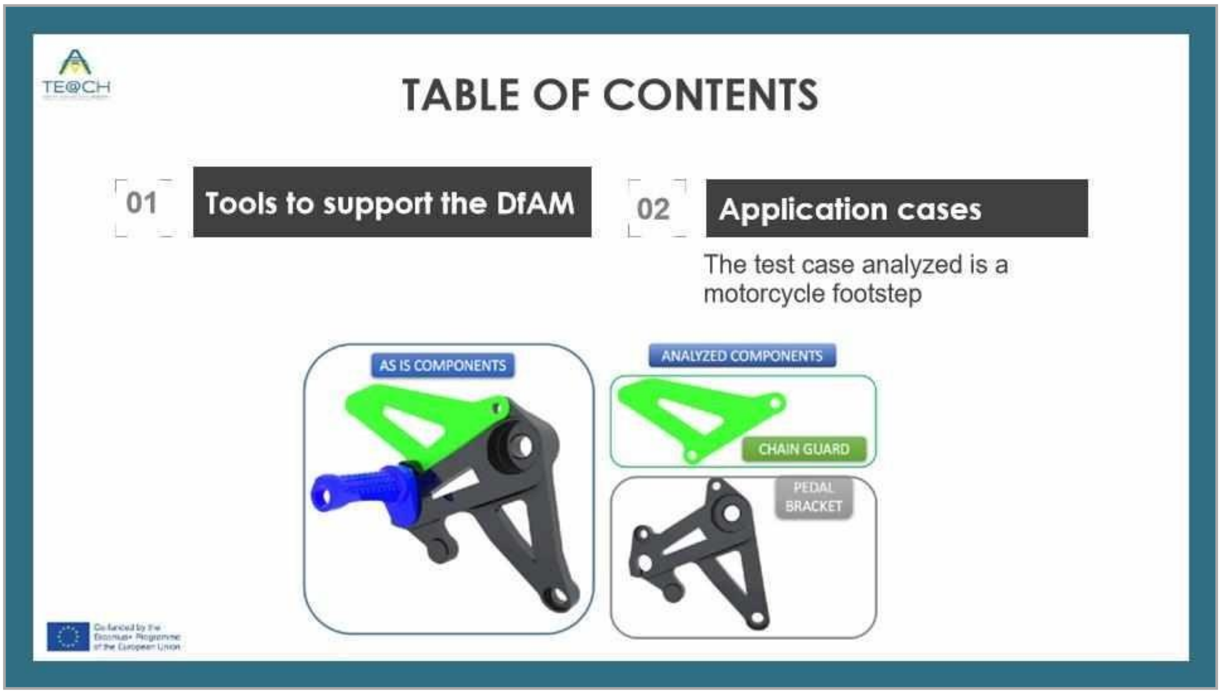
Course Content

The third unit of module two is about the topology optimization and lattice structure integration.



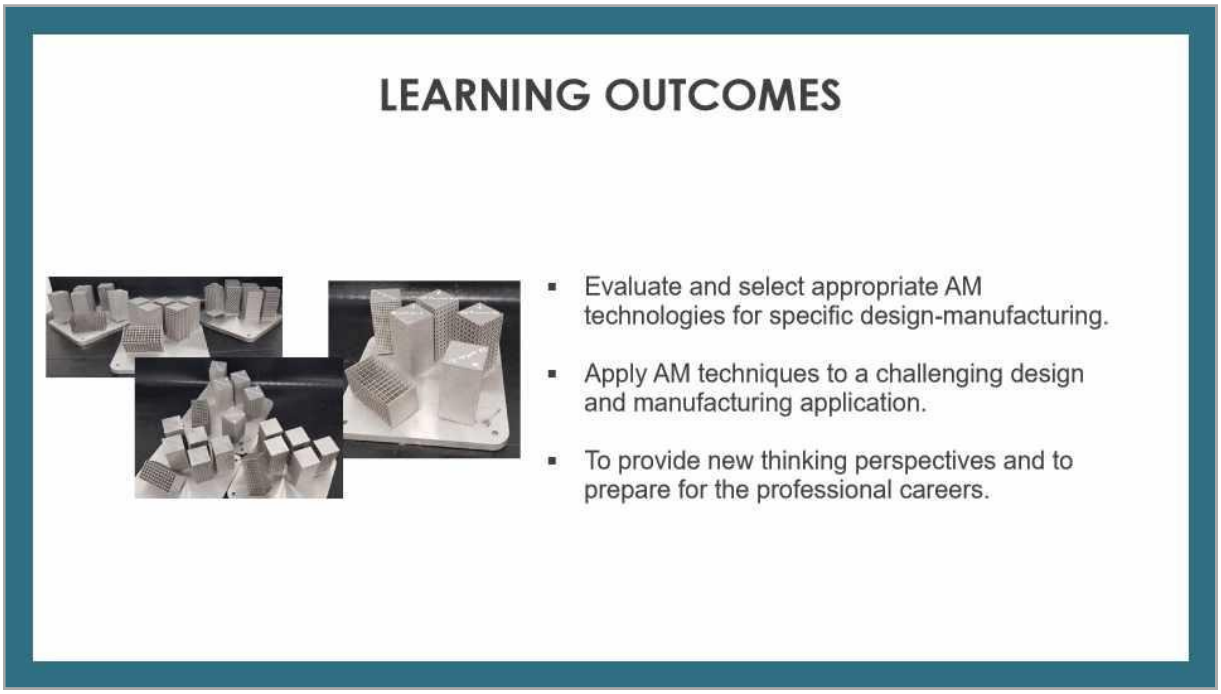
APPLICATION CASE

In this third unit we present the tools to support the Design for additive manufacturing and an application case. The test case analyzed is a motorcycle footstep.



In this unit an innovative method, applied on footstep system, have developed, in order to exploit the advantages offered by the integration of the lattice structures in the topology optimization in order to obtain an innovative and highly performing structures.

In this unit we can learn to evaluate and select appropriate AM technologies for specific design-manufacturing, to apply AM techniques to a challenging design and manufacturing application and to provide new thinking perspectives and to prepare for the professional careers.

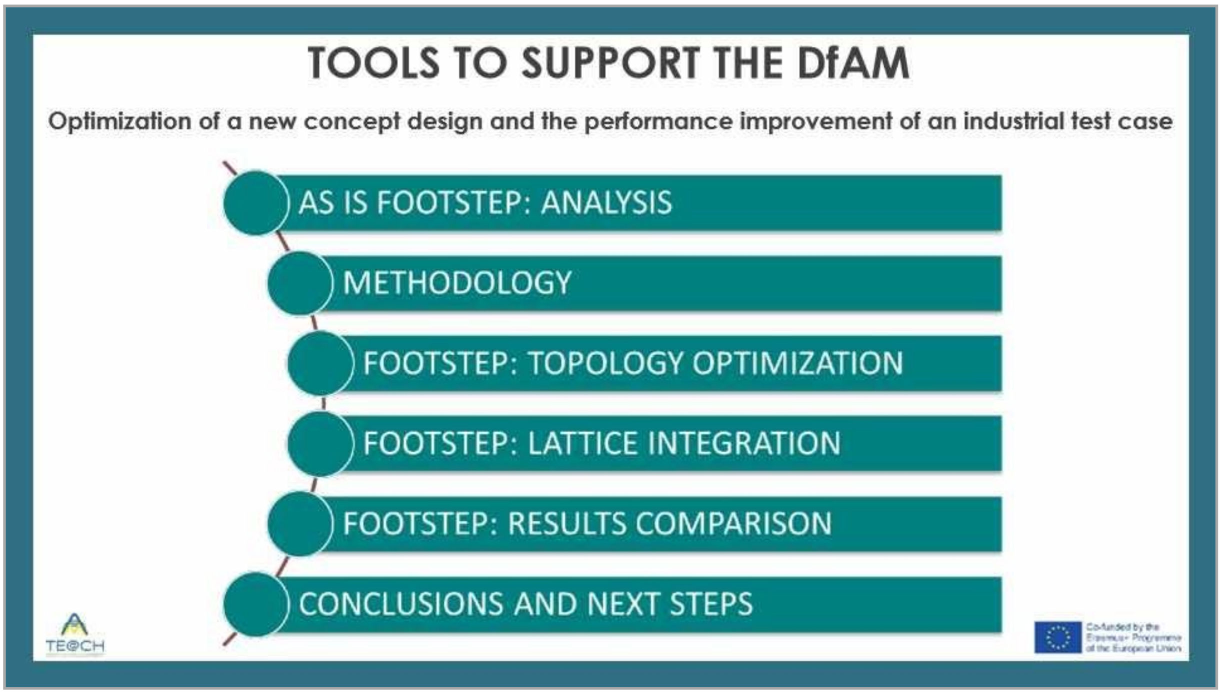


TOOLS TO SUPPORT THE DfAM

In this work “Optimization of a new concept design and the performance improvement of an industrial test case” has studied a new concept design of an industrial test case, in order to obtain an innovative geometry that allows to reduce the weight ensuring, at the same time, the required structural performances.

Moreover, it has been conducted a study to evaluate the possible advantages offered by the integration of the topology optimization and lattice structures in order to verify the required design specifications. An objective evaluation of the component performances has been obtained through the definition of appropriate Key Performance Indicators.

