POLITECNICO DI TORINO

Master’s degree in Mechatronic Engineering
A.a. 2024/2025
Sessione di Laurea Marzo 2025

Master's Thesis

Application of AutomationStudio in Automation and Robotics: Learning Strategies for Educational Purposes

Relatore

prof. Luigi Mazza

Candidato

Filippo Mazzocato

Marzo 2025

Sommario

1. Abstract

This thesis explores the potential of Automation Studio as an educational tool for teaching mechatronics engineering. Through the development and implementation of three practical projects, this research demonstrates how Automation Studio can bridge the gap between theory and practice, leading to a deeper understanding of engineering principles.

The projects aim to highlight both the current potential of the software in terms of design and control of articulated mechanical systems controlled by fluid powered actuations, and to maximize the potential of the union of the 3D manager and the mechanism manager for the design and control of a mobile vertical platform (pantograph). Finally, the last aim is to propose the use of the software for the demonstration of the operation of manipulators with the calculation of the position of the arms, joints and end effector by writing the rotation matrices according to the DH convention.

The projects focus on key areas such as the simulation of pneumatic systems, PLC programming, and the movement of components in a 3D environment, all of which are crucial aspects of mechatronics engineering. The first project introduces the Mechanism Manager, a tool that allows students to simulate the kinematic and dynamic behavior of mechanical systems. The second project focuses on the 3D modeling capabilities of Automation Studio, guiding students through the process of importing 3D drawings, assembling components, and simulating their movements in a virtual environment. The third project explores the application of the Denavit-Hartenberg convention for robotic arm kinematics, providing students with a practical understanding of coordinate frames, transformations, and rotation matrices.
The proposed projects n.2 and n.3 are being analyzed by the company for possible implementation as examples for their demonstration tutorials in training.

The use of Automation Studio in an educational setting offers several benefits. It allows students to visualize and interact with complex systems in a safe and controlled environment, which can be particularly helpful for understanding abstract concepts or those that are difficult to demonstrate physically. Automation Studio also provides a platform for students to develop and test their own designs, encouraging creativity and problem-solving skills. Additionally, the software's user-friendly interface and extensive libraries make it accessible to students with varying levels of technical expertise.

While Automation Studio offers numerous benefits for educational purposes, there are also some limitations to consider. The cost of the software may be prohibitive for some institutions. Additionally, instructors need to be adequately trained in using the software, which may require additional time and resources. Finally, the educational version of the software has a limit of the maximum number of components that can be used, as it is intended for simple projects.

Despite these limitations, the potential benefits of Automation Studio for enhancing the learning experience in mechatronics engineering are significant. The integration of Automation Studio into the mechatronics engineering curriculum can lead to a more engaging and effective learning experience. Moreover, Automation Studio can facilitate collaborative learning, as students can work together to design, simulate, and analyze complex systems.

2. Introduction

Industrial automation is the foundation of modern industry, which is always developing thanks to new technological innovations and the increasing complexity of industrial systems that aim to improve efficiency, production, and accuracy in various production processes. As a result, using advanced tools for designing, simulating, and controlling automatic systems becomes essential, such as automation software. Among these, Automation Studio from Famic Technologies meets these needs by offering powerful and versatile solutions for this sector.

Despite its importance in the industrial sector, Automation Studio is very useful for helping students to understand important engineering concepts. It provides a virtual simulation environment that reflects the theoretical knowledge learned in class and makes studying many engineering topics easier and more enjoyable, especially those that are difficult to understand with traditional teaching methods.

In this context, the purpose of this thesis is to demonstrate the potential of Automation Studio in education for teaching mechatronics engineering through the development and implementation of 3 practical projects. The choice of this software as an educational tool is due to its versatility and ability to simulate real-world scenarios, providing a practical experience that can enrich the academic curriculum and better prepare students for the challenges of the industrial world

In addition to improving the understanding of these theoretical concepts for better preparation in the field of automation, a second goal is to teach students how to use this powerful software, with the hope that, if they are interested, they can enter the competitive job market. The evaluation of these tutorials and student feedback will be important for improving and optimizing the teaching method used

3. Context and Background

3.1. The company: Famic technologies

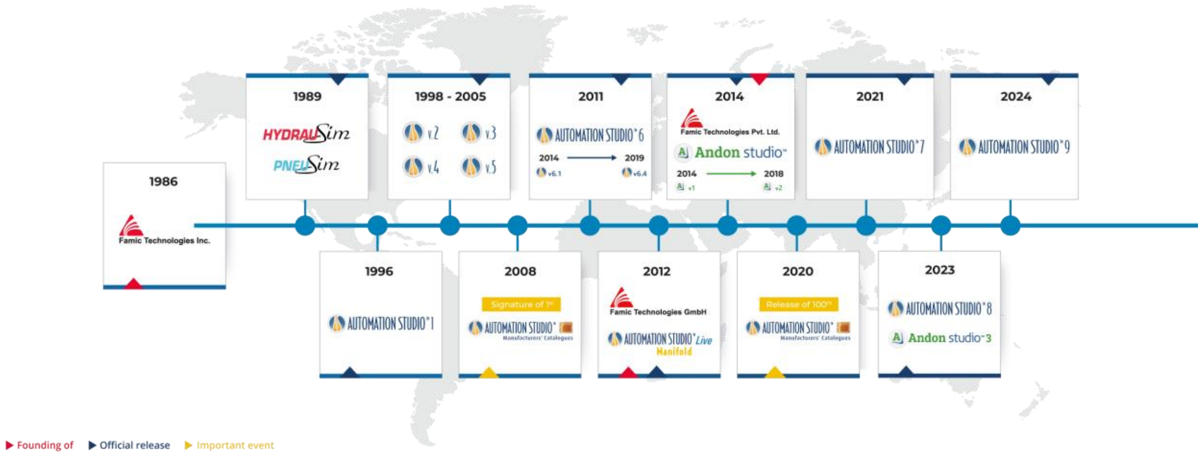
Famic technologies is an international company providing softwares for automation.
It´s founded in 1986 and has 3 offices around the world: the headquarter is in Montreal, Canada and other 2 offices are in Mannheim, Germany and Pune, India.
The team comes from different area of the world and it is specialized on different technologies, all linked together to match the modern 4.0 industry needs: from the software engineering (including database design, network support and real time system) to the automation one (including pneumatic, hydraulic, electrical, robotic and SCADA system as well as PLC programming, process simulation and HMI and so on…)

The products offered are:

- AutomationStudio Professional: which allows to create, analyze, troubleshoot and validate multi-technology circuit
- AutomationStudio Educational: which is a restricted version of the PRO one and allows to perform exactly the same things with a limited number of the same componets which can be used on a project. So, it is useful for educational pourpose to realize and simulate simpler circuit for automation.
- AutomationStudio Manifold: which is a powerful tool to create automatically a 3D hydraulic manifold, starting from a 2D schematic, which significantly reduce the time to model a 3D block, providing all the machining parameters and the technical drawings.
- AndonStudio: which allows to create and simulate production processes and to monitor the productivity in real time, optimizing all the operations in a chain line

In addition to softwares, the services offered are:

- Long relation with the clients (including contact, training, support and so on).
- A tecnical support portal full of training videos, demostration files, quick start guides and lot of pre-made exercises useful to practise and to increase the software knowledges easily



Since 2008 Famic works with many manufacturers in order to provide online catalogues with real components realized by these manufacturers, including all the specifications. This avoids the user to lose time creating complex component from a simple scheme. Below a list of manufacturers linked to Famic.

3.2. Overview of AutomationStudio Software and Its Applications

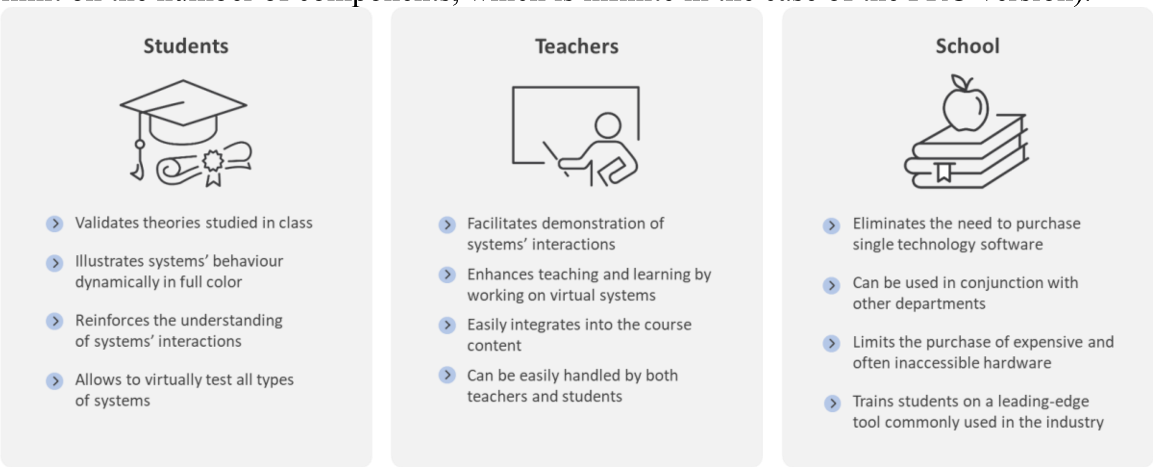
Automation Studio™ is a unique design and simulation software covering all project/machine technologies including fluid power, electrical, controls, HMI and communications through the entire product lifecycle. It helps to easily combine these various technologies to design, document and simulate complete systems and provides a user-friendly platform with access to built-in component libraries to help accelerate the design process. With integrated simulation capabilities, it makes it easy to quickly animate, analyze and validate the systems' performance.
All technologies can be linked together to create and simulate an entire machine, performing what is named as Digital Twin.

AutomationStudio provides solutions for multiple topics and avoid using 1 software for each topic. Below the list of the different technologies involved in the software

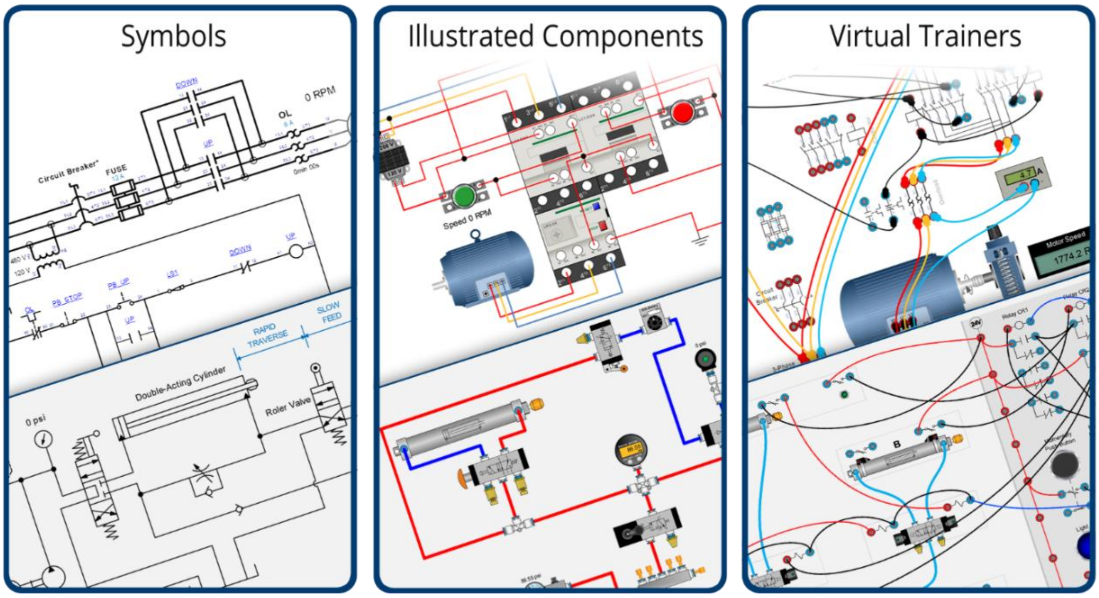
The most important benefints of the EDU license are:

- For student: it is important to test the theory that they learn during lesson (they can apply their knowledges in a virtual environment as said before)
- For treachers: they can explane complicated topic using animations to better explain the topics thanks dynamic elements, measuring tools, animated images, comments or hyperlinks to external documents.
- For School: AutomationStudio can reduce costs, as mentioned earlier. Many professors in different topic can share the software licence to multiple pourpose, so you can imagine the professor teaching hydraulic takes his lesson using the hydraulic template of AS, then the professor for electrotechnic takes his lesson using the electrotechnic template of AS and both use the same shared licence (which is possible to use once by time).

Moreover, students may have an idea about the work environment, as the EDU version is the same of the PRO one used to work for huge projects (with the only difference for the limit on the number of components, which is infinite in the case of the PRO version).



It is also possible to use the Virtual Trainers available on the website for free. They are a precompiled exercises which include components that students have to connect correctly to make them working together with a specific logic.



In addition, it is possible to make a real Hardware in comunication with AS thanks to the OPC comunication,

3.3. Key Features

https://www.famictech.com/en/Products/Automation-Studio/Educational-Edition/Features-Overview#*

The main features of the software can be summarized in the following list:

• **Circuit Design:** Allows for the design of electrical, hydraulic, and pneumatic circuits and to simulate their behaviour in a virtual environment.

• **Simulation:** Allows to simulate the behaviour of a system in a virtual environment before to implement it into a real environment, in a dynamic and visual way. In this way, it is possible to predict issues before buying and installing real components.

• **Programming and Control:** Allows to program programmable logic controllers (PLC) which govern the logic of the movements of all components thanks to Inputs (like sensor) and Output (like coils).

• **HMI interfaces:** Allows to design the Human Man Interface (HMI) used from operators to interact with the machines thanks to control panels.

• **Documentation and Reporting:** Allows to create technical documentation and reports of the projects.

• **2D and 3D environments:** Allows to create 2D and 3D animation linked with the circuit, enhancing the schematic and making it more visual. The 3D editor allows to create or import parts in STEP, STL and IGES format.

• **Thousands of symbols at hand**: Includes Comprehensive sets of libraries with ISO components that can be used to teach a wide array of subjects related to hydraulics, pneumatics, electrical and control technologies.

• **Customizable Library:** Allows to create personal libraries with required components specific to an exercise or laboratory.

• **Virtual system:** Using the Electrical and PLC Libraries as well as the SFC module, the user simply links sensors, switches, lights, conveyors, etc., to make the pre-made Virtual System operating.

• **Realistic Measuring Instruments:** allows to use realistic measuring tools: multimeter, oscilloscope, hydraulic tester, thermometer and manometer, can be used to reproduce real life measuring experience.

• **Simulation Mode:** Allows to simulate the system in different modes "Normal", "Slow Motion", "Step by Step" and "Pause" allows users to control the simulation.

• **Link between all Technologies:** Allows to link all technologies together to create a complete mechatronic system.
• **Troubleshooting:** Allows to create or activate pre-defined component failure to develop troubleshooting skills. Failures can be activated by preset conditions or manually during simulation, to observe the consequences on the system.
• **Video Files of the projects:** Allows to create video files of your projects that can be used with other applications or record the entire application for training purpose.
• **Cut and paste to other application:** Allows to Cut and Paste directly into another application with a great resolution and in colour to create assignments.
• **Insert Pictures and Text on Schematics:** Allows to Insert texts and images on the schematics to create complete documented circuits.
• **Connects to Real Devices:** Allows to connect Automation Studio to an external hardware, either using an I/O interface kit or an OPC Client Server.
• **Components Configuration:** Allows to change the property of all components in order to visualize their effect during simulation, so to create and configure valves, cylinders, motor, etc. to obtain a component graphically and technically compliant to real performances.
• **BOM:** Allows to create a customizable and dynamic Bill of Material that can be placed directly on the schematic or exported to create a report.
• **Variable Frequency Drives:** Include motor soft starters and variable frequency drives. VFDs are built according to manufacturers specifications such as Siemens, Allen Bradley, WEG, etc.
• **Fluid Power and Electrical Plotter:** Allows to plot the simulated parameters which can be exported to a text file for further analysis. It's possible to drag and drop components inside the plotter and to select the properties to be shown.
• **IEC and NEMA Electrical Standards:** Allows the possibilities to create circuits using both American and European standards.
• **Linked Videos, Hyperlinks, Files, etc.:** Allows to document the components by adding external links to videos, files, and others, to enhance understanding of these components or systems.
• **Link with Unity 3D:** Allows projects to gain benefits from the power of the Unity 3D engine and to see them evolving in their own environments with high level of realism. The feature is ideal for adding a touch of realism to digital twins developed within Automation Studio.
• **Interactive Lab Exercises:** Includes interactive exercises for hydraulics, pneumatics and electrical technologies. Each of them includes one schematic that is automatically simulated and animated in order to graphically show the behaviour of the function represented.
• **Automotive Library:** Includes all components needed for automotive grouped into a specific library, which includes the electrotechnical components, under the SAE standard.
• **Sequence diagram:** Allows to create operation sequences quickly without requiring the use of a specific control language, or an electrical control circuit.
• **Ladder Diagram LSIS:** Allows the implementation of the new ladder diagram module based on LSIS PLC specification.
• **Compressible Fluids:** Includes the simulation of new compressible fluids such as nitrogen, hydrogen, helium, methane and propane.
• **Embedded Views:** Allows to fulfills the training and technical publication requirements. It is used to add views from all different technologies into a single document. For example, it is possible to embed into a single page, a partial view of a hydraulic circuit, a 3D view and a partial view of a PLC, etc.

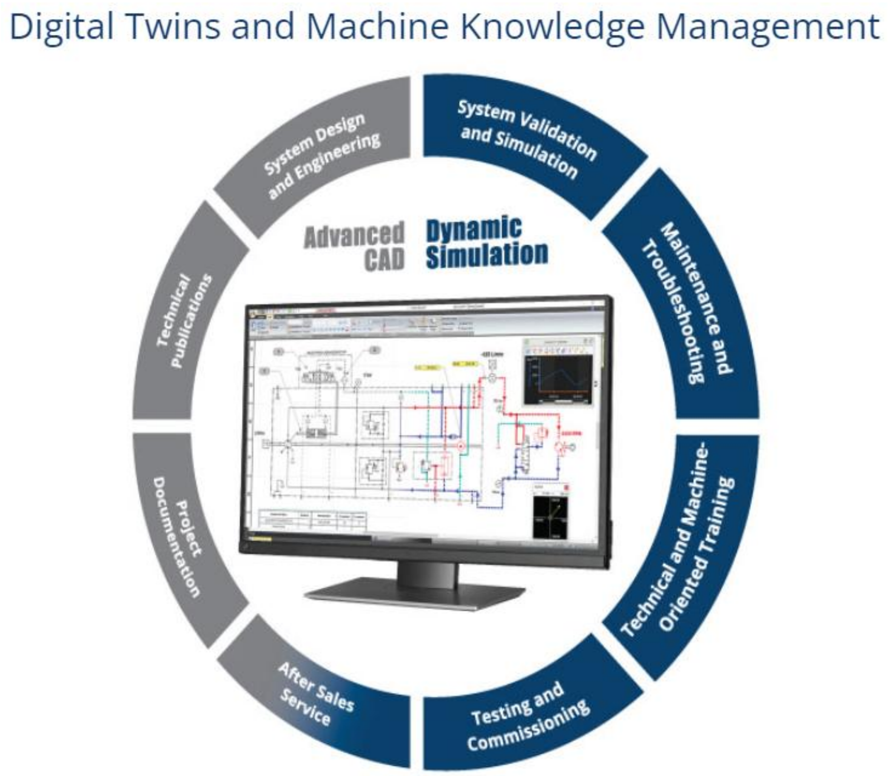
• **Mechanical connection ports on electrotechnical components:** Electrotechnical asynchronous machines, stepper motors, permanent magnet DC motors are equipped with mechanical connection ports. Position and speed sensors, as well as shaft and mechanical links, can be easily connected to machines facilitating the implementation of servo systems and linking to other modules.
• **Additional simulation paces:** Allows simulation steps from (guardare) of up to 200ms in order to enable lighter computing demands during simulation. This features is particularly useful for large projects.
• **BOM on the document:** Allows a complete redesign of the documents BOM (bill of materials). The new version provides great flexibility of customization for the displayed information and for the appearance. Additionally, you can now edit component properties directly from the BOM.
• **Electric machine:** Include the Electrotechnical Module which is now equipped with a new induction motor and a permanent magnet DC motor.
• **Dynamic Measuring Tool:** Include virtual measuring instruments which can be placed directly on the components to measure a wide range of parameters that can be recorded and viewed in the plotter.
• **Print and Export:** Allows to print to any size of paper or export the circuit in multiple formats to share with other applications.
• **Templates:** Allows to select from predefined templates or create a new one with the default information of the designer's choice (like school, logo, BOM, etc.)
• **Mechanism Manager:** Allows to link mechanical bodies to Fluid Power actuators to simulate and animate their effects, in a 2D environment.
• **Manufacturers' Catalogue:** Allows to create and simulate schematics using real life component behaviour from extensive manufacturers' catalogue that includes PDF specifications and test benches.
• **Cut-Away Animation:** Includes the animated component cross-section, illustrating the internal functioning of components. The animations are synchronized with the circuit simulation.
• **Components Sizing:** Includes calculation worksheet provided for hydraulics, pneumatics which include calculation tool provided with applicable equations and parameter definitions.
• **Co-simulation by API:** Allows to communicate via APIs with third-party simulation software allowing users to create a model-in-the-loop (MIL) testing environment and simulate Automation Studio projects with other complementary multi-physics simulation software.
• **Assembly and Group Editing Functions:** Include editing function (add, delete and move components, modify components properties…) can be used with an existing Assembly or Group, without having to Ungroup or Disassemble its components.

3.4. Specific application

Automation Studio can be used in various fields, thanks to its versatility, such as:

- Industrial Sector
- Agriculture
- Construction
- Mining
- Oil and Gas
- Forestry
- Training Center

- Material Handling
- Aerospace
- Production Machines
- Energy
- Marine Technology
- Packaging
- Component Manufacturers and System integrators
- Defense
- Training and education
- Prototyping and testing



3.5. Advantages of Using Automation Studio

The use of Automation Studio offers several key benefits that enhance its value in various applications. These advantages include:

- Effectiveness and Precision: The powerful simulation and design capabilities enhance effectiveness and precision in creating and managing automated systems.
- Cost Reduction: Simulating systems before physical implementation reduces costs associated with errors and hardware modifications,
- Advanced Training: By providing realistic simulation, the software improves the quality of training and better prepares students for real-world challenges

4. Methodology

The methodology used in this thesis is based on the creation of three practical projects developed with Automation Studio. These projects are paired with calculations, graphs, diagrams, and theoretical concepts taken from textbooks and notes from mechatronics engineering courses, to integrate theory with practice, providing students with interactive tools that help them better understand engineering principles.

These projects mainly focus on key areas such as: simulation of pneumatic systems, PLC programming, movement of components in a 3D environment that dynamically reflects the actions imposed through a Human-Machine Interface (HMI), and basic robotics principles like rotation matrices and the Denavit-Hartenberg convention. Each tutorial is designed to tackle specific learning challenges, using Automation Studio to offer realistic simulations and hands-on activities.

4.1. List of Projects

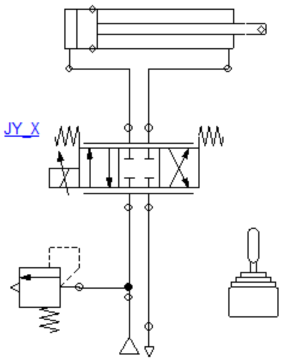
- Project 1 _ Mechanism Manager:
  The project explains how to use a specific feature of the software (Mechanism Manager), which allows the association of mechanical component forces (including the weights of the components themselves) with the forces of pneumatic pistons, thereby simulating their fluid dynamic behavior in a 2D environment.
- Project 2 _ Pantograph Lift 3D + mechanism manager:
  The project explains how to use the 3D environment of AutomationStudio and how to move components in 3D using the implemented fluid dynamic circuit.
- Project 3 _ DH convention for robotic explanation:
  The project consists of several examples of manipulators (robotic arms) that the professor of the robotics course explained during the class. It specifically references rotation matrices and the DH convention. Students will be able to move a robot dynamically in 3D and observe:
  - In the HMI environment: the rotation matrices with dynamic values (which change depending on how the robot moves)
  - In the 3D environment: they can see the different frames orient themselves as defined by the rotation matrices

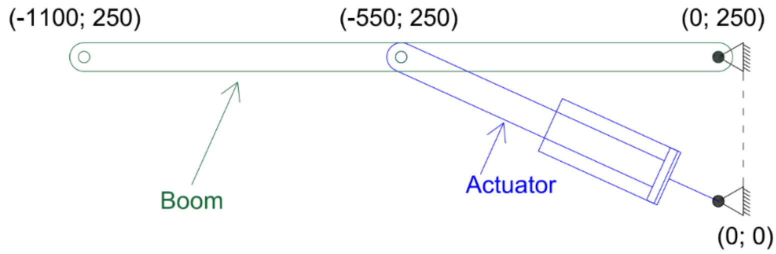
4.2. Project 1: Mechanism Manager

4.2.1. Introduction

The aim of this project is to explain, in a first approach, how to use the mechanism manager of AutomationStudio.
The Mechanism Manager in AutomationStudio allows to create mechanical links between bodies and fluid power actuators to simulate their kinematic and dynamic interactions.
The Mechanism is an assembly of bodies connected to manage forces and movements in the machine.

In this example is represented a Boom Lift Mechanism in which a boom, affected by loads, is moved by an actuator thanks to a fluid circuit. Using the joystick of the circuit is possible to control the mechanism.



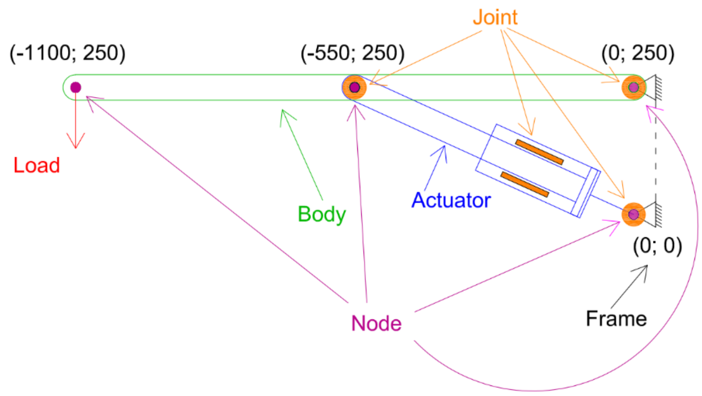


The pneumatic circuit is composed by:

- 1 compressor.
- 1 limit valve.
- 1 proportional valve (controlled by the joystick)
- 1 actuator

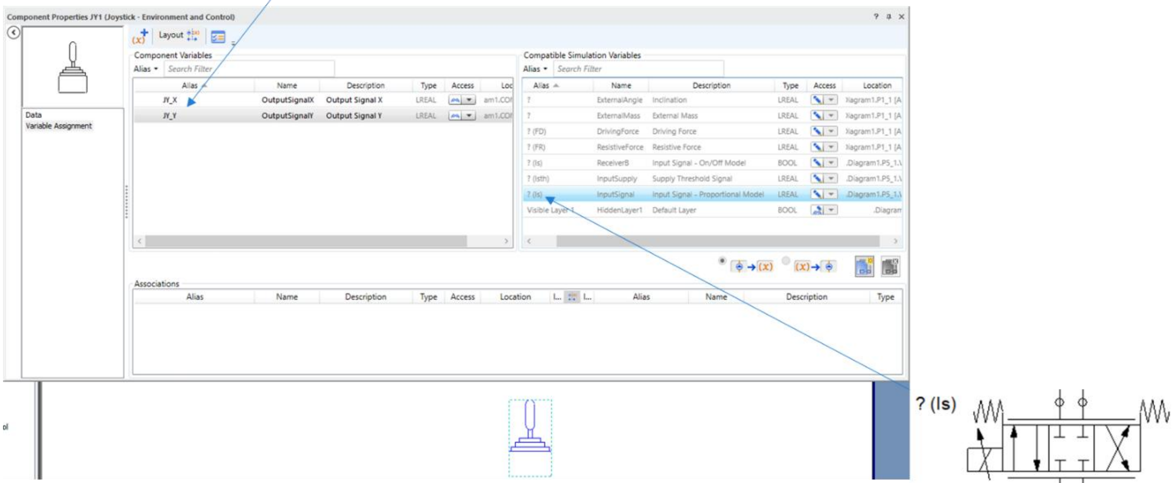
4.2.2. Terminologies

- **Frame**: fixed body or a point in a mechanism
- **Node**: point where a mechanical joint can be made and/or a force can be applied
- **Body**: a part of the machine acted upon by the actuators or the loads and/or attached to the frame
- **Joint**: point where connection between two links is designed to provide desired movement, for example sliding movement or rotational movement



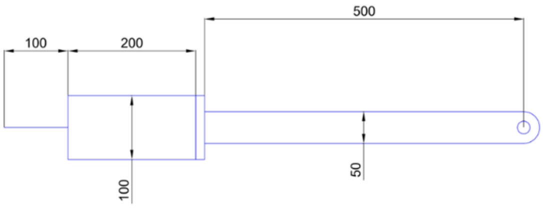
4.2.3. Joystick

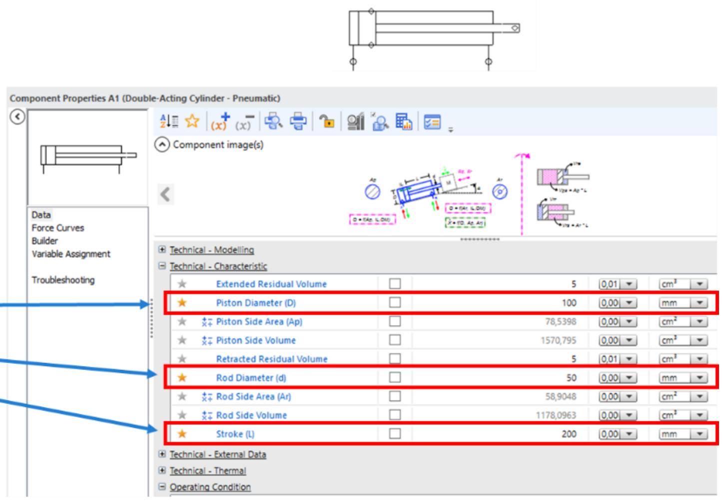
Connect the Y variable of the joystick
to the valve coil input signal



4.2.4. Actuator properties

Set correctly the properties of the actuator

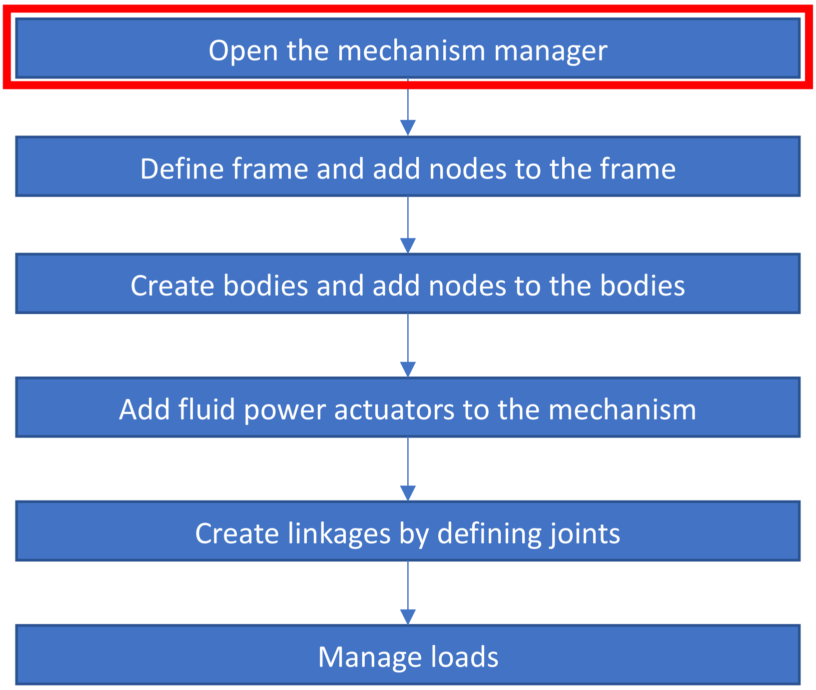




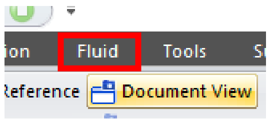
- **Piston Diameter = 100 mm**
- **Rod Diameter = 50 mm**
- **Cylinder Stroke = 200 mm**
- **Cylinder Fixture: -100 mm**
- **Rod Fixture = 500 mm**

Defined in the Mechanism Manager

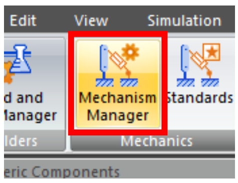
4.2.5. Step on creating the mechanism



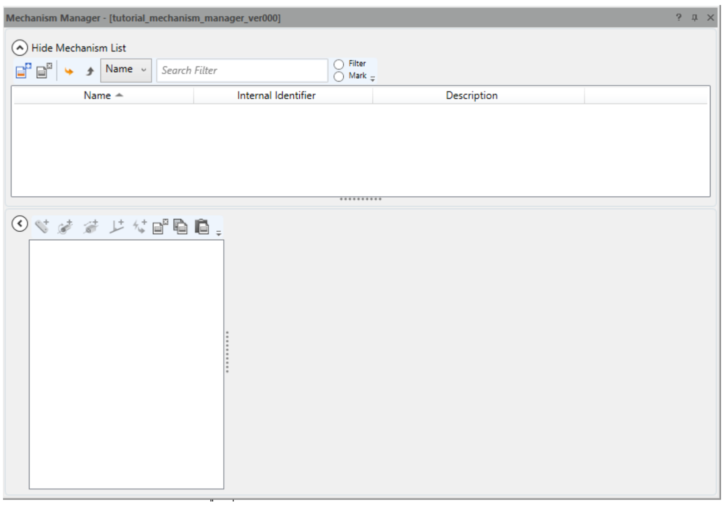
4.2.6. Open the mechanism manager



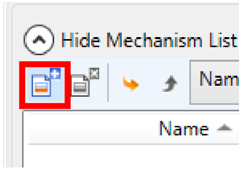
1) Click on the “fluid” section



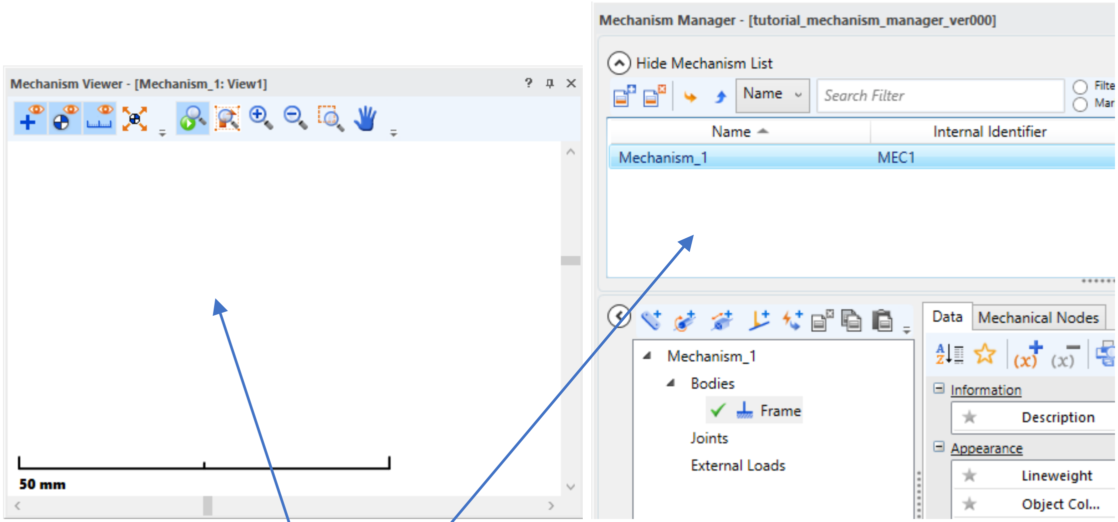
2) Click on the “Mechanism Manager”



