Intellectual Output_O1:
EMERALD e-book for developing of biomimetic mechatronic systems

MODULE 2
Computer Aided Engineering

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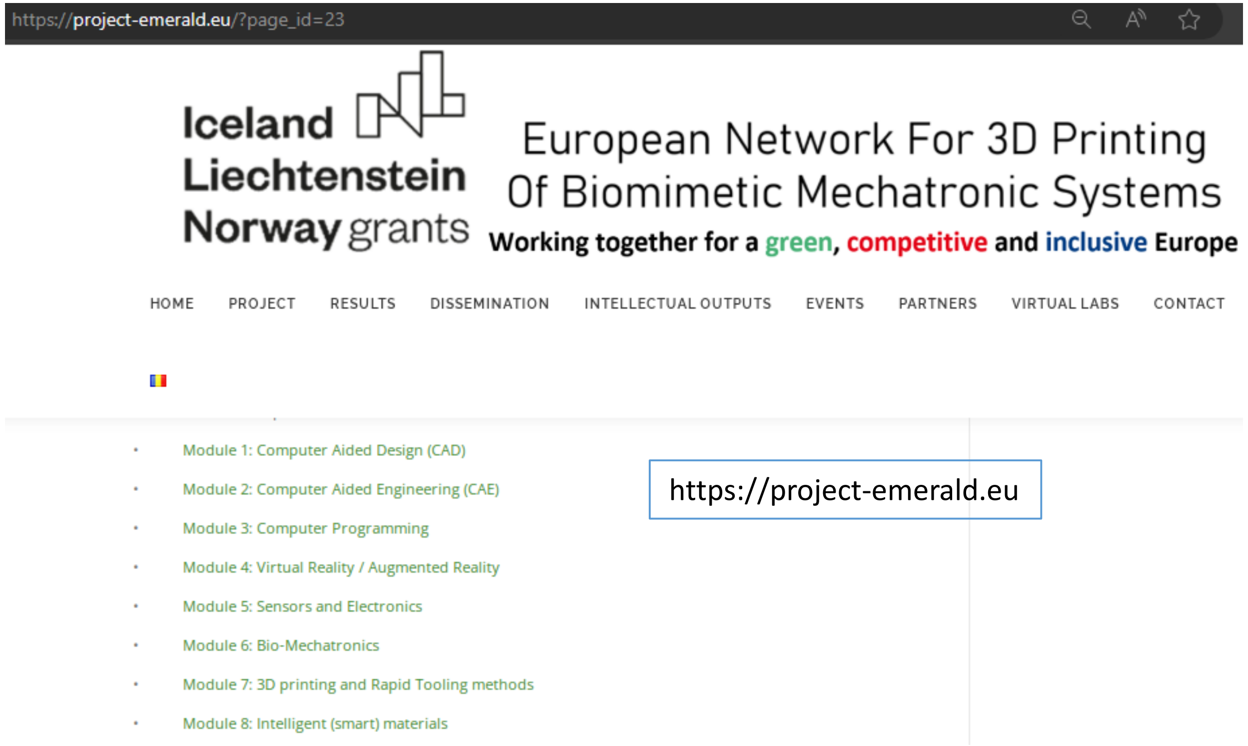

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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 2 – CAE

Project Title	**European network for 3D printing of biomimetic mechatronic systems 21-COP-0019**
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MODULE 2: Computer Aided Design

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1. Numerical Solution of Engineering Problems

The variety of problems that occur in practice is reflected in the multitude of calculation methods used at present. These methods have been gradually developed, along with the accumulation of technical and theoretical knowledge and, in the last seven decades, simultaneously with the evolution of digital computers. A basic classification of the calculation methods used in engineering distinguishes two large categories:

- Exact (or analytical) methods
- Approximate methods.

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1. Numerical Solution of Engineering Problems

Nowadays, the following approximate methods of numerical type are mainly used in engineering:

- Finite difference method (FDM)
- Finite element method (FEM)
- Boundary element method (BEM).

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2. Features of the Finite Element Method

FEM builds the approximation of the exact solution as follows:

- The spatial domain occupied by the physical system under analysis is divided into a finite number of non-overlapping subdomains called (finite) elements.
- Polynomial approximations of the problem unknowns are defined over each element.
- Each polynomial depends on the unknown values associated to a finite set of points called nodes.
- The element approximations are assembled into a global approximation of the problem unknowns.

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2. Features of the Finite Element Method

In the specific case of elasticity problems, the steps performed when elaborating and solving a finite element model are as follows:

- Selecting the finite element type which is the most suitable for the problem under analysis
- Meshing the analysis domain
- Generating element approximations for the problem unknowns
- Including the element approximations in the expression of the potential energy
- Enforcing the minimum condition on the finite element approximation of the potential energy and assembling the set of equations emerging from this condition
- Applying the boundary conditions by reducing the set of equations
- Solving the set of equations for the nodal unknowns
- Reconstructing the element approximations and assembling them into a global approximation
- Analyzing the numerical results.

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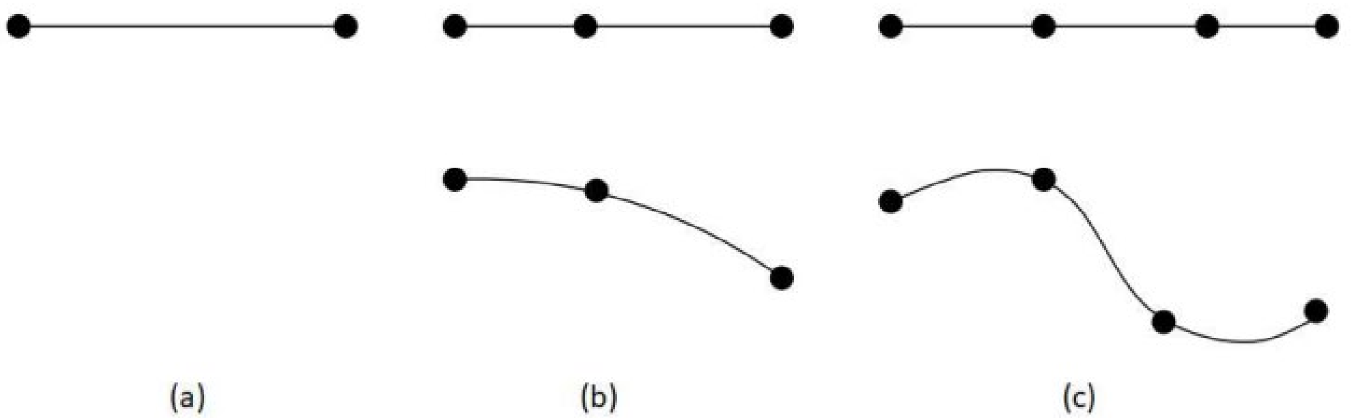
3. Common Types of Finite Elements

A general classification (but not comprehensive, unfortunately) defines three categories of finite elements differentiated by their dimensionality:

- One-dimensional elements
- Two-dimensional elements
- Three-dimensional elements.



One-dimensional finite elements: (a) First order (or linear). (b) Second order (or quadratic). (c) Third order (or cubic)