In the last decade, the use of structural optimization has rapidly increased. The upstream phases of design process represent 5% of the involved time of a product development, but engage 75% of the global development costs. The integration of optimization in the early phases of a project is thus very important. The use of numerical simulation to optimize products has become essential to test different forms, materials, but also to better understand the involved physical phenomena. Thus any change in geometry induced by the analysis can greatly increase the delay. Besides the possibility to test original solutions, the use of numerical optimization can address the problem of computing integration in the early stages of the design process. It is then necessary to establish a methodology for capitalization and knowledge management. Topology optimization enables profound insight into the optimal material distribution for a given structural objective, applied loading and boundary conditions. The topologically optimal geometry is often geometrically complex and incompatible with traditional manufacturing methods. Additive manufacture can accommodate significantly more complex geometries than traditional manufacture; however, it is necessary that specific design rules be satisfied to ensure manufacturability. The advent of the AM opens new scenarios in terms of definition of innovative geometries that are not feasible with the conventional processes (such as lattice structures). In order to exploit the AM capabilities, new topology optimization tools are emerging that allow to define innovative concepts that could reach structural performance greater than the result obtainable with conventional topology optimization.


TOOLS TO SUPPORT THE DfAM
Optimization of a new concept design and the performance improvement of an industrial test case
AS IS FOOTSTEP: ANALYSIS
METHODOLOGY
FOOTSTEP: TOPOLOGY OPTIMIZATION
FOOTSTEP: LATTICE INTEGRATION
FOOTSTEP: RESULTS COMPARISON
CONCLUSIONS AND NEXT STEPS
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TEST CASE

The test case analyzed is a motorcycle footstep.

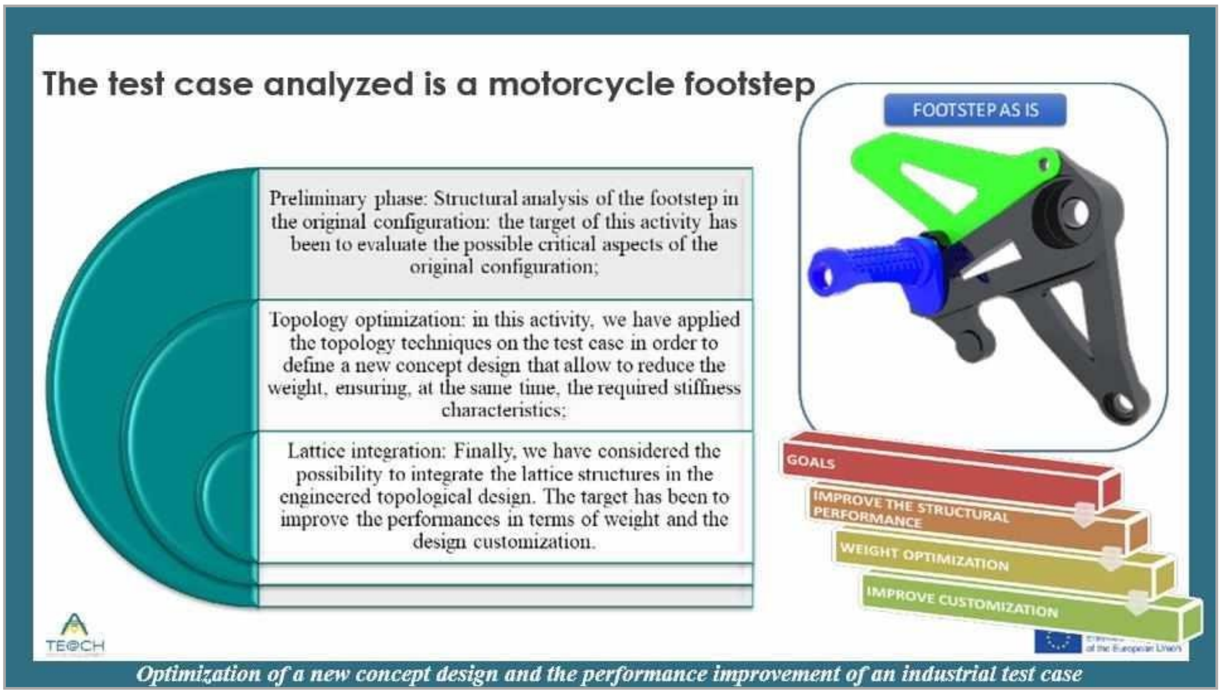
The work reports a structural optimization study of a footstep. In particular, this work has expected three steps:

1. Structural analysis of the footstep in the AS IS configuration: the target of this activity has been to evaluate the possible critical aspects of this configuration.

2. Topology optimization: in this activity, the Authors have applied the topology techniques on the test case in order to define a new concept design that allow to reduce the weight, ensuring, at the same time, the required stiffness characteristics.

3. Lattice integration: at the least, we have considered the possibility to integrate the lattice structure in the engineered topological design. The target has been to improve the design performances in terms of weight and stiffness.

An objective evaluation of the component performances has been obtained through the definition of appropriate Key Performance Indicators.



METHODOLOGY

Starting from the topology optimization a novel methodology has been developed considering the lattice integration in the topology engineered solutions. The target of this methodology has been to obtain an innovative concept of a footstep that exploits the advantages that the lattice integration offers.

Here the adopted workflow for the methodology developed in this work, where, the different steps to obtain the innovative final design are reported.

As can be detected by the represented workflow the proposed method includes an initial step (Project Specification) in which the main key points of the problem are defined (loads, material, constraints, acceptable deformation). After that:

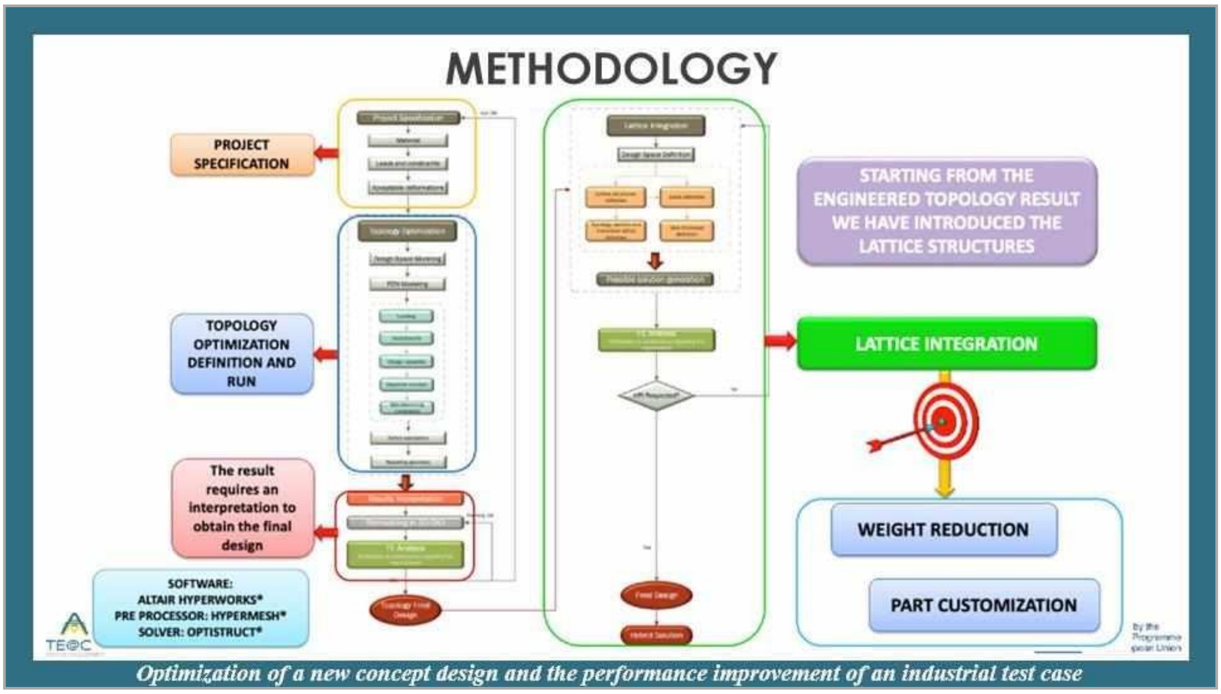
A classical topology optimization approach able to provide a new design solution in accordance with the given: design variables, objective function and last, but not least manufacturing constraints. Of course, the given possible result of this first option has to be processed in order to obtain a feasible CAD model which is a needed input to verify the structure performances of the obtained solution. In this case, of unacceptable result for the given choice, what has been just described, can be executed again until an appropriate solution is provided.

Thanks to the additive technologies the topology solution is integrated by what has been called "Lattice Integration methodology". In this case the defined design space, fixed on final topology design, is considered as the volume in which different options for: lattice structures, their main dimensions, skin definitions can be considered.

As the workflow reports, it believe that the best solution can be provided by the Lattice Integration methodology.

The component material considered in this study has been the Nickel Alloy IN625.