3) Result

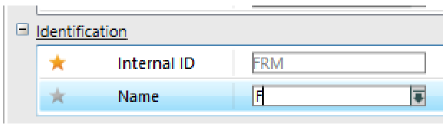


4) Add a new mechanism

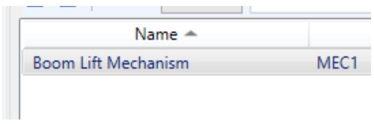


5) Result:

- the mechanical viewer window allows to monitor the mechanic created
- The mechanism manager allows to create and to link together all the objects needed for the mechanism (bodies, frames, nodes, joints, loads…)

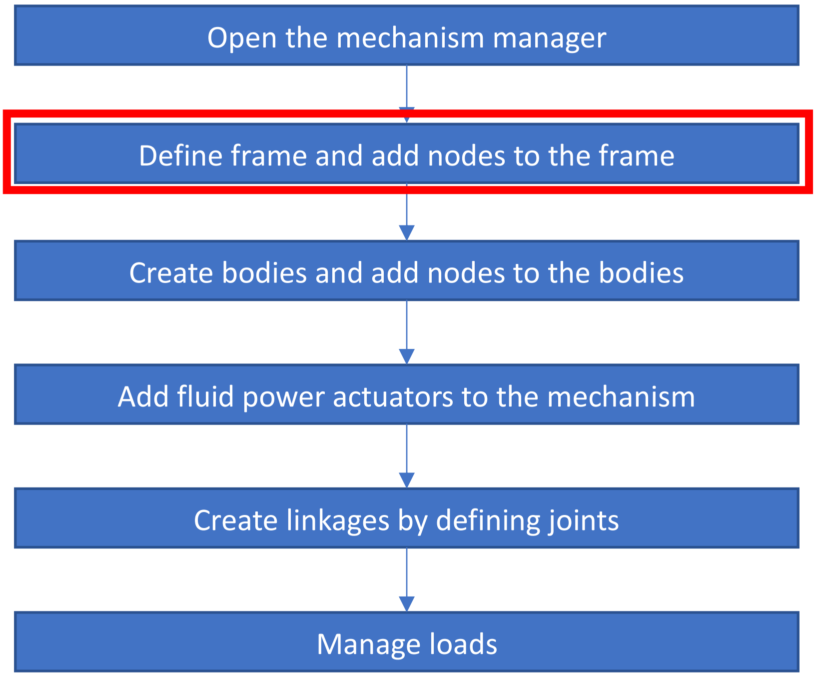


6) Eventually, change the name of the mechanism

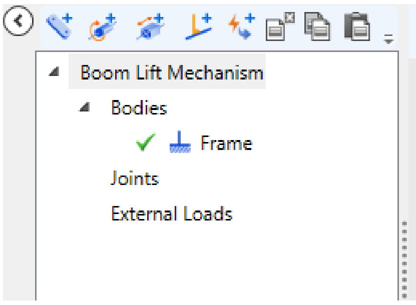


7) The name of the project appears changed on the list

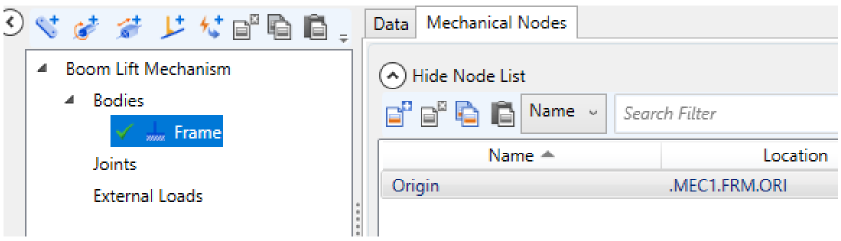
4.2.7. Step on creating the mechanism



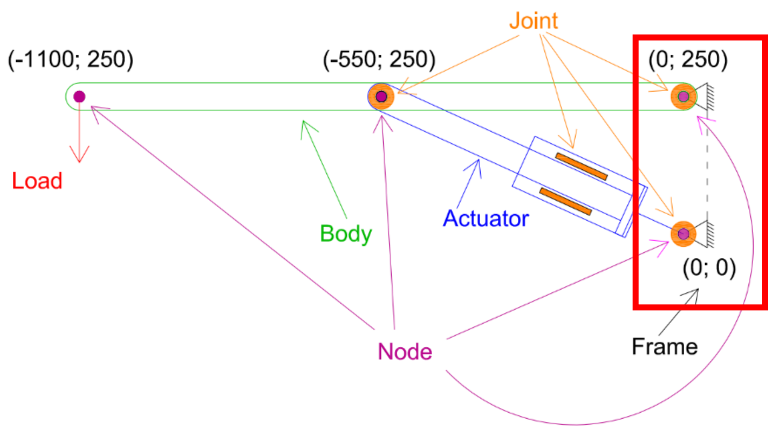
4.2.8. Define frame and add nodes to the frame



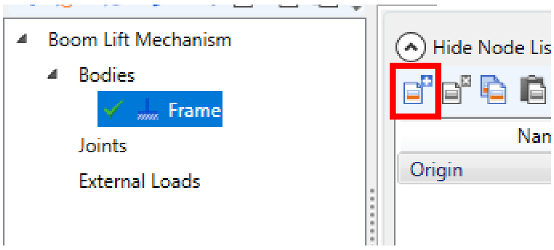
8) By default, a fixed frame is created



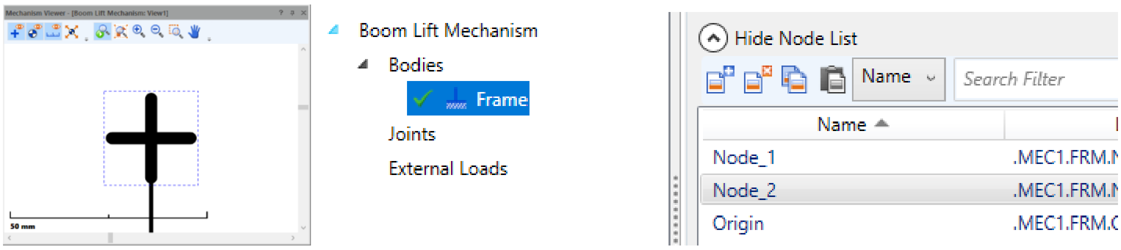
9) Each frame contains a fixed node (its origin).



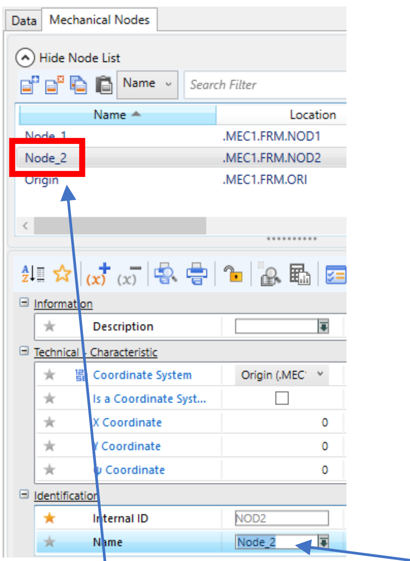
10) From the scheme is possible to see that there are 2 nodes associated to the fixed frame: (0;0) (0;250)



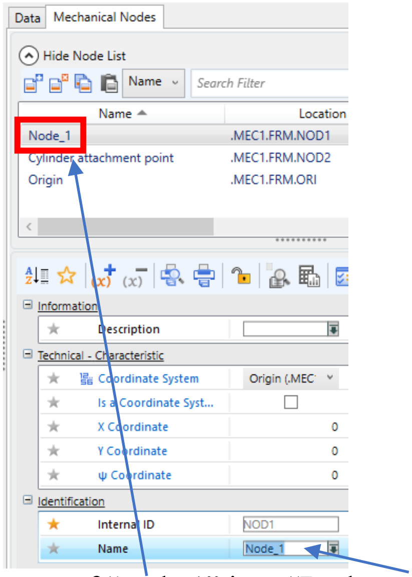
11) So, add 2 new nodes in the same frame (in the "Mechanical Nodes" window)



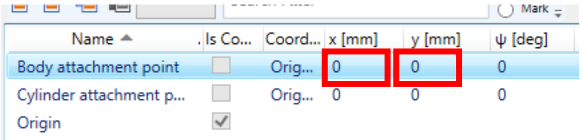
12) Result: in the mechanical viewer appears the 2 added points



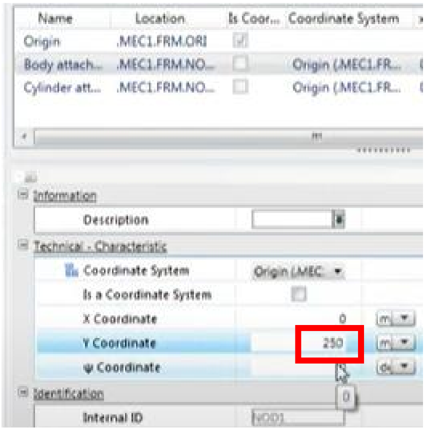
13) Change the name of "node 2" into "Cylinder attachment point"



14) Change the name of "node 1" into "Body attachment point"

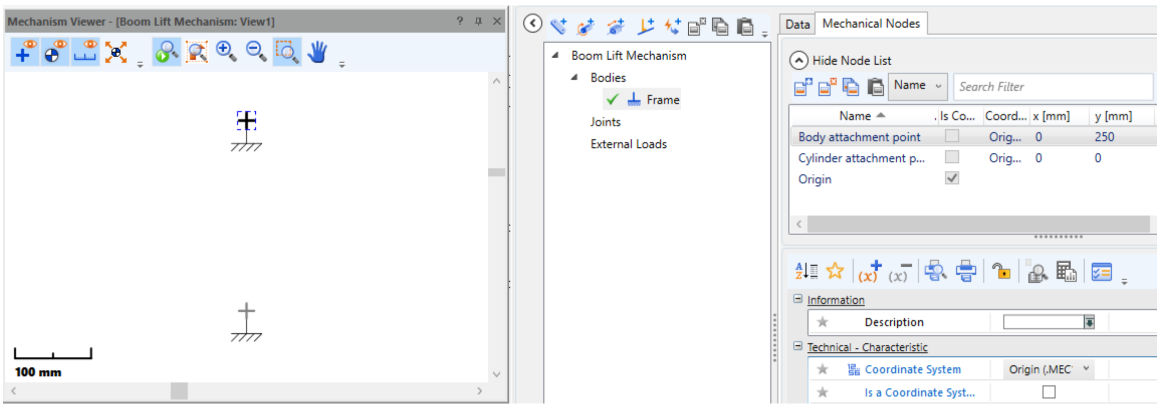


15) Now, the "Body attachment point" need to change its coordinates (y=250)



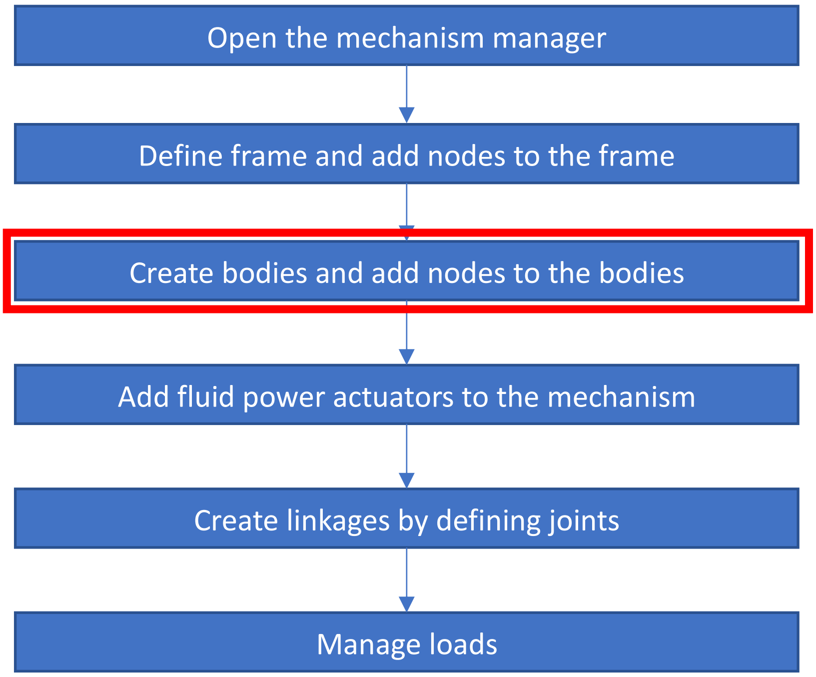
(RIFARE)

16) Impose the value of 250 on the Y coordinate (unit in mm)

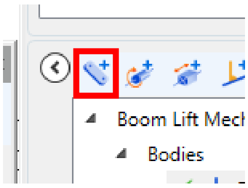


17) Result

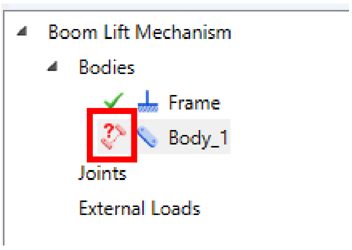
4.2.9. Step on creating the mechanism



4.2.10. Create bodies and add nodes to the bodies

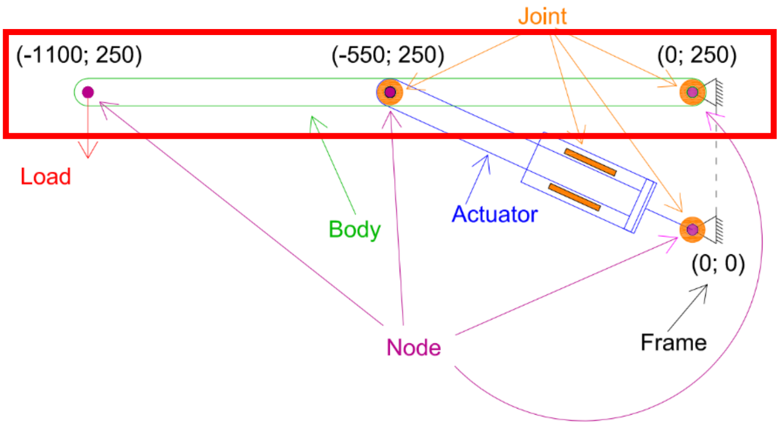


18) Add a body

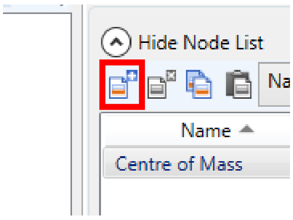


19) Result: question mark indicates that this body is not linked to any other mechanics or is not configured properly

20) Change the name into “Boom” (colour and line thickness eventually)

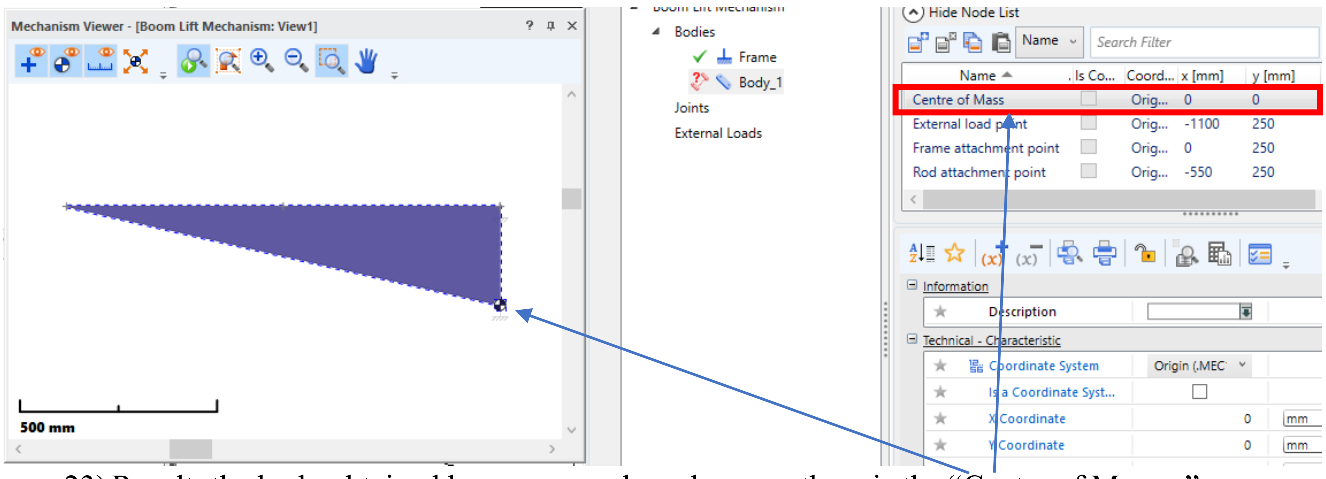


21) From the scheme is possible to see that there are 3 nodes associated to the body: (0;250) (-550;250) (-1100;250)



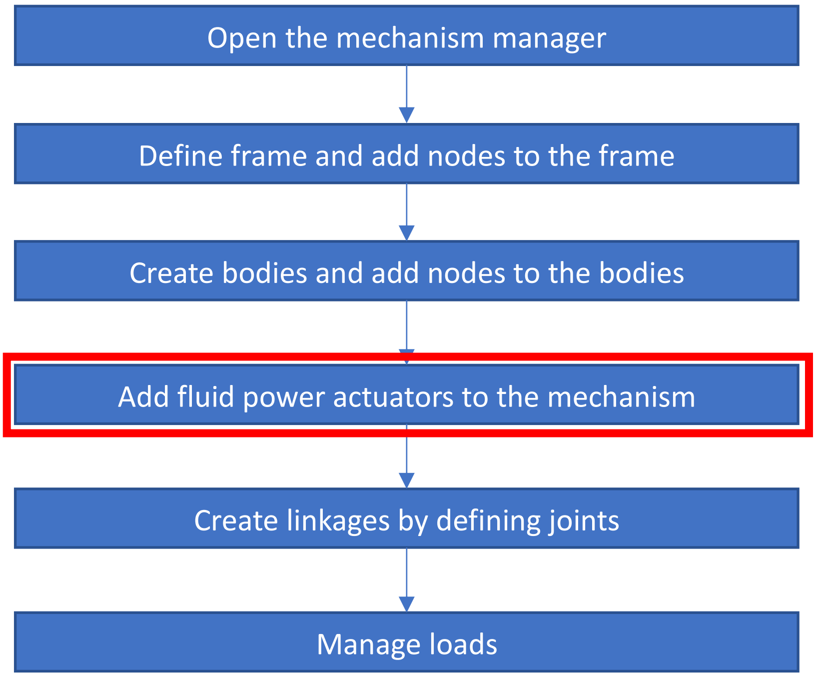
22) Like the step 11, create 3 nodes and assign the following names and coordinates properly:

(0; 250) → Frame attachment point
(-550; 250) → Rod attachment point
(-1100; 250) → External load point

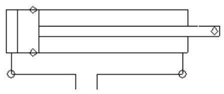


23) Result: the body obtained has a wrong shape because there is the "Centre of Masses" point at the origin. So, change its coordinates to (-550; 250) →

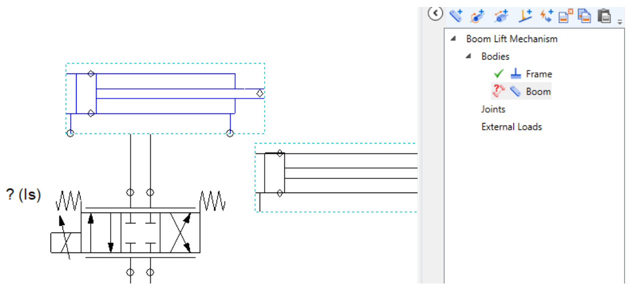
4.2.11. Step on creating mechanism



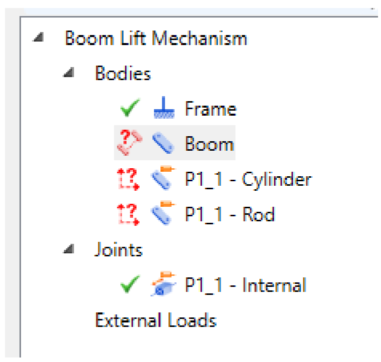
4.2.12. Add fluid power actuators to the mechanism



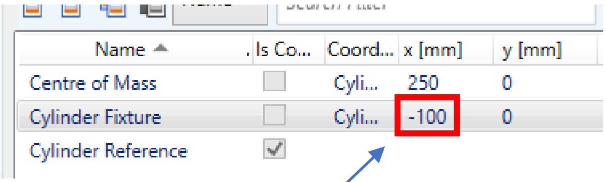
24) Remember to be sure that the actuator properties has been selected correctly before to use it on the Mechanism Manager (slide 6)



25) Drag and drop the actuator inside the list of the components of the project

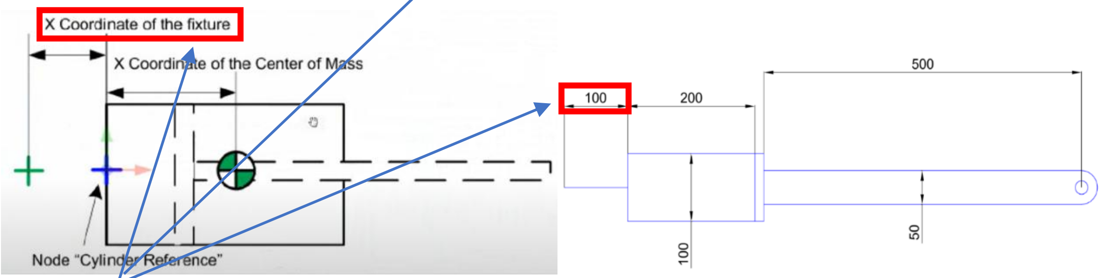


26) Result: Automatically it creates 2 bodies (cylinder and rod) associated each other through a sliding joint

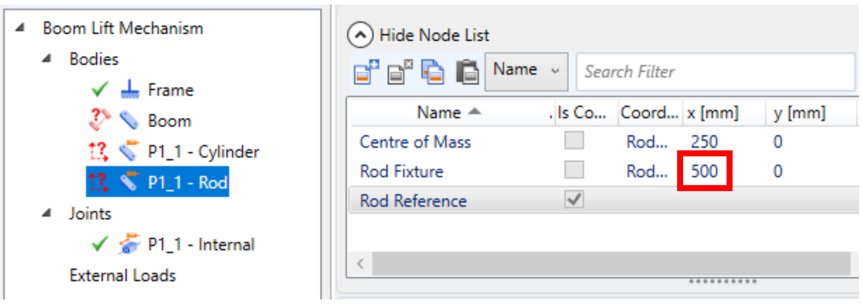


27) By default the cylinder has 3 nodes:

- Cylinder Reference
- Centre of Mass
- Cylinder Fixture

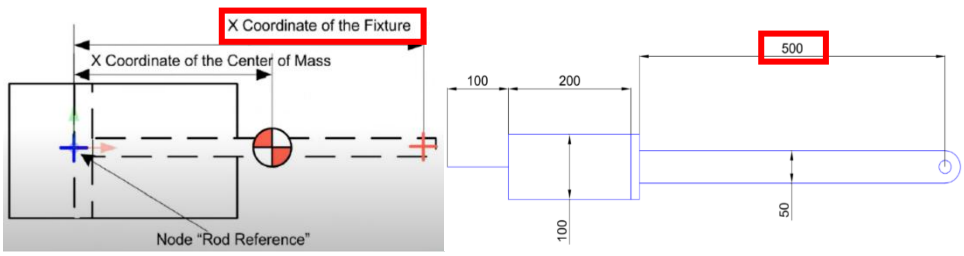


28) The cylinder fixture represents the point in which the cylinder is attached. A negative value means that the attachment point is behind the cylinder reference



29) In a same manner, by default the rod has 3 nodes:

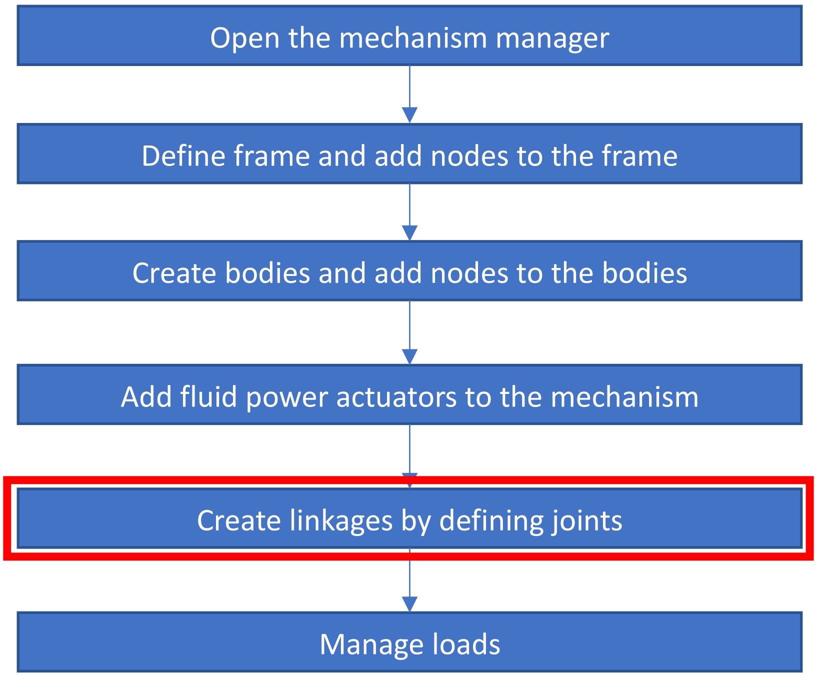
- Rod Reference
- Centre of Mass
- Rod Fixture



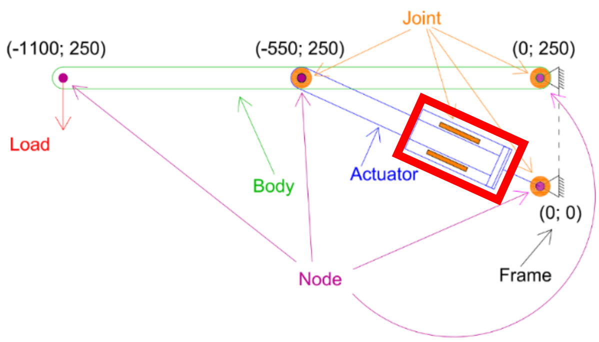
30) Set a positive value of rod fixture

Note: It is no longer possible to modify the maximum stroke of the piston, once the actuator is fixed on the mechanism manager

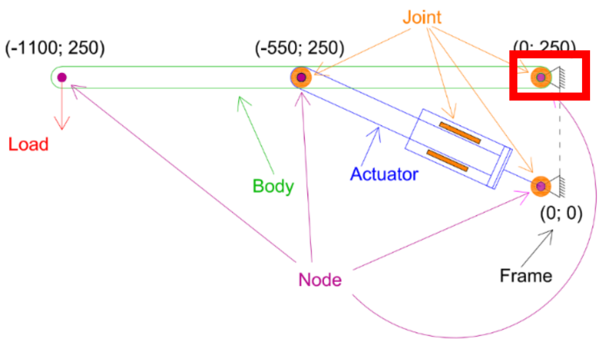
4.2.13. Step on creating mechanism



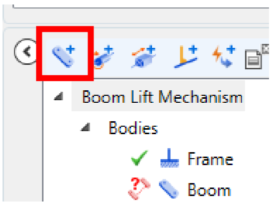
4.2.14. Create linkages by defining joints



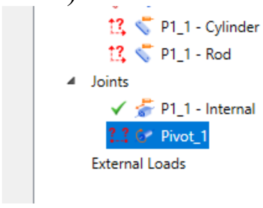
31) As said before (step 26), the sliding joint has been created automatically



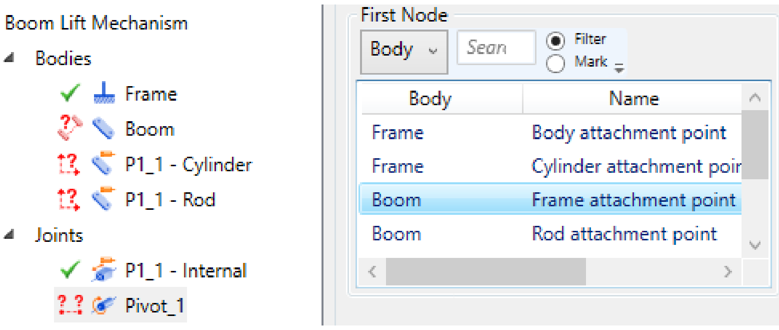
32) Now create a link between the body and the hinge



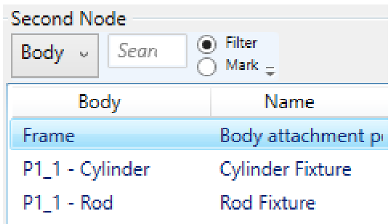
33) Add a Pivot Joint



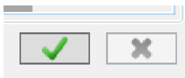
34) Result



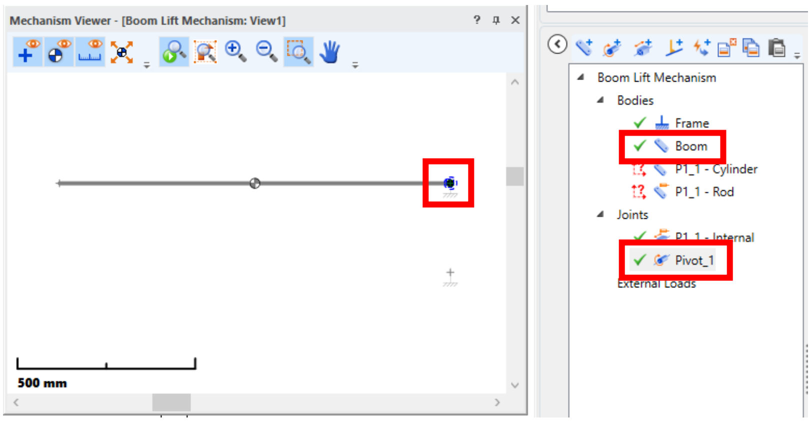
35) Select the "Frame attachment point" of the body "boom" as first node



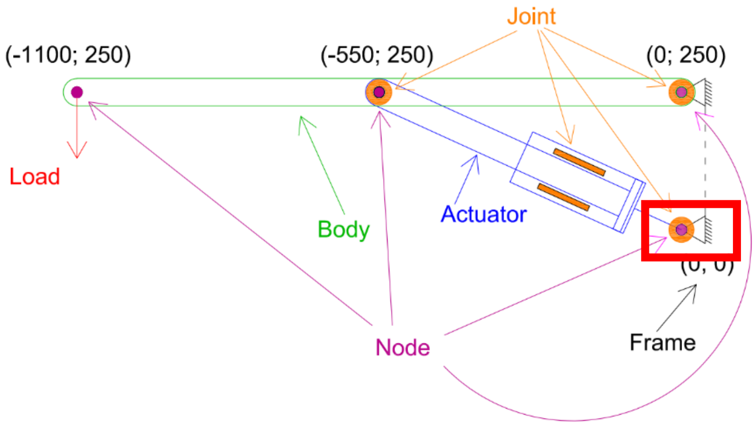
36) Once selected, a list of possible choices appears on the Second Node part. Select the "Body attachment point" of the frame.



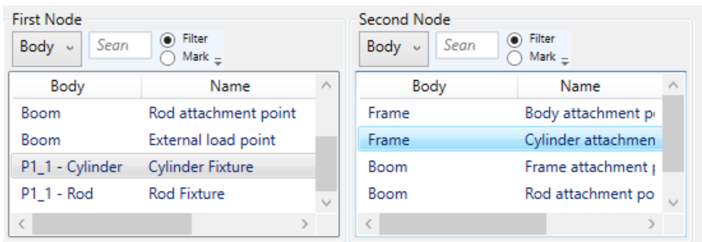
37) Confirm



38) Result: a small link appears on the Mechanism Viewer and a green tick on the joint "Pivot_1" and on the body "boom"



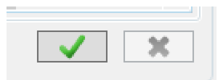
39) Now create a link between the cylinder and the hinge



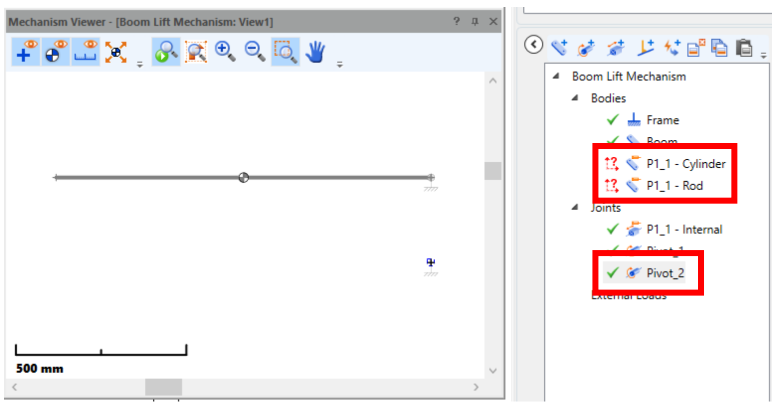
40) Select:

First Node → Cylinder Fixture of the body "Cylinder"

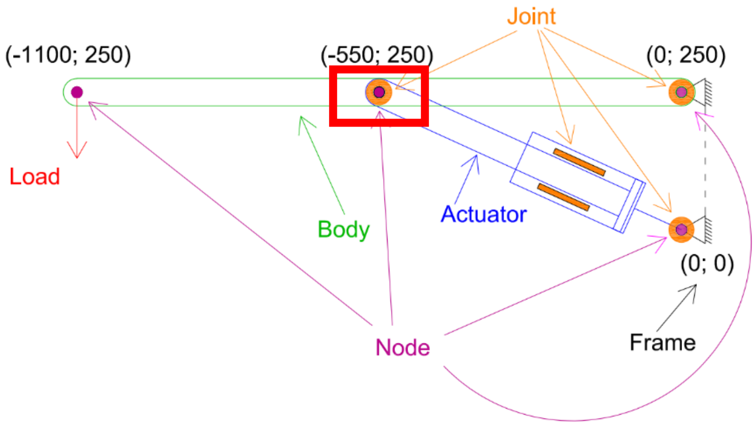
Second Node → Cylinder attachment point of the frame



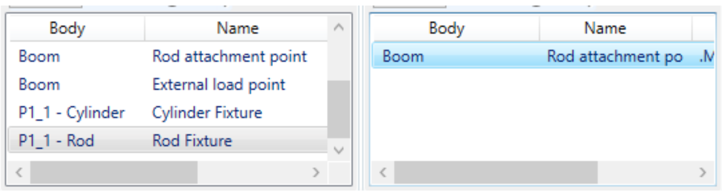
41) Confirm



42) Result: a green tick on the joint "Pivot_2", but the bodies "Rod" and "Cylinder" have the question mark→ the rod need to be fixed with the boom

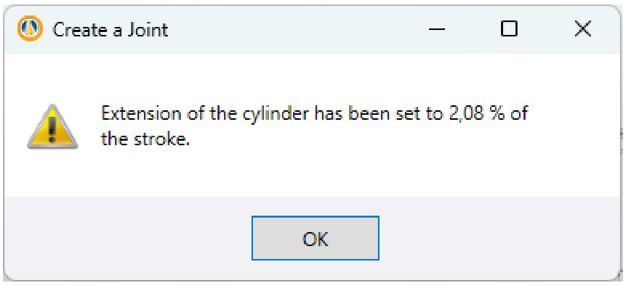


43) Now create a link between the rod and the boom

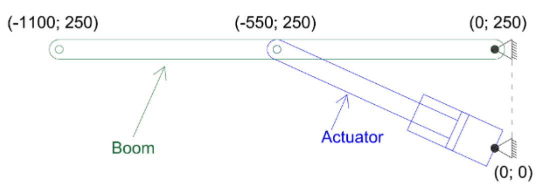


44) Select:
First Node → “Rod Fixture” of the body “Rod”
Second Node → “Rod attachment point” of the body “boom”

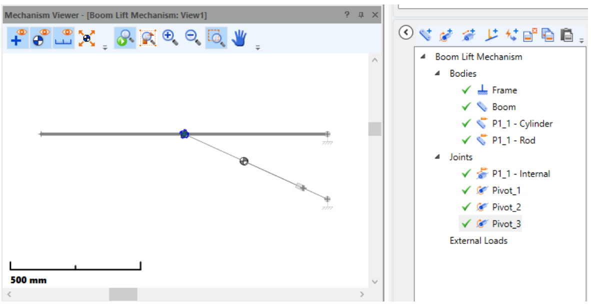
45) Confirm



46) Result: a message appears! This means that the extension of the cylinder (actuator characteristic indicating the stroke value in the starting position, in percentage of the total stroke) has been imposed to the only possible value for this geometry

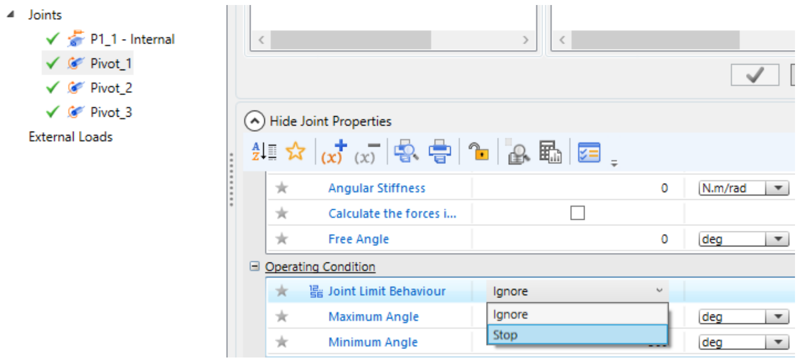


<u>For example:</u> by selecting a value of the Cylinder Fixture equal to 0, the system became as shown in the scheme. In this situation the extension (stroke in the starting position) is greater

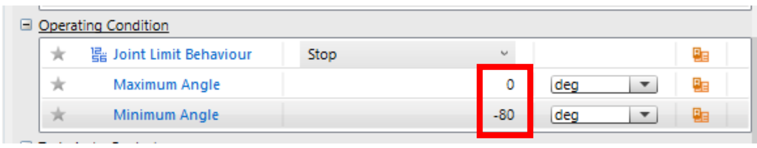


47) Result: all component has the green tick and the actuator appears on the mechanism viewer.