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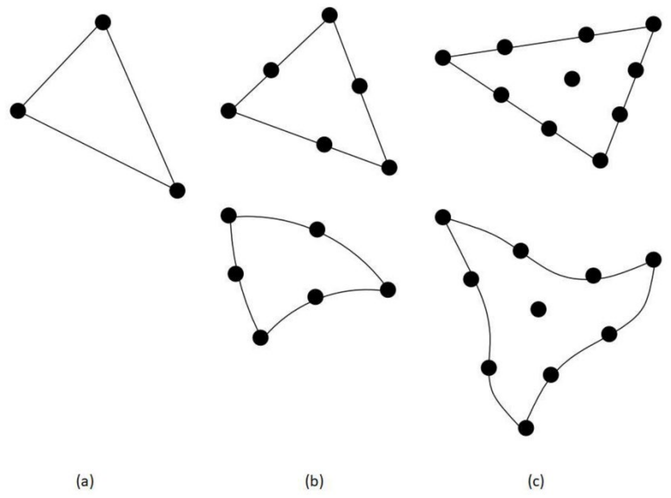
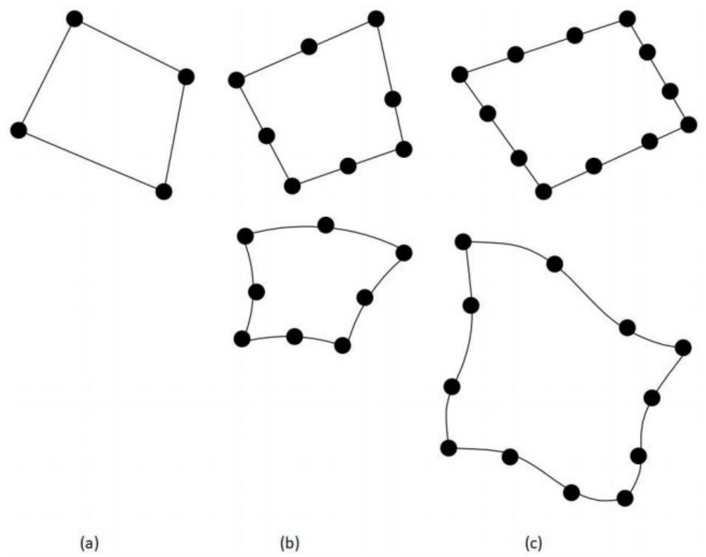
Two-dimensional elements



Triangular finite elements: (a) First order (or linear). (b) Second order (or quadratic). (c) Third order (or cubic)



Quadrilateral finite elements: (a) Bilinear. (b) Biquadratic. (c) Bicubic

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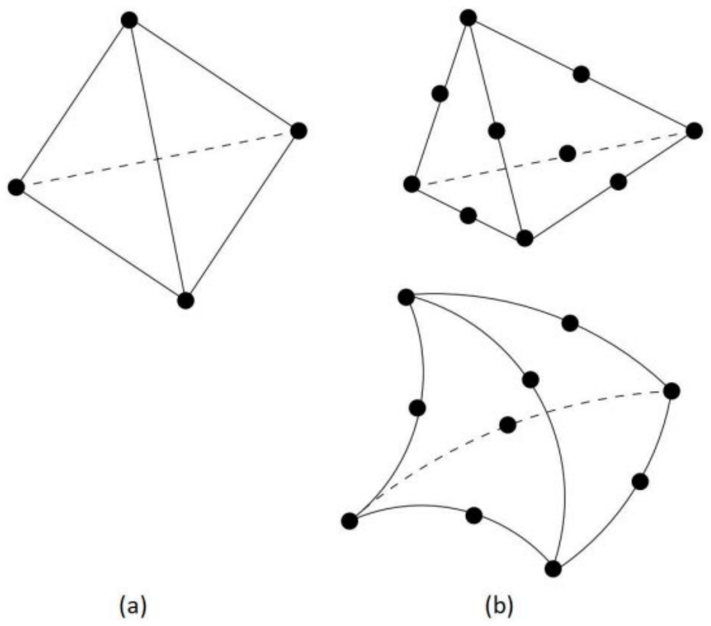
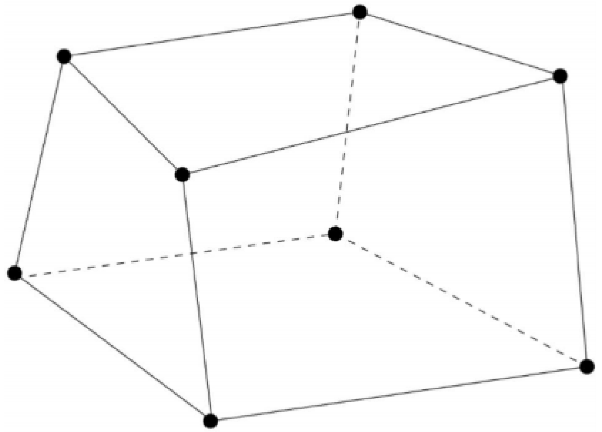
Three-dimensional elements



Tetrahedral finite elements: (a) First order (or linear).
(b) Second order (or quadratic)



Hexahedral finite element of the trilinear type

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3.2. General rules to be applied when selecting the finite element type

In practice, the following rules can be applied:

- When solving two-dimensional problems, bilinear quadrilateral elements should be used instead of the linear triangular ones (the former elements, having polynomial approximations of a higher degree, provide more accurate solutions at the cost of a moderate growth in the number of nodes).

- Similarly, in the case of three-dimensional problems, trilinear hexahedral elements provide more accurate solutions than the linear tetrahedral elements (however, this improvement in performance implies a doubled number of nodes at the level of each element).

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4. Example: Finite Element Analysis of a Wrist Hand Orthosis

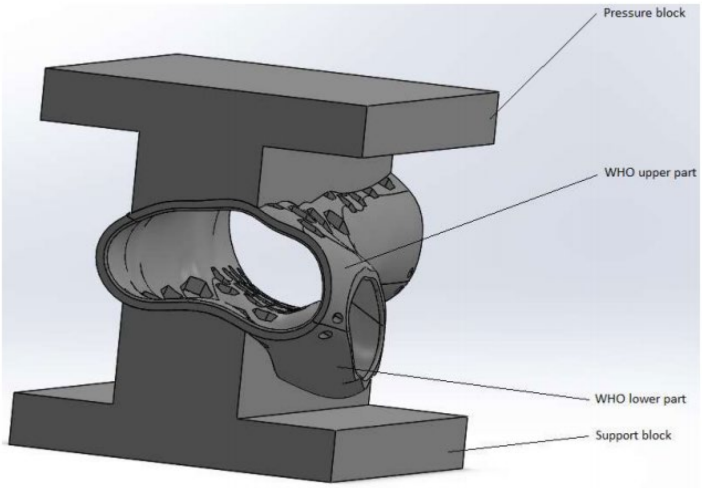

Figure 4.1: Principle of the compression test simulated for evaluating the strength characteristics of the wrist hand orthosis (WHO)

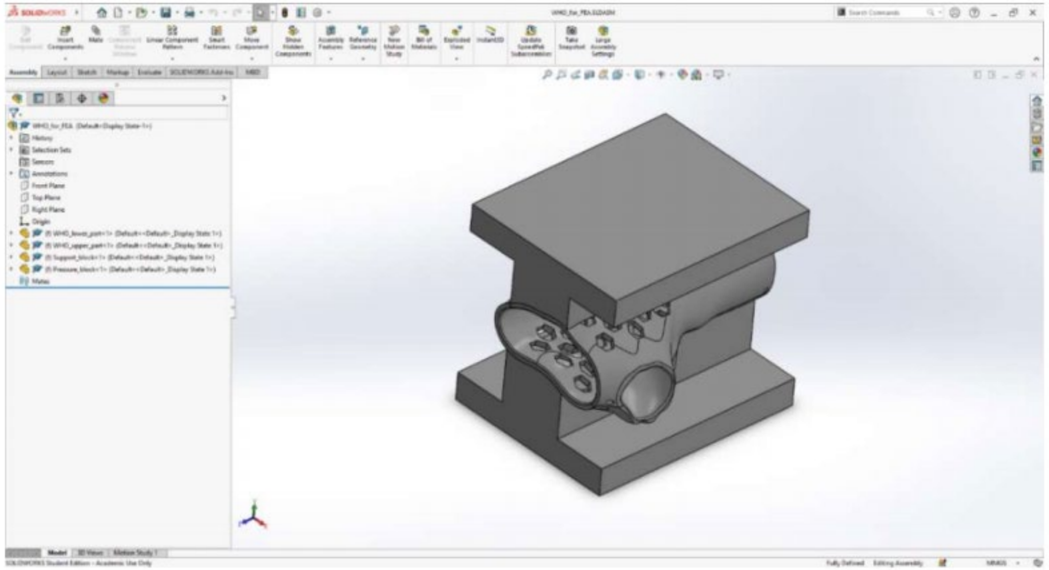

Figure 4.2: WHO assembly model open in SolidWorks

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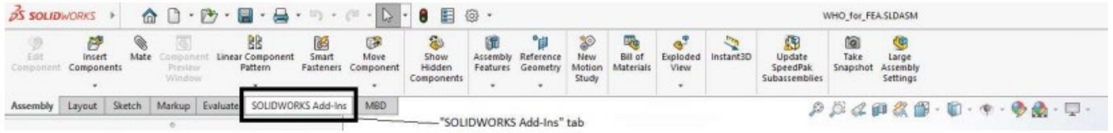