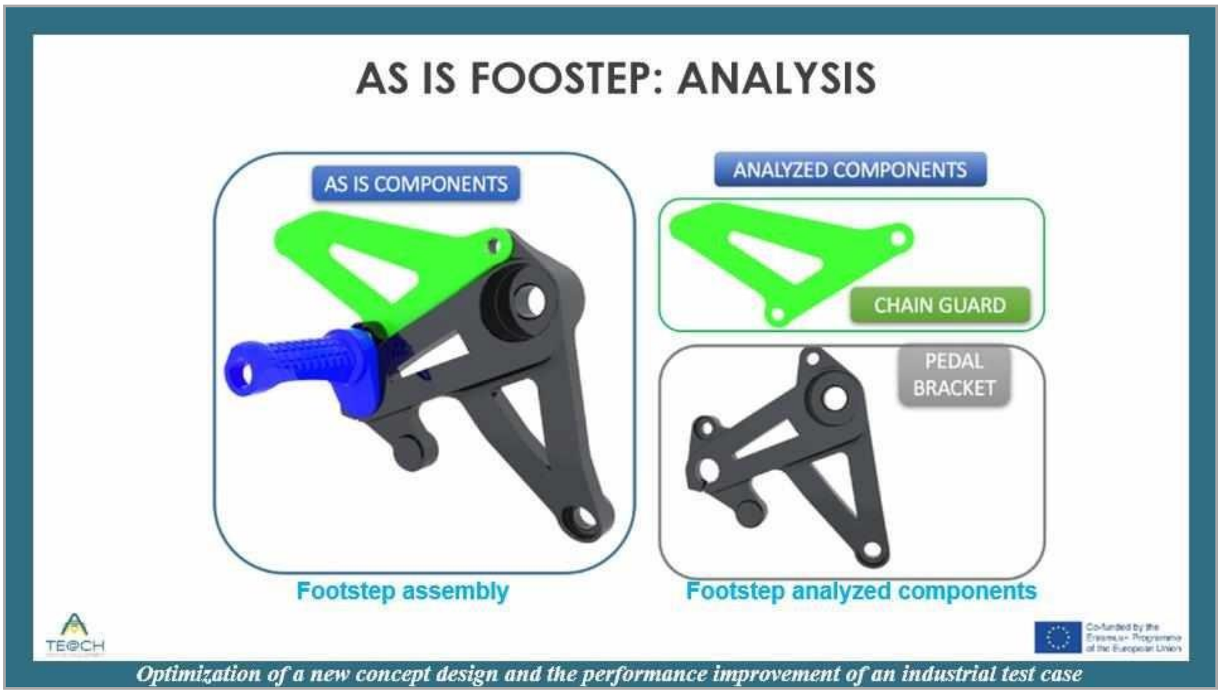
The considered Product KPIs are: Maximum Displacement (mm), Maximum Von Mises Stress (MPa) and Weight (kg).



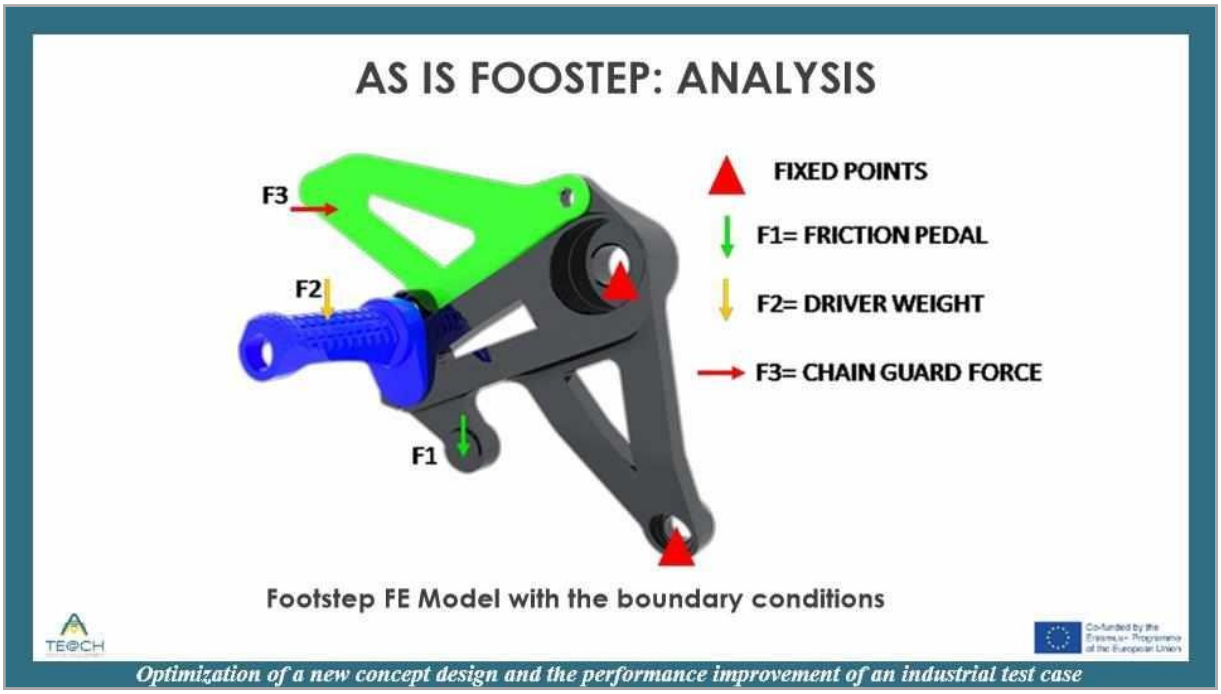
ANALYSIS

Footstep components have been studied in order to improve the performance in terms of stiffness and weight. In particular have been study the two components:

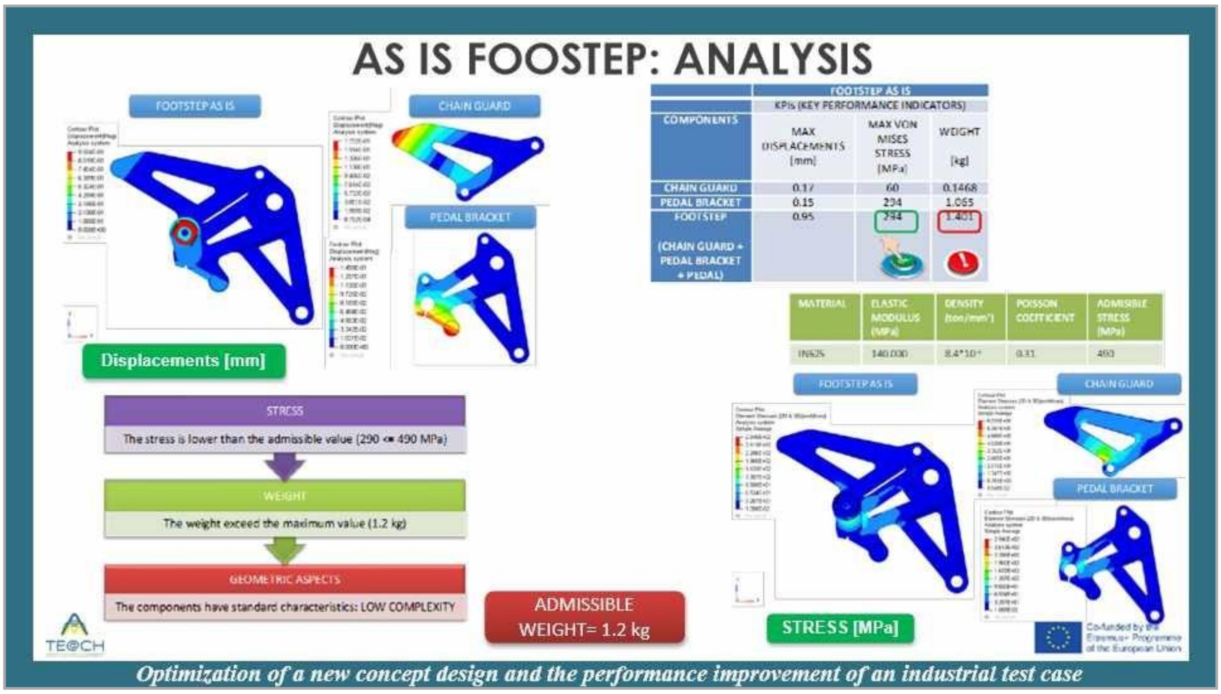
1. Chain guard it has only aesthetics and protection function
2. Pedal bracket it has a structural function.



In order to analyze the stiffness of AS-IS footstep components, a linear static analysis has been carried out using HyperMesh® as pre-processor and Optistruct® as linear FE code of the suite Altair HyperWorks®. The Figure shows the boundary conditions applied to the model to simulate the real behavior of the structure. The FE model of the analyzed structure has been modelled using tetra solid element (CTETRA4).



The material has been modelled using an isotropic material law (MAT1 in Optistruct). The structural analysis, of AS-IS component, has been performed to verify structural performances like: stress/strain distributions and displacements. The Figures show displacements (mm) and Von Mises Stress (MPa) distribution of the analyzed model. The results highlights that the analysed operative conditions are not critical for the structural point of view but the weight (footstep weight = 1.401 kg) exceed the acceptable limit (Maximum acceptable weight = 1.2 kg).