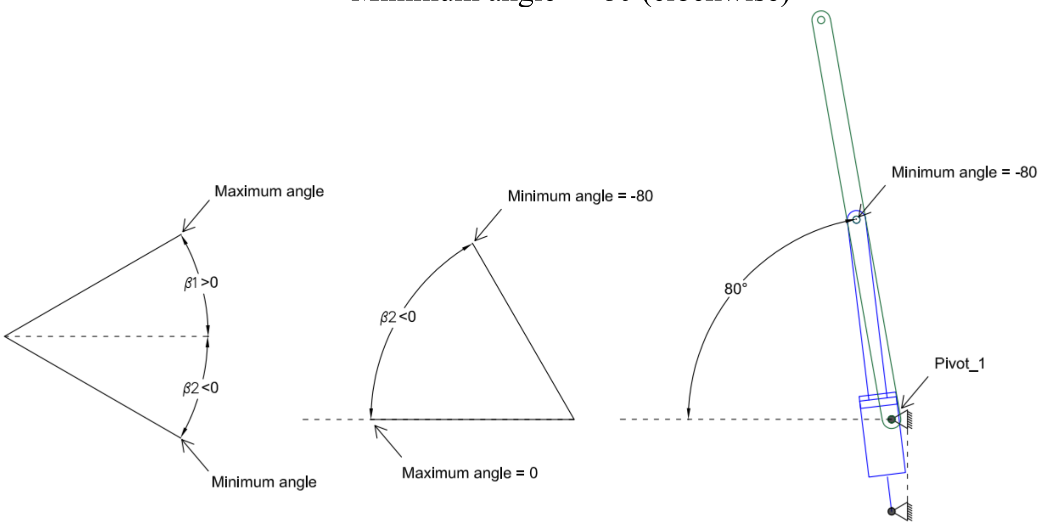
The mechanism is created



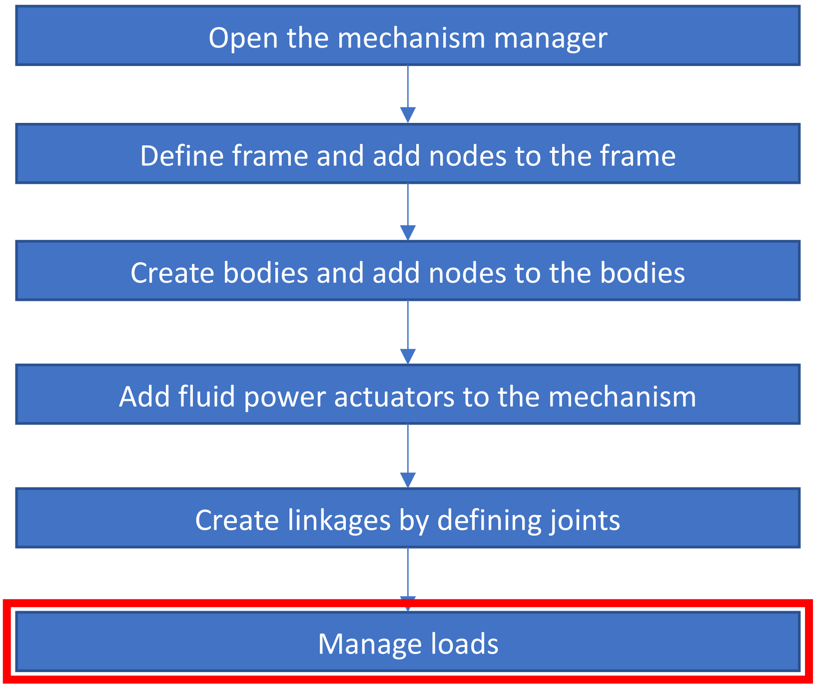
48) To give constraints to the joint rotation of Pivot_1, select the "Joint Limit Behaviour" on the "Operating Condition" settings and change it to "Stop"



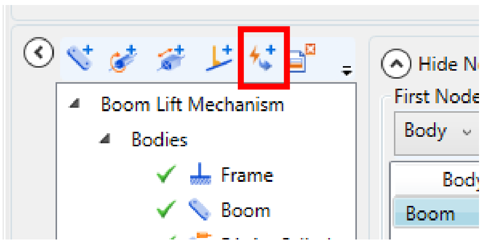
49) Set:
Maximum angle = 0 (anti-clockwise)
Minimum angle = -80 (clockwise)



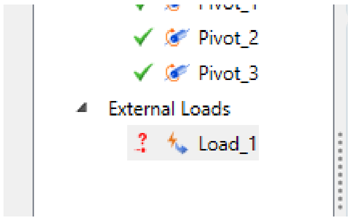
4.2.15. Step on creating mechanism



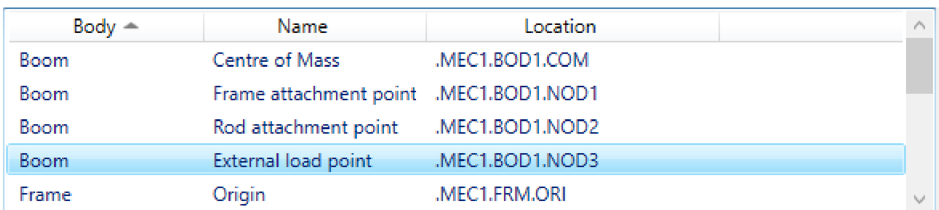
4.2.16. Manage loads



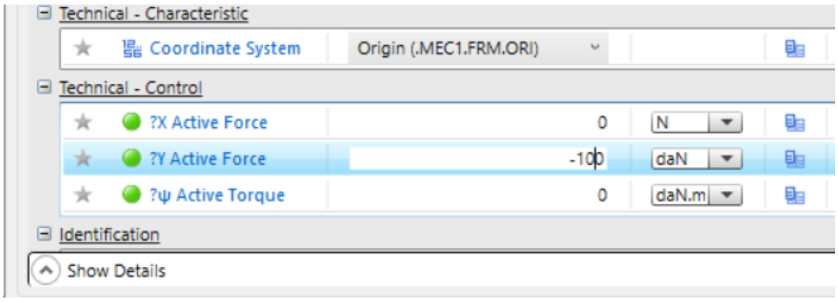
50) Add an external load



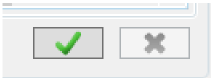
51) Result



52) Select the "External load point" of the body "boom" as the point in which the load is applied

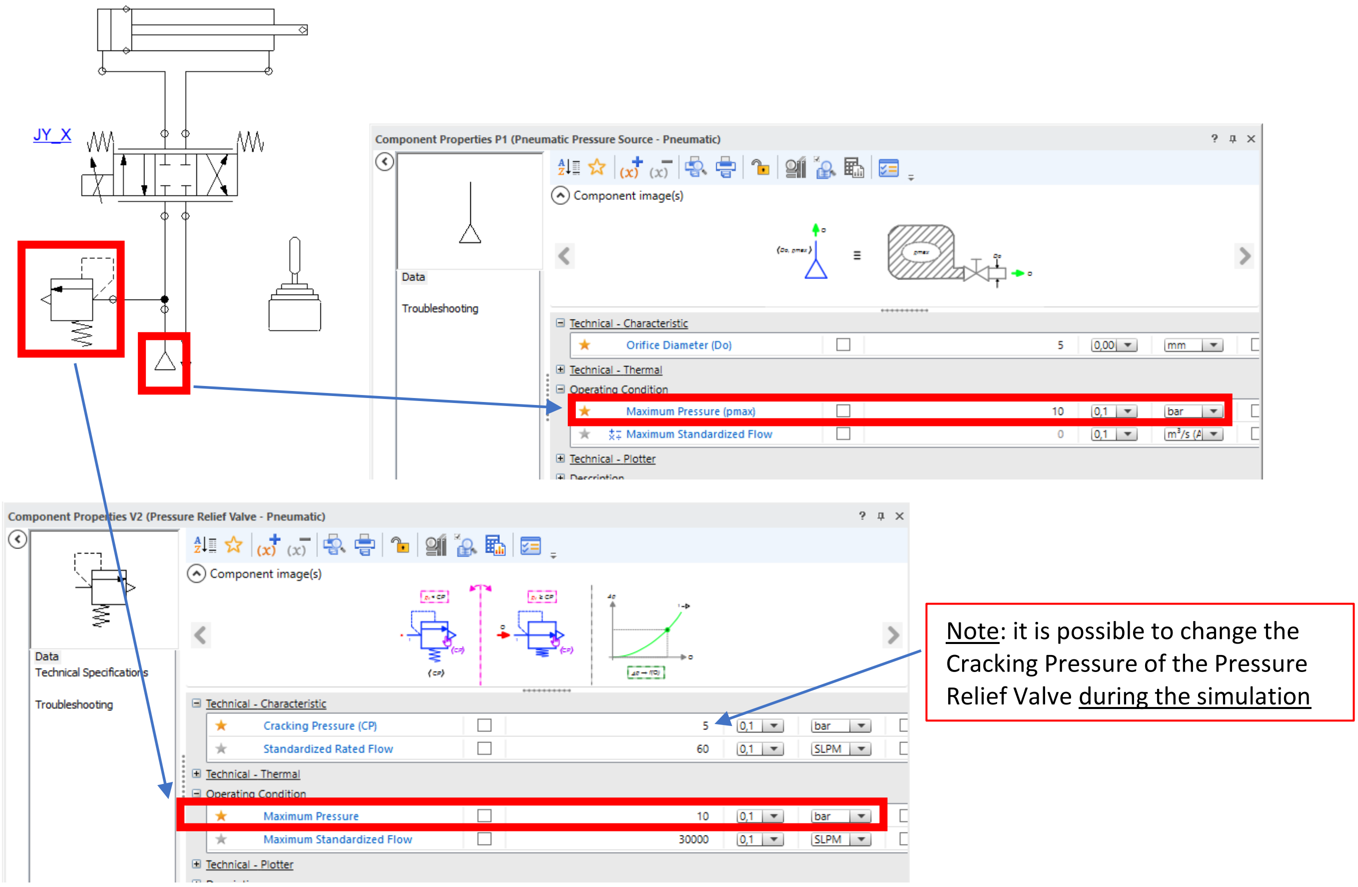


53) Set the value of the load in the Y direction (negative means down direction) equal to -100 daN in the "technical – control" properties

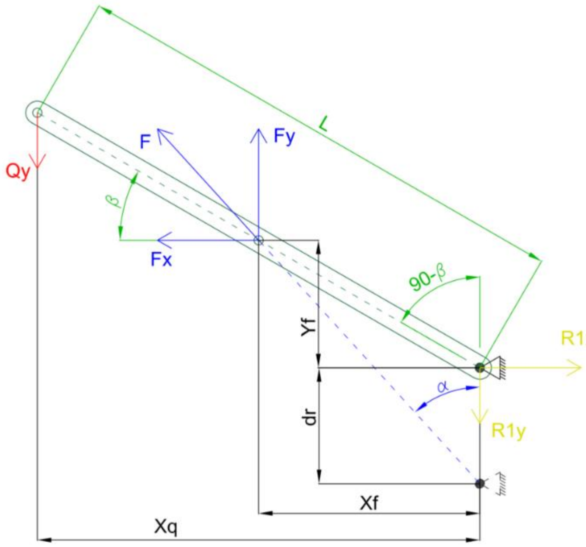


54) Confirm

4.2.17. SIMULATION

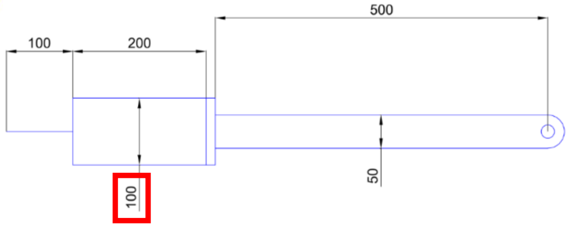


55) Before to run the simulation, it is important to set the maximum pressure of the Pneumatic Pressure Source and the maximum pressure of the Pressure Relief Valve



Parameters:

- L = Length of the boom
- β = Slope of the boom
- dr = drop
- Q = Load
- D = Piston diameter



Equations:

- $X_q = L * \sin(90^o - \beta)$
- $X_f = \frac{L}{2} * \sin(90^o - \beta)$
- $Y_f = \frac{L}{2} * \cos(90^o - \beta)$
- $\alpha = \tan^{-1}(\frac{X_f}{Y_f + dr})$
- $F_x = F_y * \tan(\alpha)$
- $F_y * X_f - F_x * Y_f - Q_y * X_q = 0$ (torques equilibrium around the hinge)
- $F = \sqrt{F_x^2 + F_y^2}$
- $A = \pi \frac{D^2}{4}$
- $P = \frac{F}{A}$

56) In order to understand how much the maximum pressure should be, it is possible to compute the minimum pressure that allows the actuator to lift the mechanism by studying the torques equilibrium of the rigid body

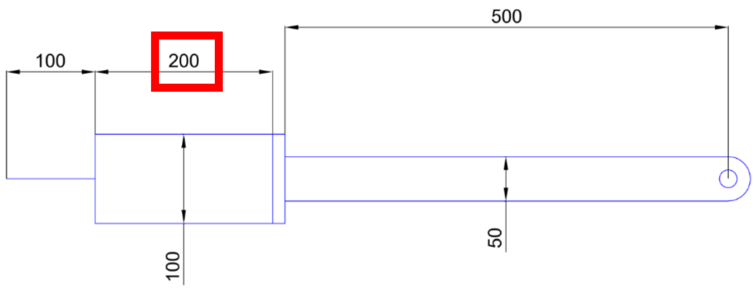
Equations:

- $X_q = L * \sin(90^o - \beta)$
- $X_f = \frac{L}{2} * \sin(90^o - \beta)$
- $Y_f = \frac{L}{2} * \cos(90^o - \beta)$
- $\alpha = \tan^{-1}(\frac{X_f}{Y_f + dr})$
- $F_x = F_y * \tan(\alpha)$
- $F_y = \frac{Q_y * X_q}{X_f - Y_f * \tan(\alpha)}$
- $F = \sqrt{F_x^2 + F_y^2}$
- $A = \pi \frac{D^2}{4}$
- $P = \frac{F}{A}$

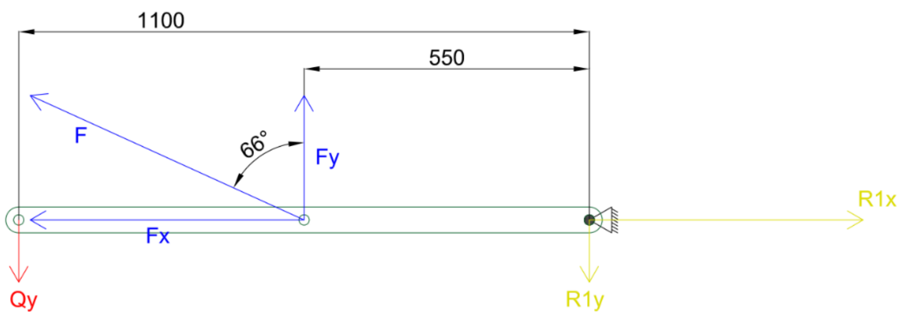
57) Solving the torques equilibrium around the hinge it is possible to find Fy (and so the force F applied to the actuator) related to the load Q.

PARAMETERS		
β	80	grad
L	1100	mm
dr	250	mm
Q	100	daN
D	100	mm
EQUATIONS		
Xq	191,01	mm
Xf	95,51	mm
Yf	541,64	mm
α	6,88	grad
Fy	633,3154113	daN
Fx	76,40519817	daN
F	638	daN
A	0,0079	m^2
P	8,12	bar
ACTUATOR STROKE CONSTRAINTS		
Cf	-100	mm
Rf	500	mm
Lact	797,38	mm
Stroke	197,38	mm

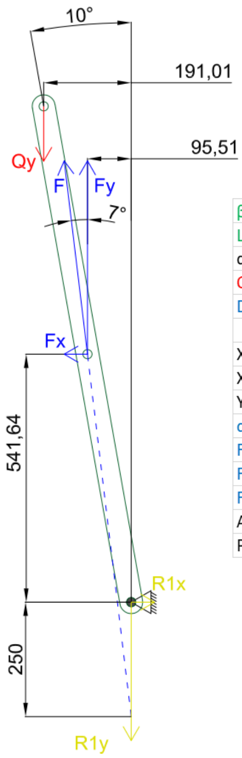
58) Using excel is easy to evaluate the pressure needed to maintain the equilibrium by changing the parameters.
(to interact: right click → worksheet → open)



59) Be sure to obtain values of the stroke lower than the maximum (200mm) (slide 6)



60) Solving the system in this configuration (β=0; Q=100daN), the minimum value of the pressure inside the actuator that allows movement is P=6,15 bar

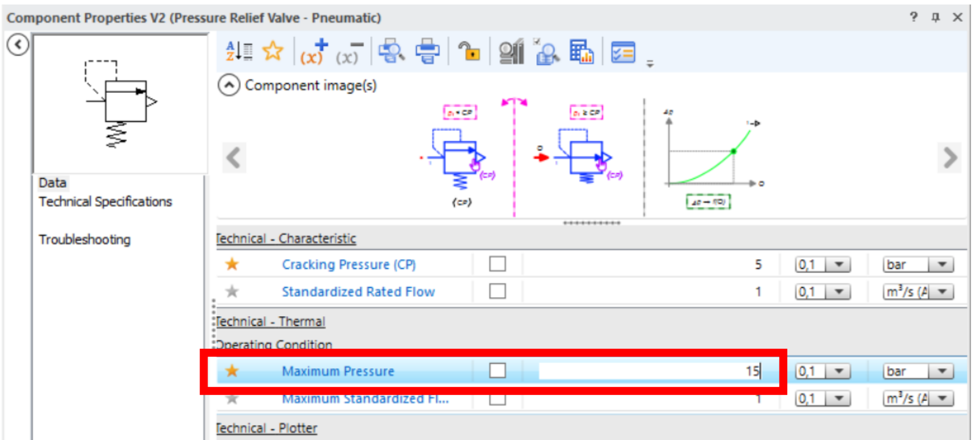


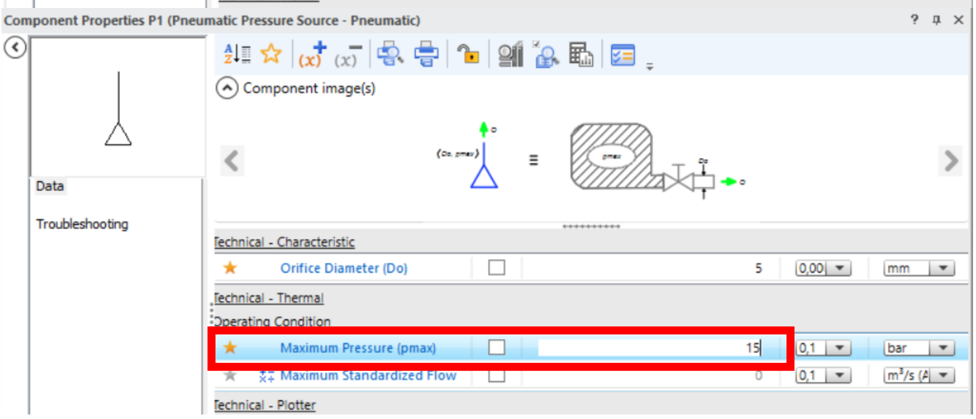
β	0	10	20	30	40	50	60	70	80
L	1100	1100	1100	1100	1100	1100	1100	1100	1100
dr	250	250	250	250	250	250	250	250	250
Q	100	100	100	100	100	100	100	100	100
D	100	100	100	100	100	100	100	100	100
Xq	1100,00	1083,29	1033,66	952,63	842,65	707,07	550,00	376,22	191,01
Xf	550,00	541,64	516,83	476,31	421,32	353,53	275,00	188,11	95,51
Yf	0,00	95,51	188,11	275,00	353,53	421,32	476,31	516,83	541,64
α	65,56	57,47	49,71	42,22	34,92	27,77	20,74	13,78	6,88
Fy	200	276,4052	350,4889	420	482,8265	537,0596	581,0512	613,4648	633,3154
Fx	440	433,3154	413,4648	381,0512	337,0596	282,8265	220	150,4889	76,4052
F	483	514	542	567	589	607	621	632	638
A	0,0079	0,0079	0,0079	0,0079	0,0079	0,0079	0,0079	0,0079	0,0079
P	6,15	6,54	6,90	7,22	7,50	7,73	7,91	8,04	8,12

Note:

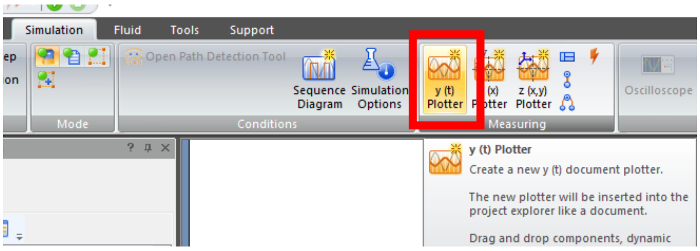
- The joint allows rotations of the boom up to 80 degree, as imposed at the step 49.
- Q has a positive value in this computation

61) Solving the system in this configuration (β=80º;Q=100daN), the minimum value of the pressure inside the actuator that allows to maintain the boom in the equilibrium position is 8,12 bar → the operating pressure must be greater (15 bar can be enough)

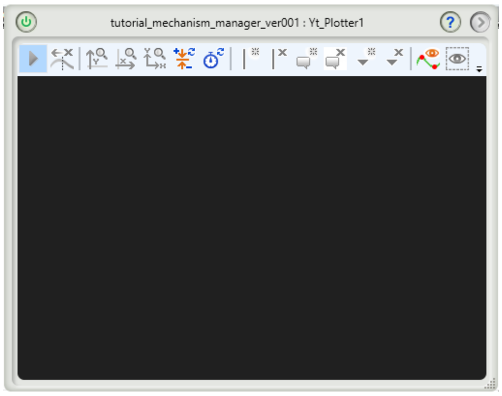




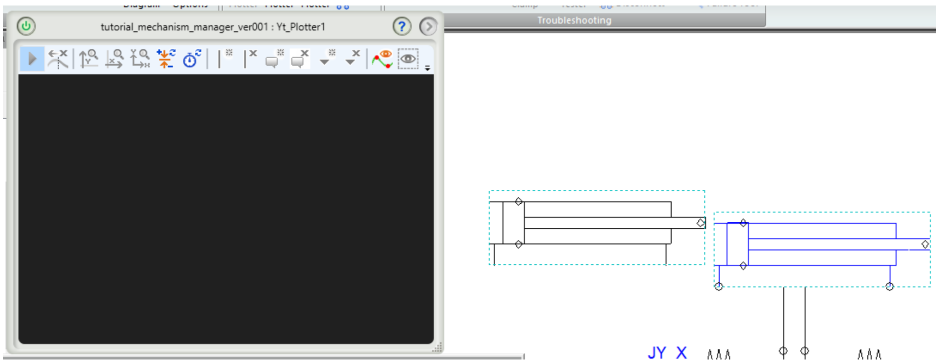
62) Set the value of 15 bar for the maximum pressure of the Pneumatic Pressure Source and the maximum pressure of the Pressure Relief Valve



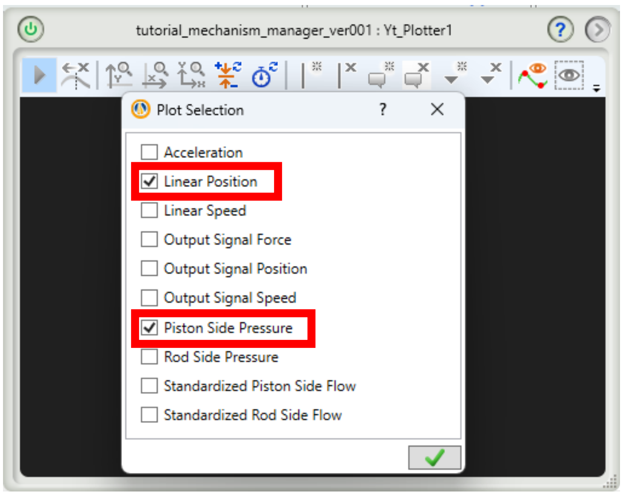
63) Last steps: open the y(t) Plotter, on the simulation window, to evaluate the pressure inside the actuator and its linear position during the simulation



64) Result

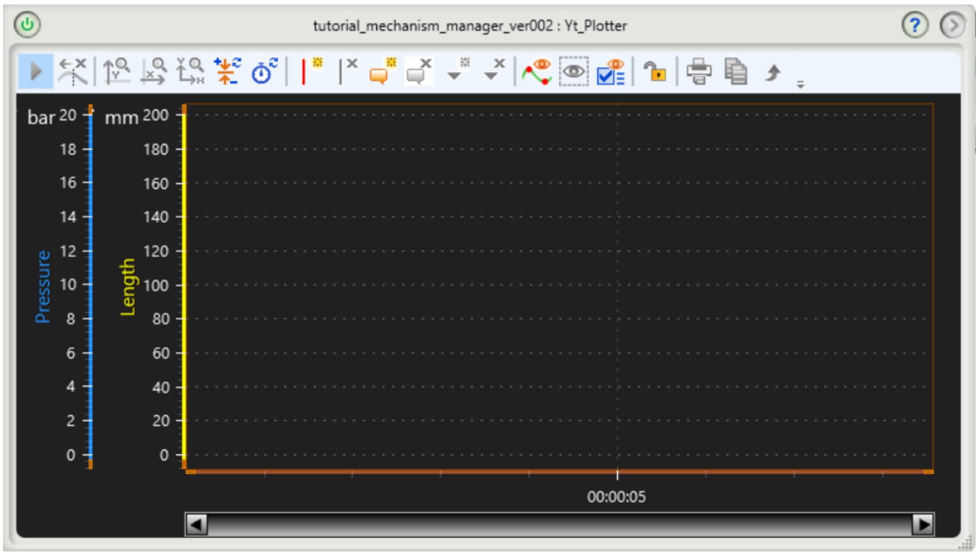


65) Drag and drop the actuator inside the plotter

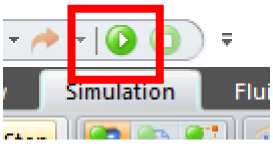


66) Select the 2 variables of the actuator to show

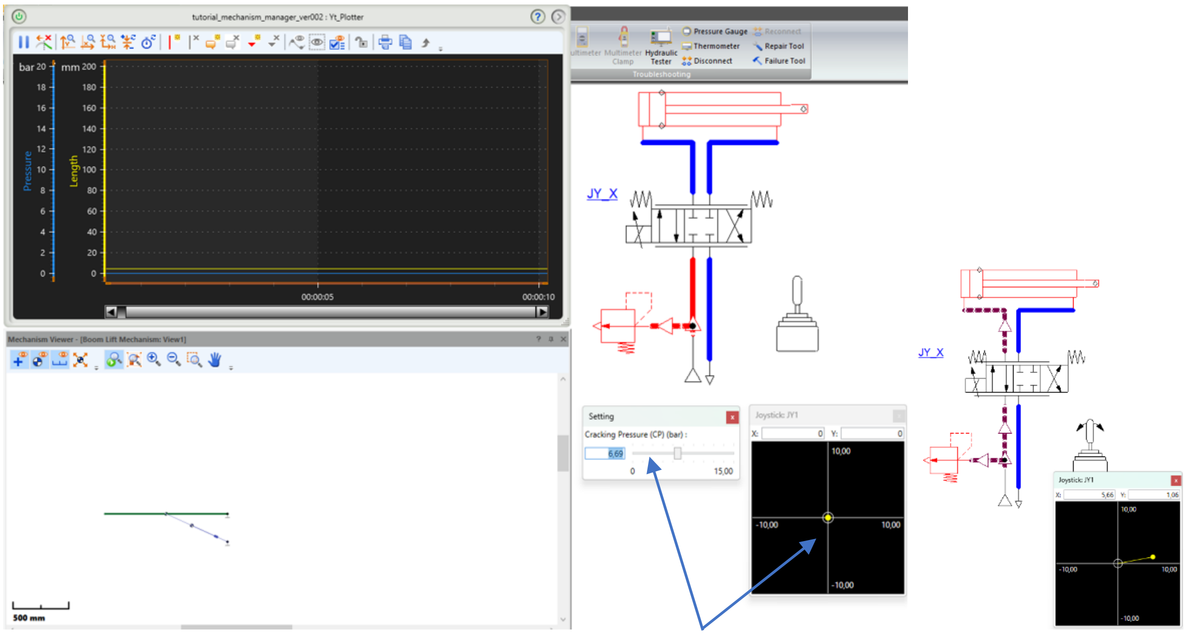
67) Confirm



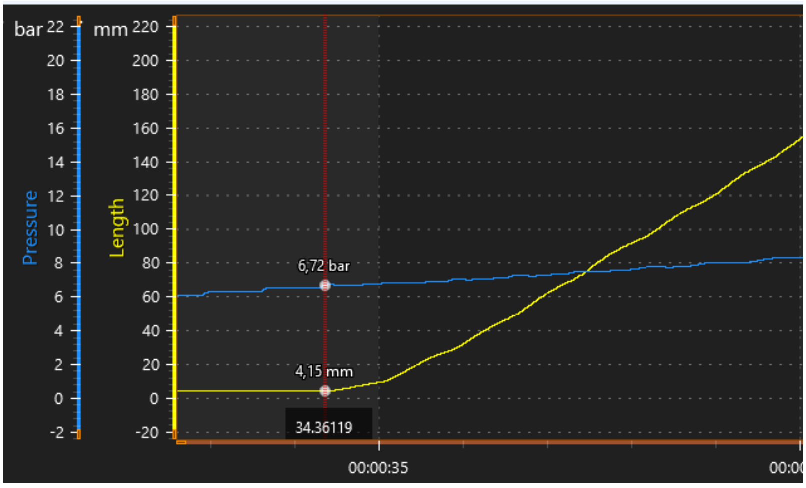
68) Result



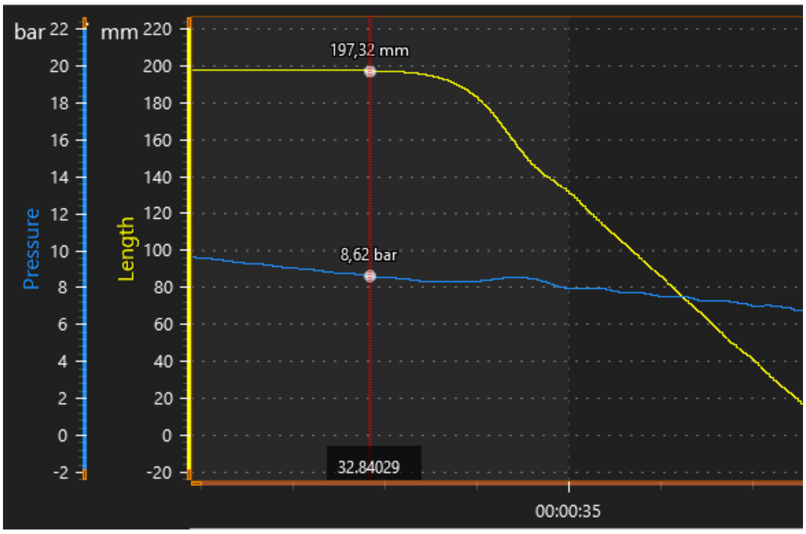
69) FINALLY, RUN THE SIMULATION



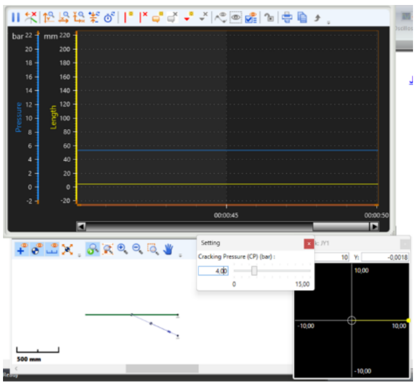
70) During the simulation, play with the joystick and the Cracking Pressure of the valve and evaluate the behaviour of the system