Figure 4.3: “SOLIDWORKS Add-Ins” tab in the “Command Manager” toolbar

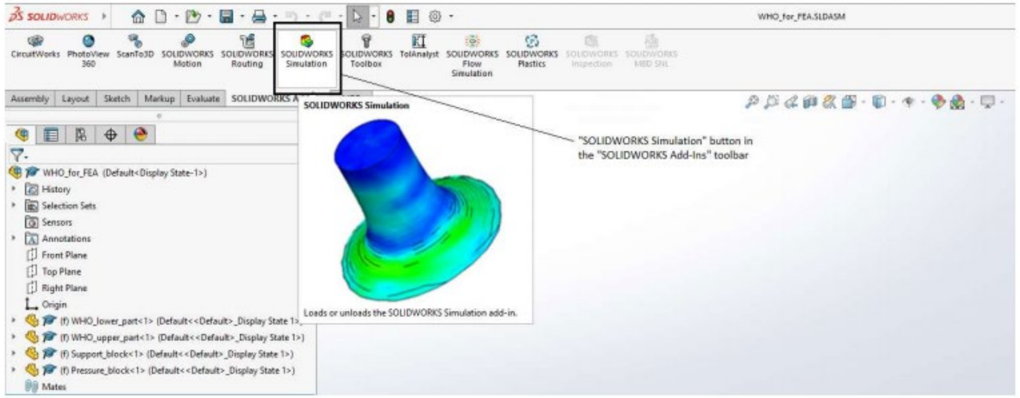

Figure 4.4: “SOLIDWORKS Simulation” button in the “SOLIDWORKS Add-Ins” toolbar

Figure 4.5: “Simulation” tab included in the “Command Manager” toolbar after the activation of the SolidWorks Simulation module

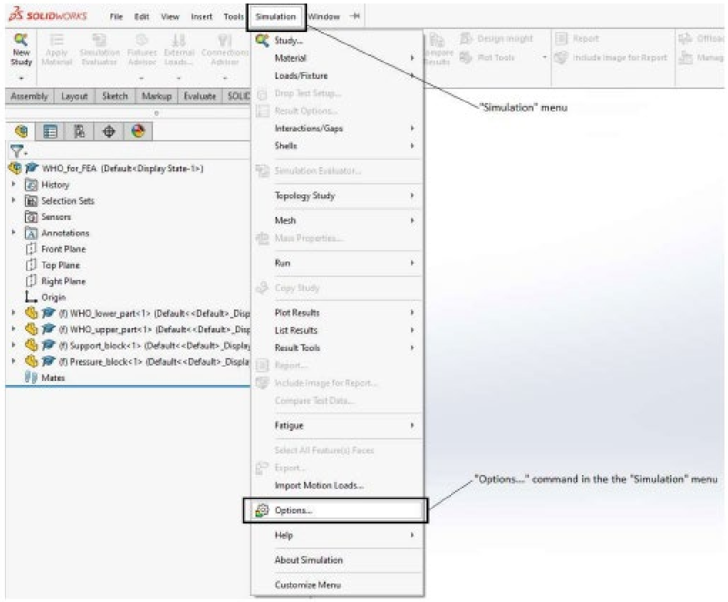

Figure 4.6: “Options...” command in the “Simulation” menu

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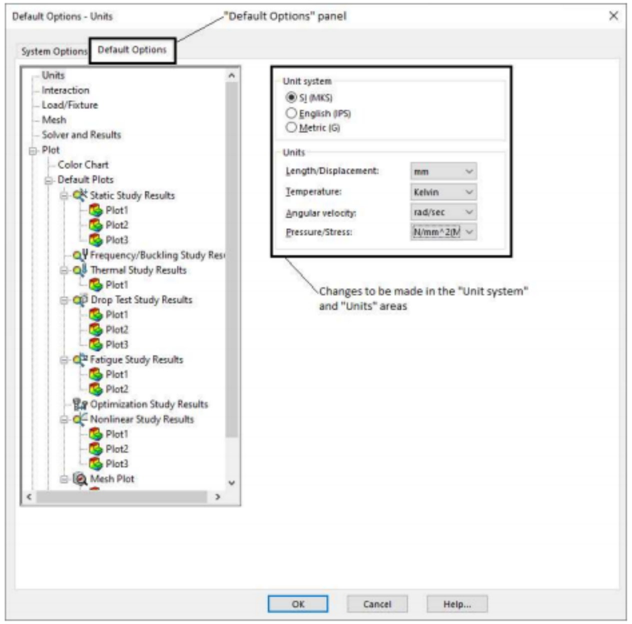

Figure 4.7: Changes to be made in the “Default Options” panel of the “System Options – General” window

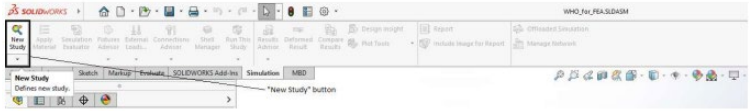

Figure 4.8: Creation of a new FEA model

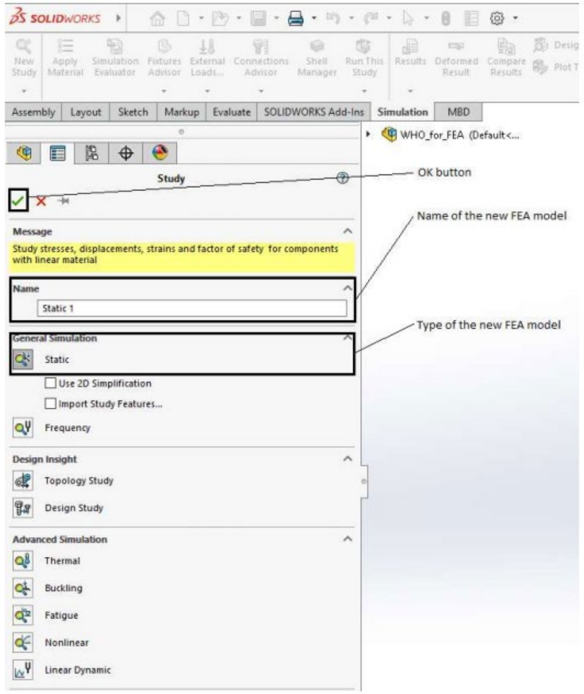

Figure 4.9: Defining the name and type of the new FEA model

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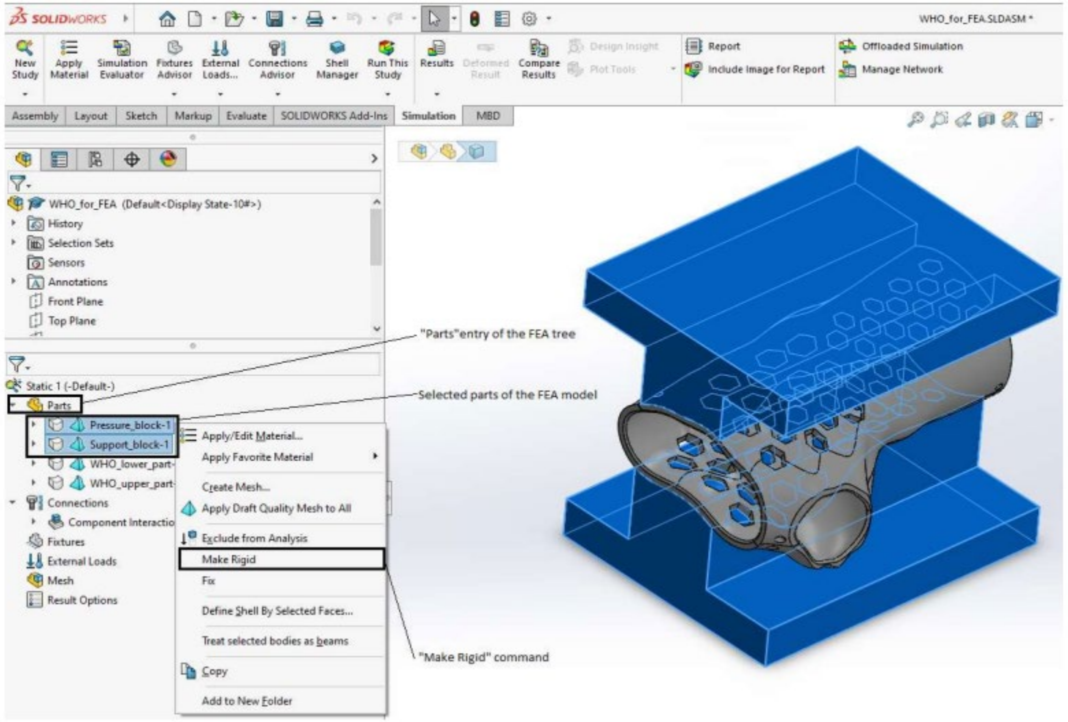