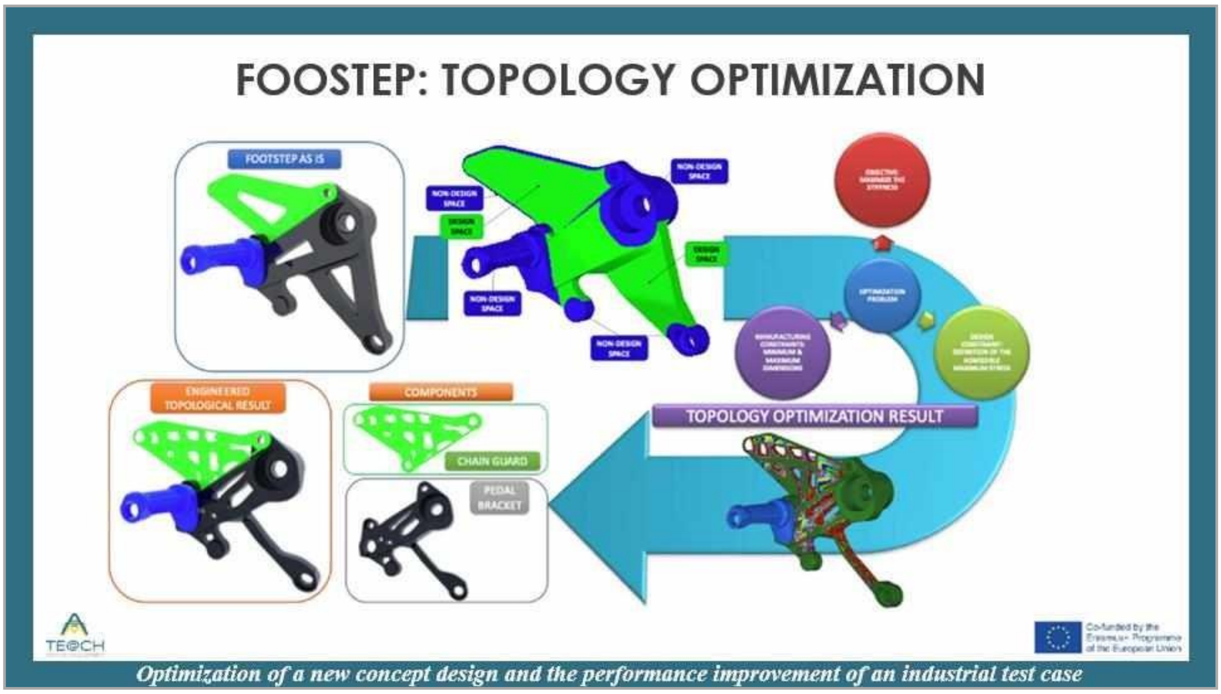


FOOSTEP: TOPOLOGY OPTIMIZATION

Considering the structural analysis results, the primary target has been to develop a new concept that allow to reduce the weight ensuring or improving, at the same time, the structural performances.

In order to reach the prefixed target, A component re-design have studied through structural topology optimization using the commercial computer-aided engineering (CAE) software package Optistruct®.

Topology optimization in Optistruct® is a mathematical technique that produces an optimized shape and material distribution for a structure within a given design space for the given set of loads. The Optistruct® algorithm alters the material distribution of the structure to optimize it for the user defined objective under the given constraints.

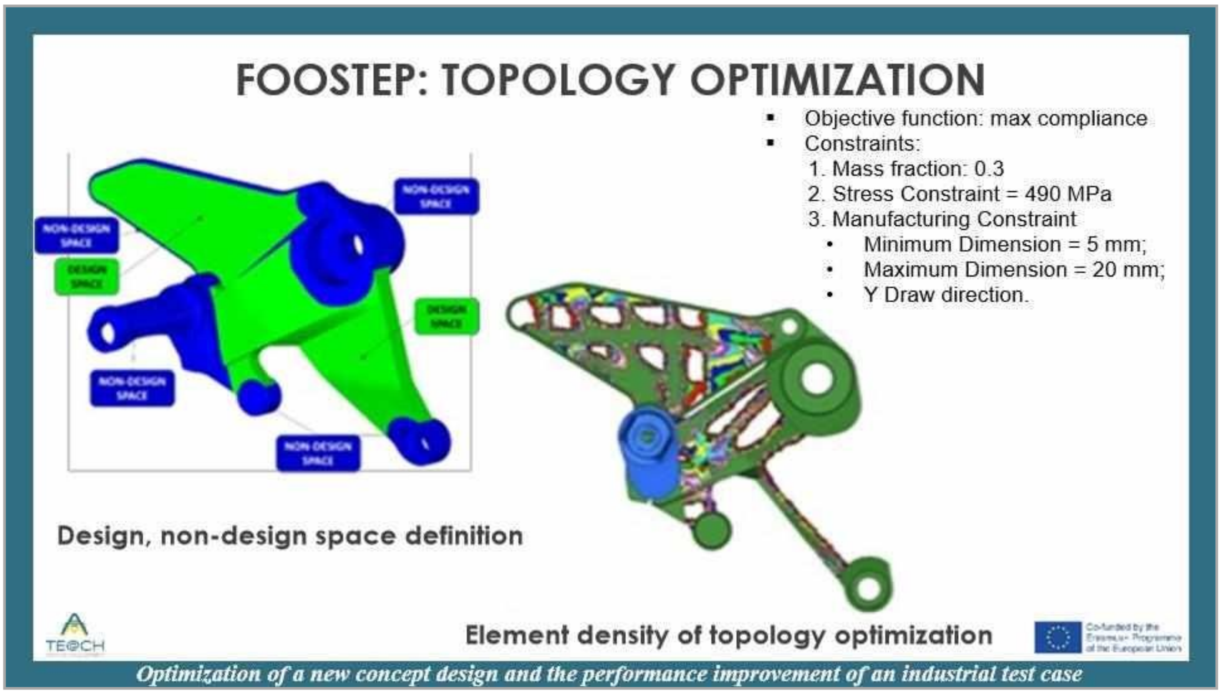


Have applied a topological optimization technology to obtain a structural shape in response to the given loads. The first figure shows the footstep assembly with the design and non-design space zones: the first one represents the area where it is possible to explore new design solutions, the second is the one which cannot be changed. In the “non - design” areas the boundary conditions have been applied. The “design” space represents the optimization domainThe second figure shows the overlap between the original component and the total design volume of the “design” and non- design space. The Design space dimensions have been defined taking into account the footstep functionality.

The topology optimization problem has been defined as:

• 4Design space definition and the relative design variables;

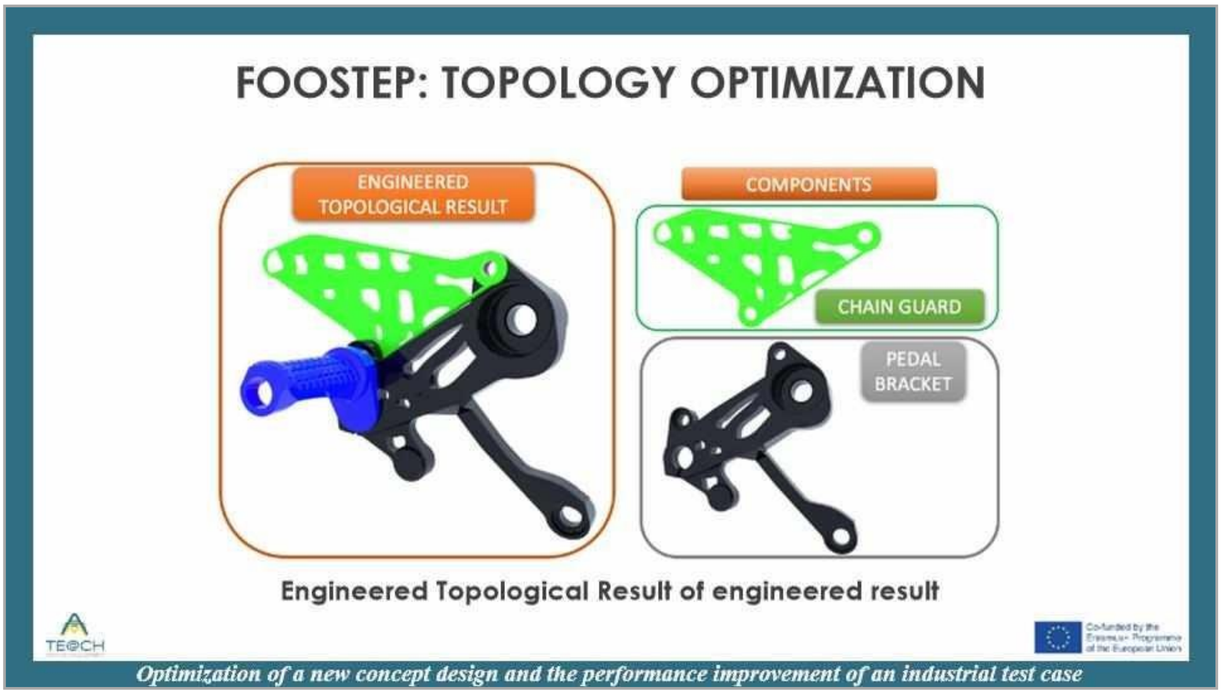
• 5Objective function that, for the specific study, has been defined as minimization of the compliance, in order to maximize the stiffness of the part. In fact, for a structure with an applied forces (F) subcase, the compliance (C) can be considered a reciprocal measure of the stiffness (K): 6C=1/2 and 7 ∗(U T).