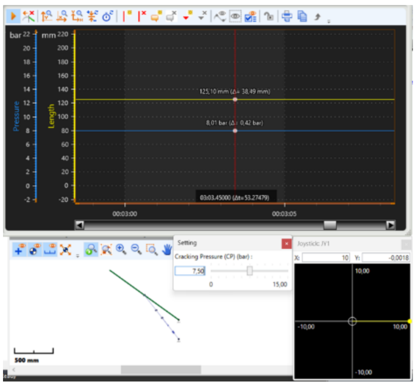
71) It is possible to see that the system starts to move when the pressure inside the actuator reaches the value found at the step 59 (6,15 bar)



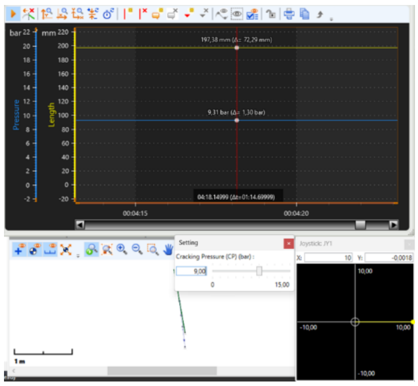
72) It is possible to see that the piston maintains its outstroke position when the pressure inside the actuator remains greater than the value found at the step 60 (8,12 bar)



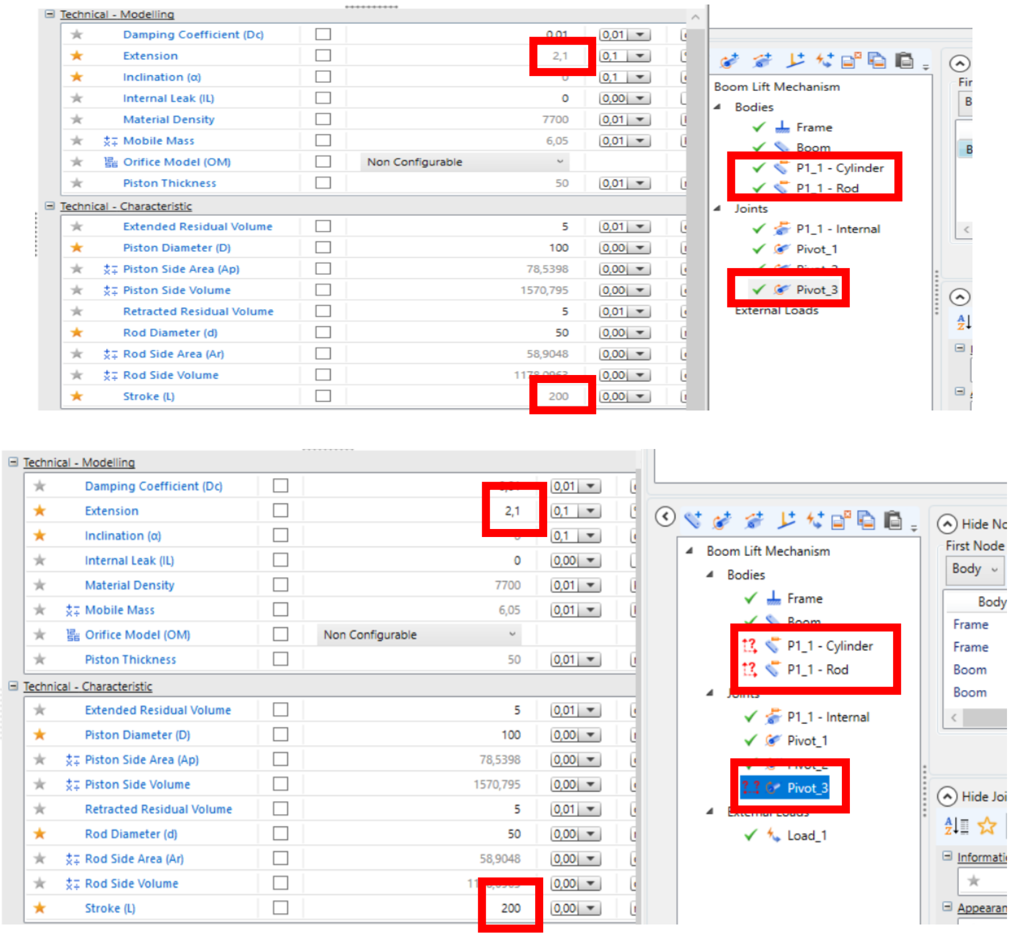
P < 6,15 bar



6,15 bar < P < 8,12 bar

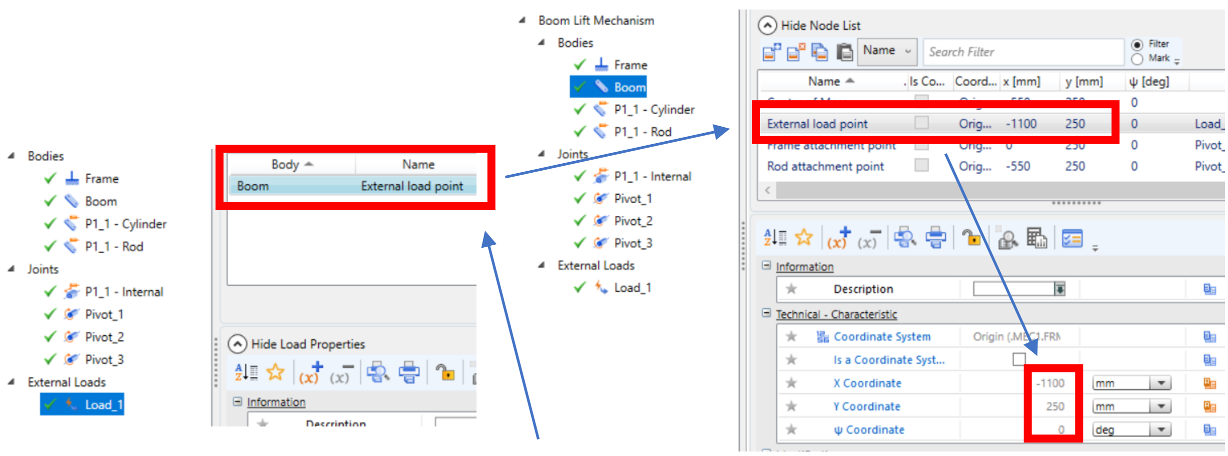


P > 8,12 bar

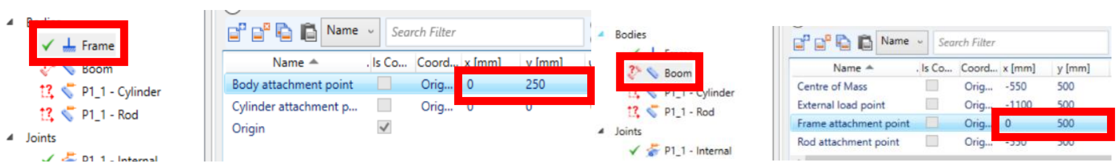


73) To modify the mechanism, remember that:

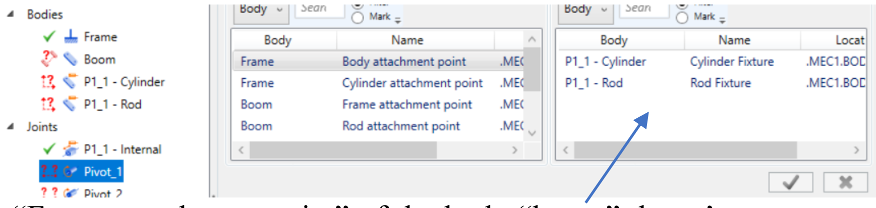
- It is <u>no longer possible</u> to modify the maximum stroke or the extension of the piston once it is linked in the mechanism manager



- It is <u>no longer possible</u> to change the coordinate of a node (body or frame) once it is used for a linkage or an External Load, as well as the Cylinder and Rod Fixtures

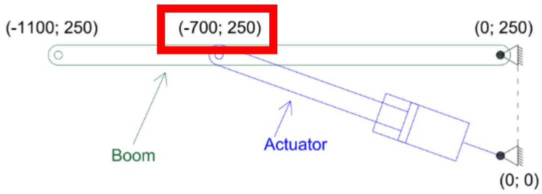


- It is <u>not possible</u> to link 2 nodes with different coordinates in a pivot joint

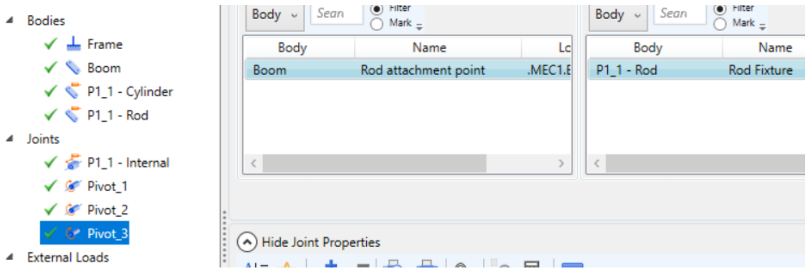


Note: “Frame attachment point” of the body “boom” doesn’t appear on the list of the possible choices

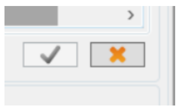
74) So, to modify the shape or dimension of bodies, manually delete the pivot joint linking the nodes that need to be changed



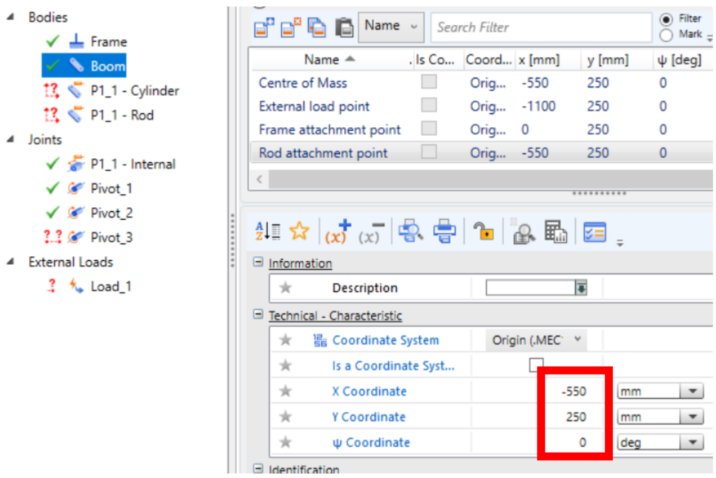
75) Try to modify the point in which the rod is attached to the body



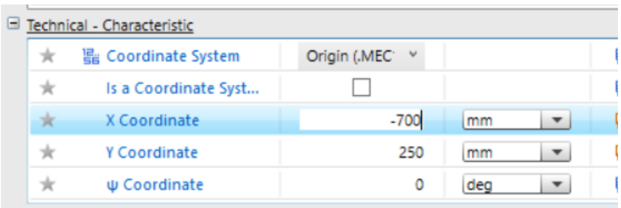
76) Select the pivot joint related this node



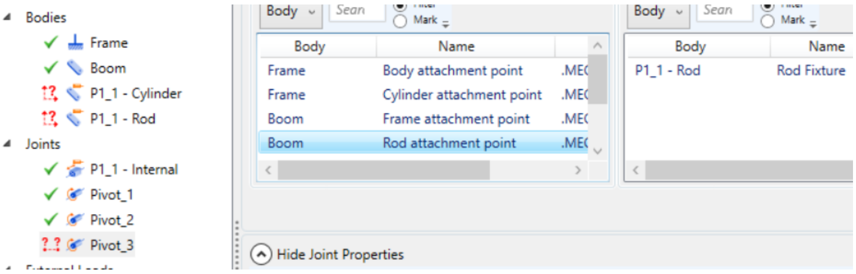
77) Invalidate Selection



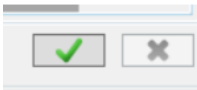
78) Result: the “rod attachment point” of the body “boom” can now change its coordinates



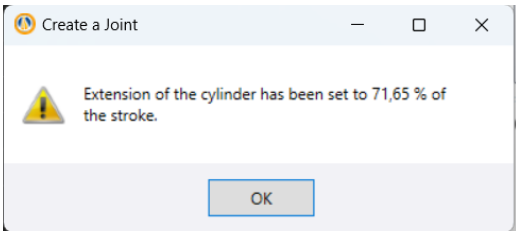
79) Change the X coordinate to (-700;250)



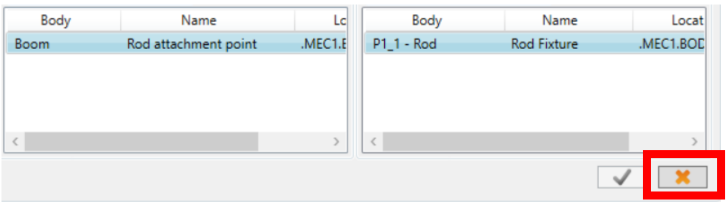
80) Rebuild the pivot joint



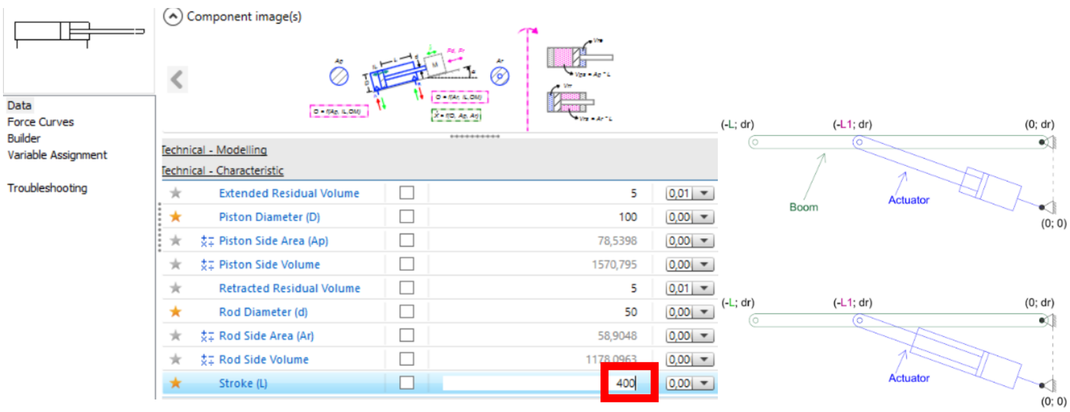
81) Confirm



82) Result: the extension is too much large

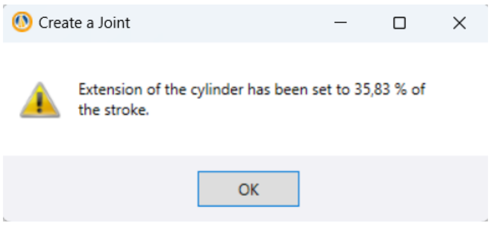


83) So, Invalidate Selection once again

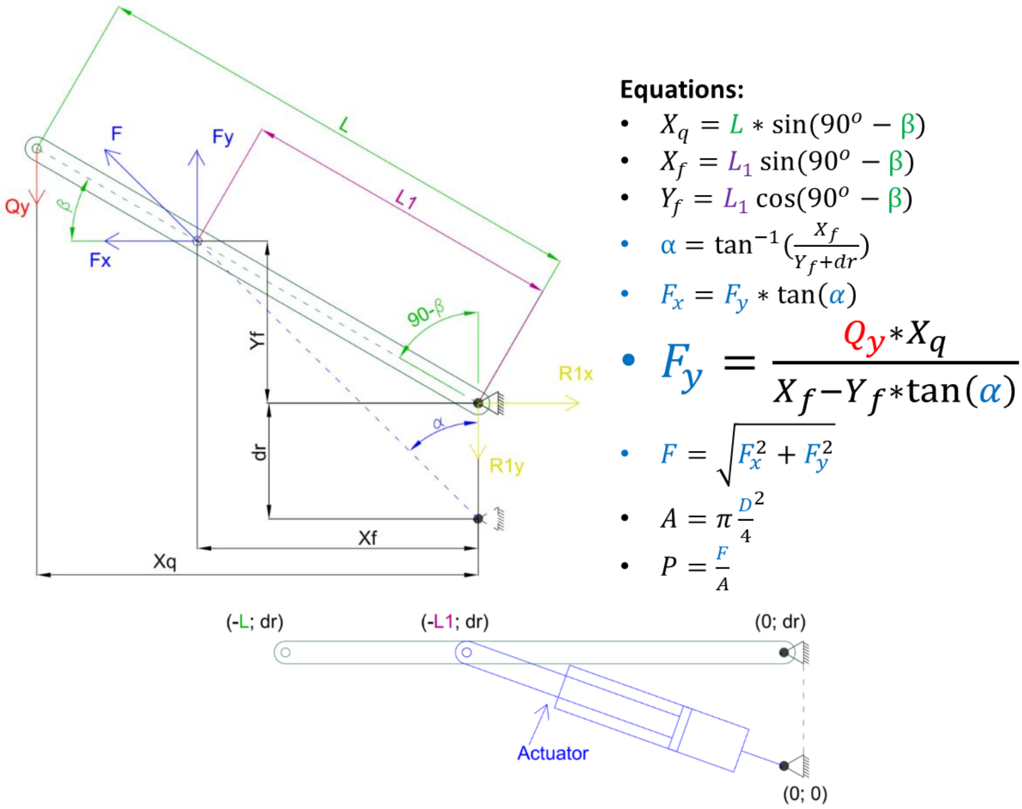


84) Change the maximum stroke to 400 mm on the actuator parameters

85) Rebuild the pivot joint (step 79)



86) Result



Equations:

- $X_q = L * \sin(90^o - \beta)$
- $X_f = L_1 \sin(90^o - \beta)$
- $Y_f = L_1 \cos(90^o - \beta)$
- $\alpha = \tan^{-1}(\frac{X_f}{Y_f + dr})$
- $F_x = F_y * \tan(\alpha)$
- $F_y = \frac{Q_y * X_q}{X_f - Y_f * \tan(\alpha)}$
- $F = \sqrt{F_x^2 + F_y^2}$
- $A = \pi \frac{D^2}{4}$
- $P = \frac{F}{A}$

87) Equations of the torques equilibrium (as well as the excel file) change a bit

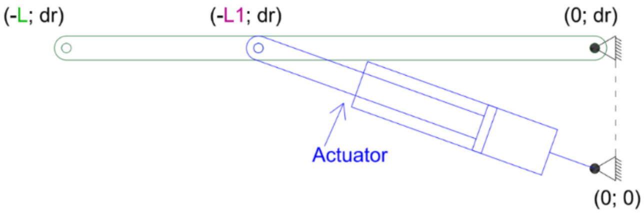
PARAMETERS		
β	80	grad
L	1100	mm
L1	700	mm
dr	250	mm
Q	100	daN
D	100	mm

EQUATIONS		
Xq	191,01	mm
Xf	121,55	mm
Yf	689,37	mm
α	7,37	grad
Fy	590,4582685	daN
Fx	76,40519817	daN
F	595	daN
A	0,0079	m^2
P	7,58	bar

ACTUATOR STROKE CONSTRAINTS		
Cf	-100	mm
Rf	500	mm
Lact	947,20	mm
Stroke	347,20	mm

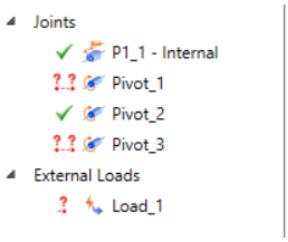
(to interact: right click → worksheet → open)

88) Verify the maximum stroke

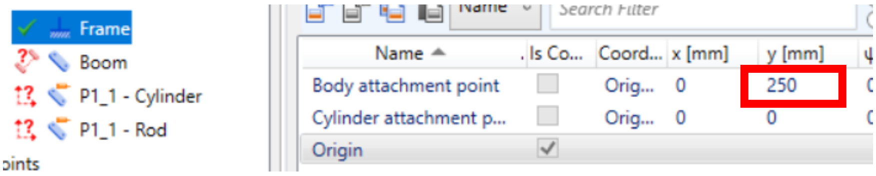


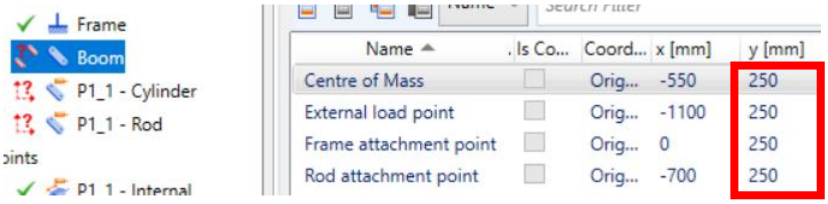
89) To modify the drop "dr", it may seem a bit complicated because it need to change the coordinates of:

- (0;dr) → Body attachment point of the frame
- (0; dr) → Frame attachment point of the body "boom"
- (-L1; dr) → Rod attachment point of the body "boom"
- (-L; dr) → External load point of the body "boom"
- (-L1;dr) → Centre of Mass of the body "boom"



90) Invalidate selection (step 76) for the 2 pivot joints related to the boom and the external load





91) Change coordinates

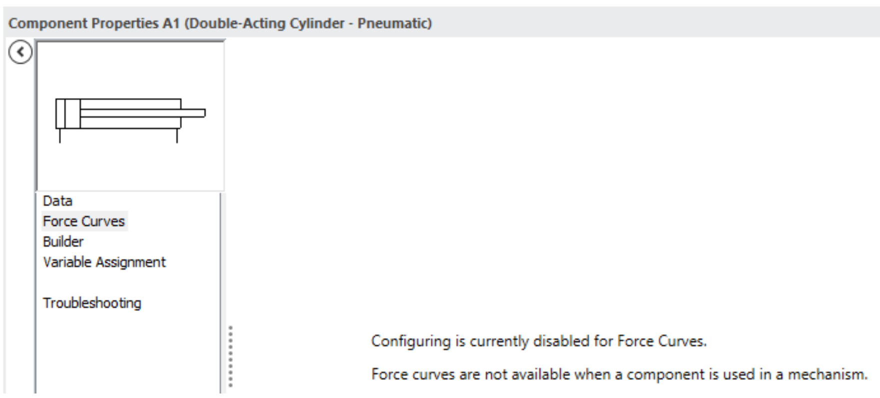
92) Rebuild the pivot joint (step 79)

93) Check, using excel, the pressure needed to work and the maximum stroke and restart the simulation

4.2.18. Conclusion

The Mechanism Manager allows to associate the behaviour of a mechanic system (composed by bodies and joints and affected by loads) to the behaviour of a fluid system (composed by actuators, pipes, valve… and controlled by its logic)

It is no longer possible to manage loads through the actuator properties once the actuator is managed by the Mechanism Manager



The Amplitude of the signal (X) of the joystick, linked to the proportional valve, is related to the speed of the mechanism

Gas makes the system oscillating

Enjoy!

4.3. Project 2: Pantograph Lift 3D + mechanism manager

4.3.1. Introduction

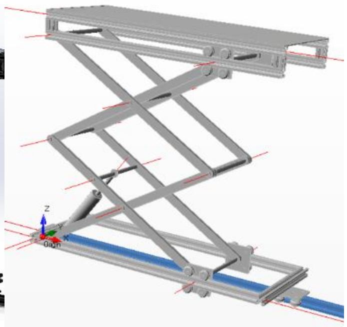
The aim of this task is to model a Pantograph Lift in the 3D environment of AutomationStudio, where movements are linked to the Mechanism Manager and affected by external loads.
For this aim it is shown step by step how to realize it, importing the 3D drawings from SolidWorks.

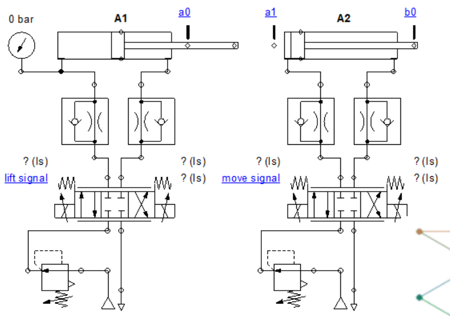
The Mechanism Manager in AutomationStudio allows to create mechanical links between bodies and fluid power actuators to simulate their kinematic and dynamic interactions.

The 3D environment in AutomationStudio allows to create 3D assemblies of components and to link their movements to the fluid power actuators.

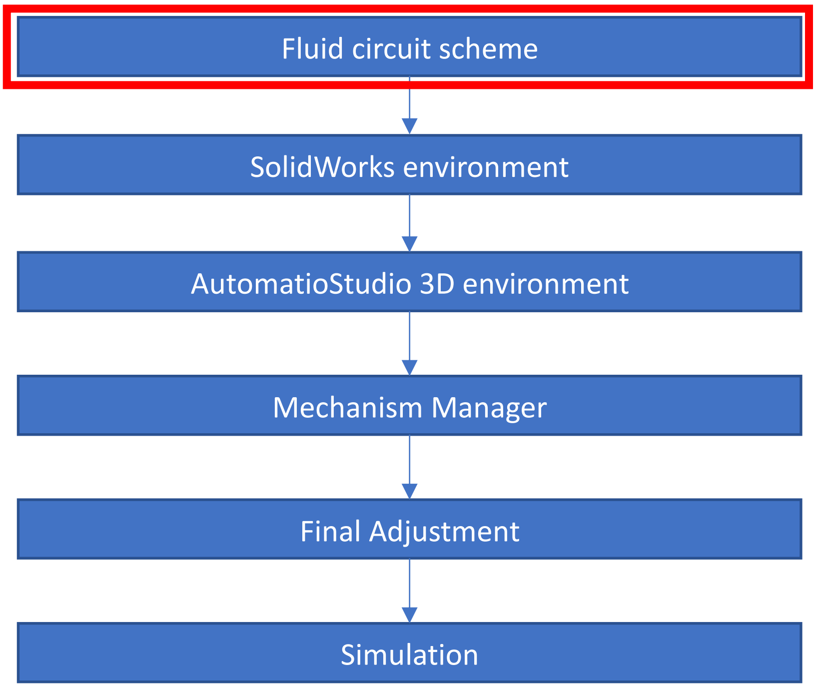
In this example:

- The drawings are previously realized on SolidWorks and then imported into the 3D environment of AutomationStudio.
- The movements of the lift actuator (vertical) and the trolley along the fixed bar (horizontal) are linked to the 2 actuators on the fluid scheme.
- The lift actuator is also involved into the mechanism manager to study the behaviour while loads are applied

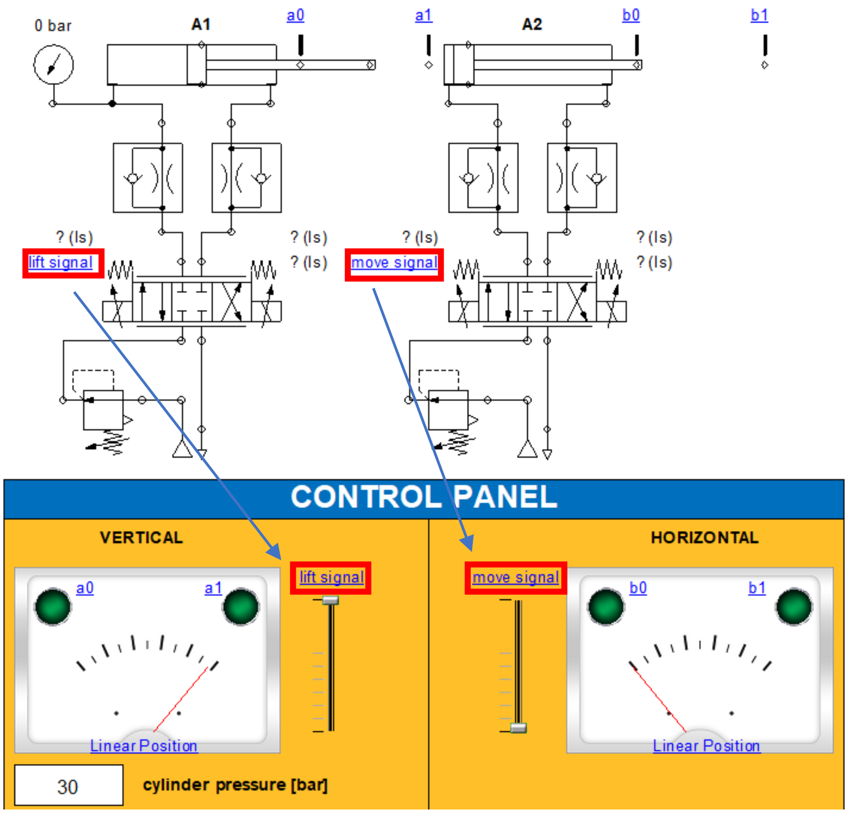




4.3.2. Steps



4.3.3. Fluid circuit scheme



The fluid circuit is divided in 2 simple branches, both composed by:

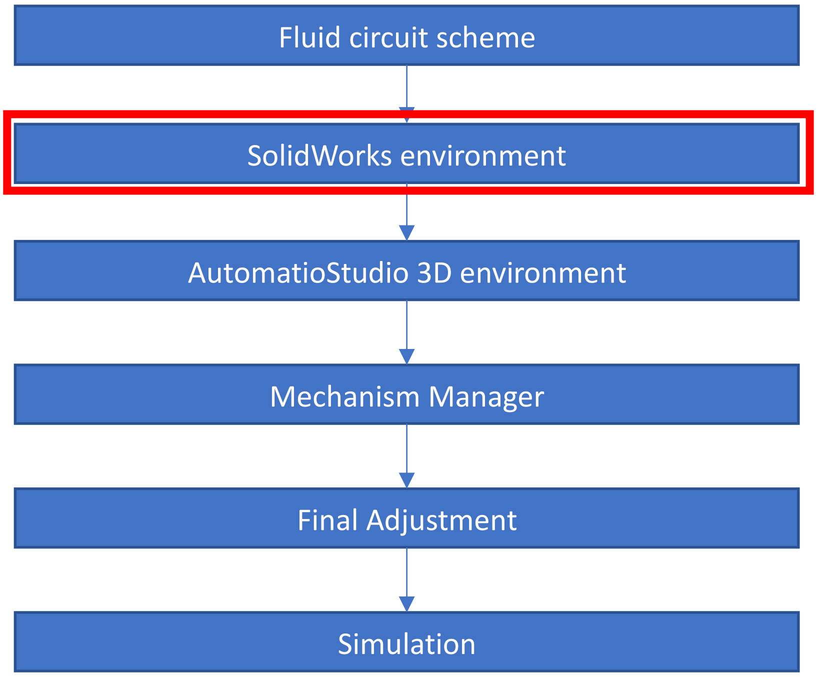
- 1 compressor.
- 1 pressure reducing valve.
- 1 proportional valve

- 1 actuator
- 2 throttle valves

The right branch, responsible for the vertical movement of the lift, has the proportional valve variable linked to the lift signal of the control panel.

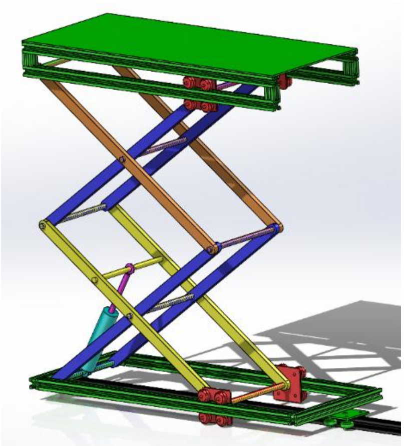
The left branch, responsible for the horizontal movement of the lift, has the proportional valve variable linked to the move signal of the control panel

4.3.4. Steps



4.3.5. SolidWorks environment

Before to start, notice that the 3d environment of AutomationStudio considers the assemblies done by SolidWorks as single parts (relative motions inside an assembly will be not possible once it is imported in AutomationStudio).

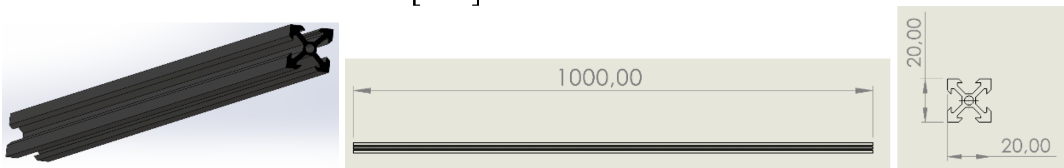


The pantograph lift is composed by the following parts:

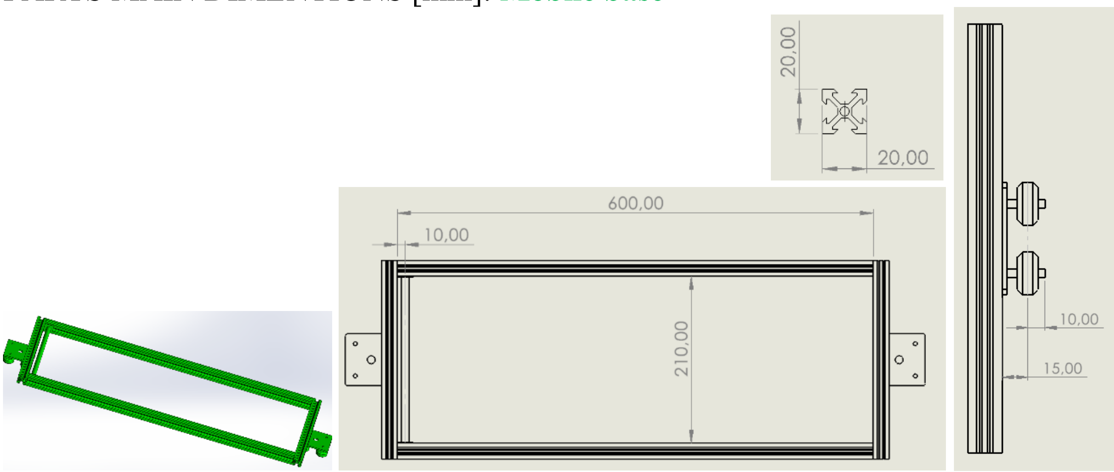
- 1x fixed bar
- 1x mobile base
- 2x trolley
- 2x narrow boom
- 1x boom with rod attachment
- 1x large boom
- 1x workbench
- 1x cylinder
- 1x rod

In the next slides are shown the main dimension of each part useful to create the assembly.