Figure 4.10: Defining the pressure block and support block as perfectly rigid bodies

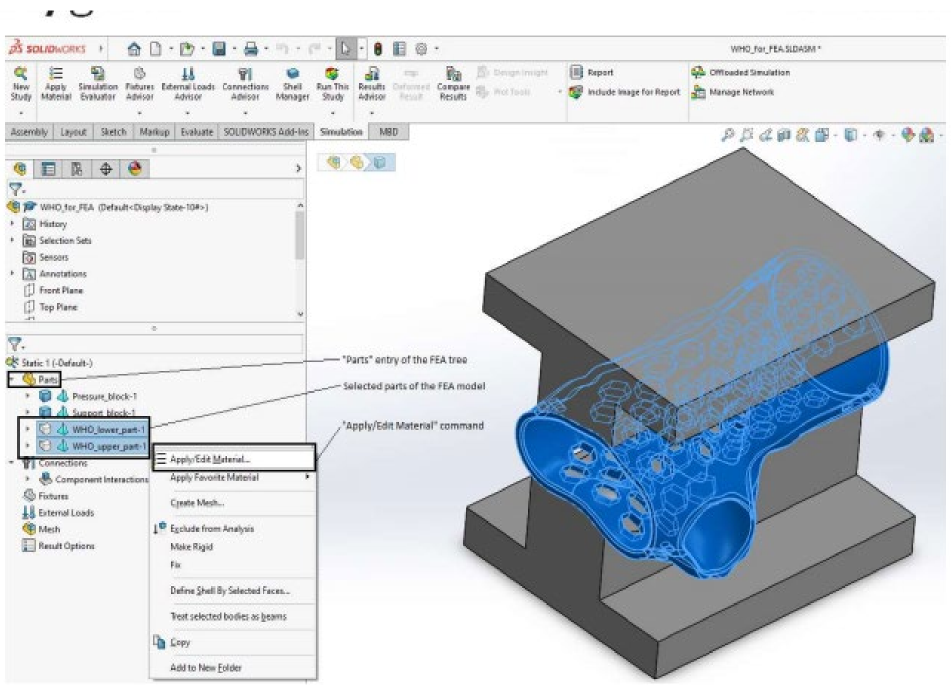

Figure 4.11: Defining the material properties of the lower and upper parts of the orthosis

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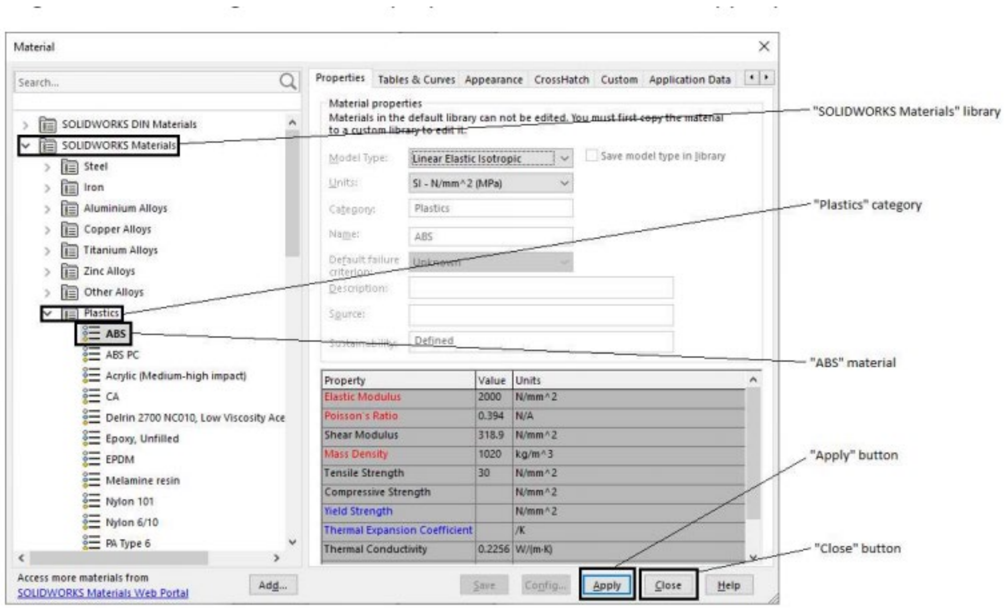

Figure 4.12: Associating the ABS material to the lower and upper parts of the orthosis

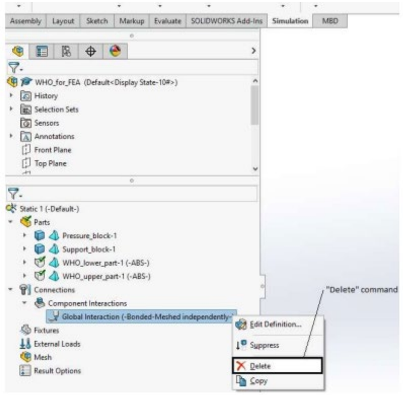

Figure 4.13: Removing the “Global Interaction” option from the FEA tree

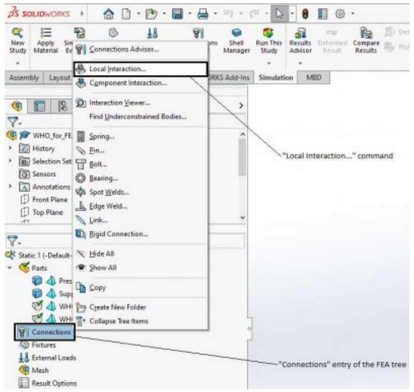

Figure 4.14: Defining a pair of contact surfaces by means of the “Local Interaction…”

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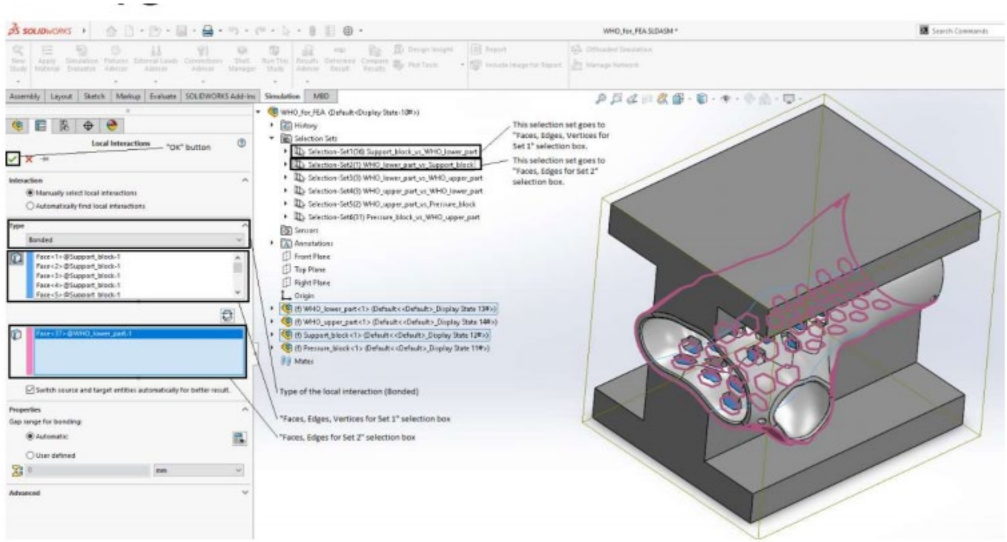

Figure 4.15: Defining the contact interaction between the support block and the lower part of the orthosis