The described methodology shows the steps carried out to obtain the topology optimization procedure in terms of given shape by the optimizer (optimized design) and the concept design (engineered design). As can be detected by the represented workflow there is the initial step (topology optimization) in which the main key points of the problem are defined (loads, material, constraints, acceptable deformation). After that, a classical topology optimization approach is applied to provide a new design solution in accordance with the given: design variables, objective function and last, but not least manufacturing constraints. Of course, the given possible result has to be processed in order to obtain a feasible CAD model which is a needed input to verify the structure performances of the obtained solution.

For the concept design a FEM analysis has been carried out. In particular, the FE model, that consist of Linear Tetra elements, it has been created in the Altair HyperMesh® environment and the linear structural analysis has been performed with Altair Optistruct® code.

The figure shows the engineered topological result.

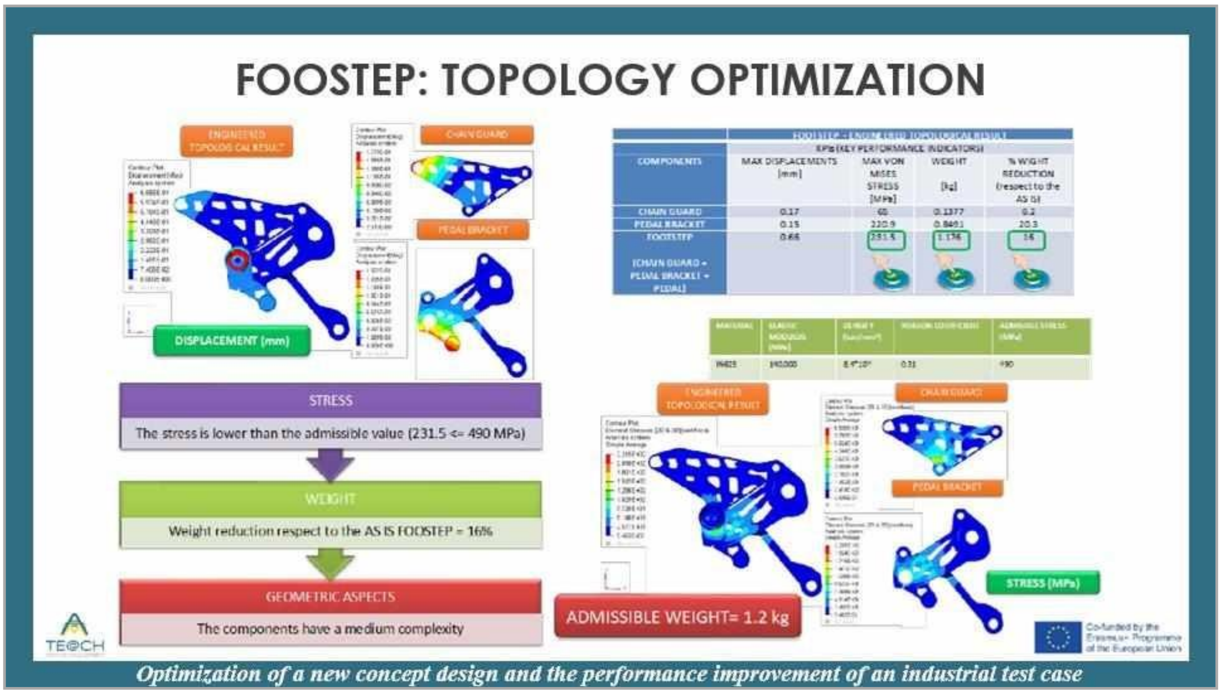


In order to characterized the design performance three KPI (Key Performance Indicators) have been considered: Displacement (mm), Stress (MPa) and Weight (kg). It is possible to review the displacement KPI distribution and Von Mises Stress KPI.

The results highlights that there are not critical issues: the Maximum Von Mises Stress is equal to 231.5 MPa < admissible stress equal to 490 MPa.

The Table shows results comparison in terms of the KPI of topological engineered footstep components and the following considerations are evident:

- The stress and displacement of the topological solution is comparable to the AS IS design;
- The engineered topological design is lighter than the AS IS design and respects the weight constraint (Maximum admissible weight = 1.2 kg);
- The weight reduction percentage (respect to the AS IS) is equal to 16%.



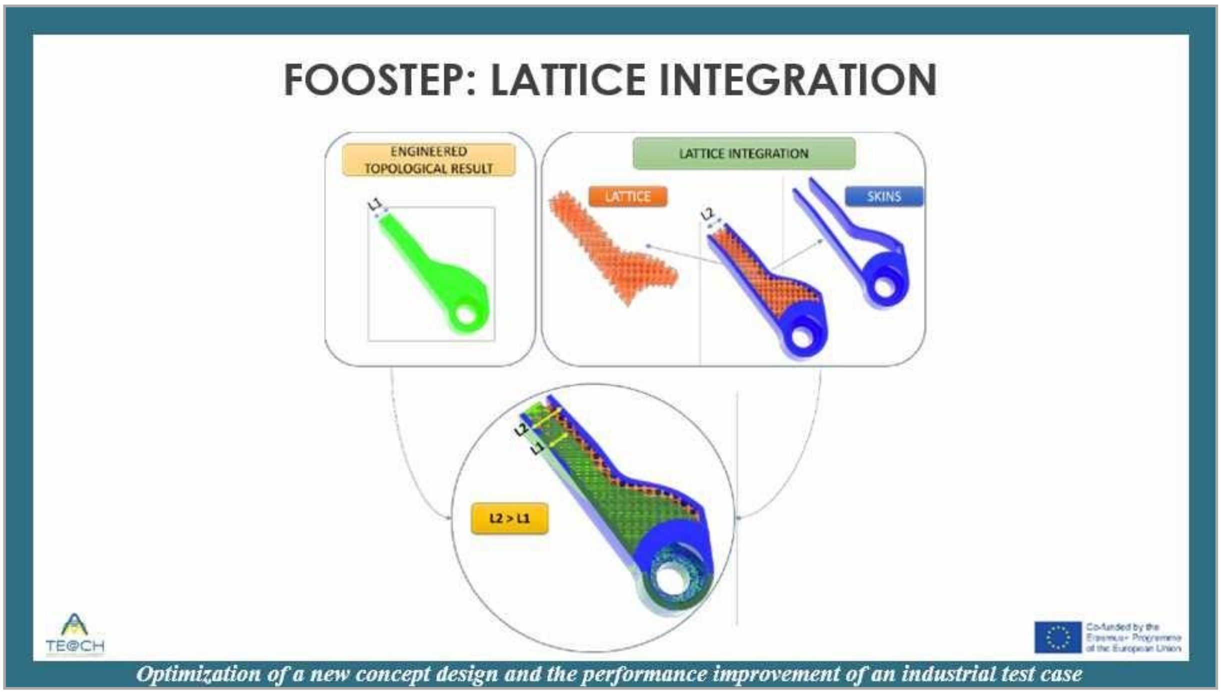
FOOSTEP: LATTICE INTEGRATION

Topology optimization enables identification of the optimal structural connectivity for a specific design scenario, boundary conditions and available spatial envelope. The geometric complexity of the topologically optimal design is typically incompatible with traditional manufacturing methods. Additive manufacture therefore provides an opportunity to manufacture components that more closely approximate the optimal geometry than traditional methods.

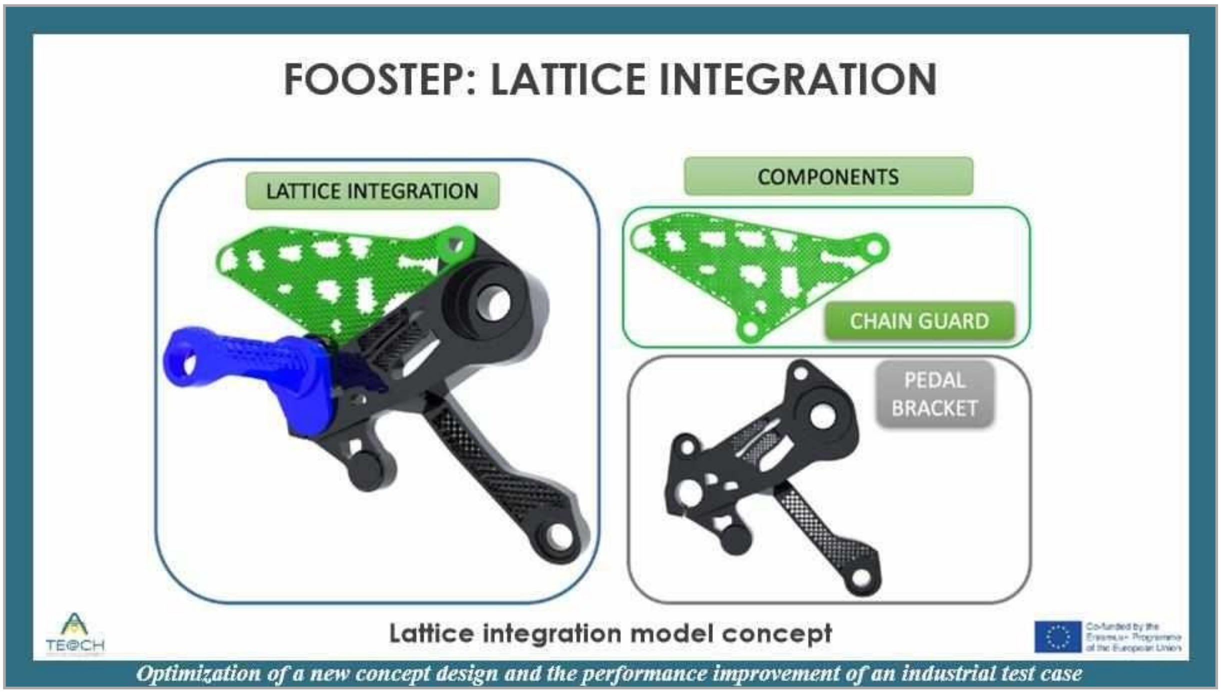
Starting from the optimized topology concept a new design configuration has been developed considering the integration of the lattice structures in the engineered topology design by the following sub-phases:

- Identification of interest zones for the lattice insertions. This phase has taken into account of the geometry regularity (possibility to identify rib features) and footstep functionality.

- Insertion of lattice structures in technological interest zones and testing of the defined solution as shown in the figure.

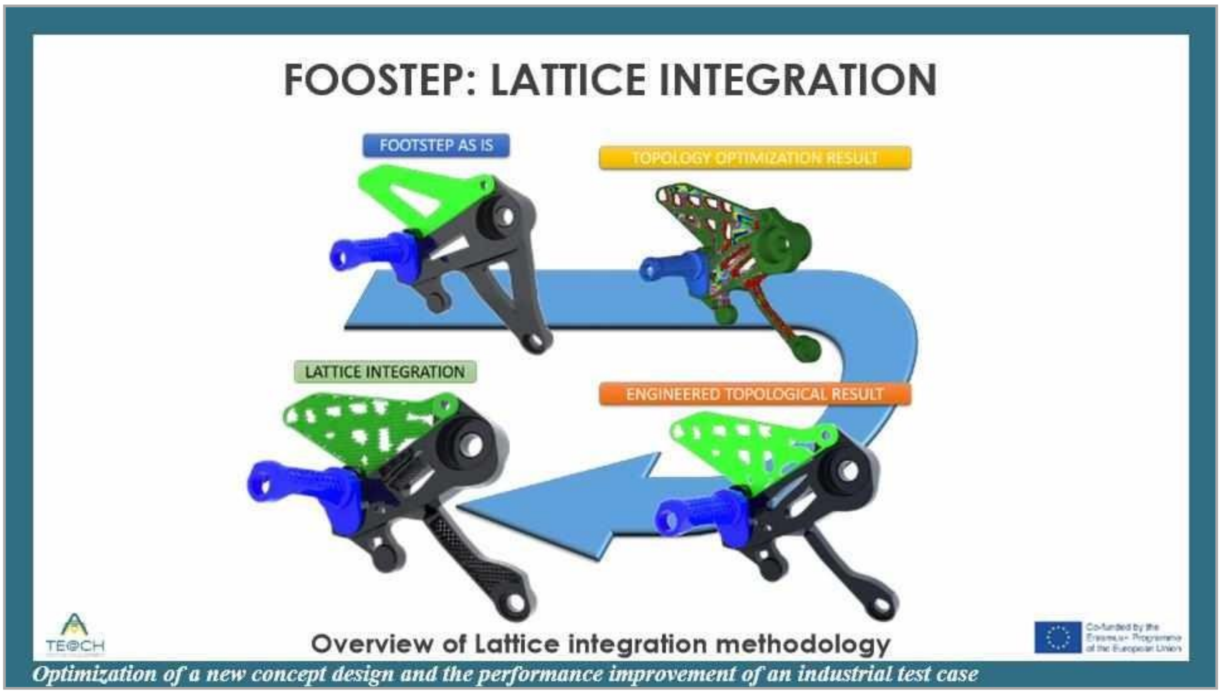


The goal of this methodology is to obtain an innovative concept that guarantees the same or better stiffness but allows to obtain a weight reduction.

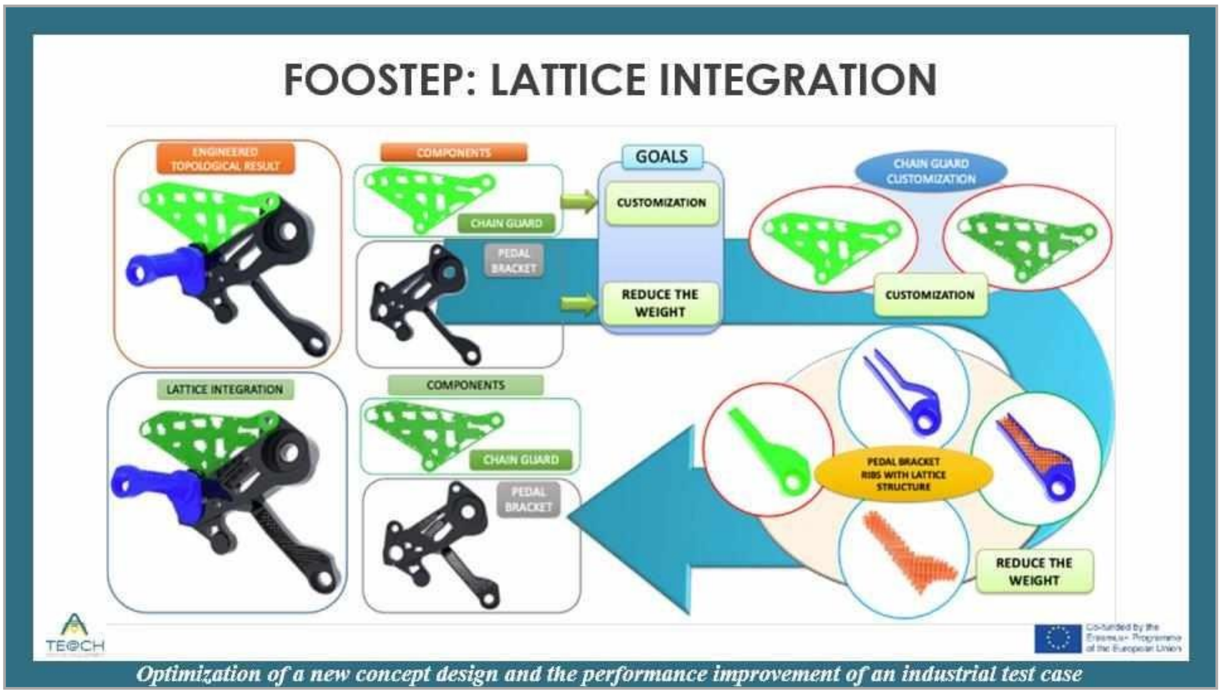


The general objective has been to evaluate the effectiveness in the lattice integration for the setup of highly performing innovative geometries in terms of weight reduction and mechanical characteristics in order to match the following advantages:

- Simple process in the case of topological optimization tools to support the creation of high-performance engineered profiles;
- Components performance improvement through the introduction of the lattice structures.



The aim of the work has been to evaluate the potentiality offered by the integration the lattice structures in the topology optimization methodology for obtaining innovative and highly performing structures. For the innovative concept design a FEM analysis has been carried out.

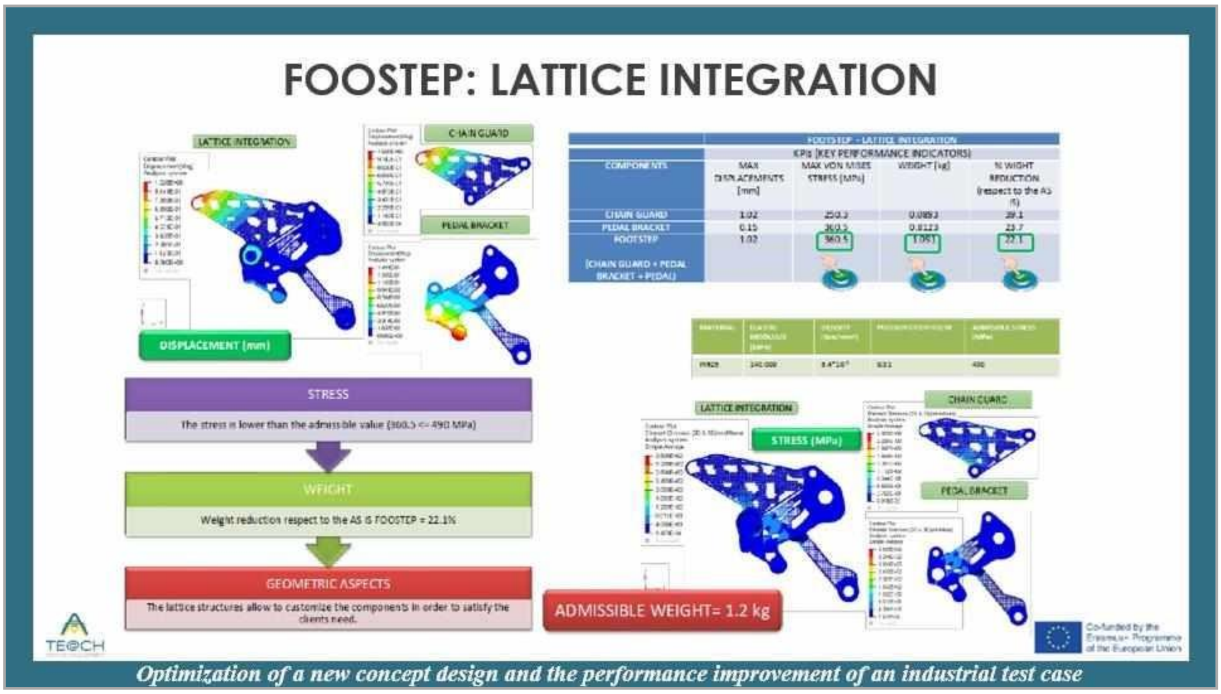


It is possible to review the results in terms of Displacement (mm) and in terms of Von Mises stress (MPa) for the studied case.