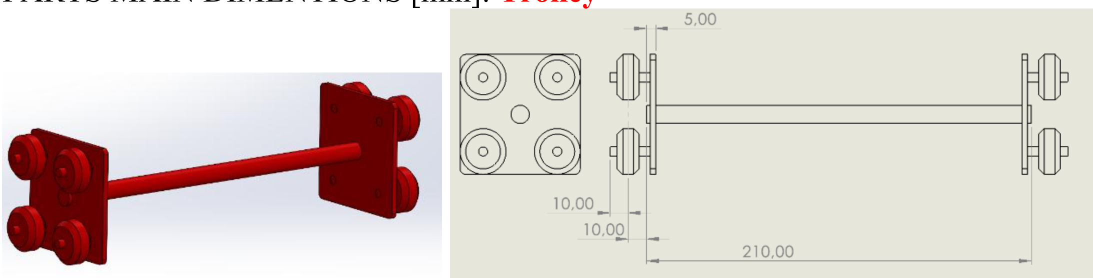
PARTS MAIN DIMENTIONS [mm]: **Fixed bar**



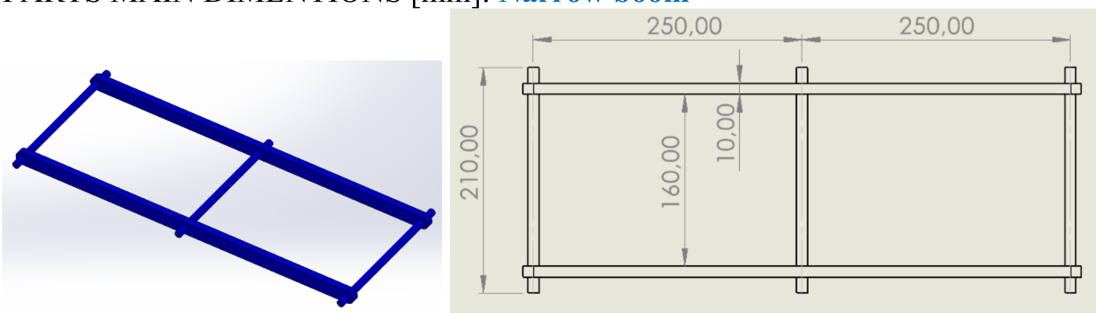
PARTS MAIN DIMENTIONS [mm]: **Mobile base**



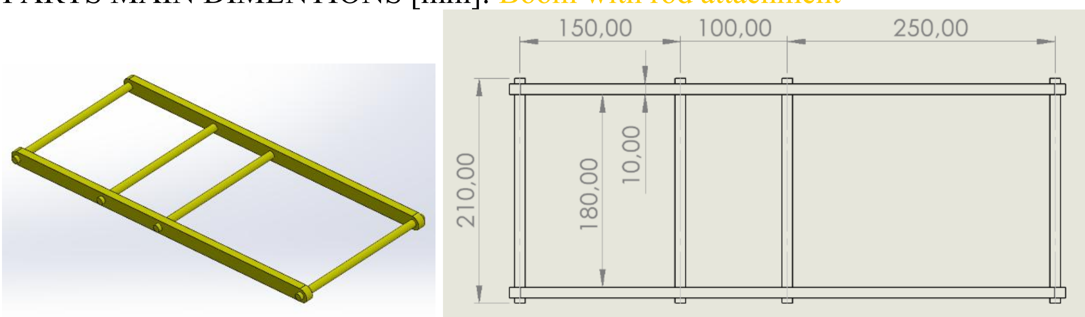
PARTS MAIN DIMENTIONS [mm]: **Trolley**



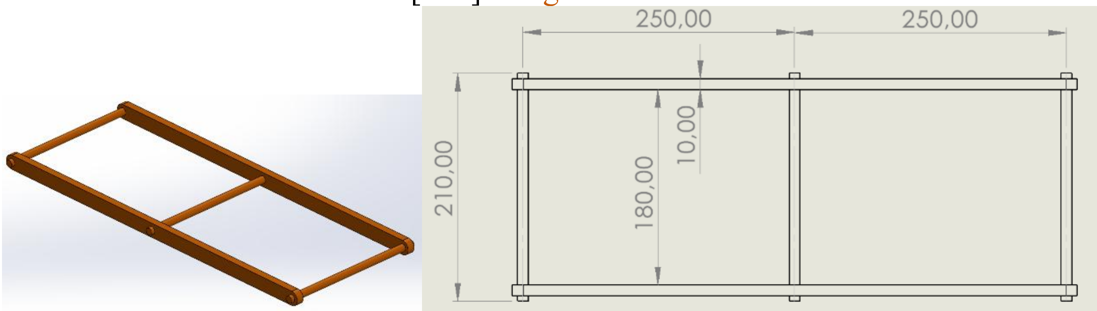
PARTS MAIN DIMENTIONS [mm]: **Narrow boom**



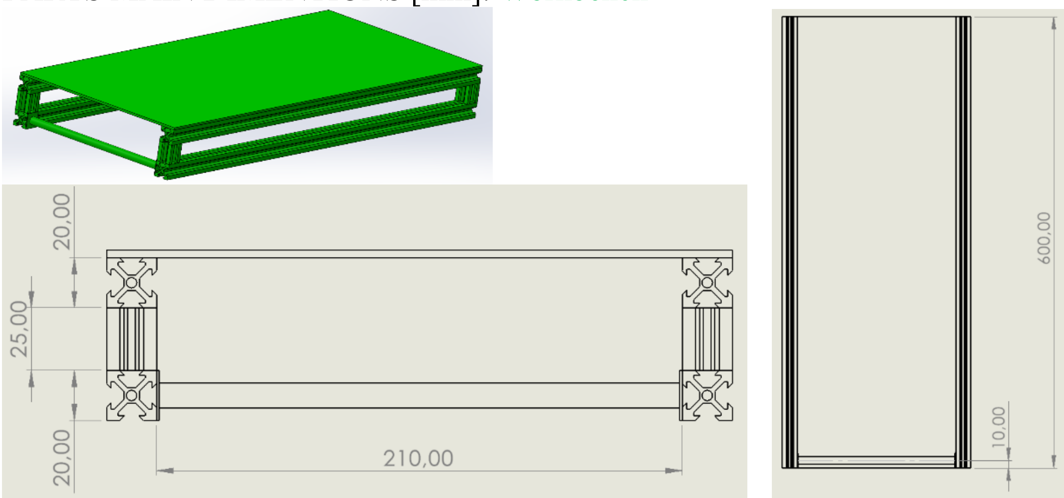
PARTS MAIN DIMENTIONS [mm]: Boom with rod attachment



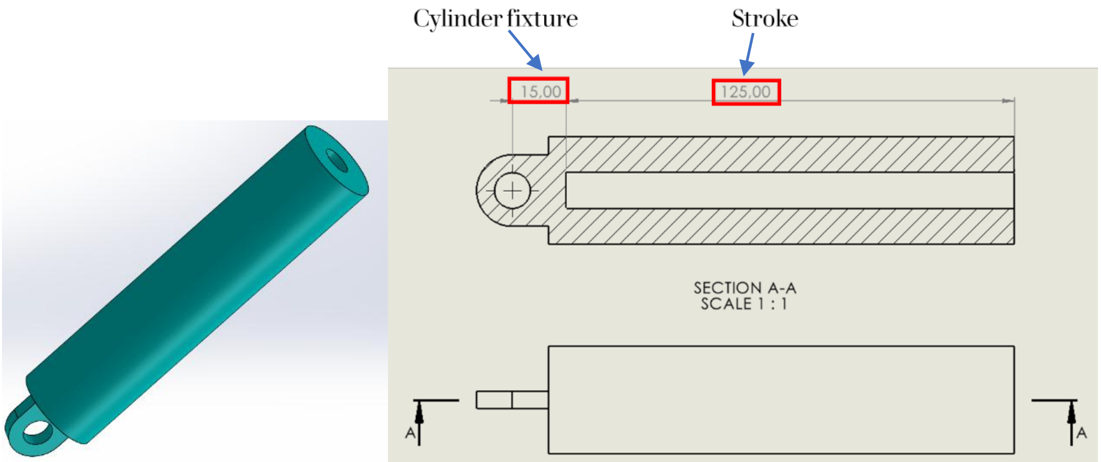
PARTS MAIN DIMENTIONS [mm]: Large boom



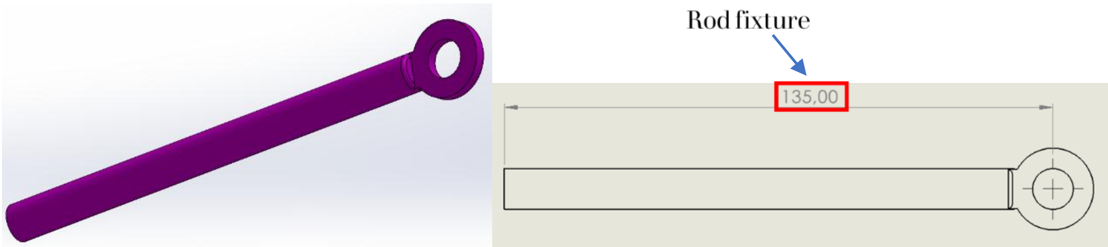
PARTS MAIN DIMENTIONS [mm]: Workbench



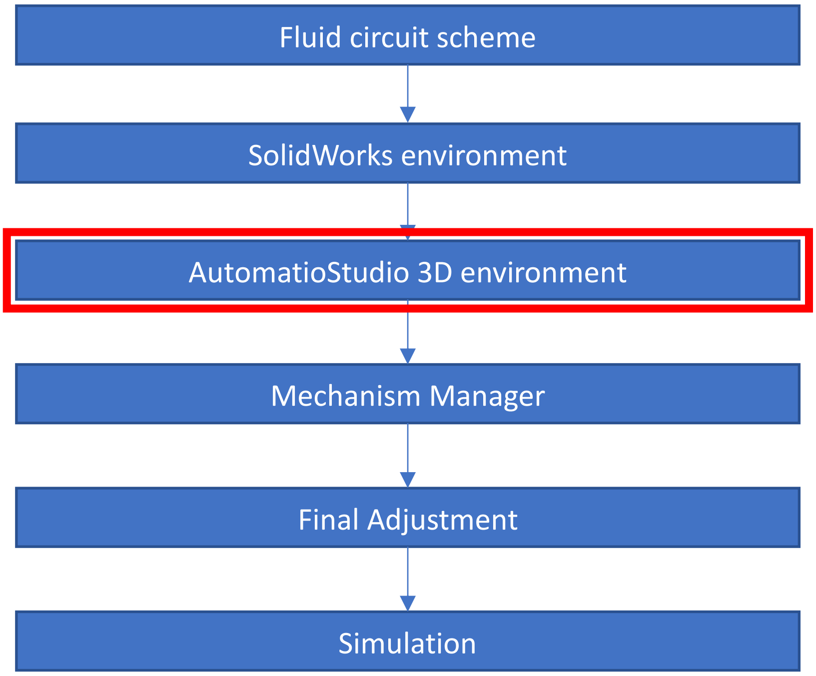
PARTS MAIN DIMENTIONS [mm]: Cylinder



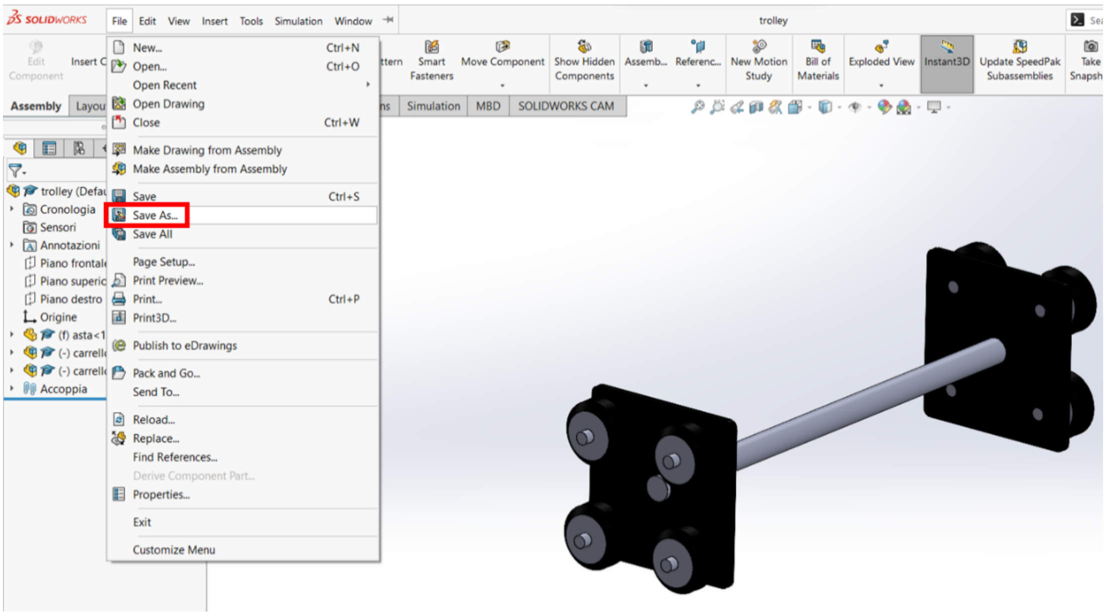
PARTS MAIN DIMENTIONS [mm]: Rod

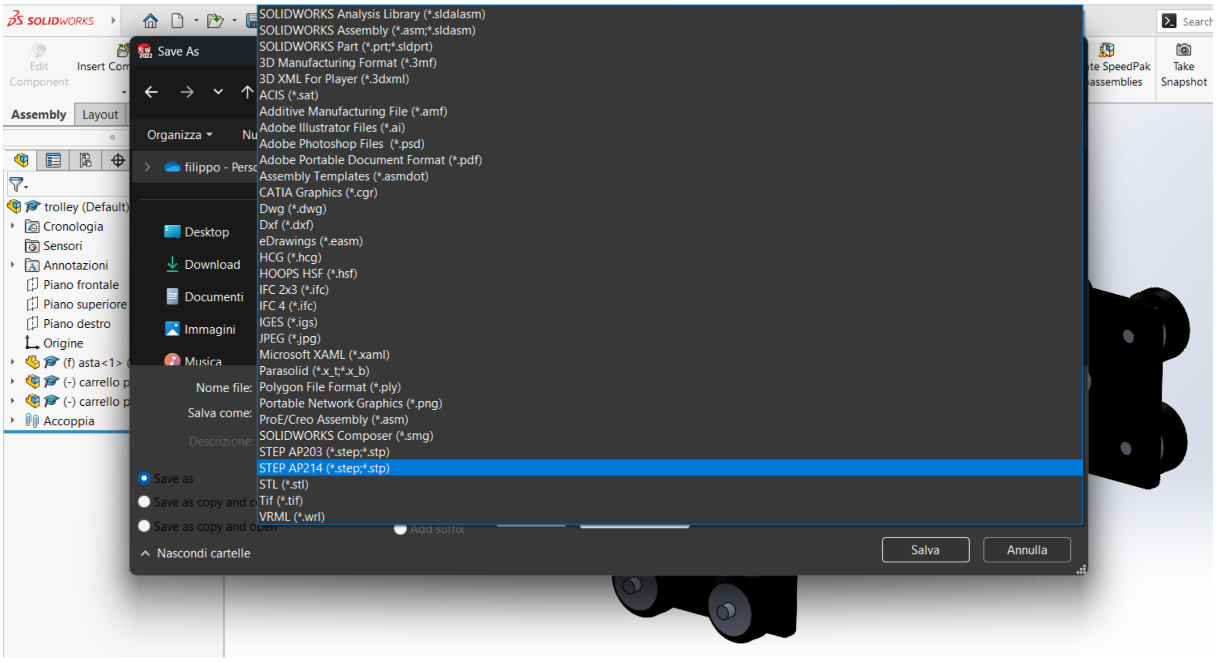


4.3.6. Steps

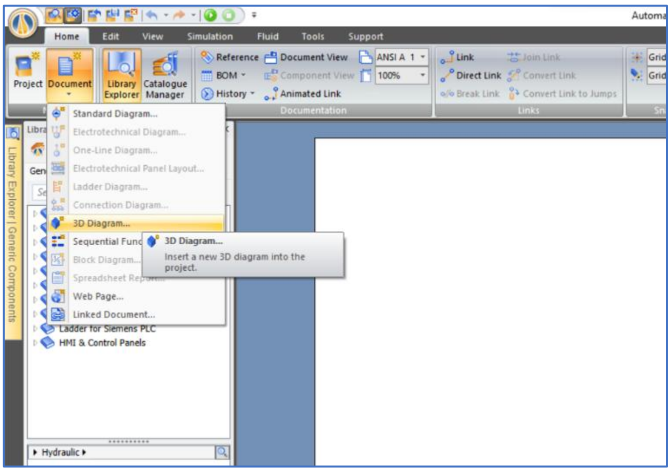


4.3.7. AutomatioStudio 3D environment

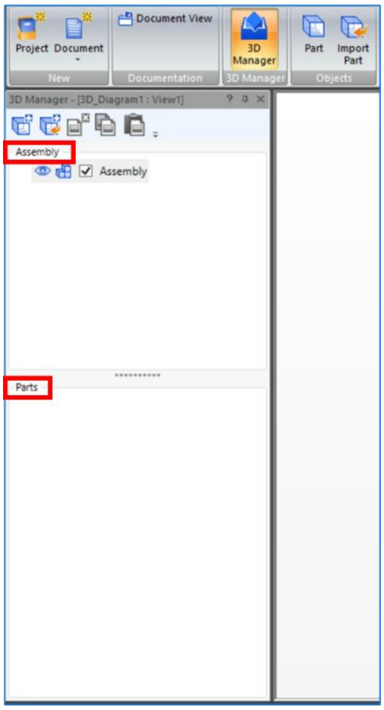




1) Once the parts are done in the Solidworks environment, they must to be imported in Automationstudio. So, all the drawing must to be saved into a format accessible from Automationstuio: STEP or IGES

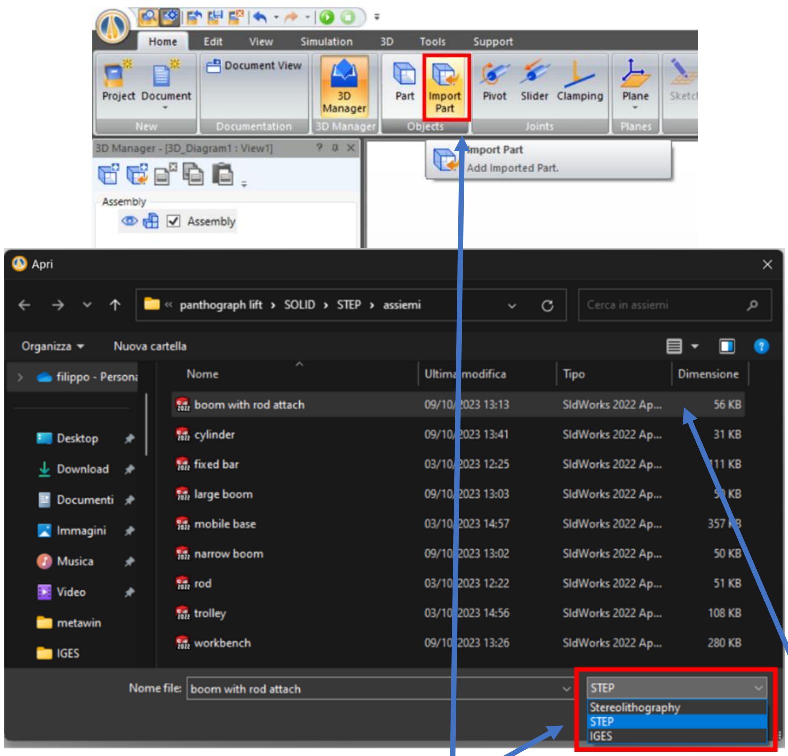


2) Then open a 3d diagram on Automationstudio



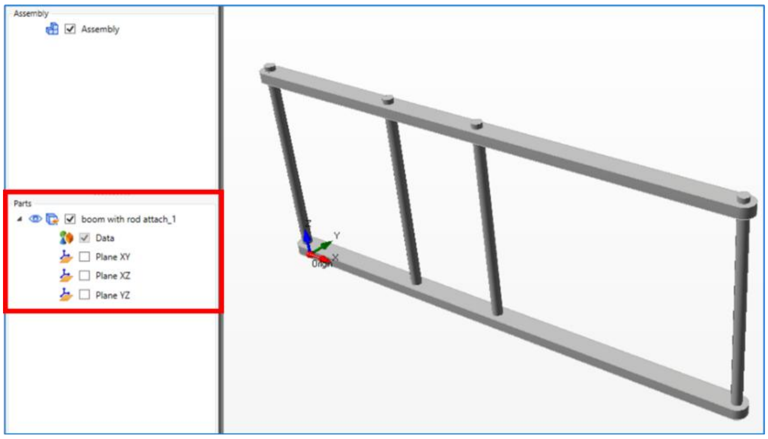
3) The 3d manager appears and it is divided in 2 section:

- Parts, in which the single parts are imported or created directly
- Assembly, in which the parts are combined to create the assembly thanks to joints or clamps



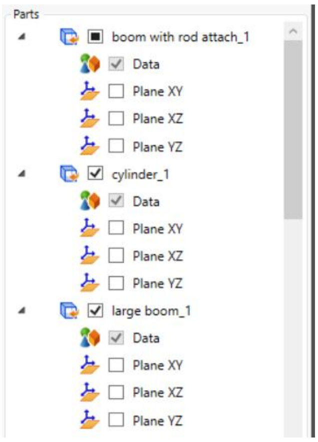
4) To import the first part click on “import part” and select the drawing

Note: remember to select the same format of the drawing previously saved

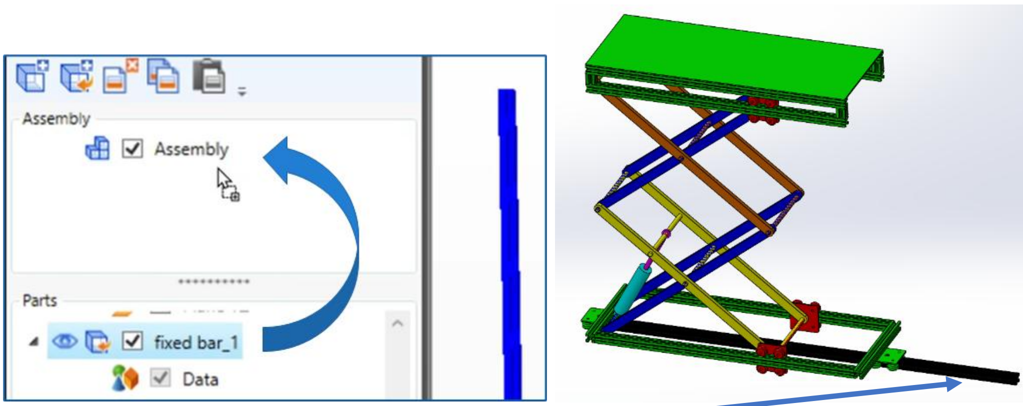


5) The drawing appears into the Parts section in which it is not possible to change coordinates and orientations (it is possible only while creating the assembly)

Note: the frame of each part of the component is defined previously on Solidworks.



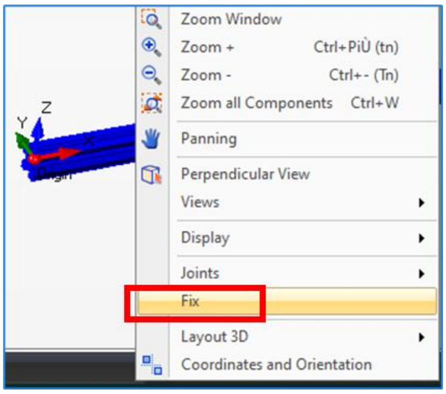
6) Repeat the step 4 to import all the other drawings



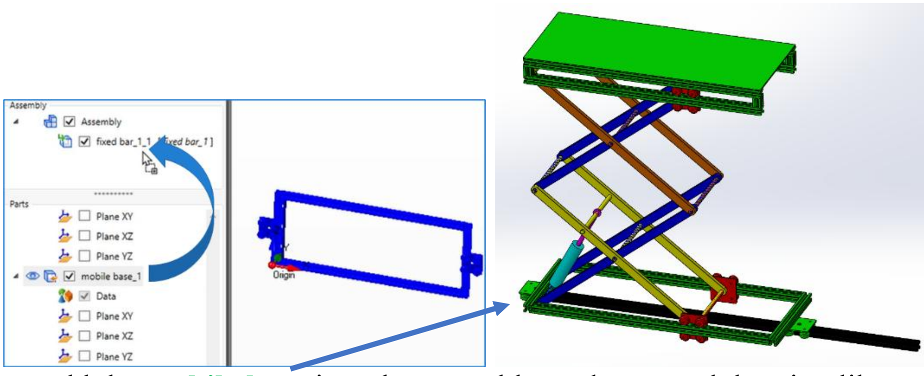
7) Once all drawing are imported, select the **fixed bar** as the first one to create the assembly. Then drag and drop it inside the assembly

Note: it is suggested to choose as first the component that will be fixed (the fixed bar in this case)

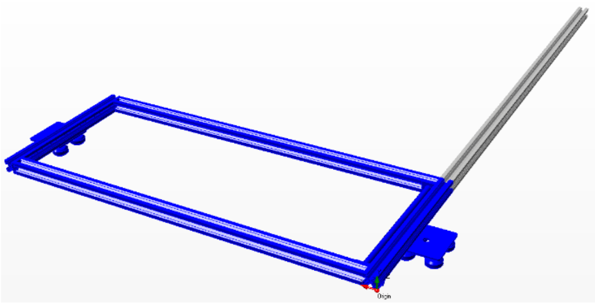
8) The part appears on the assembly in which is possible to change the coordinates (of the origin of this part) and the orientation



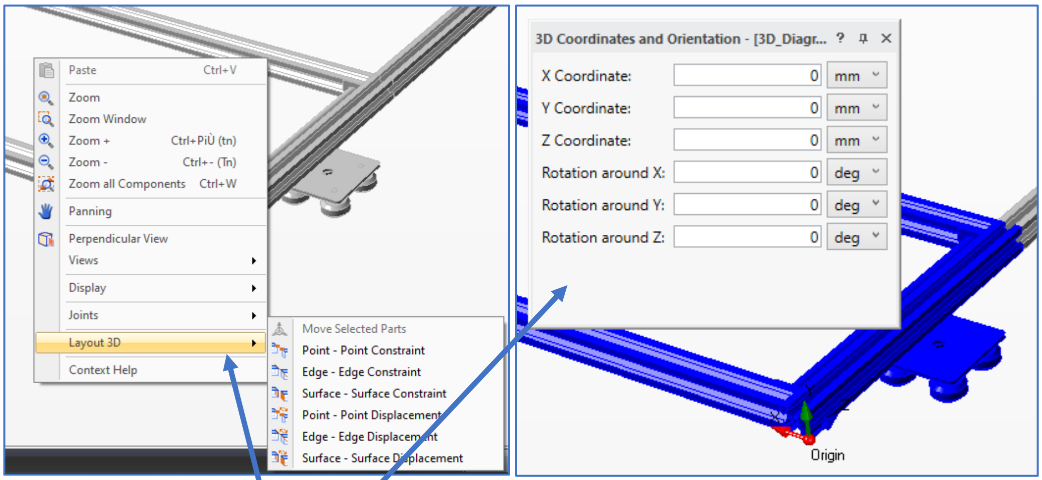
9) To fix the component on the space, right click on the component and tick "Fix"



10) Now, add the **mobile base** into the assembly as the second drawing like on the step 7



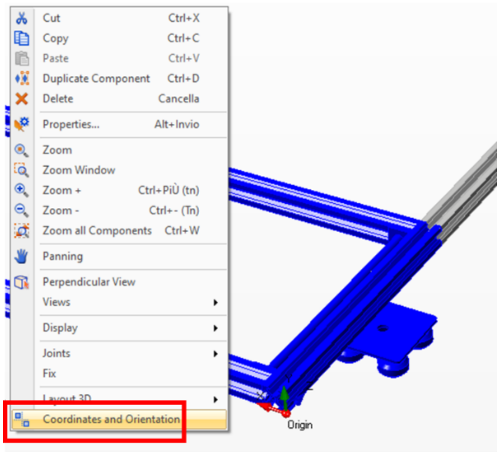
11) This component need to be oriented and positioned properly



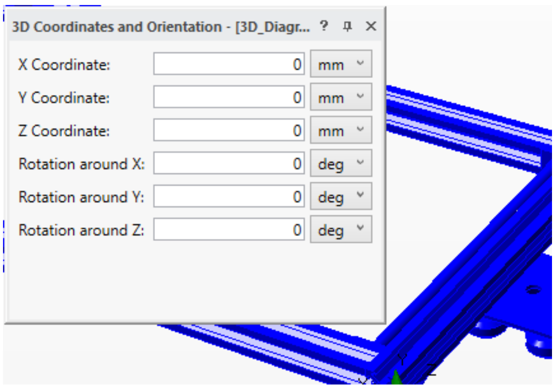
12) two possible procedures can be performed to place correctly the second component:

A) To define coordinates and orientation

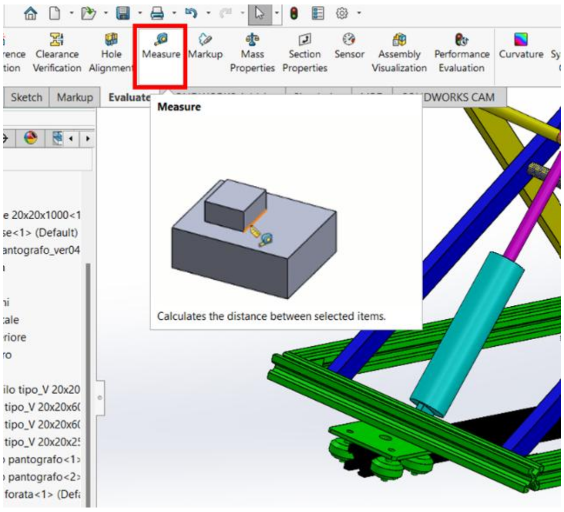
B) To align the 2 components by using constraints



12_A1) In order to change coordinates and orientations of the component, right click on it and select "Coordinates and Orientation"

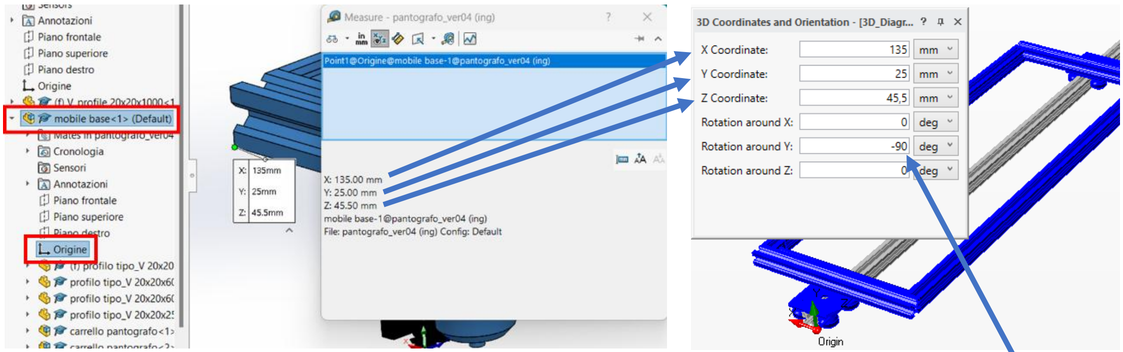


12_A2) Result



12_A3) By using this method it is needed to know the position and the orientation of the component frame with the respect to the assembly fixed frame.

If the assembly has been previously done in Solidworks environment, the command "measure" can be used to find the coordinate of the component frame rapidly

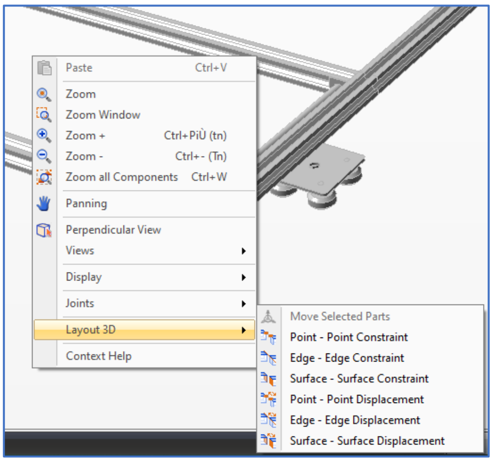


12_A4) Selecting the component origin, it appears its coordinates. Just copy them into the related window of Automation Studio

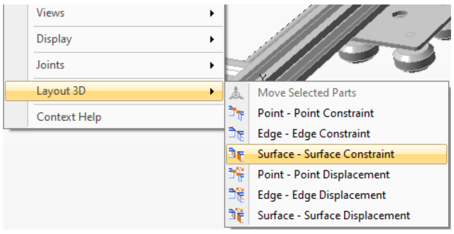
Note: rotations follows the mathematical matrix rotation rules using X,Y,Z angles. In this case it is easy to understand that the rotation needed is the only -90 degree rotation around Y axis

12) two possible procedures can be performed to place correctly the second component:

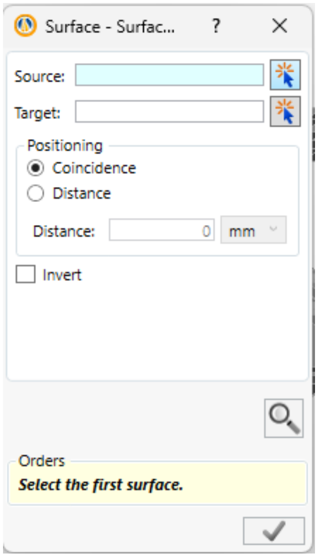
- To define coordinates and orientation
- To align the 2 components by using constraints



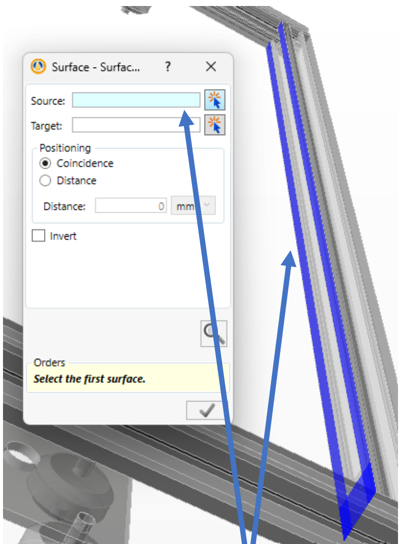
12_B1) In order to place properly the second component using this method, right click on the blank space → Layout 3D.
This allows to move the second component (maintaining the first one steady) by imposing relations between: 2 points, 2 lines or 2 surfaces.
Note: these constraints don't block the component after the alignment, it can be moved again after



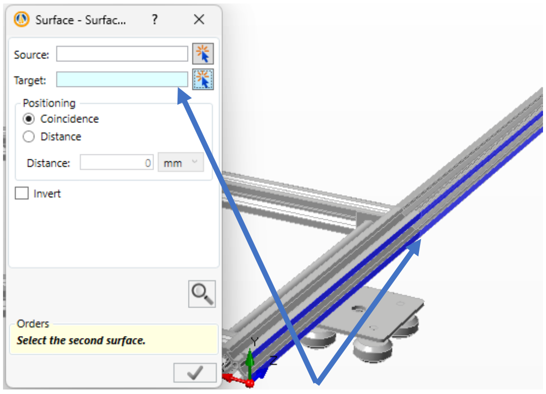
12_B2) Select the Surface-Surface Constraint



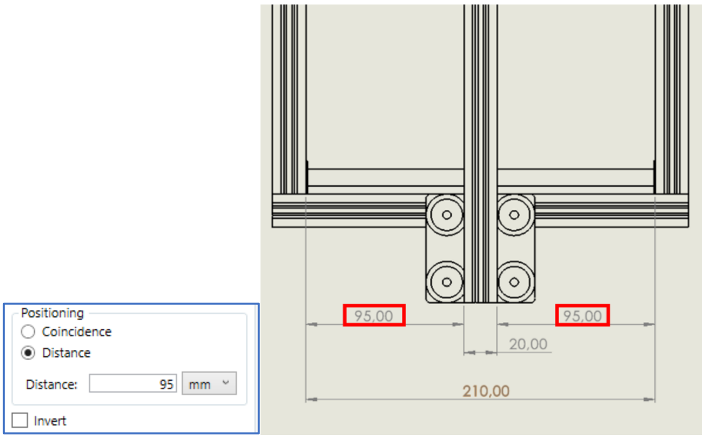
12_B3) Result: in this windows it is requested to select the surface of the movable component as a Source and the surface of the steady component as a Target. Moreover it is requested to define if this 2 surfaces must to be coincident or parallel with a certain distance (that is this case)