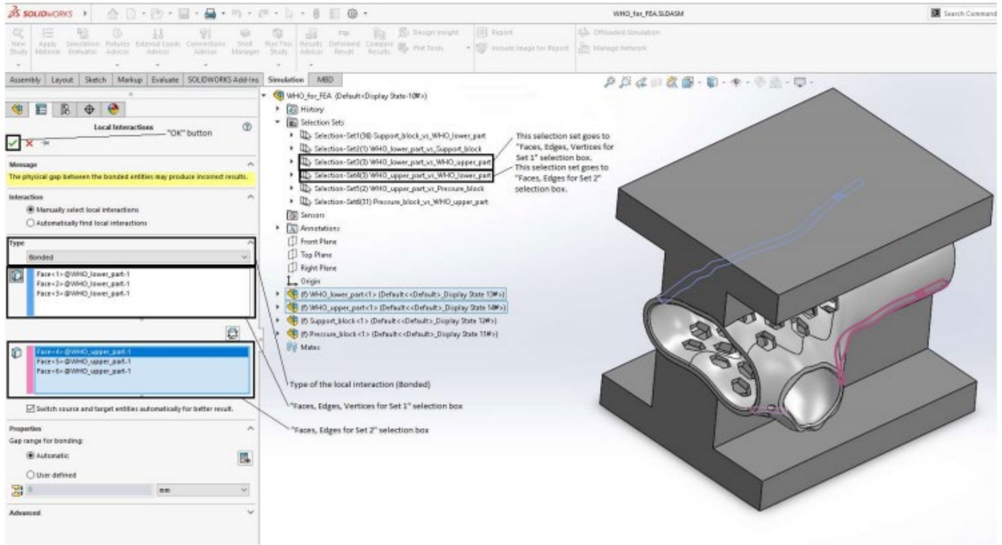

Figure 4.16: Defining the contact interaction between the lower and upper parts of the orthosis

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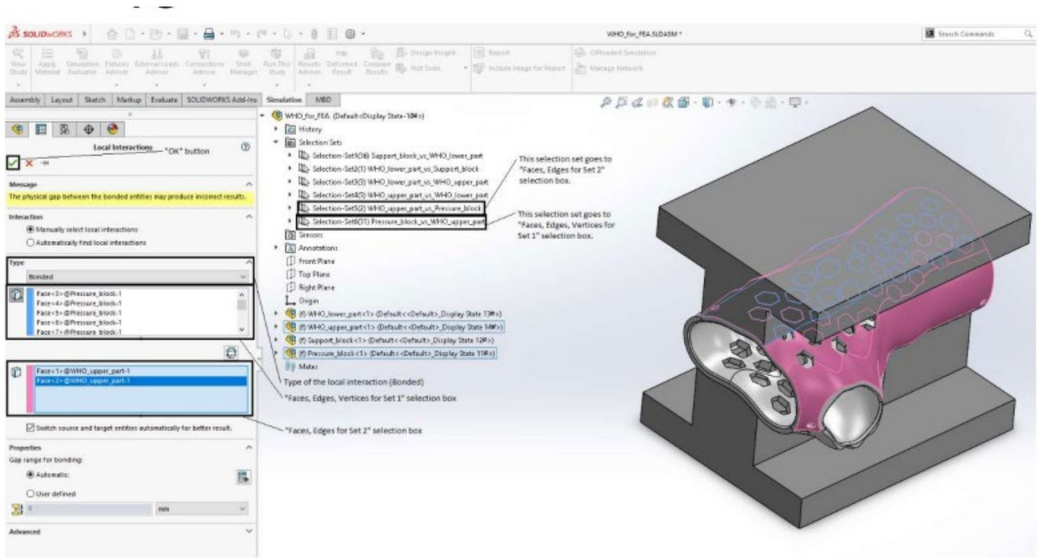

Figure 4.17: Defining the contact interaction between the pressure block and the upper part of the orthosis

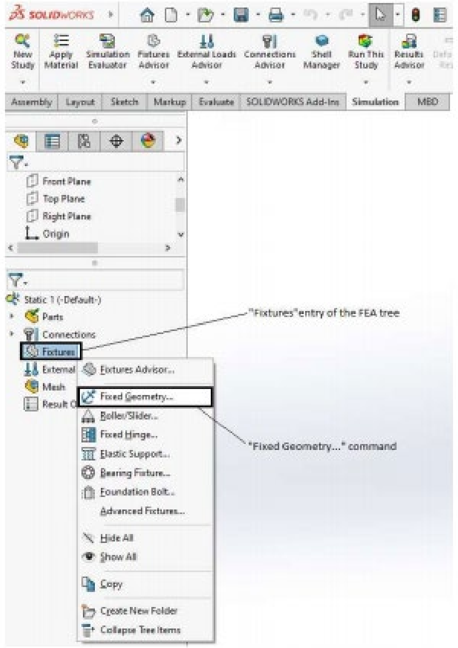

Figure 4.18: Defining a full locking boundary condition

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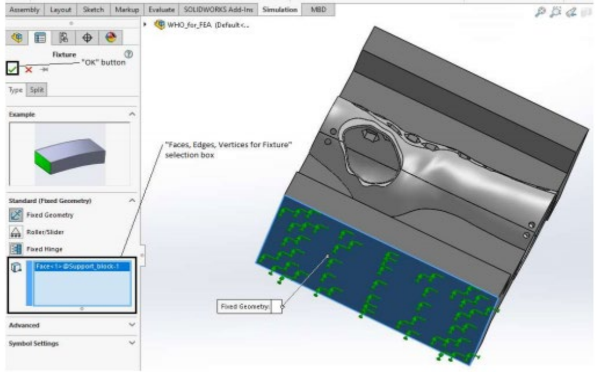

Figure 4.19: Full locking boundary condition enforced on the lower face of the support block