The results highlights that there are not critical issues: the Maximum Von Mises Stress is equal to 360.5 MPa < admissible stress equal to 490 MPa.

The Table shows the results comparison in terms of the defined KPIs of the innovative concept and the following considerations are evident:

- The stress of the lattice integration solution is lower than the admissible stress (admissible stress = 490 MPa);
- The lattice integration design respects the weight constraint (Maximum admissible weight = 1.2 kg) and it is lighter than the AS IS and topological design;
- The weight reduction percentage (respect to the AS IS) is equal to 22.1%.



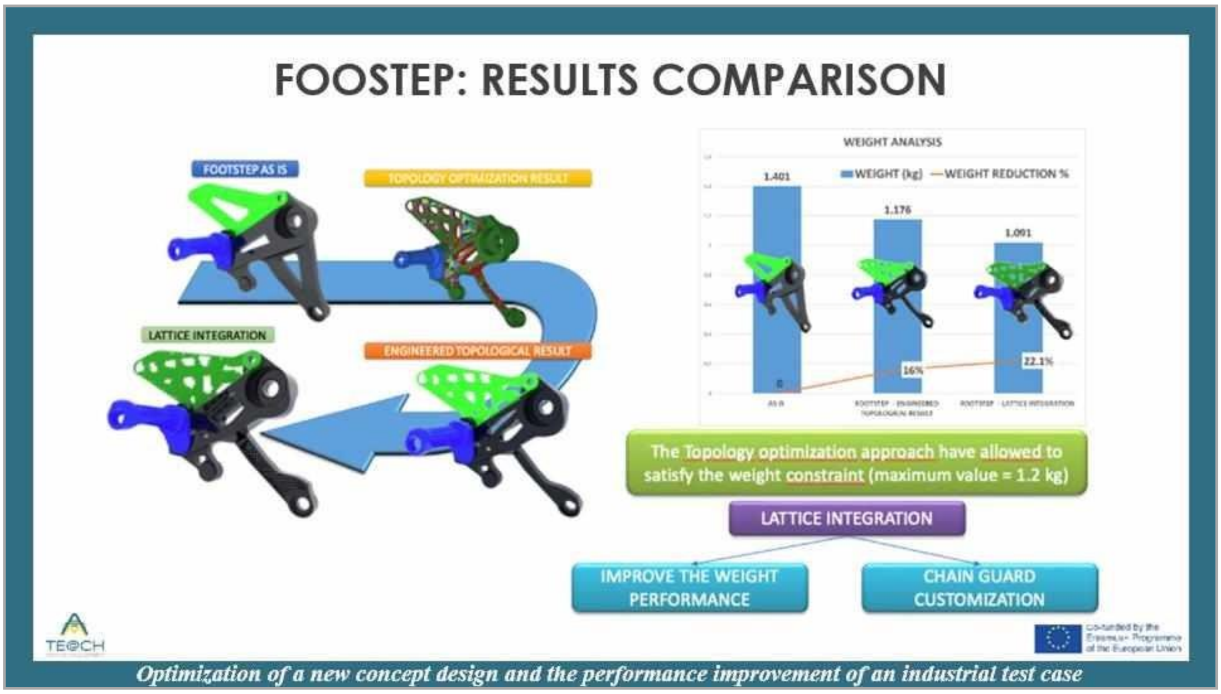
RESULT COMPARISON

This slide shows the comparison results, in term of weight reduction. It is evident as the lattice integration methodology is innovative and robust in terms of structural performance and weight. In fact, this solution allows to reduce the weight (22.1 % respect to the AS IS design) and ensure the structural constraint (the maximum operative stress is lower than the admissible stress).

In this work an innovative method, applied on footstep system, have developed, in order to exploit the advantages offered by the integration of the lattice structures in the topology optimization in order to obtain an innovative and highly performing structures. In particular, considering the topology results, a further weight reduction ensuring the structural performances, it has been obtained by means the integration of the lattice structures in some zones of the engineered topological design.

- The objective has been to propose a novel approach that allows to obtain innovative geometries able to further reduce the weight respect to the topological methodology.

- Further researches will be conducted in order to verify the component performances by means a numerical and experimental comparison.



ADDITIVE MANUFACTURING INTEGRATION WITH TOPOLOGY OPTIMIZATION METHODOLOGY FOR INNOVATIVE PRODUCT DESIGN

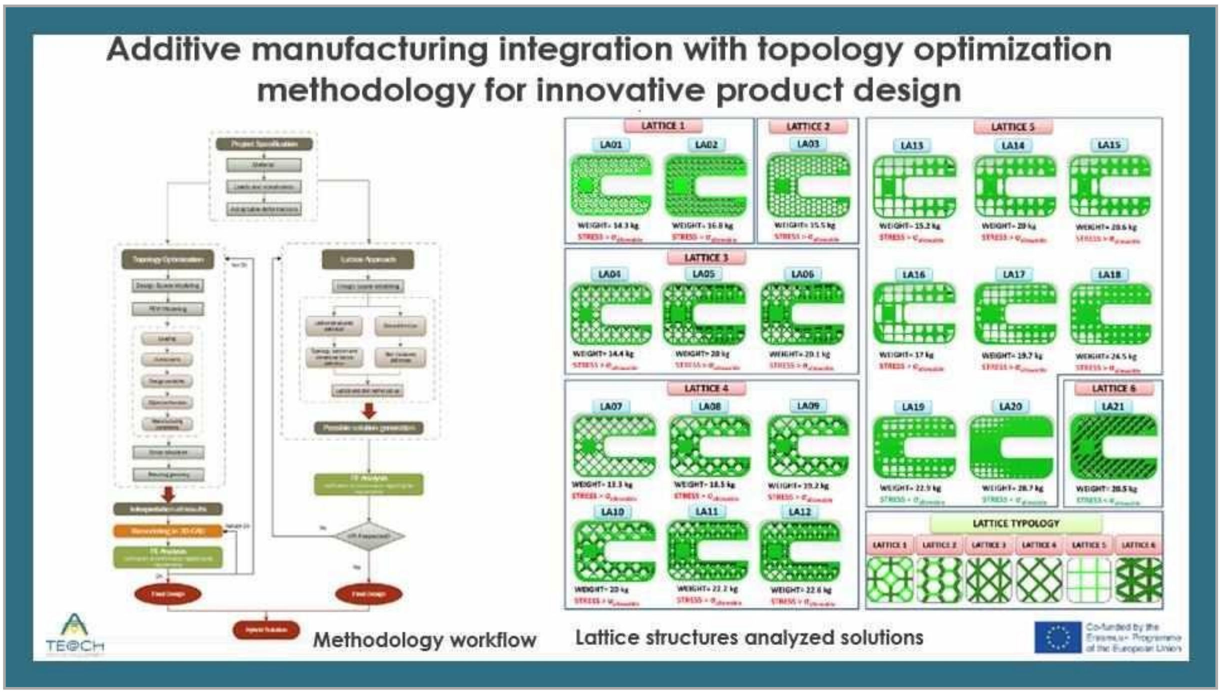
This slide shows the research activity carried out to evaluate the integration of the topology optimization with the lattice structure approach.

The activity has started frome the choice of a simple geometry as case study (C-CLIP).

In the right image several designs of the test case with only lattice structure approach is shown.

The left graph, instead, describe the developed methodology that consist of two different branch. The first one is the tradional workflow for the topology optimization. The second one is the lattice approach.

Starting from the obtained results from the both methodology, the study has presented an hybrid approach that combines both methodology.