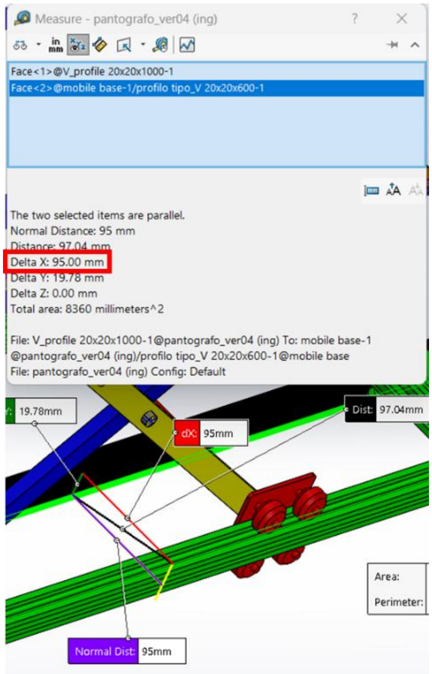
12_B4) Select the internal long surface of the mobile base as Source



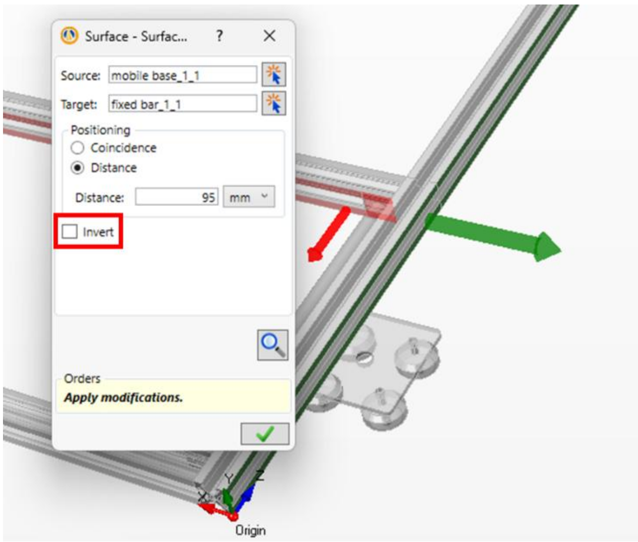
12_B5) Select the surface of the fixed bar as Target



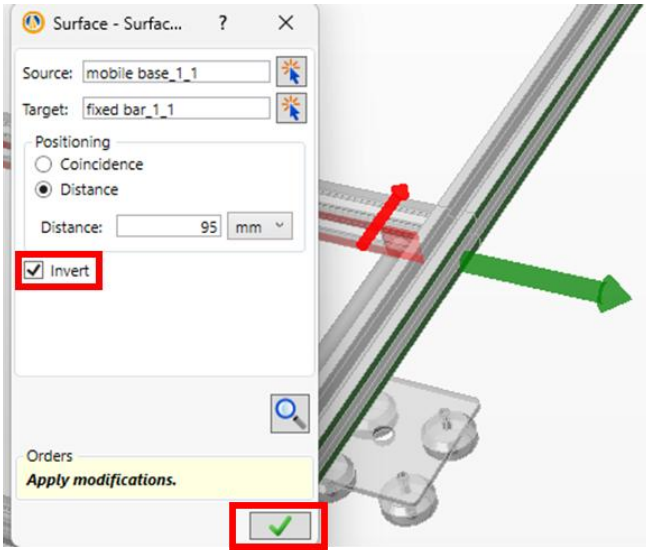
12_B6) Impose a distance of 95 mm found by measuring or on the Solidworks assembly or on the 2d drawing: (210-20)/2 = 95 mm (look at the next slide)



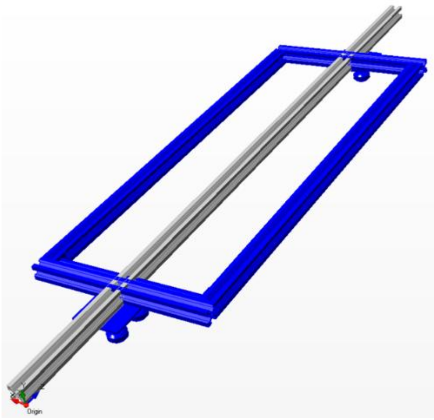
12_B7) Result: the red arrow will be align to the green one in the same direction.
In this case the red arrow must to be inverted in order to obtain the correct orientation



12_B7) Result: the red arrow will be align to the green one in the same direction.
In this case the red arrow must to be inverted in order to obtain the correct orientation

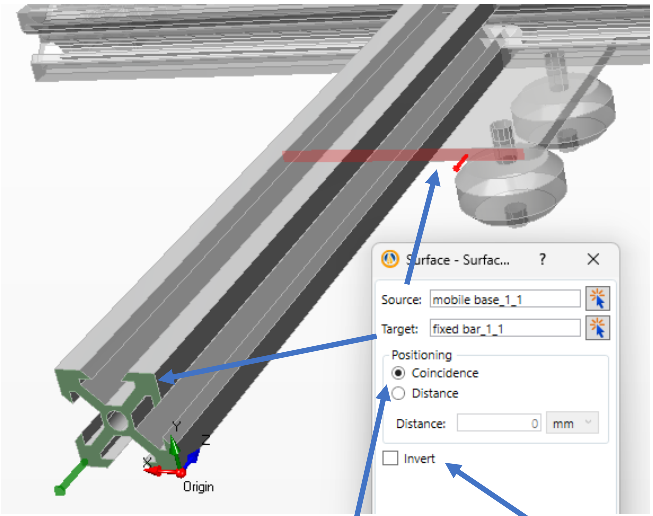


12_B8) Invert and confirm

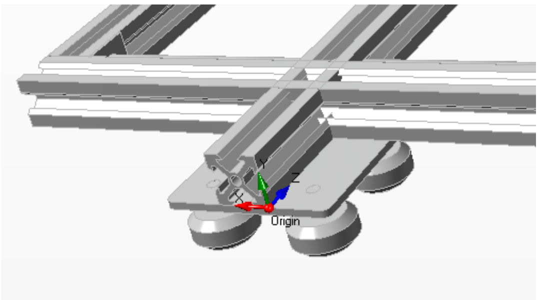


Note: in this tutorial is used principally the method B to place all the other components

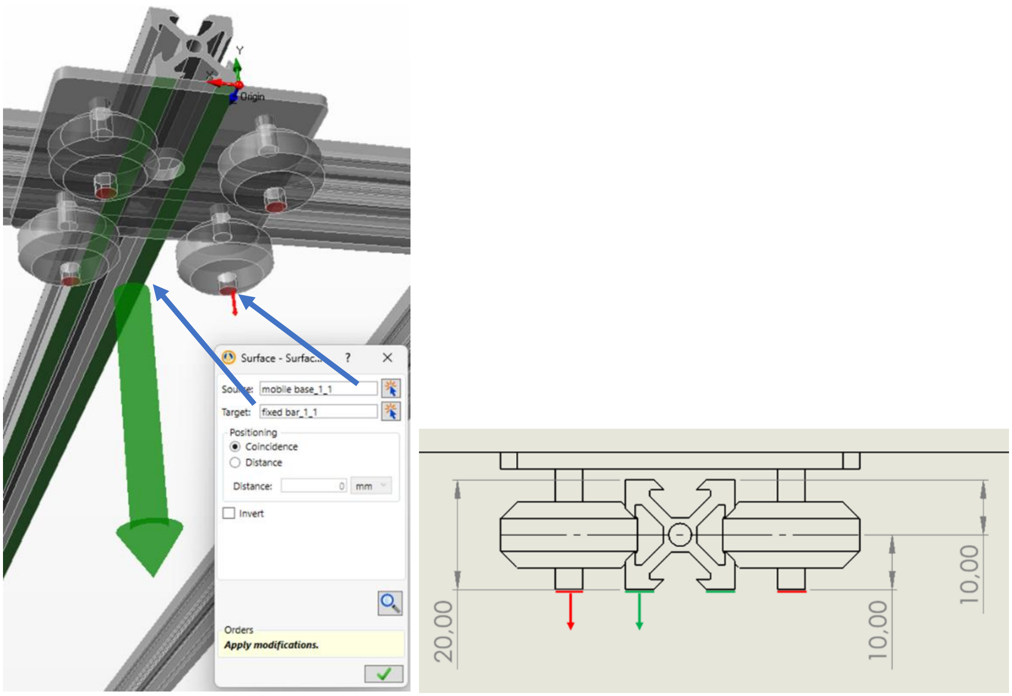
12_B9) Result: the component is now well positioned along the x axis and well oriented. It is missing only the correct z and y positions



13) To assign the correct position along z axis repeat the same operation using Surface-Surface constraints. Select the last surface of the mobile base as Source and the last surface of the fixed bar as Target (both parallel to the XY plane). Positioning must to remain "<u>Coincidence</u>" and the red arrow "<u>Non-inverted</u>"

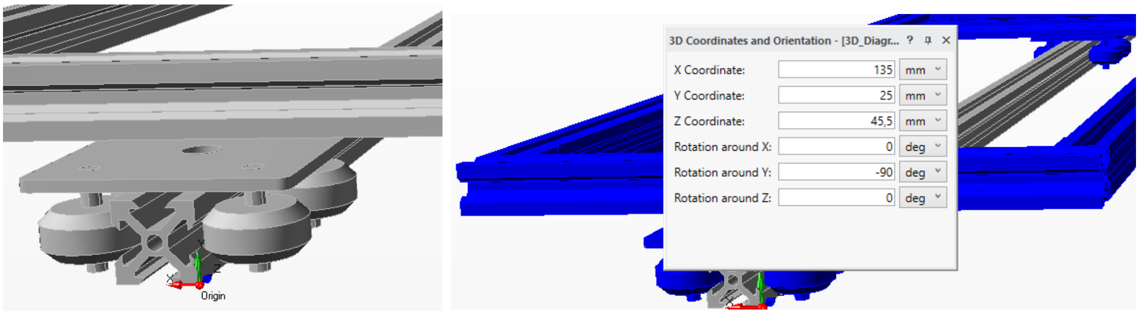


14) Result: now it is missing only the correct y position

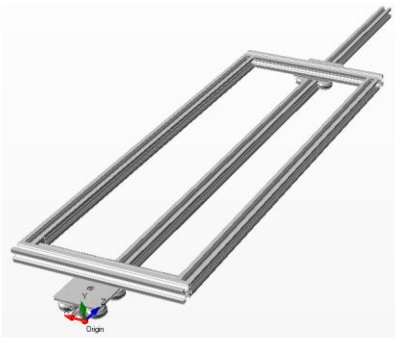


15) To assign the correct position along y axis repeat the same operation using Surface-Surface constraints. Select the bottom surface of the wheel axle of the mobile base as

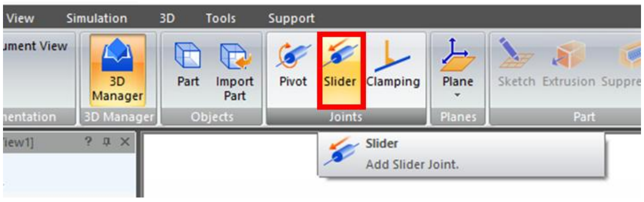
Source and the bottom surface of the fixed bar as Target (both parallel to the XZ plane).
Positioning must to remain “Coincidence” and the red arrow “Non-inverted”



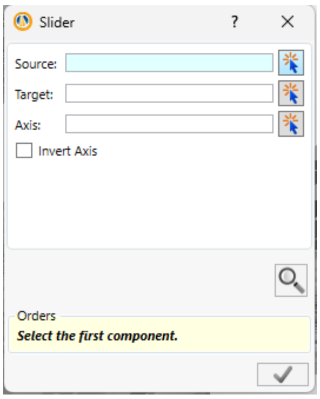
16) Result: the second component is well placed now.
Note: the coordinates of the mobile base now are the same found using the first method (slide



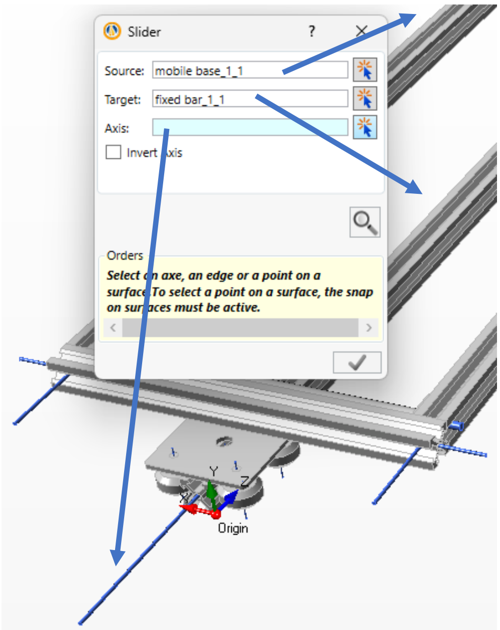
17) The last step for the second component is to impose a sliding movement along the fixed bar



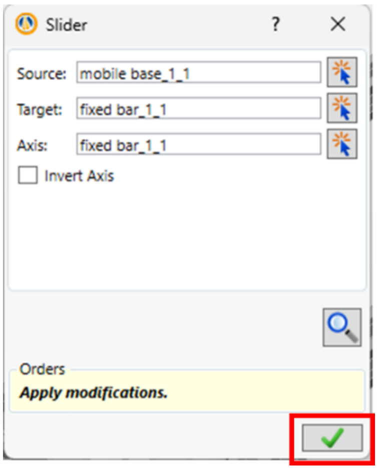
18) Select “Slider”



19) Result: also in this windows it is requested to select the movable component as a Source and the steady component as Target. Then it is requested to select the sliding axis

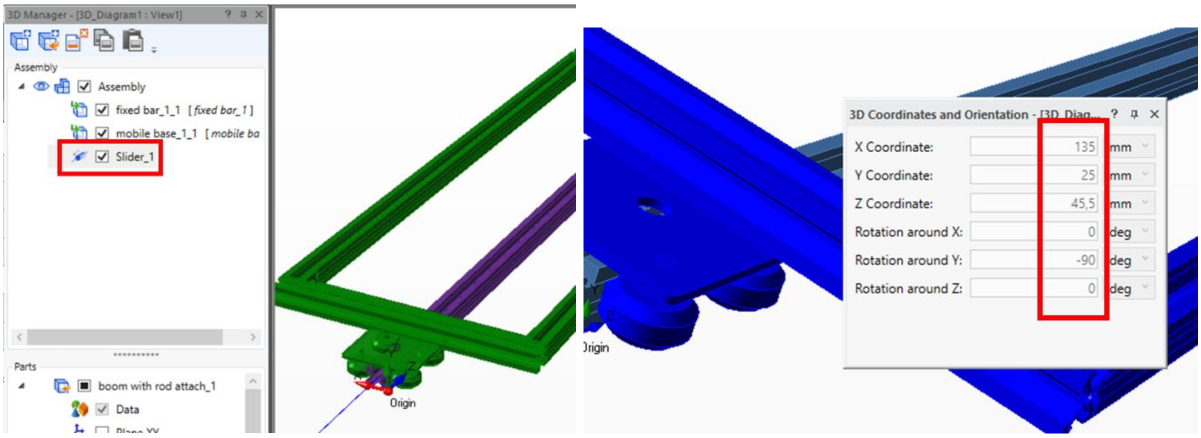


20) Select the mobile base as Source and the fixed bar as Target. Then the possible movement axes appears, so choose the middle one of the fixed bar clicking on it.



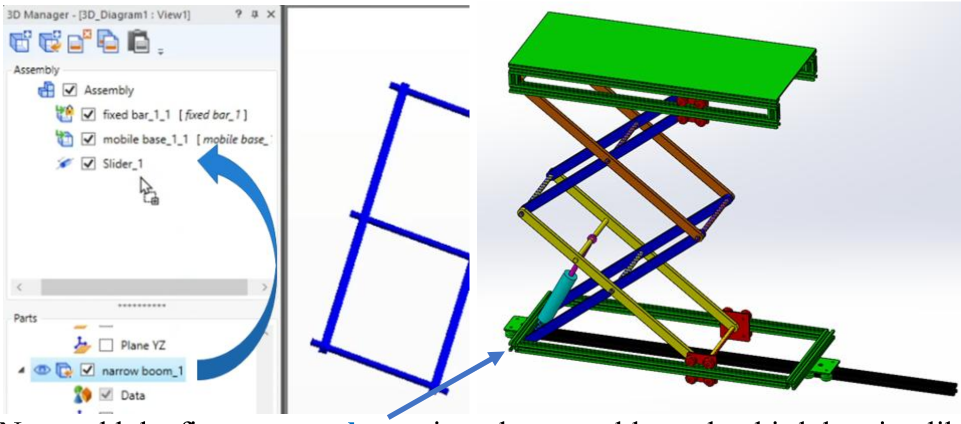
21) Confirm

Note: it is not possible to select the fixed bar as Source because it is fixed on the space (look at step 9), but the Source is what must to move in this sliding

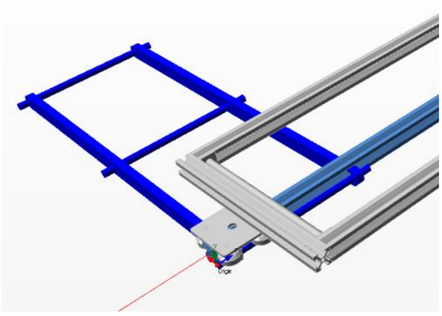


22) Results: the slider appears on the list of the assembly component. By selecting it shows the green Source, the violet Target and the blue axis.

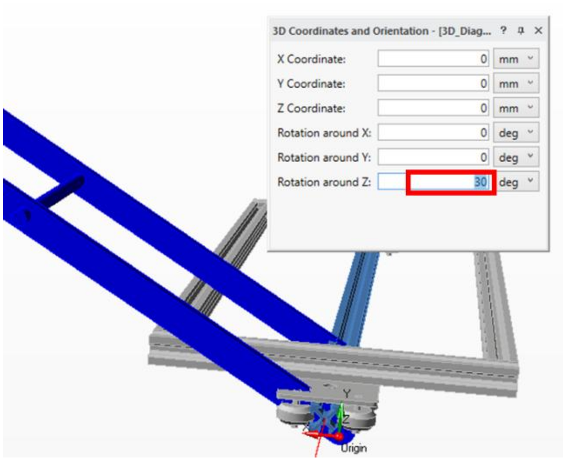
Now it is no longer possible to change position and orientation of the second component. It is only possible to select the second component as Target to place or to joint another third component



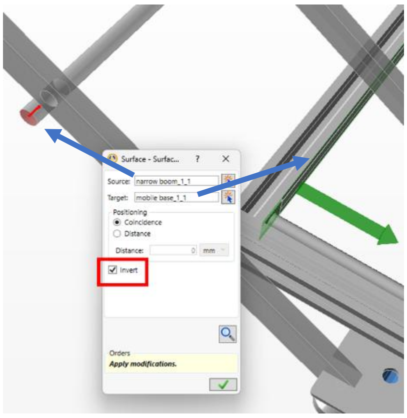
23) Now, add the first **narrow boom** into the assembly as the third drawing like on the step 7



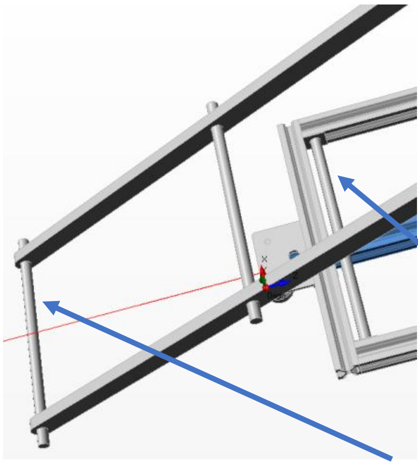
24) Also this component need to be oriented and positioned properly and, in this case, it is convenient to combine the 2 method…



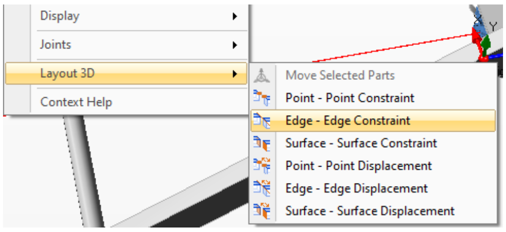
25) Select the narrow boom and assign 30 degree Rotation around Z (method A)



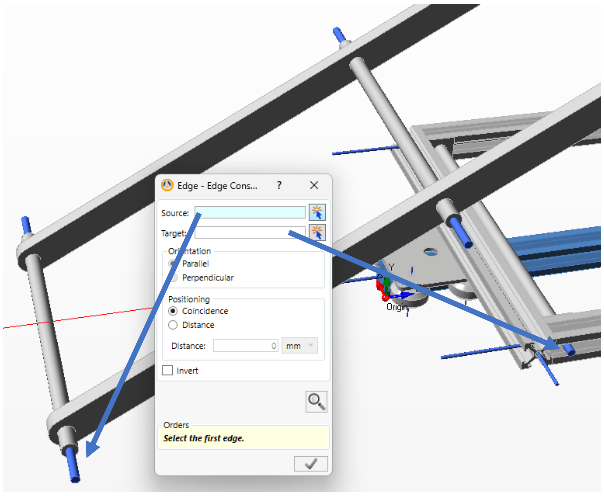
26) Then, (method B) align the flat surface of the pin of the boom with the internal surface of the mobile base (Coincidence). In this case it is needed to invert the red arrow



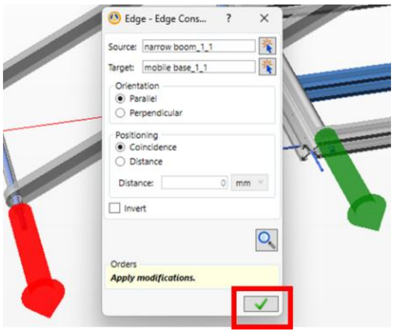
27) Result: now it is needed to align the bottom pin of the boom to the pin of the mobile base



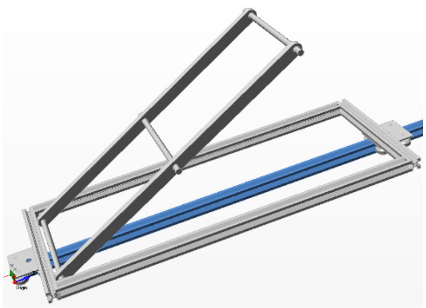
28) In this case in is convenient to align the 2 axis (of the 2 pins) using Edge-Edge Constraints.



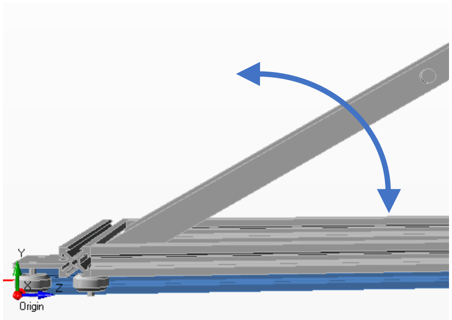
29) Result: all possible axes became visible and, as same, it is requested to select the axis of the movable component (Source) and the axis of the steady component (Target).



30) Select the axis of the bottom pin of the boom as Source and the axis of the pin of the mobile base as Target. Then maintain the orientation as Parallel and the Positioning as Coincidence and confirm.

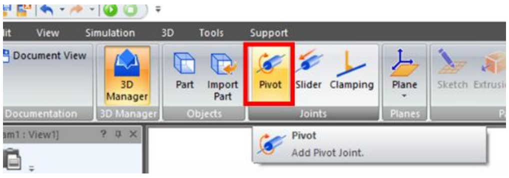


31) Result: the narrow boom is well placed now and the 2 pins are superimposed

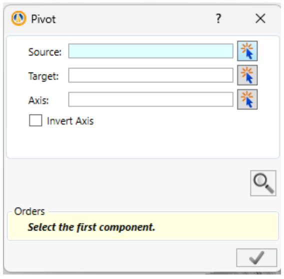


32) The last step for this component is to impose a pivot movement around the pin of the mobile base.

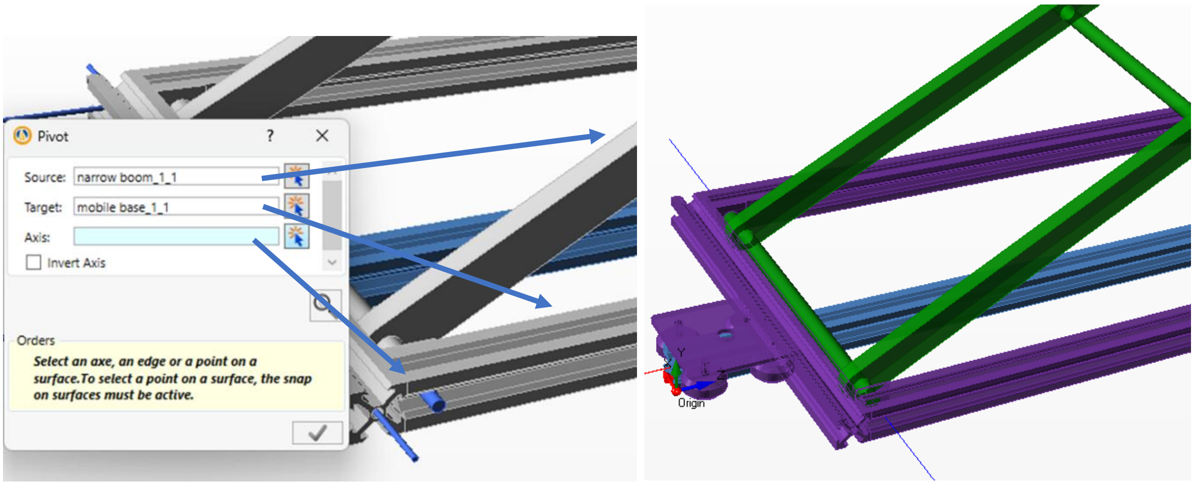
Note: the superimposition of the 2 pins allows to check, during the simulation, if the joint is done correctly



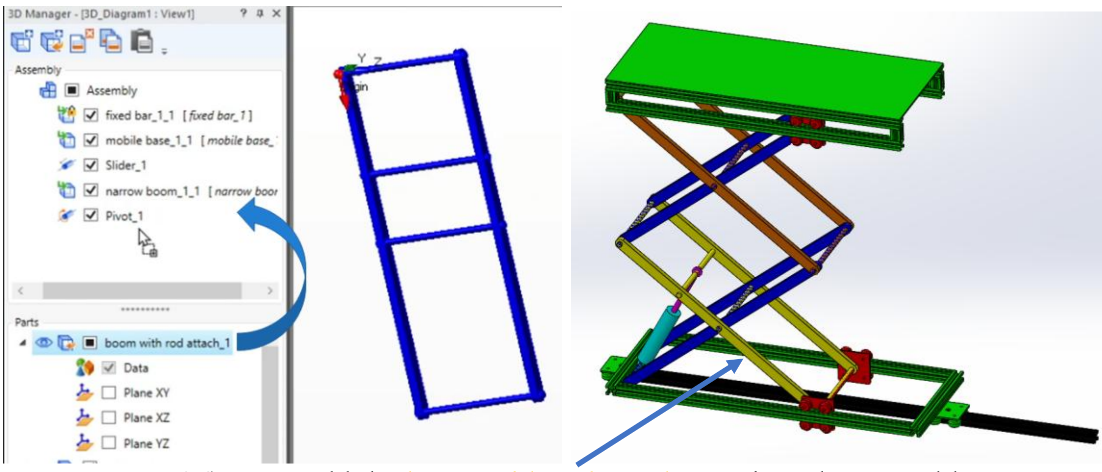
33) Click on Pivot



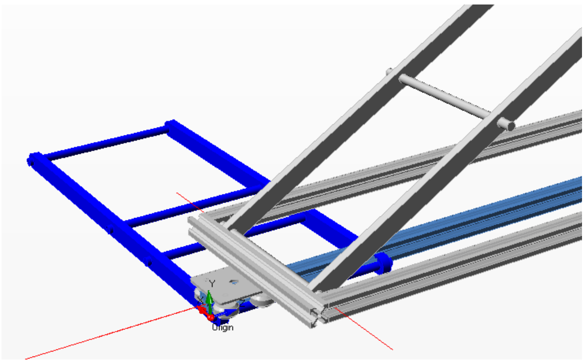
34) As before Source and Target are the same of the slider (step 19). Then it is requested to select the pivot axis



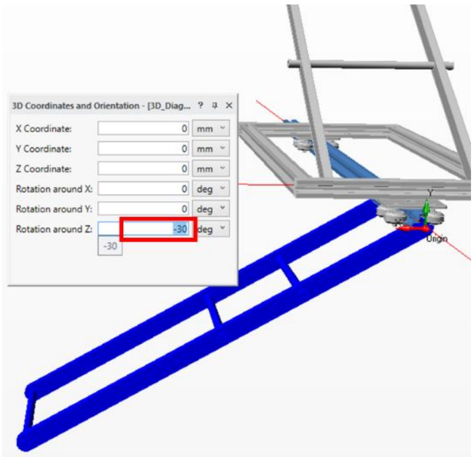
35) Select the narrow boom as Source, the mobile base as Target and the pin axis as Axis. Then confirm



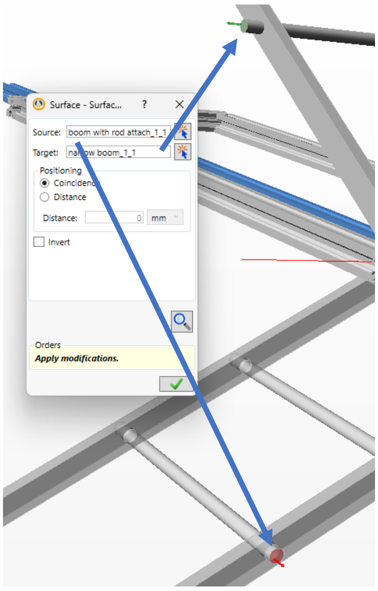
36) Now, add the boom with rod attachment into the assembly



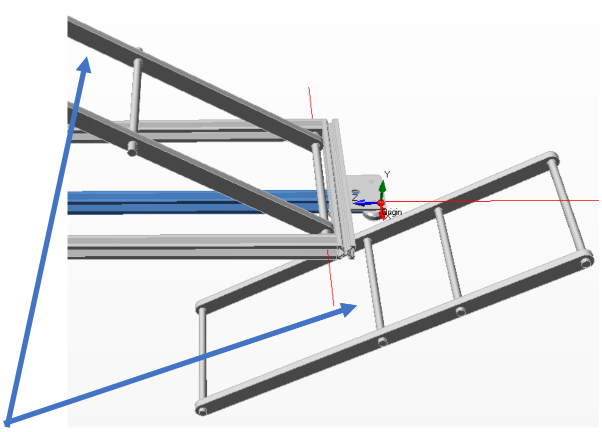
37) Also this component need to be oriented and positioned properly and, in this case, it is convenient to combine the 2 method…



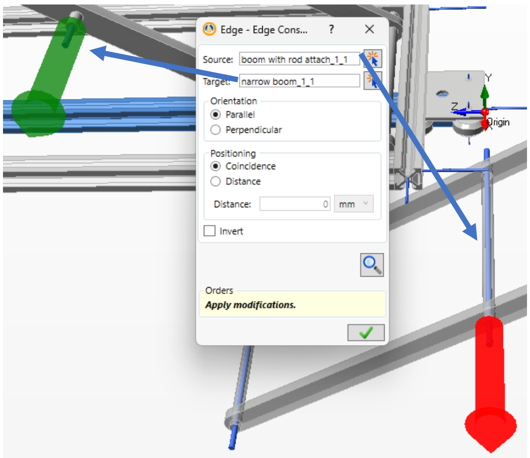
38) Select the boom with rod attachment and assign -30 degree Rotation around Z



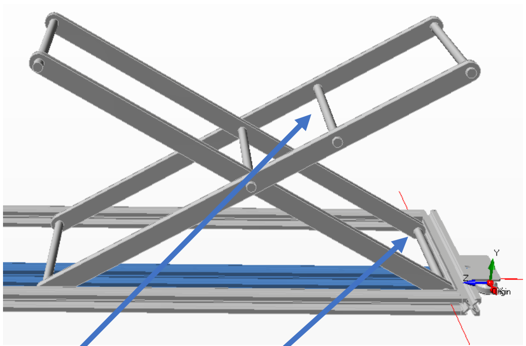
39) Then, align the flat surface of the pin of the boom with rod attachment to the flat surface of the pin of the narrow boom (Coincidence). In this case it is not needed to invert the red arrow



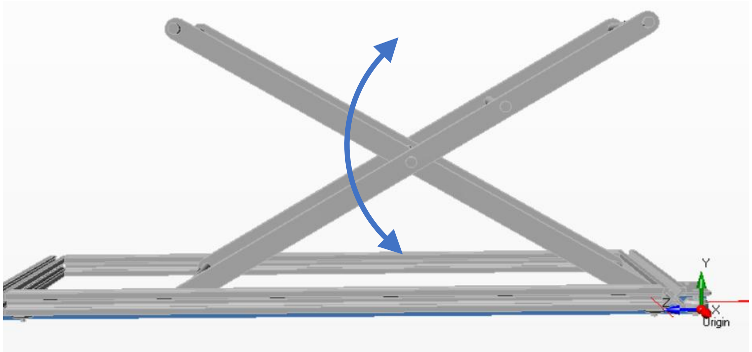
40) Result: now it is needed to align the middle pin of the boom with rod attachment to the middle pin of the narrow boom



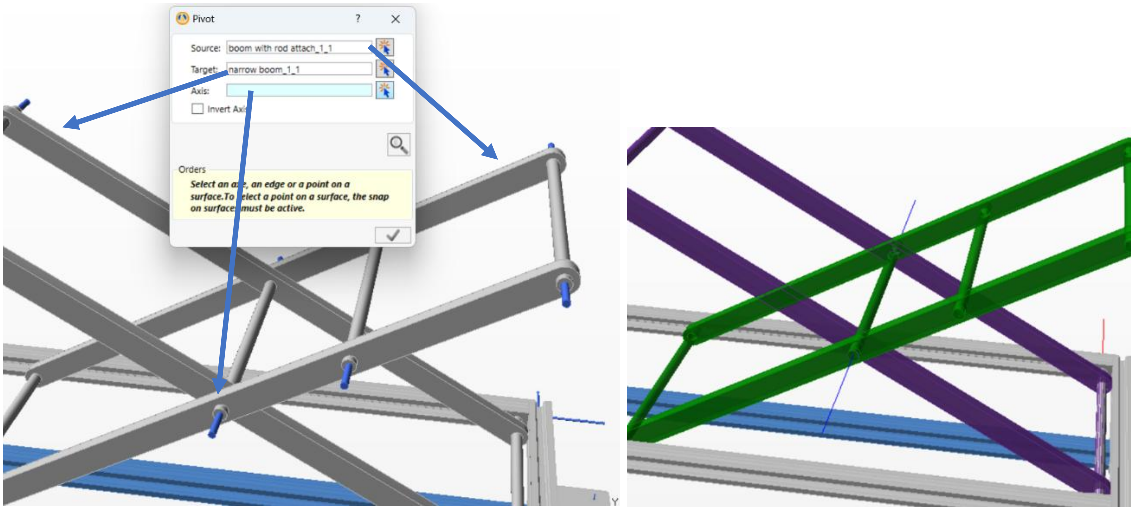
41) By using Edge-Edge Constraints, select the axis of the boom with rod attachment as Source, the axis of the narrow boom as Target and maintain the orientation as Parallel, the position as <u>Coincidence</u> and the red arrow <u>non inverted</u>. Confirm