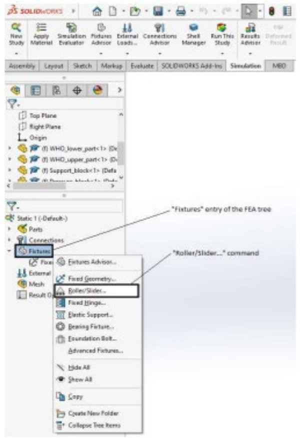

Figure 4.20: Defining a sliding boundary condition

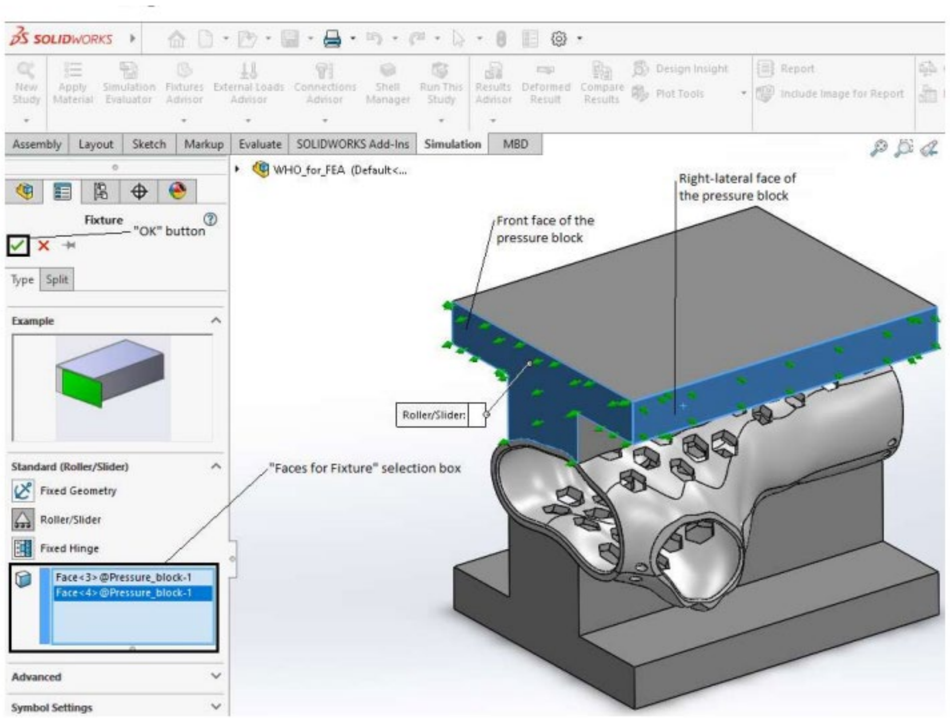

Figure 4.21: Enforcing the vertical sliding of the pressure block

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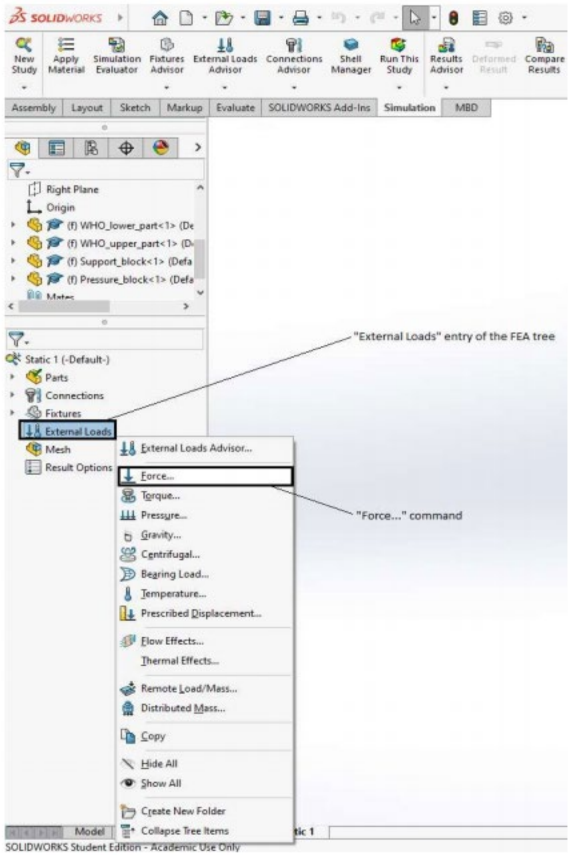

Figure 4.22: Defining a force-type boundary condition

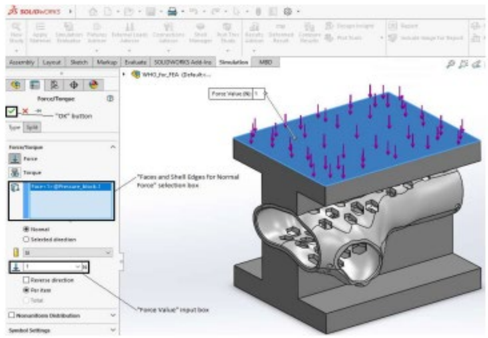

Figure 4.23: Defining the normal force that acts on the upper face of the pressure block

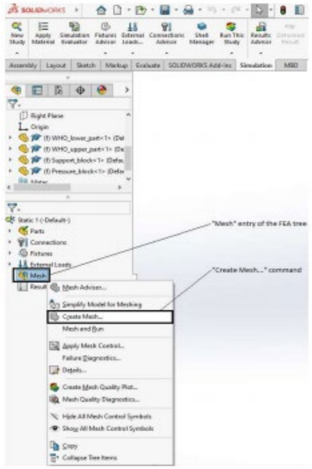

Figure 4.24: Initiating the generation of the finite element mesh

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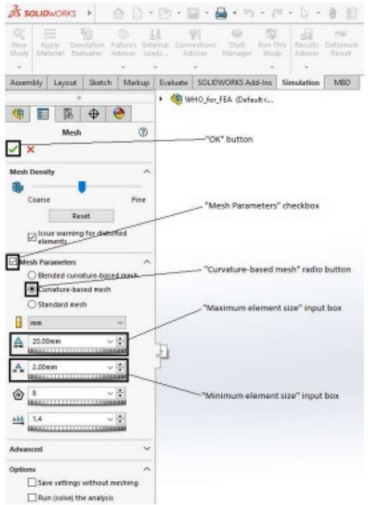

Figure 4.25: Defining the control parameters of the finite element mesh

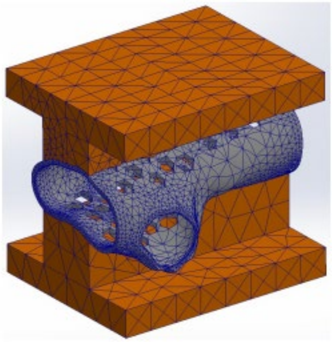

Figure 4.26: Finite element mesh generated by SolidWorks Simulation

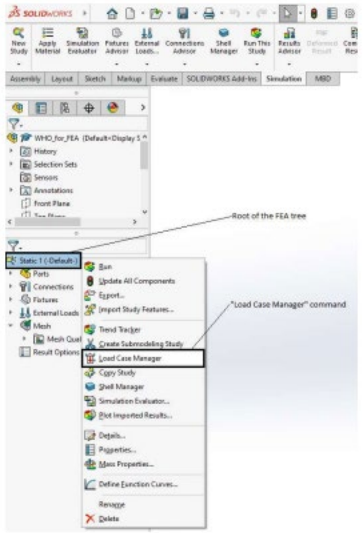

Figure 4.27: Accessing the Load Case Manager

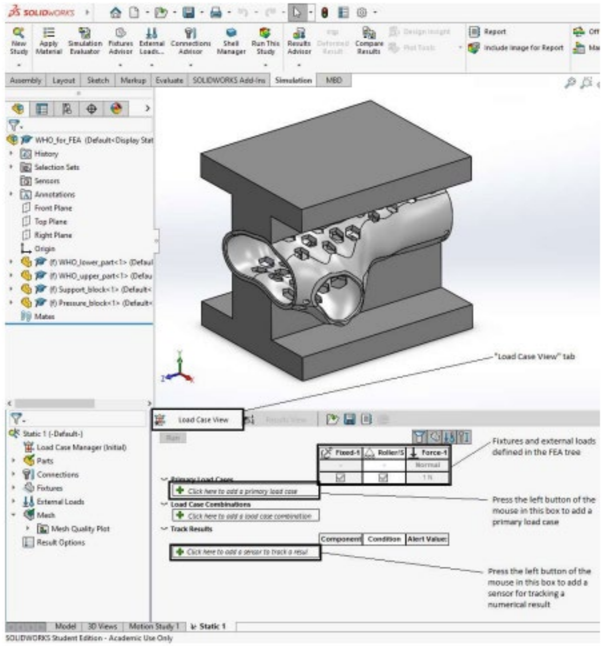

Figure 4.28: "Load Case View" tab displayed at the bottom of the SolidWorks graphics area

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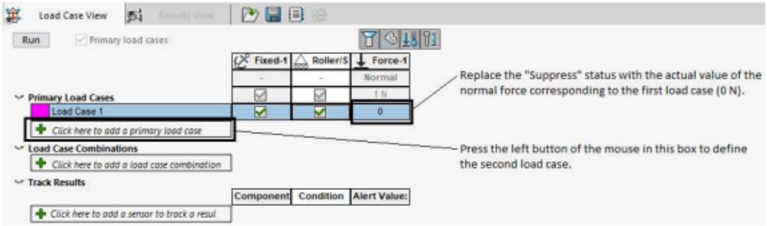

Figure 4.29: Defining the first load case (normal force of 0 N)

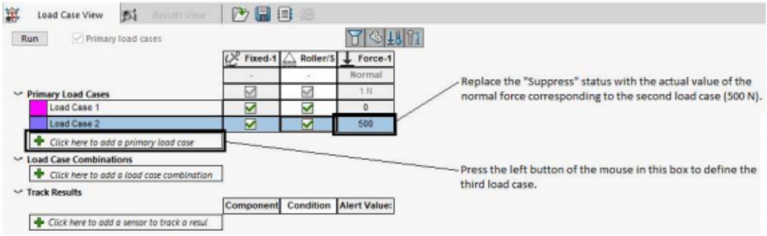

Figure 4.30: Defining the second load case (normal force of 500 N)

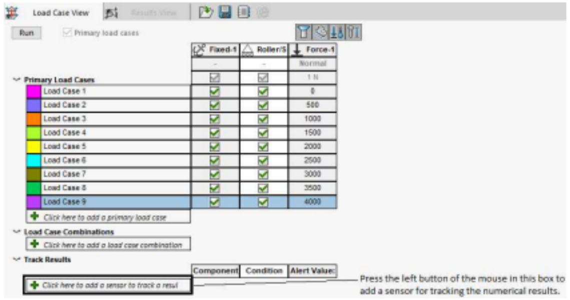

Figure 4.31: Actual values of the normal force acting on the upper face of the pressure block