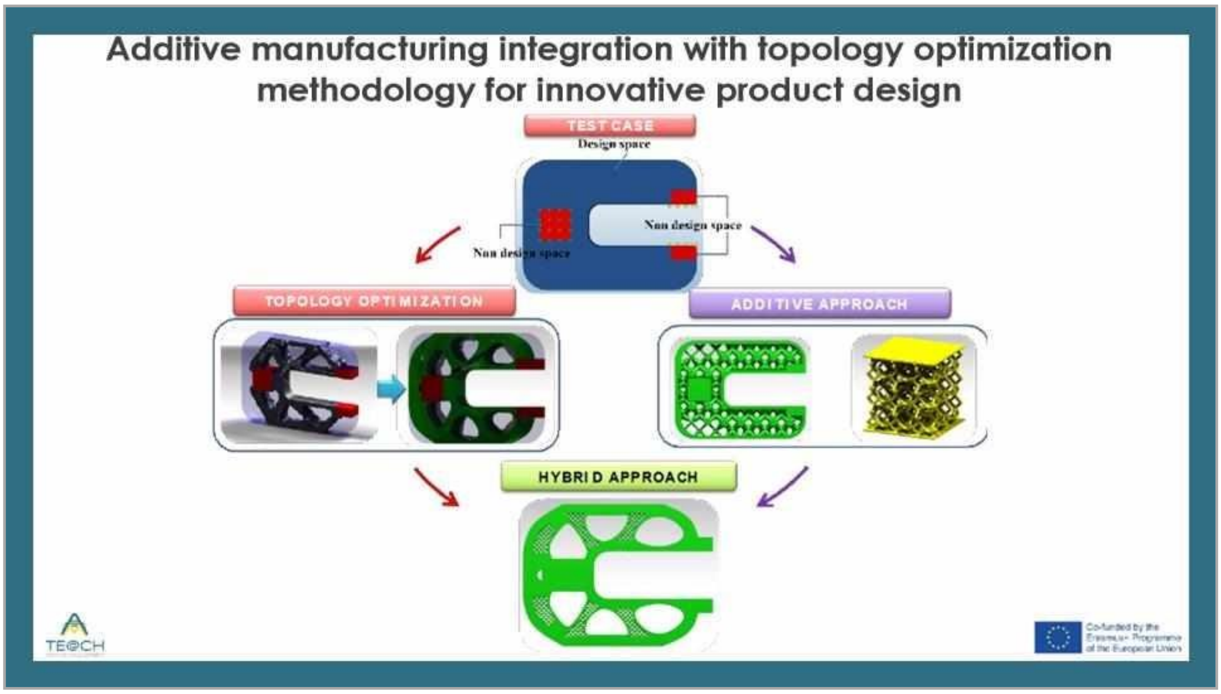
In this picture the obtained result from the hybrid approach is shown.

The top image represents the starting test case.

The results are extremely different for the topology optimization and the lattice approach. Indeed in the lattice approach the whole blu zone (design space) has been filled with the lattice structure.

In the case of topology optimization the not required material for the operative conditions has been removed.

The hybrid approach allow to refine the topology solution further reducing the mass.



ANALYSIS OF THE RESULTS

To monitor the performance of the adopted approach several Key Performance Indicators (KPIs) are defined. Each one of these last analyzes a particular aspect. In particular:

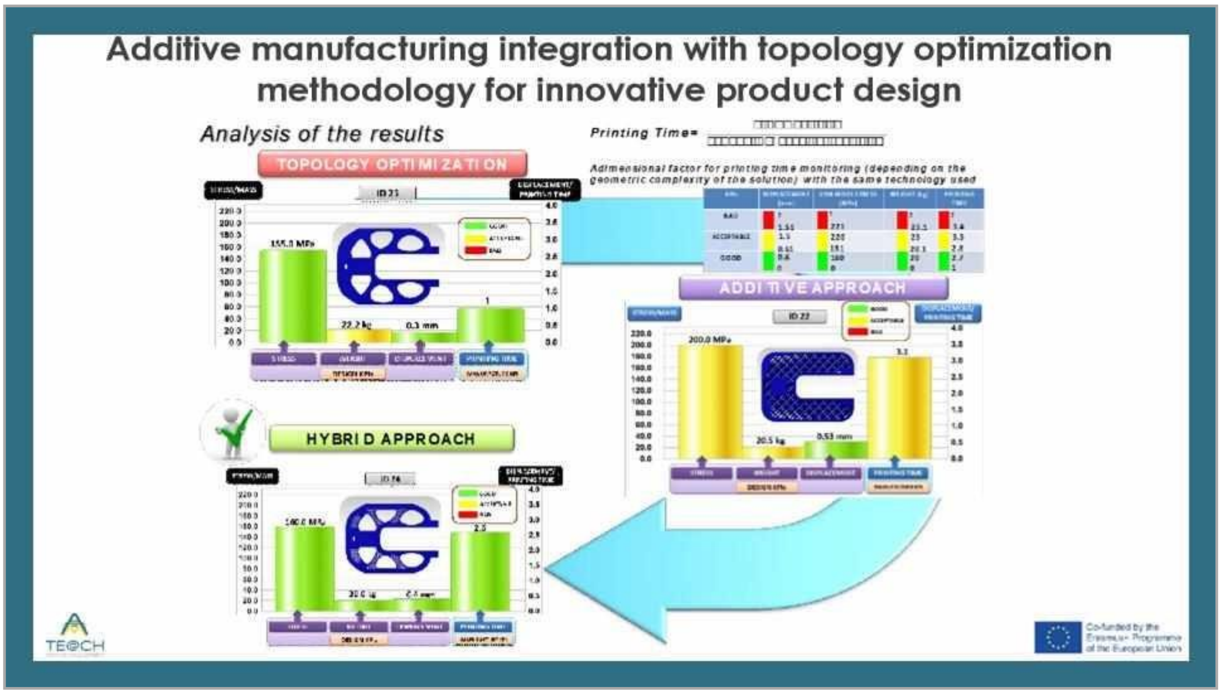
Stress represents the maximum value of stress for a such operative condition,

Displacement represents the maximum value of displacement caused by the operative condition

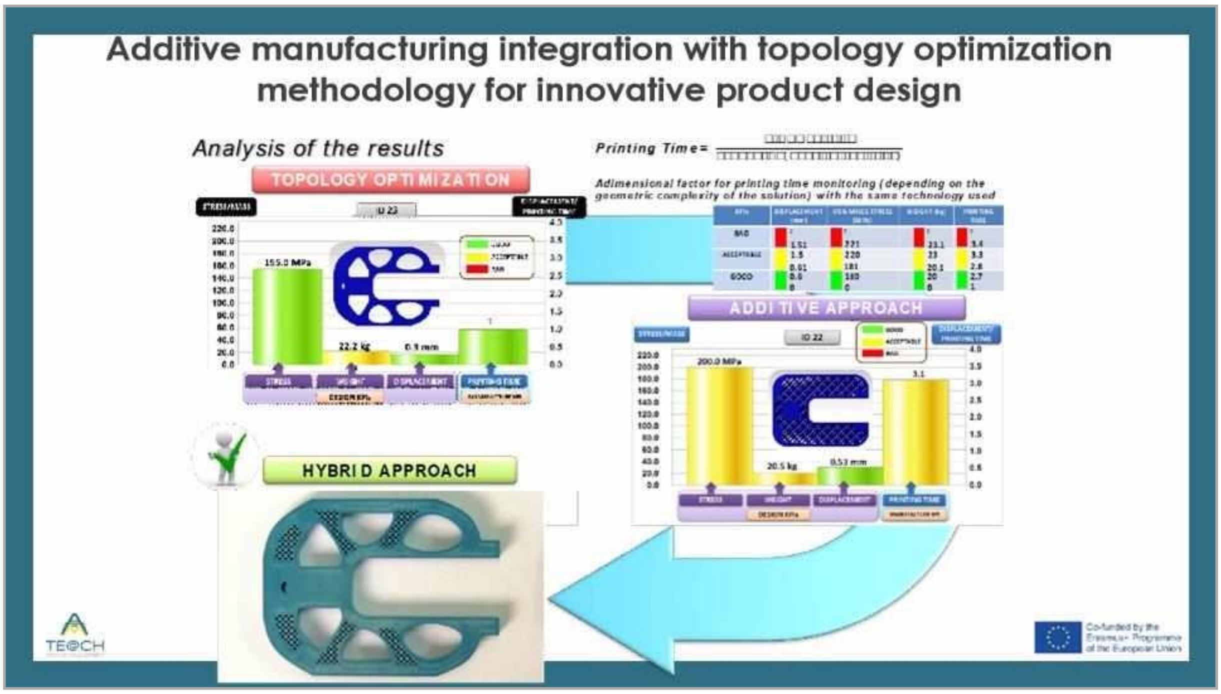
Weight is the mass carachteristics of the obtained component

Printing time representes the needed time to print the component.

Considering the before mentioned KPIs the hybrid approach represent the best solution.



The obtained component has been manufactured with a 3D printing technology with high precision. This technology allows to print components with WAX material and, generally, the typical application is the jewelry field.



For further information and contact details, have a look here:

ITS Aerospazio Puglia
https://www.itsaerospaziopuglia.it/
Cittadella della Ricerca S.S.7 km 7,300
72100 Brindisi (BR)
Puglia, Italy

University of Salento
Department of Engineering for Innovation
https://www.dii.unisalento.it/
Complesso Ecotekne - Edificio “Corpo O”
Via per Monteroni
73100 LECCE (LE)
Puglia, Italy

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