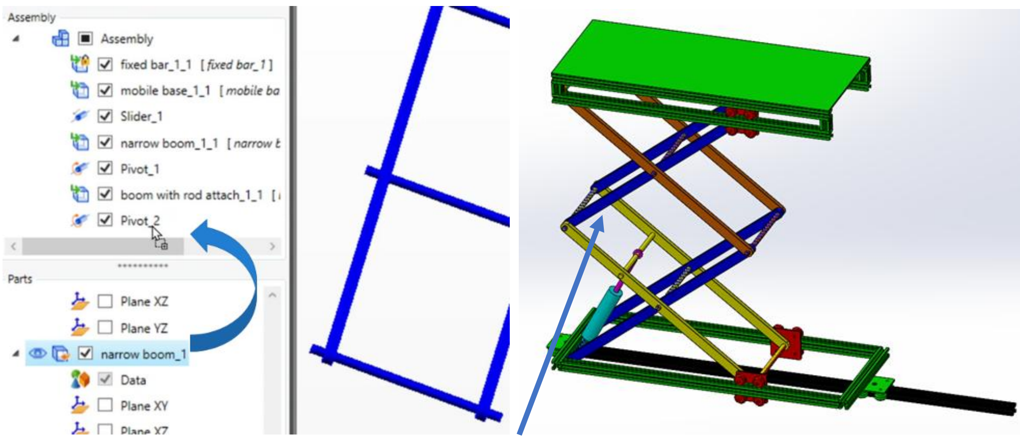
42) Result: the boom with rod attachment is now well placed
Note: the pins used for rod attachment and cylinder attachment must result in the same side if all is done correctly



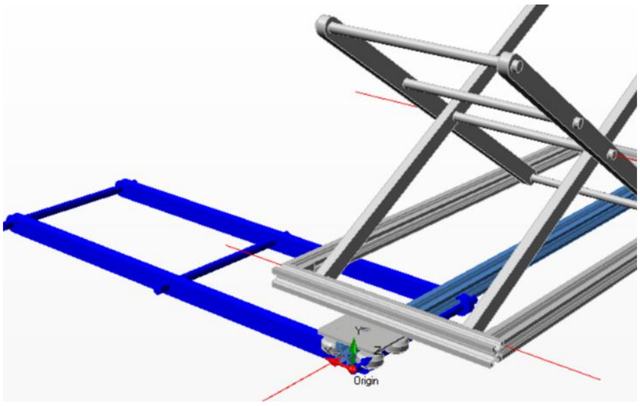
43) The last step for this component is to impose a <u>pivot</u> movement around the pin of the narrow boom



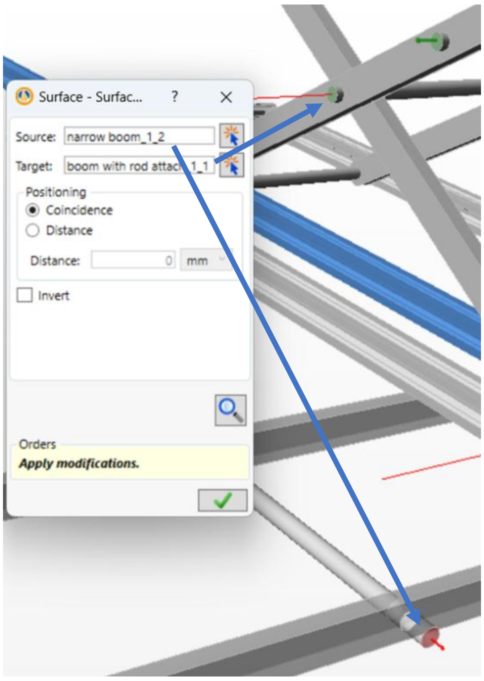
44) Select the boom with rod attachment as Source, the narrow boom as Target and the pin axis as Axis. Then confirm



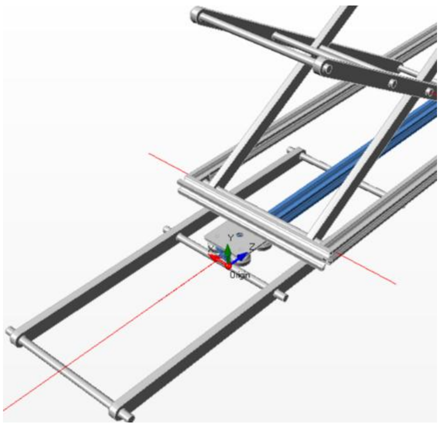
45) Now, add the second narrow boom into the assembly as on the step 23



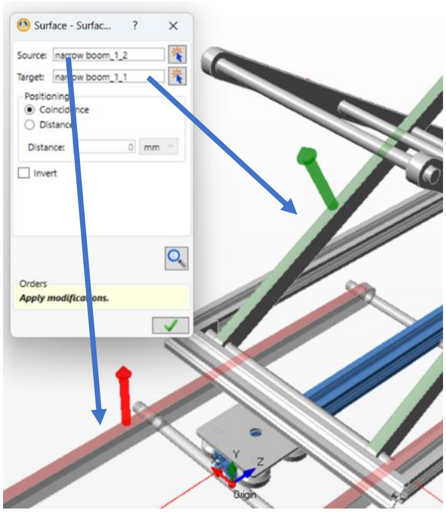
46) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method (using the parallel conditions to impose the same slope of the previous components)



47) Align the flat surface of the pin of the narrow boom to the flat surface of the pin of boom with rod attachment (<u>Coincidence</u>). In this case it is <u>not</u> needed to invert the red arrow. Confirm

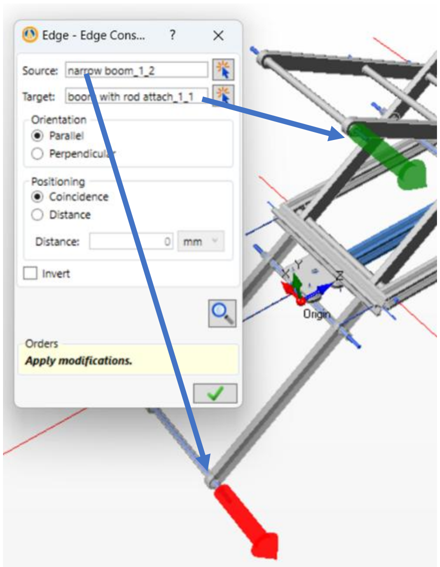


48) Result



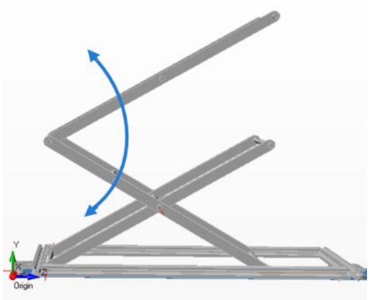
49) Then, align the flat horizontal surface of the second narrow boom to the sloped surface of the first narrow boom (Coincidence). In this case it is not needed to invert the red arrow. Confirm

50) Result

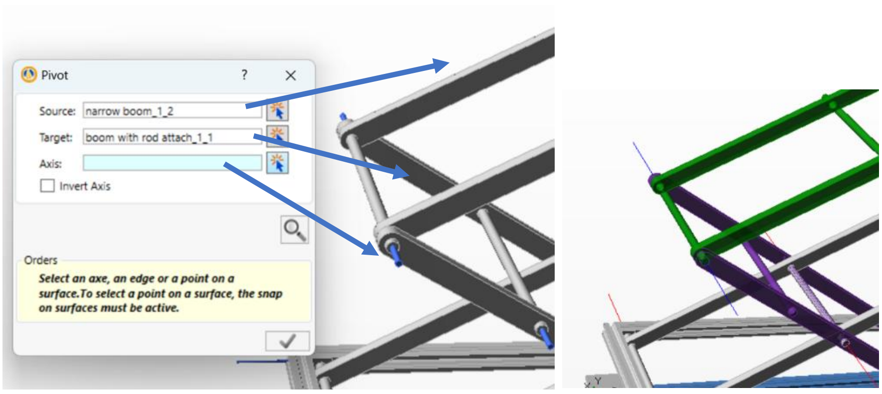


51) Then, align the axis of the bottom pin of the second narrow boom with the axis of the top pin of the boom with rod attachment

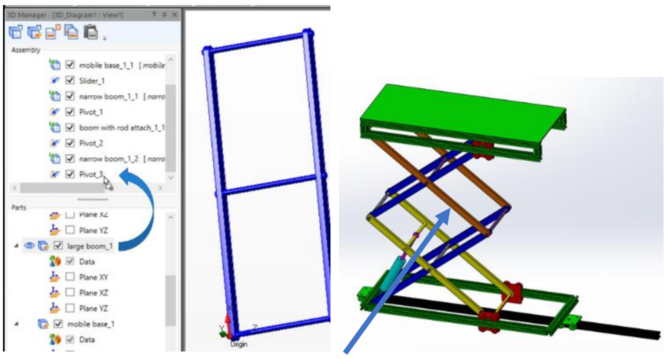
52) Result. The second narrow boom is now well placed



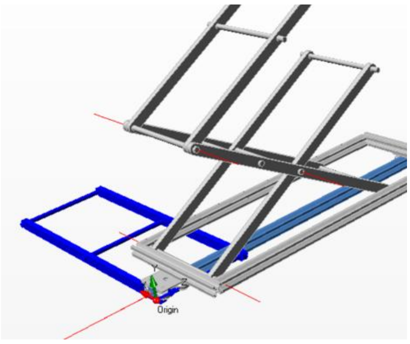
53) The last step for this component is to impose a pivot movement around the top pin of the boom with rod attachment



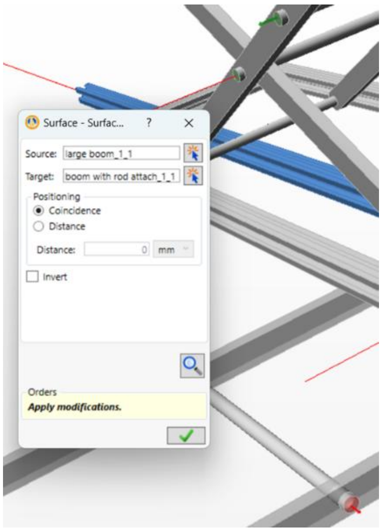
54) Select the second narrow boom as **Source**, the boom with rod attachment as **Target** and the pin axis as **Axis**. Then confirm



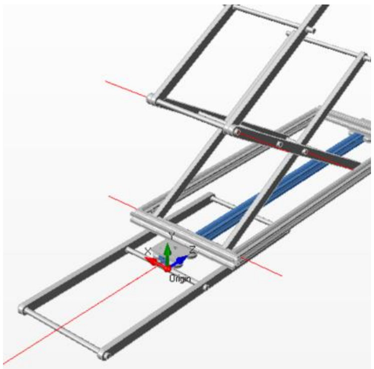
55) Now, add the large boom into the assembly



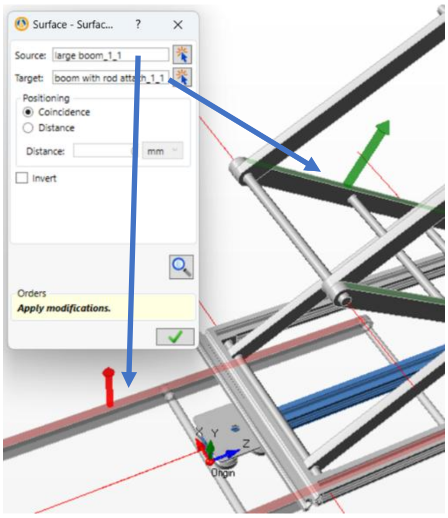
56) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method (using the parallel conditions to impose the same slope of the previous components)



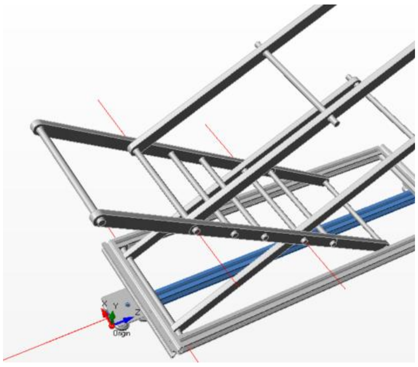
57) Align the flat surface of the pin of the large boom to the flat surface of the pin of the boom with rod attachment (Coincidence). In this case it is not needed to invert the red arrow. Confirm



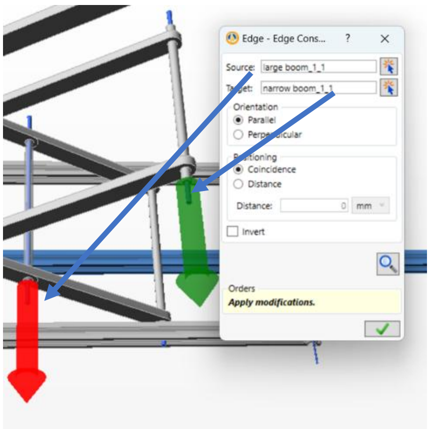
58) Result



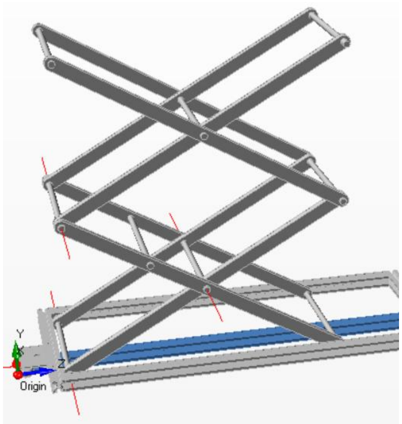
59) Then, align the flat horizontal surface of the large boom to the sloped surface of the boom with rod attachment (Coincidence). In this case it is not needed to invert the red arrow. Confirm



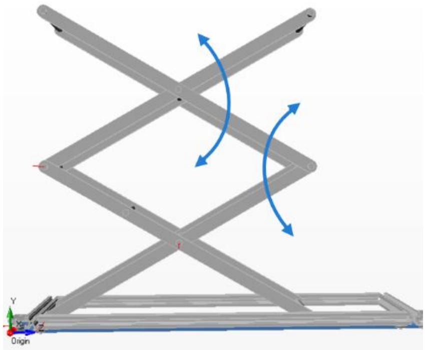
60) Result



61) Then, align the axis of the bottom pin of the large boom with the axis of the top pin of the first narrow boom

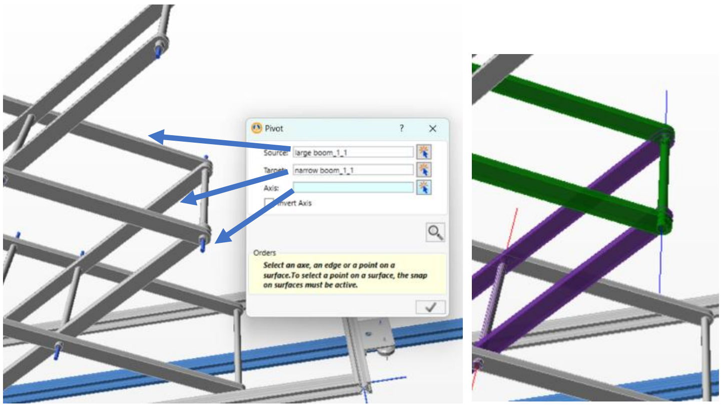


62) Result. The large boom is now well placed

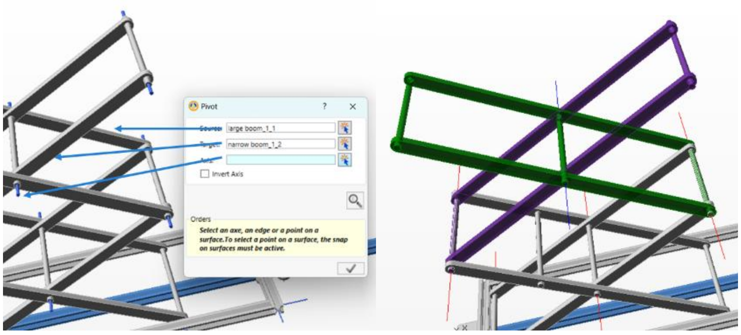


63) The last steps for this component are:

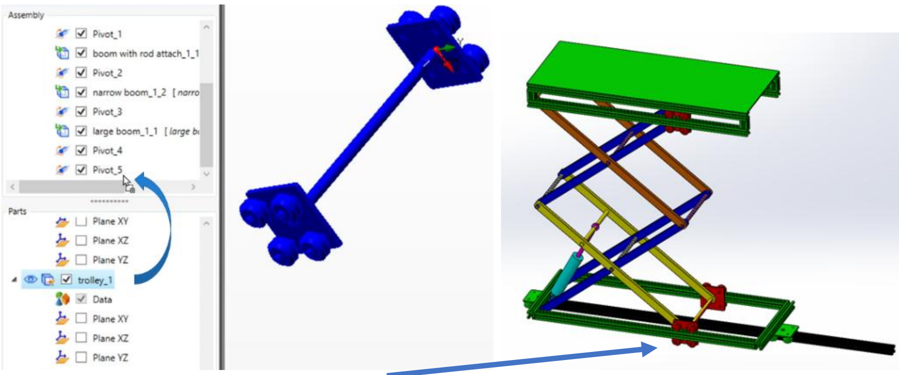
- to impose a <u>pivot</u> movement around the top pin of the first narrow boom
- to impose a <u>pivot</u> movement around the middle pin of the second narrow boom



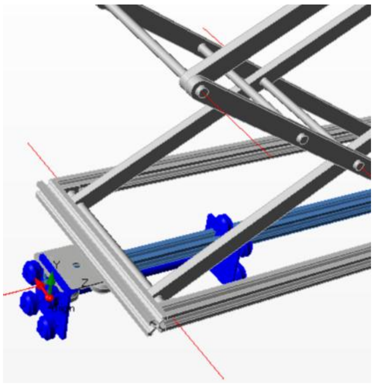
64) Select the large boom as **Source**, the first narrow boom as **Target** and the pin axis as **Axis**. Then confirm



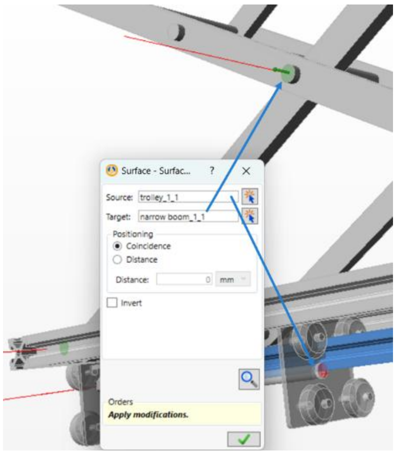
65) Select the large boom as **Source**, the second narrow boom as **Target** and the pin axis as **Axis**. Then confirm



66) Now, add the first **trolley** into the assembly. It will be the lower one

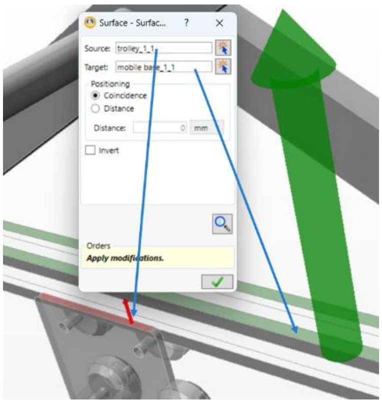


67) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method

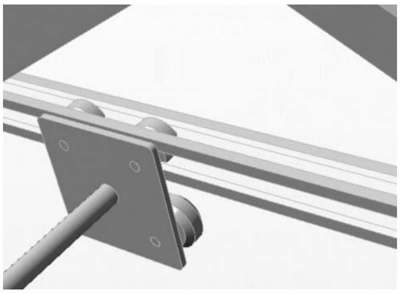


68) Align the flat surface of the pin of the trolley to the flat surface of the pin of the first narrow boom (Coincidence). In this case it is <u>not</u> needed to invert the red arrow. Confirm

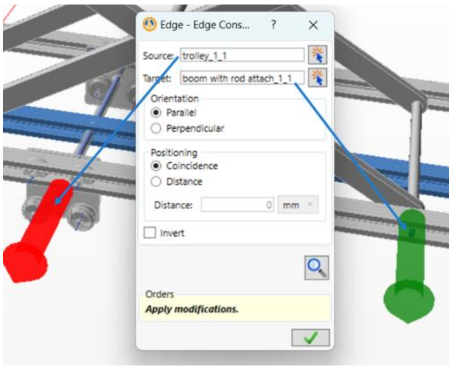
69) Result



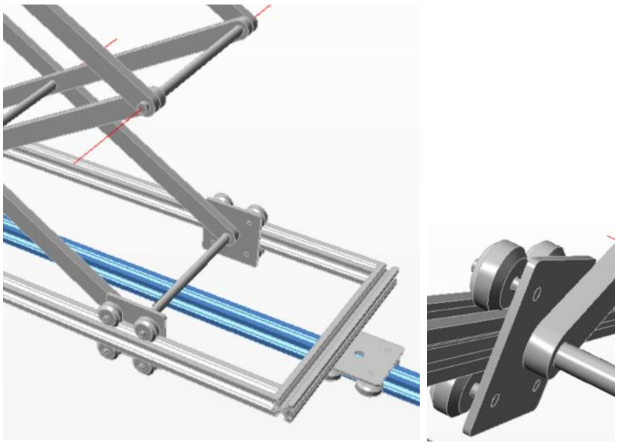
70) Align one of the flat horizontal surface of the trolley to the flat horizontal surface of the mobile base (or the fixed bar eventually). This is not done to place the trolley, but to be sure that wheels are well oriented along the horizontal direction.



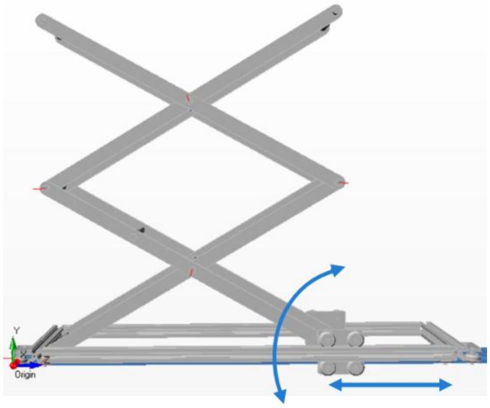
71) Result



72) Align the axis of the trolley to the bottom pin of the boom with rod attachment

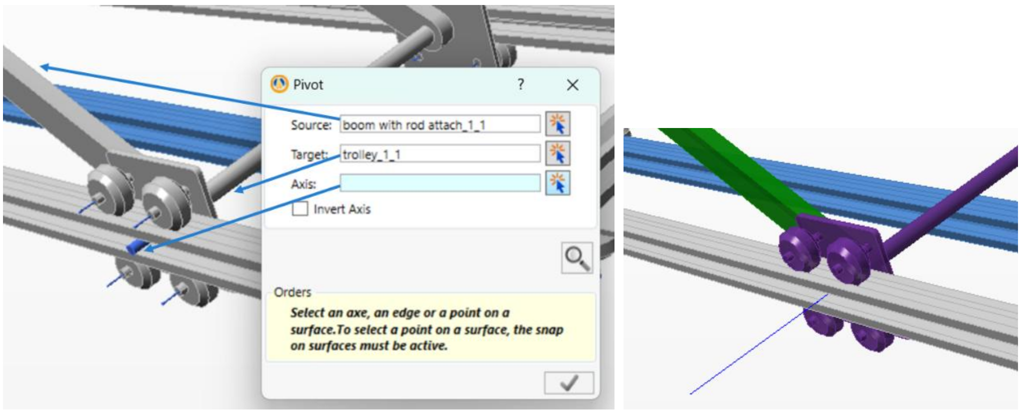


73) Result

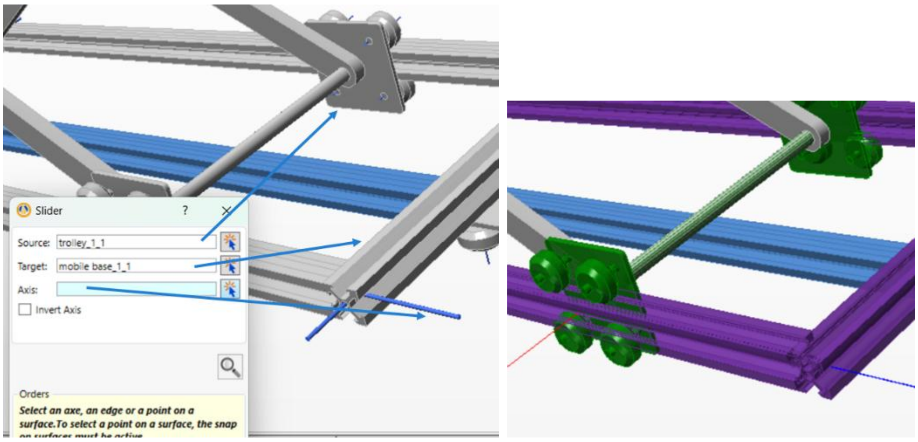


74) The last steps for this component are:

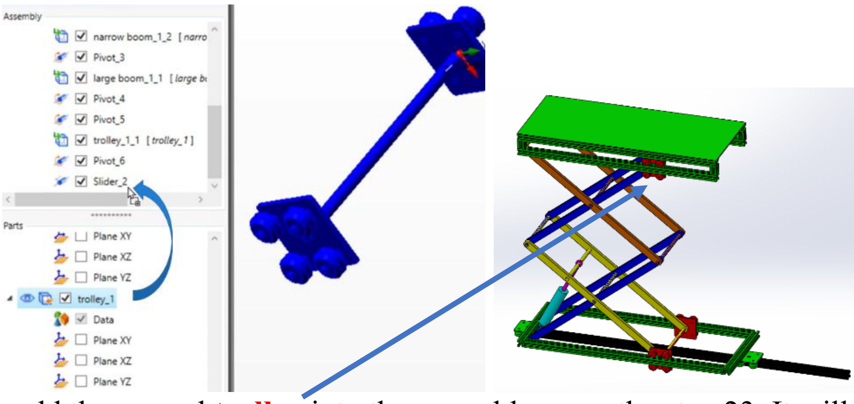
- to impose a <u>pivot</u> movement around the bottom pin of the boom with rod attachment
- to impose a <u>sliding</u> movement along the mobile base



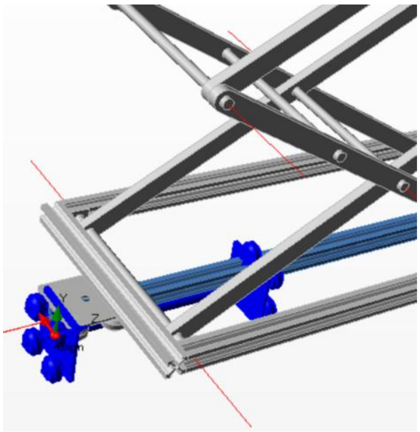
75) <u>Pivot</u>: Select the boom with rod attachment as **Source**, the trolley as **Target** and the pin axis as **Axis**. Then confirm



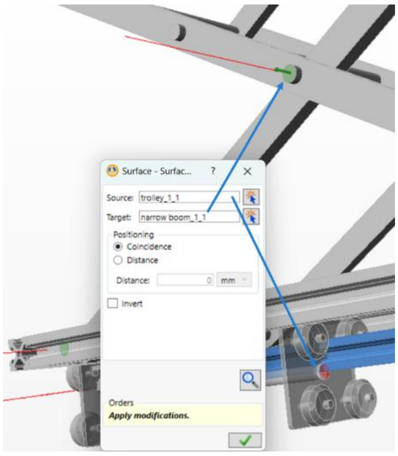
76) <u>Sliding</u>: Select the trolley as **Source**, the mobile base as **Target** and one of the axis of the mobile base along the Z direction as **Axis**. Then confirm



77) Now, add the second **trolley** into the assembly as on the step 23. It will be the upper one

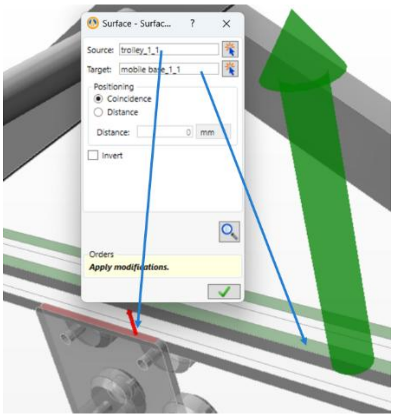


78) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method

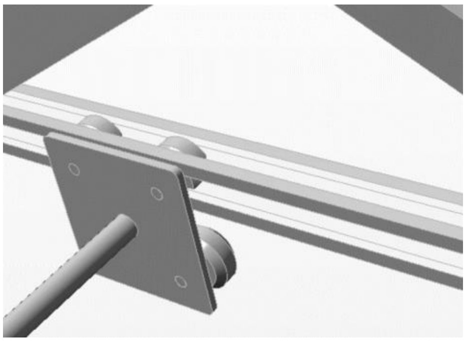


79) (Same as before) Align the flat surface of the pin of the trolley to the flat surface of the pin of the first narrow boom (Coincidence). In this case it is not needed to invert the red arrow. Confirm

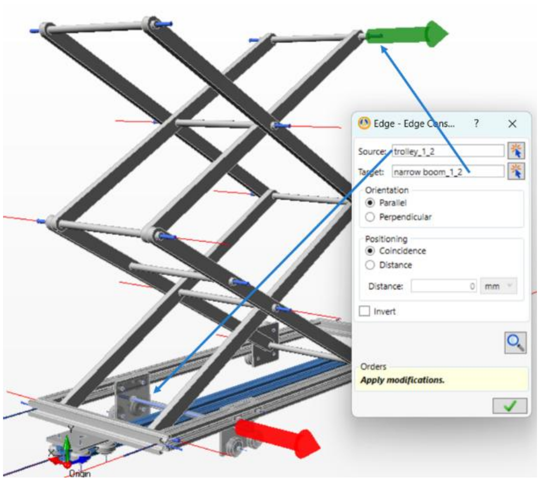
80) Result



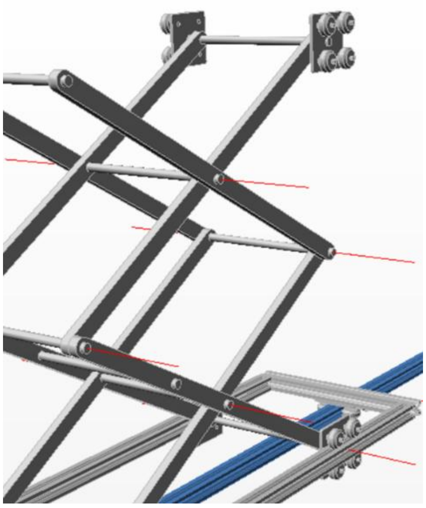
81) (Same as before) Align one of the flat horizontal surface of the trolley to the flat horizontal surface of the mobile base (or the fixed bar eventually). This is not done to place the trolley, but to be sure that wheels are well oriented along the horizontal direction.



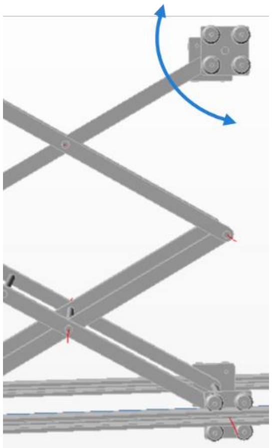
82) Result



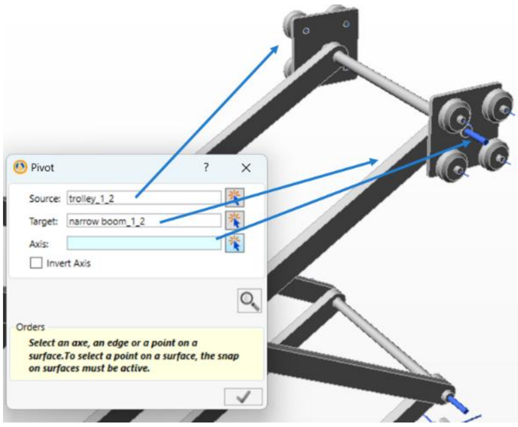
83) Align the axis of the trolley to the top pin of the second narrow boom



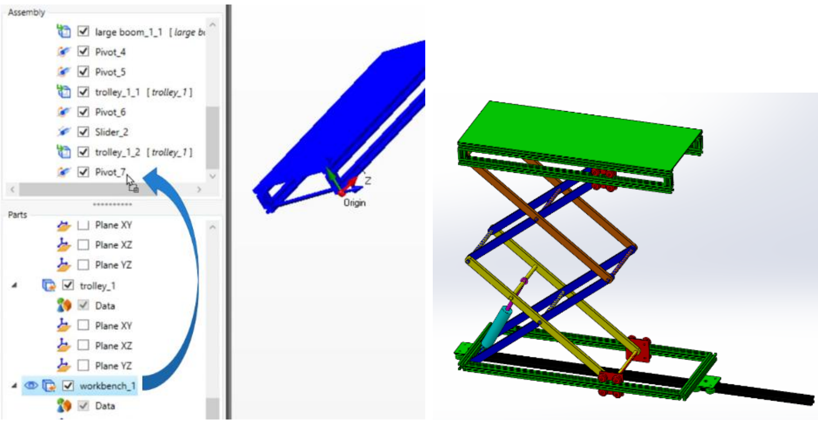
84) Result



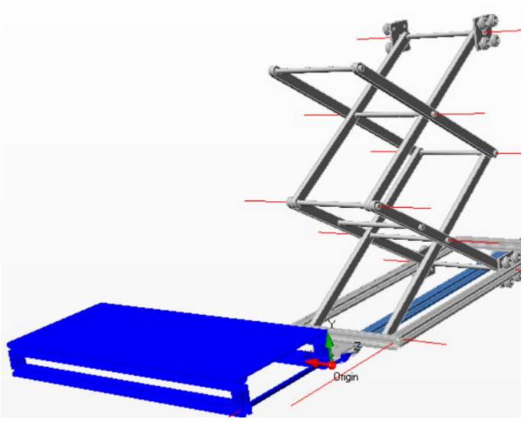
85) The last step for this component is to impose a pivot movement around the top pin of the second narrow boom



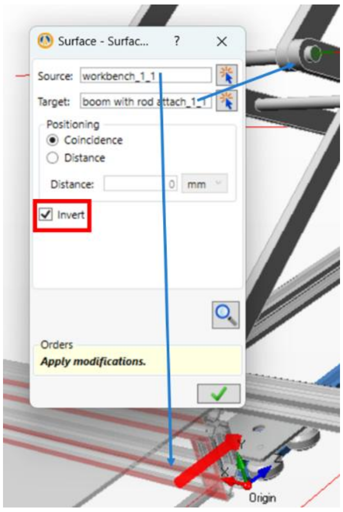
86) Select the trolley as **Source**, the second narrow boom as **Target** and the pin axis as **Axis**. Then confirm



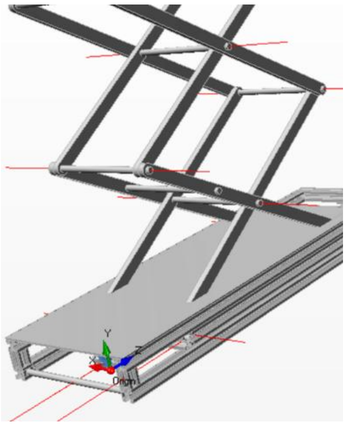
87) Now, add the workbench into the assembly as the assembly



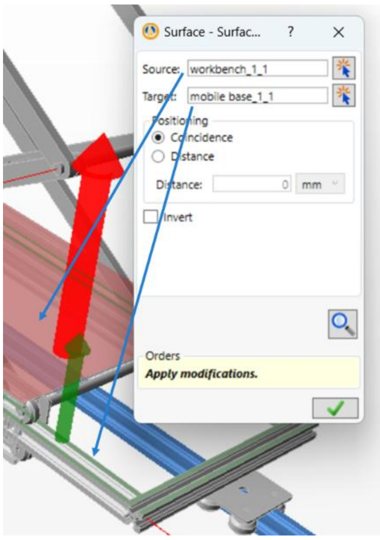
88) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method



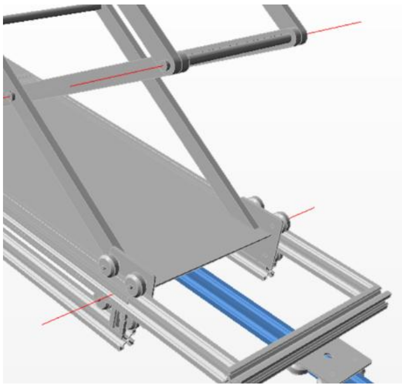
89) Align the flat internal surface of the workbench to the flat surface of the bottom pin of the boom with rod attachment (Coincidence). In this case it is needed to invert the red arrow. Confirm



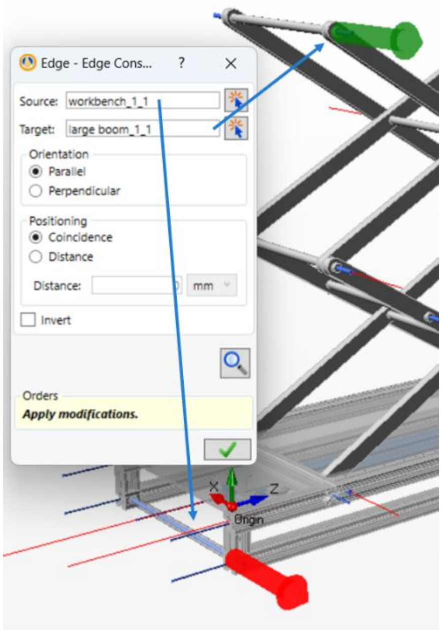
90) Result



91) Align one of the flat horizontal surface of the workbench to the flat horizontal surface of the mobile base (or the fixed bar eventually). This is not done to place the trolley, but to be sure that the workbench is horizontal.