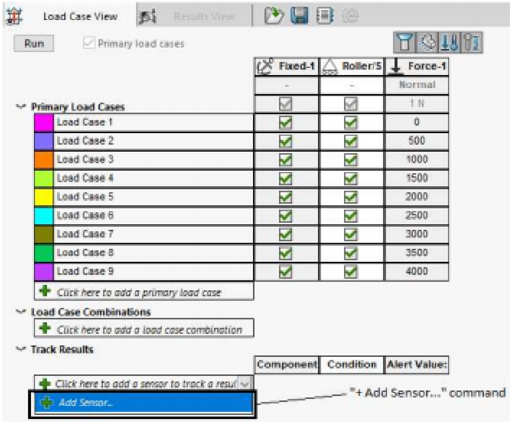

Figure 4.32: Initiating the definition of a sensor for tracking the numerical results

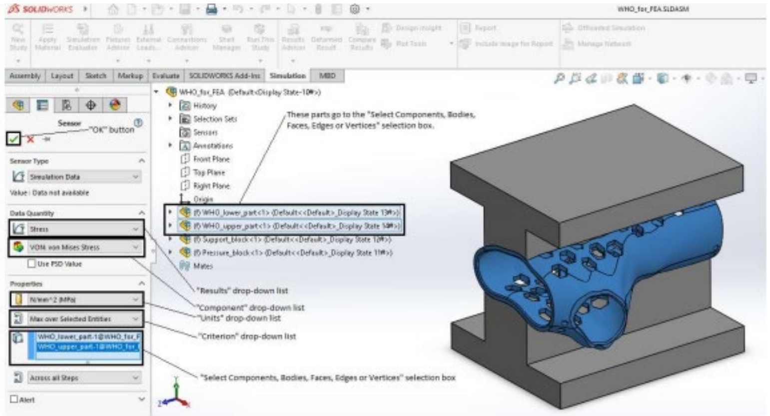

Figure 4.33: Definition of a sensor for tracking the maximum value of the von Mises equivalent stress at the level of the lower and upper parts of the orthosis

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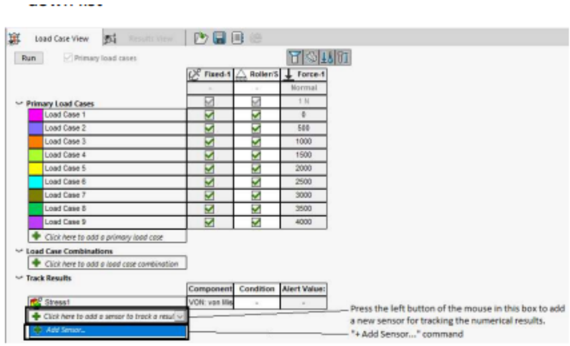

Figure 4.34: Initiating the definition of a new sensor for tracking the numerical results

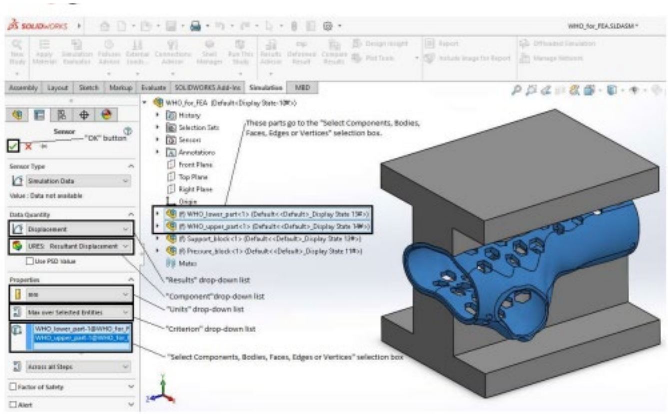

Figure 4.35: Definition of a sensor for tracking the maximum deflection at the level of the lower and upper parts of the orthosis

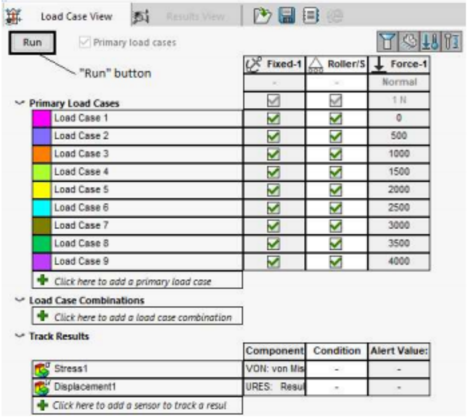

Figure 4.36: Transferring the finite element model to the SolidWorks Simulation solver

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4.3. Interpretation of the numerical results

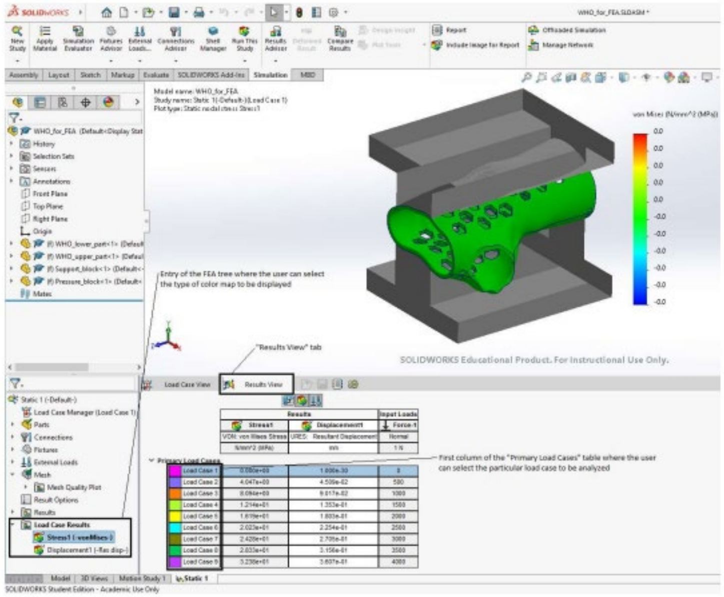

Figure 4.37: Analyzing the numerical results associated to different load cases with the help of the "Results View" tab and the "Load Case Results" entry of the FEA tree

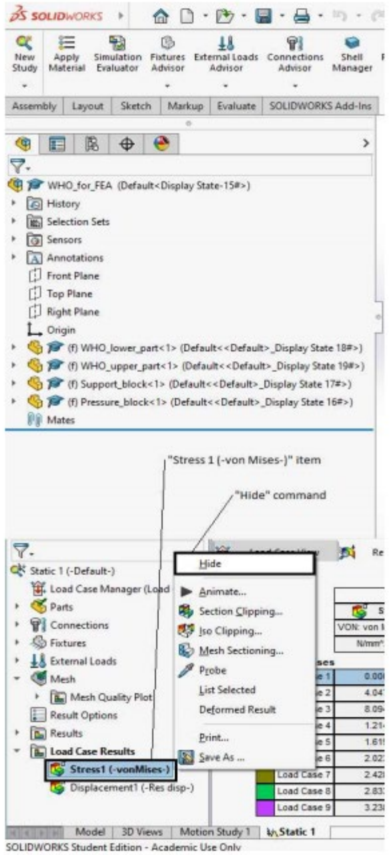

Figure 4.38: Hiding the color map "Stress1 (-von Mises-)"

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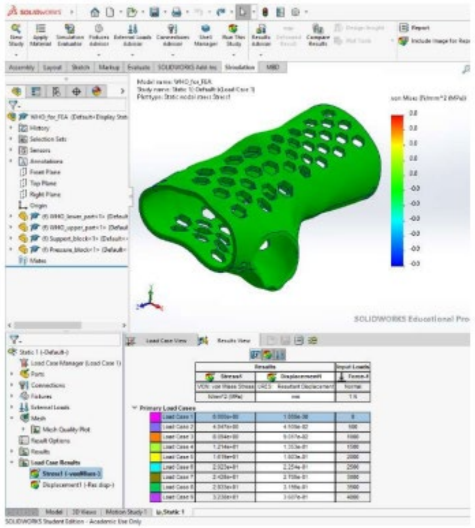
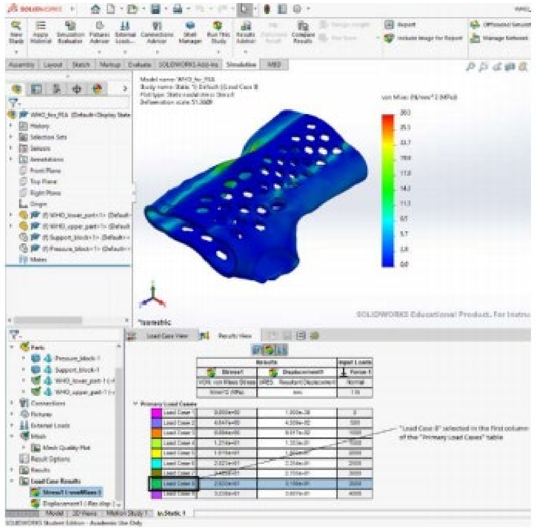
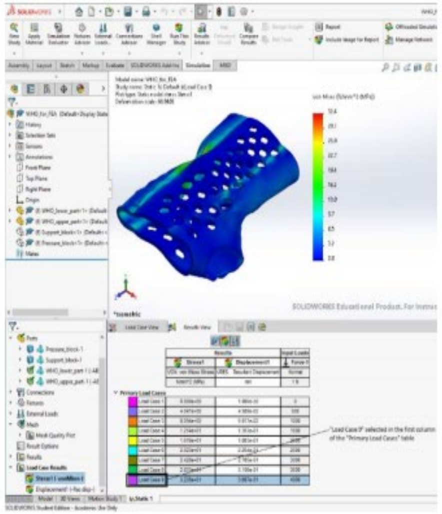
4.3. Interpretation of the numerical results



Color map showing the distribution of the von Mises equivalent stress at the level of the lower and upper parts of the orthosis (first load case)



Color map showing the distribution of the von Mises equivalent stress at the level of the lower and upper parts of the orthosis (eighth load case: compression force of 3500 N)



Color map showing the distribution of the von Mises equivalent stress at the level of the lower and upper parts of the orthosis (ninth load case: compression force of 4000 N)

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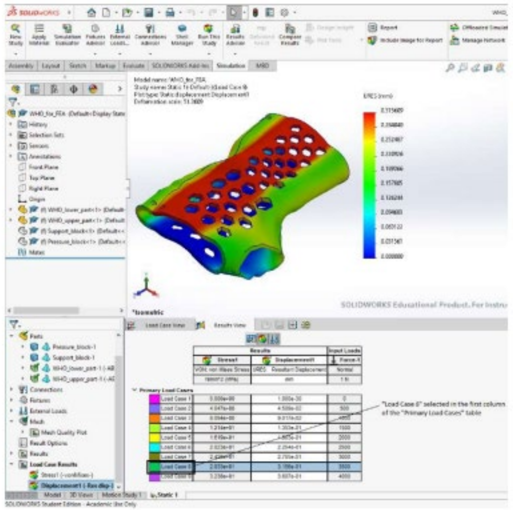
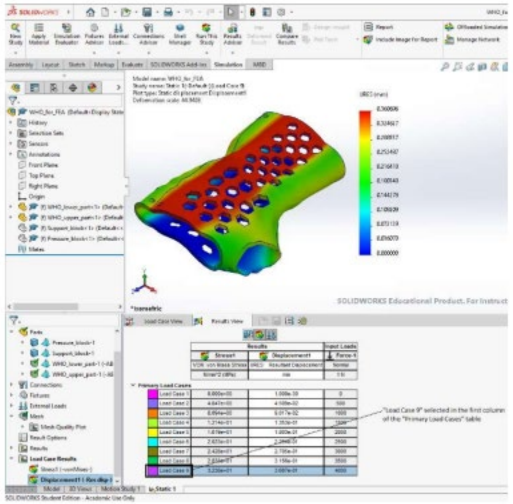
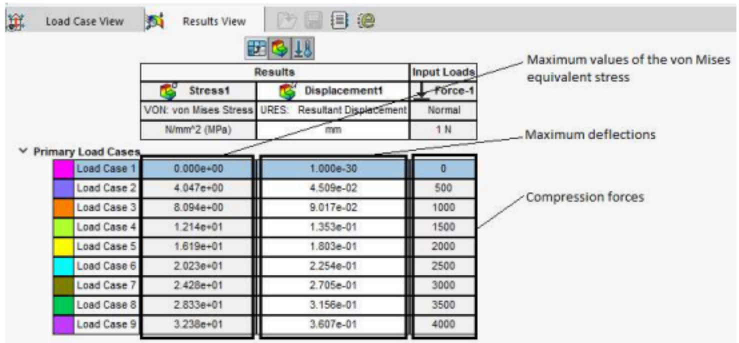
4.3. Interpretation of the numerical results



Color map showing the deflections at the level of the lower and upper parts of the orthosis (eighth load case: compression force of 3500 N)



Color map showing the deflections at the level of the lower and upper parts of the orthosis (ninth load case: compression force of 4000 N)



Maximum value of the von Mises equivalent stress, maximum deflection, and compression force corresponding to different load cases listed in the "Primary Load Cases" table

Table 4.1: Compression force, maximum value of the von Mises equivalent stress, and maximum deflection corresponding to different load cases (see also Figure 4.47)

Load case	Compression force *F* [N]	Maximum value of the von Mises equivalent stress $\sigma_{eq,max}$ [MPa]	Maximum deflection d_{max} [mm]
1	0	0.00	0.000
2	500	4.05	0.045
3	1000	8.09	0.090
4	1500	12.14	0.135
5	2000	16.19	0.180
6	2500	20.23	0.225
7	3000	24.28	0.271
8	3500	28.33	0.316
9	4000	32.38	0.361

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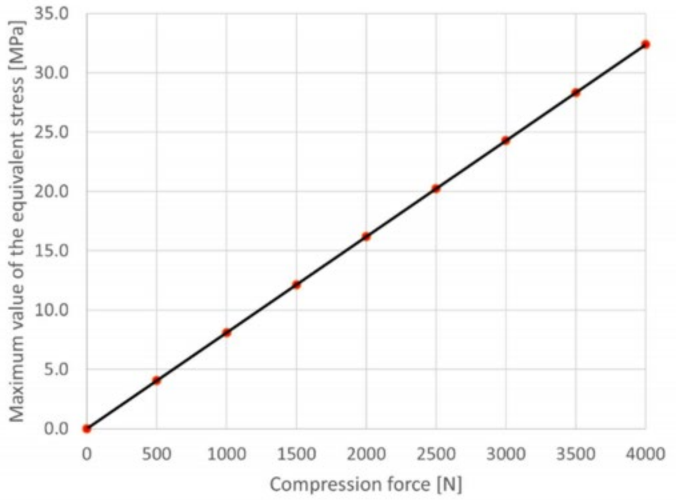
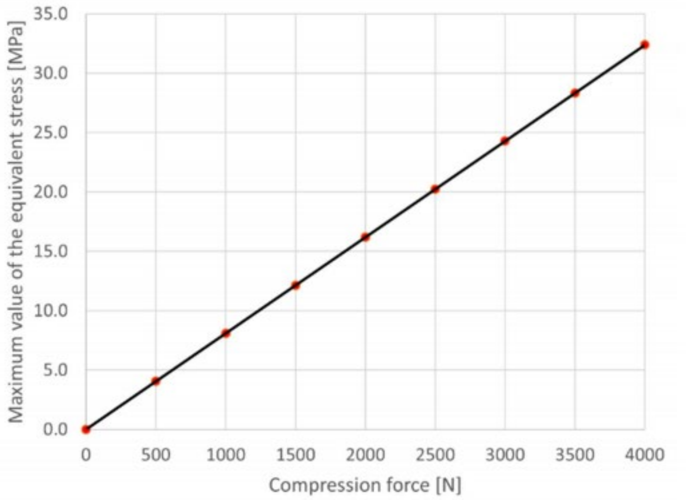


Dependence σeq,max vs F: red dots – numerical results taken from Table 4.1; black line – linear regression



Dependence dmax vs F: red dots – numerical results taken from Table 4.1; black line – linear regression

The results of the finite element analysis show that the wrist hand orthosis exhibits a high compression strength.
The critical value of the compression force Fm ≈ 3706 N is much greater than the greatest load that normally occurs when patients wear such medical devices. Of course, the overall strength of the wrist hand orthosis is fully assessable only by analyzing its behavior in different loading conditions.

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