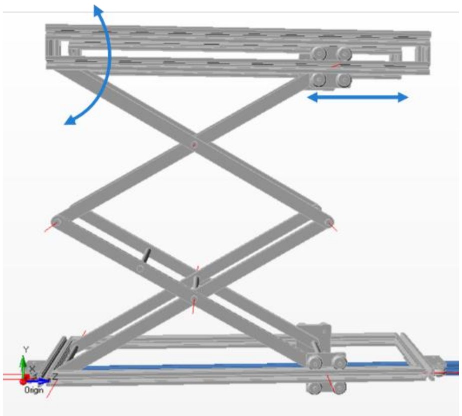


92) Result



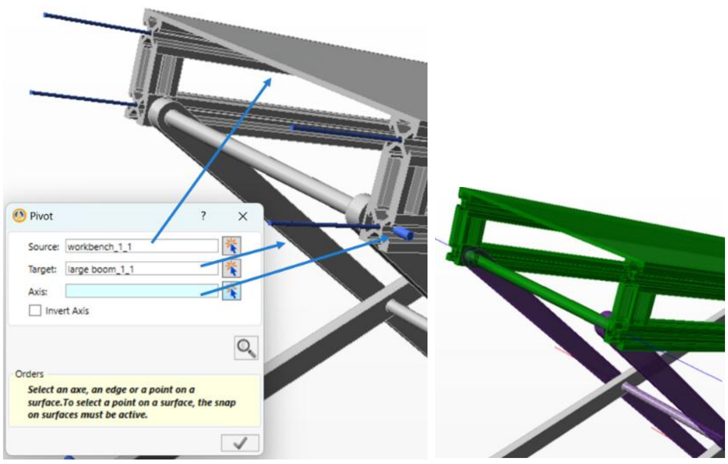
93) Align the axis of the pin of the workbench to the top pin of the large boom

94) Result

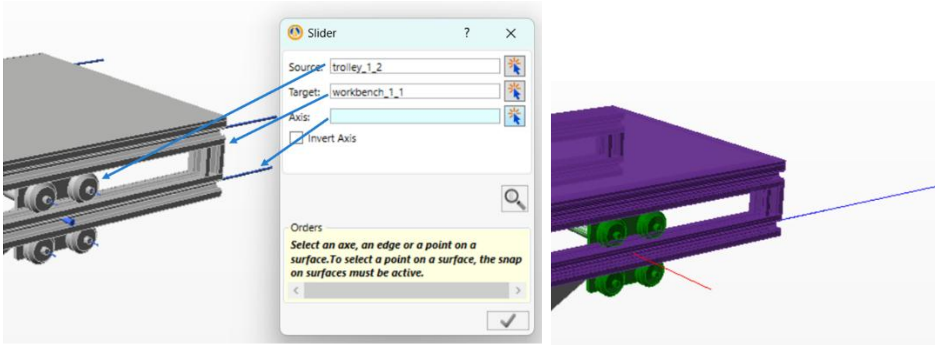


95) The last steps for this component are:

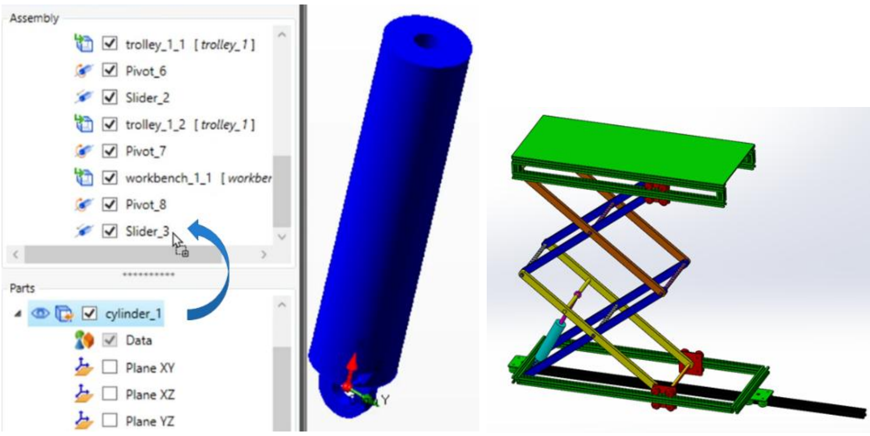
- to impose a pivot movement around the bottom pin of the second narrow boom
- to impose a sliding movement for the upper trolley along the workbench bar



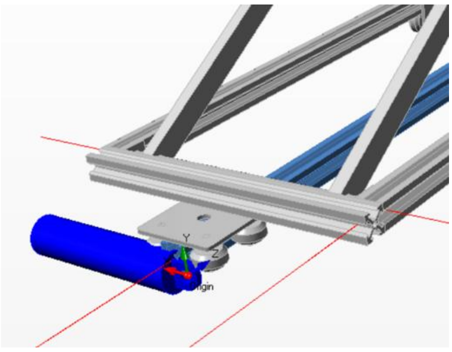
96) Pivot: Select the workbench as **Source**, the large boom as **Target** and the pin axis as **Axis**. Then confirm



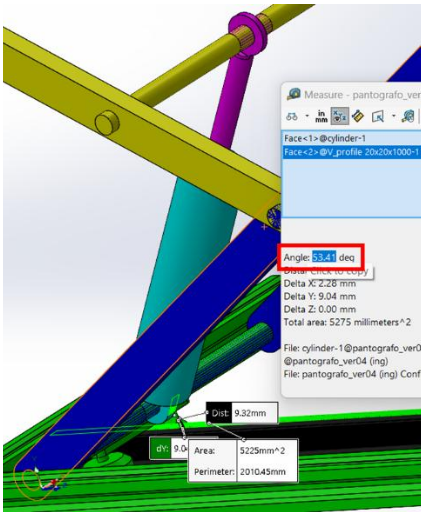
97) Sliding: Select the trolley as **Source**, the workbench as **Target** and one of the axis of the workbench along the Z direction as **Axis**. Then confirm



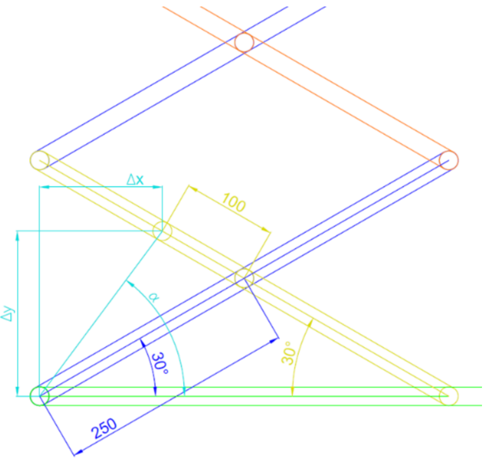
98) Now, add the cylinder into the assembly as on the step 23



99) Also this component need to be oriented and positioned properly and, in this case, it is convenient to combine the 2 method…

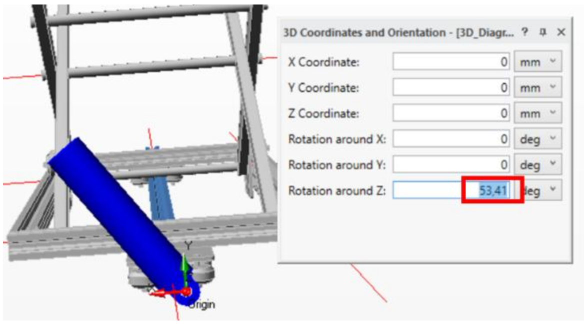


$$\alpha = \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right) = \tan^{-1}\left(\frac{250*\sin(30)+100*\sin(30)}{250*\cos(30)-100*\cos(30)}\right)$$

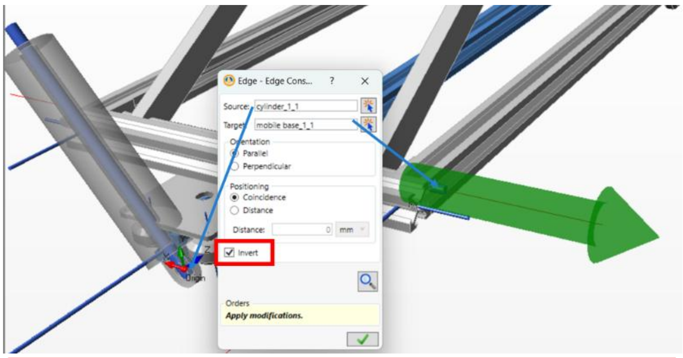


100) In order to find the slope of the cylinder it is possible to:

- Measure it on the Solidworks environment
- Evaluate it thanks to geometrical consideration



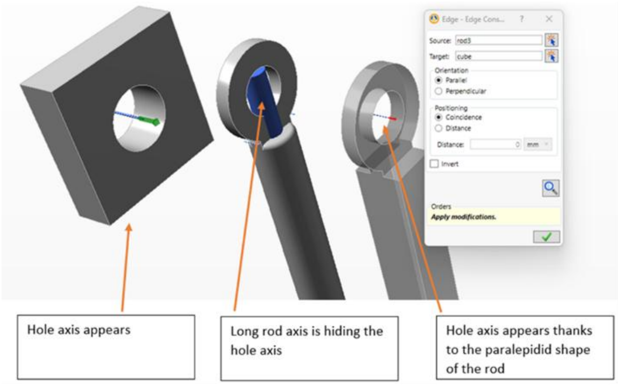
101) Select the cylinder and assign 53,41 degree Rotation around Z



Note: look at the next slide to find the hidden hole axis

102) Then, align the axis of the hole of the cylinder attachment to the axis of the pin of the mobile base. In this case it is needed to invert the red arrow

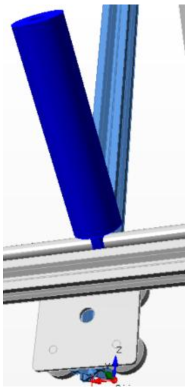
HIDDEN HOLE AXIS



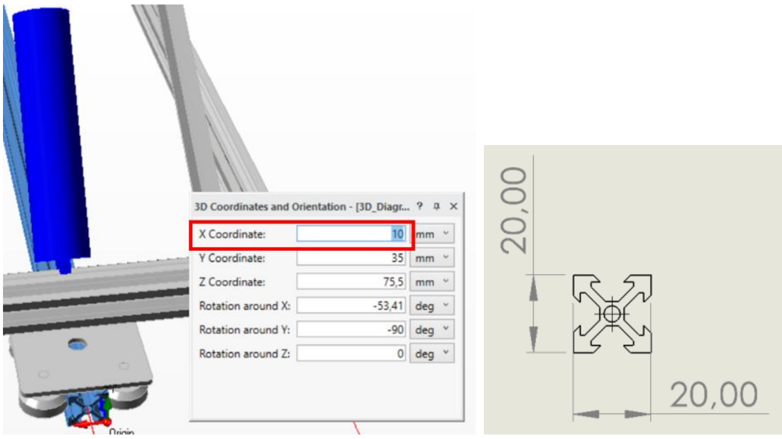
(A) (B) (C)

The software recognizes the axes of all cylindrical figures, but it highlights them differently depending on whether the cylindrical surfaces are internal (so the axes appear short and narrow) or external (so the axes appear long and wide). Sometimes it happens (as in figure B) that the axis of an external surface hides the axis of a hole. To select the hidden axis, simply observe internally to the axis that hides it.

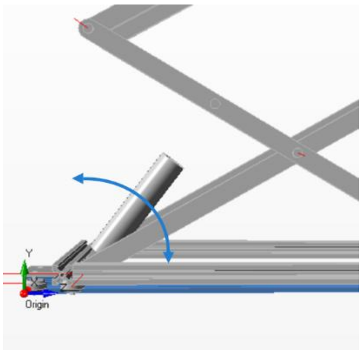
Look at the video named as:
Automation Studio.7 - 3D hidden axis



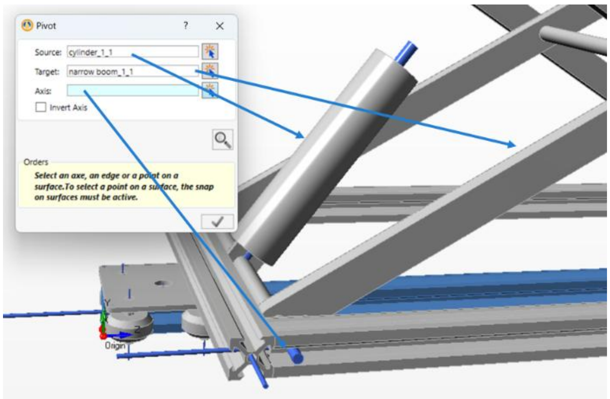
103) Result: the component must to be positioned along the x axis

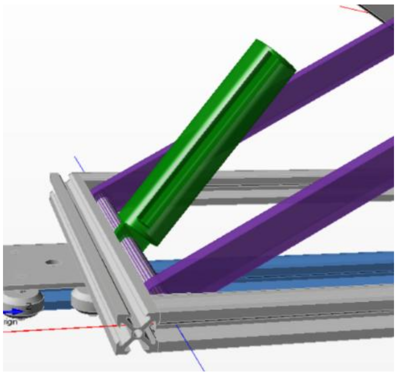


104) Assign the value 10 at the X coordinate in order to place correctly the position of the origin of the cylinder in the middle of the fixed bar

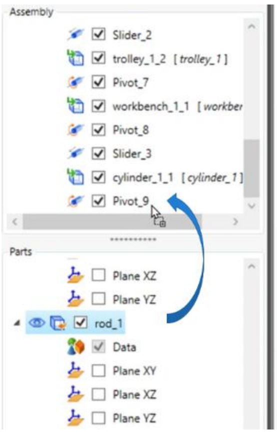


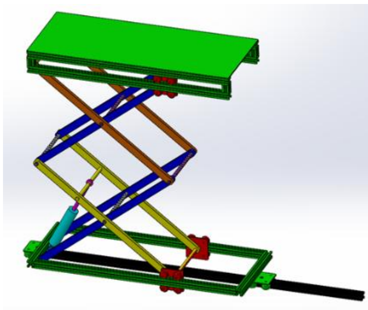
105) The last step for this component is to impose a <u>pivot</u> movement around the bottom pin of the first narrow boom



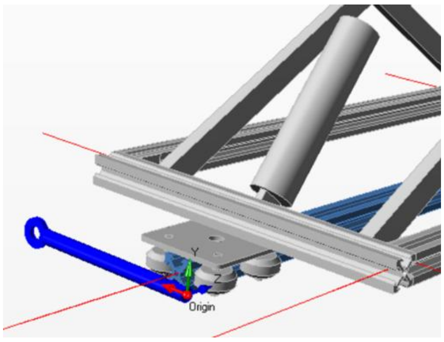


106) Select the cylinder as **Source**, the mobile base as **Target** and the pin axis as **Axis**. Then confirm

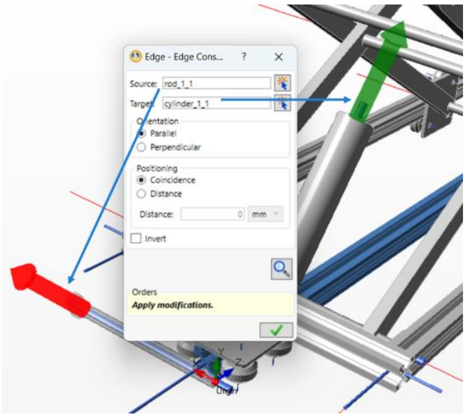




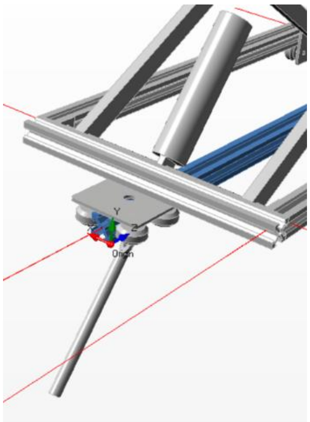
107) Now, add the rod into the assembly.



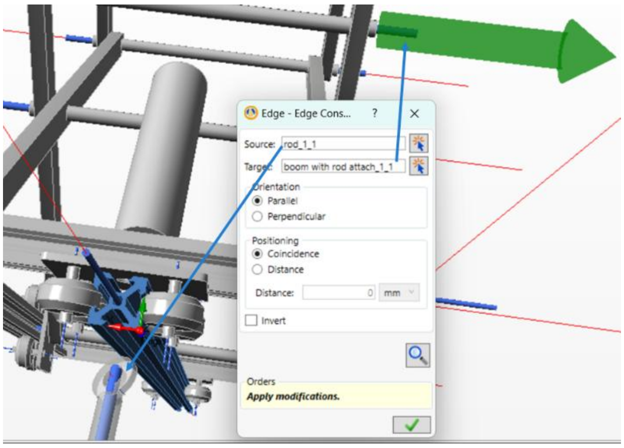
108) Also this component need to be oriented and positioned properly and, in this case, it is convenient to use only the second method



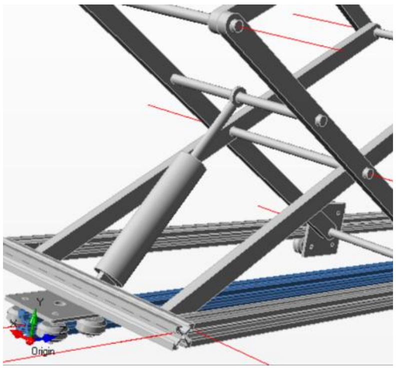
109) Now, align the axis of the rod to the axis of the cylinder.



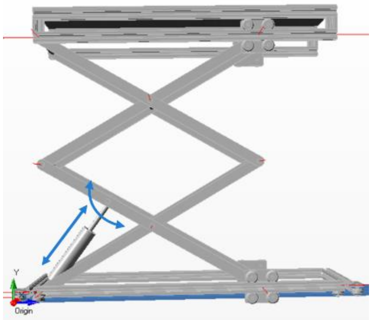
110) Result



111) Now, align the axis of the hole (hidden) of the rod to the axis of the pin of the boom with rod attachment.

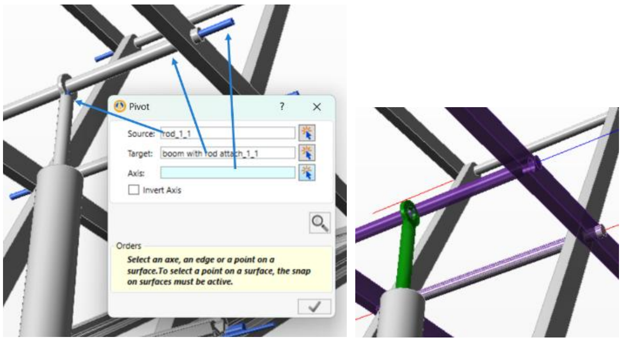


112) Result

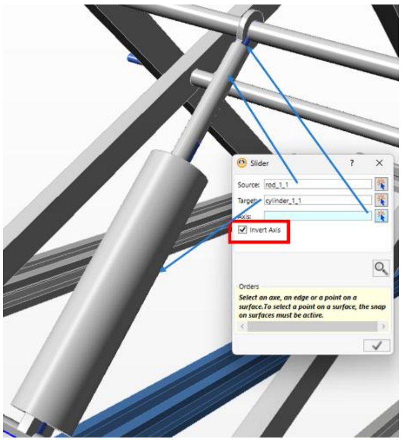


113) The last steps for this component are:

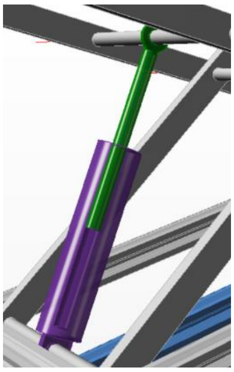
- to impose a pivot movement around the pin of the boom with rod attachment
- to impose a sliding movement along the cylinder



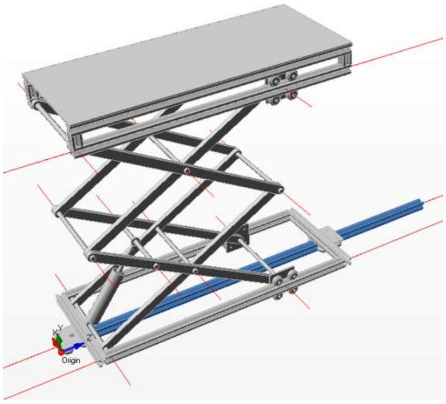
114) Pivot: Select the rod as **Source**, the boom with rod attachment as **Target** and the pin axis as **Axis**. Then confirm



115) Sliding: Select the rod as **Source**, the cylinder as **Target** and the axis of the cylinder as **Axis**. Then invert the axis and confirm

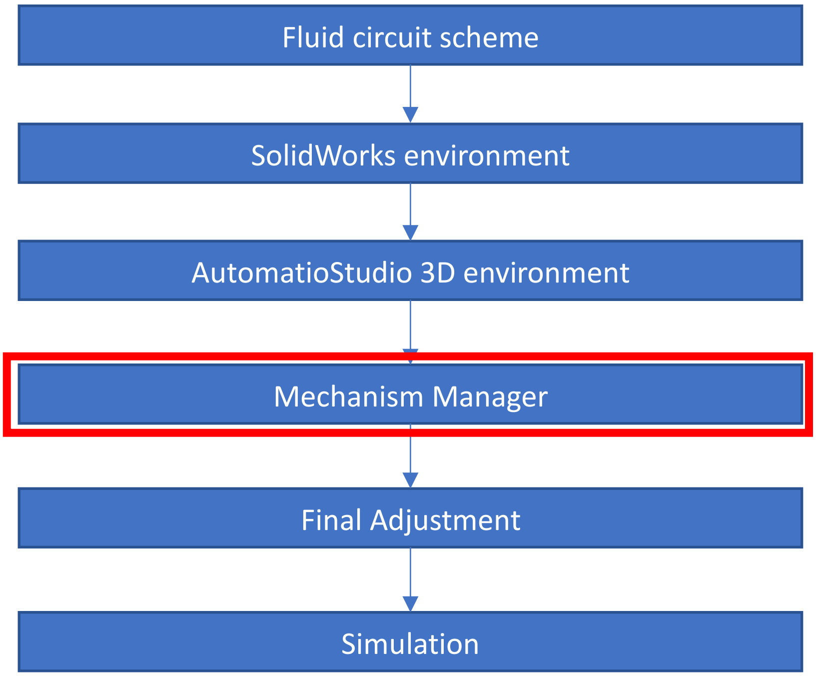


Note: In this case the Axis must to be inverted in order to link correctly the variable related to the linear position of the actuator A1 (step 212)

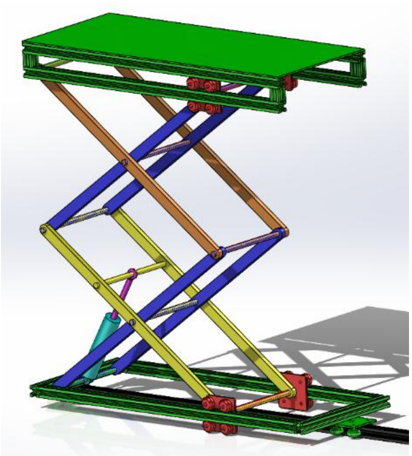


116) The assembly is now completed in the 3D environment of AutomationStudio. It is possible to see all the axis involved in joints (pivot or sliding) highlighted in red and the fixed component in blue

4.3.8. Steps



4.3.9. Mechanism Manager



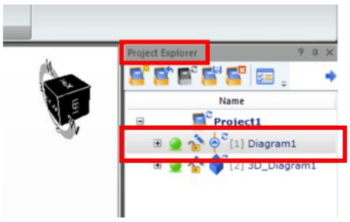
The pantograph lift is composed by the following parts that will be the bodies on the mechanism manager:

- 1x fixed bar
- 1x mobile base
- 2x trolley
- 2x narrow boom
- 1x boom with rod attachment
- 1x large boom
- 1x workbench
- 1x cylinder
- 1x rod

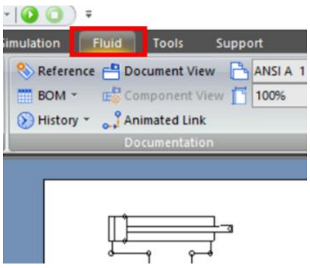
117) The Mechanism manager is a 2D environment in which it is possible to recreate the pantograph lift thanks to mechanical link between bodies, involving fluid power actuators and loads.

In the mechanism manager, bodies represent the parts on the assembly of the 3D environment

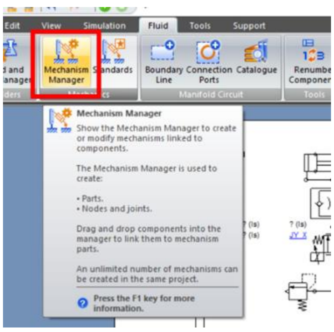
118) First of all, to open the mechanism manager, it is needed to return on the fluid diagram…



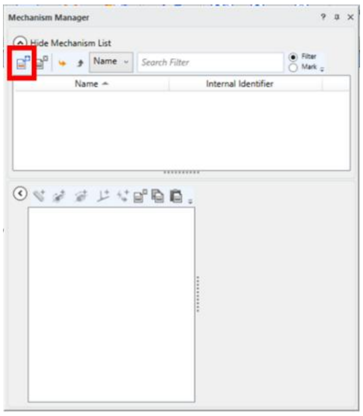
119) Double click on the Diagram1 at the project explorer window



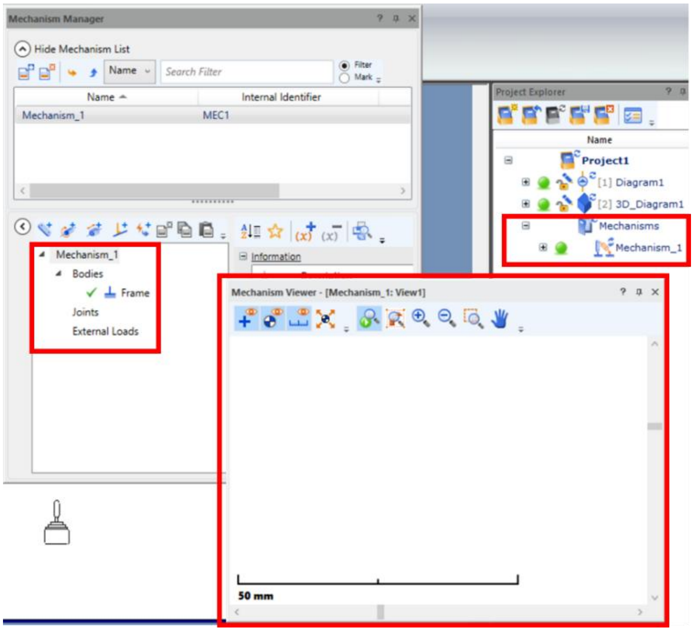
120) Click on the fluid section



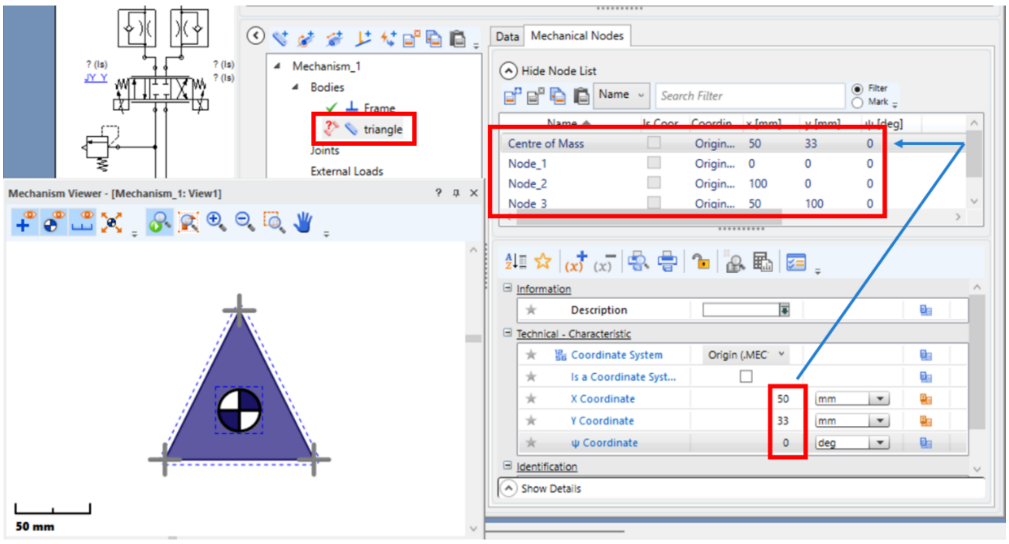
121) Then, click on Mechanism Manager to open it



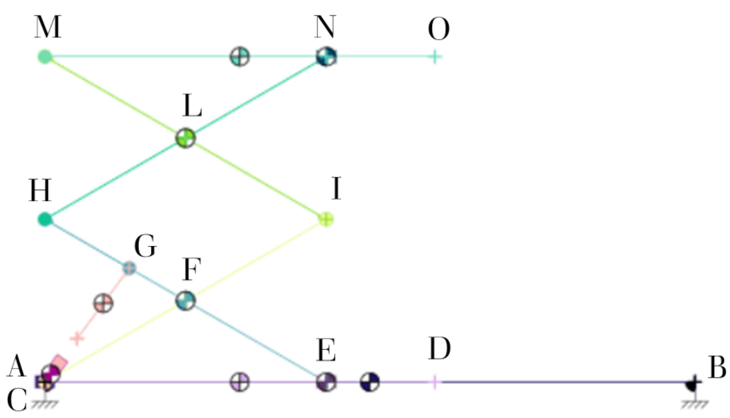
122) The mechanism manager window is open, so add a new mechanism



123) Results. A new mechanism is created and it is visible on the project explorer window. As well as the related mechanism 2D viewer and the list of bodies, joints and loads involved in this mechanism on the mechanism manager window

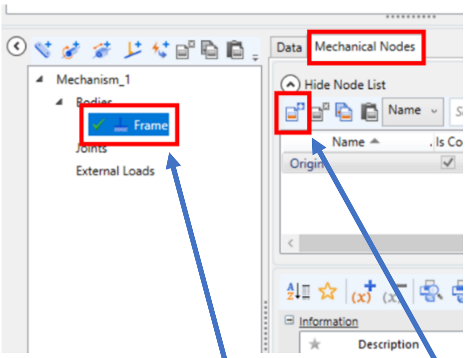


Note: In the mechanism manager, bodies are realized by defining nodes (points). This nodes are also used to apply loads or joints. Below an example in which a body called “triangle” is realized by defining the 3 vertices



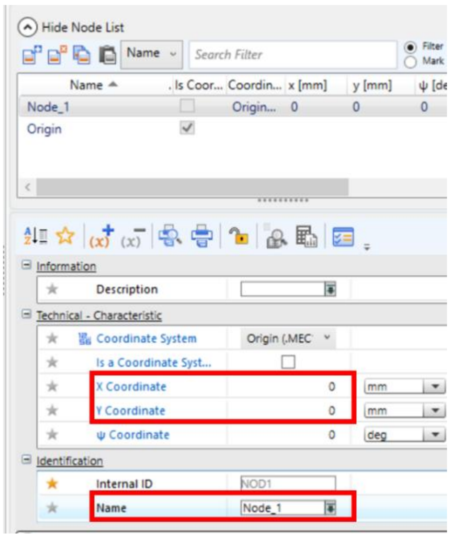
	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

124) In this tutorial, each body is represented by a rigid line that includes all nodes used to joint other bodies. On the left it is shown all nodes and the related coordinated [mm]

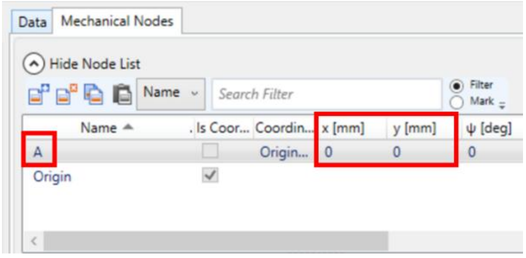


125) The first step is to add the 2 nodes (A and B) of the fixed frame in which the fixed bar is clamped. Select the body “Frame” and click “Add” on the node list of the Mechanical Nodes window

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

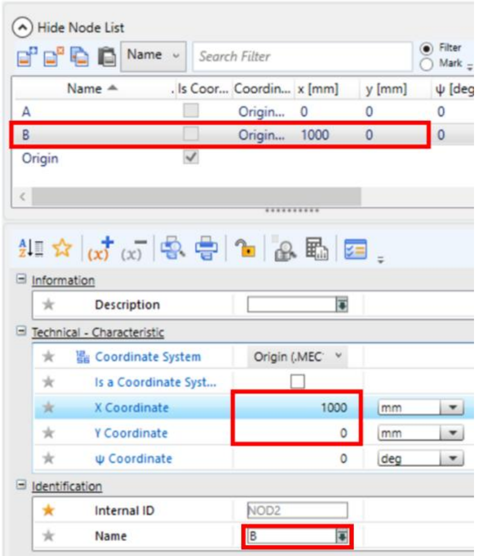


126) Node_1 is added on the list of nodes of this body. Rename it as “A” and assign the related coordinates (from the table)

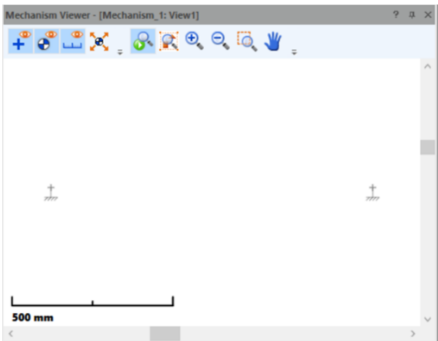


127) Results

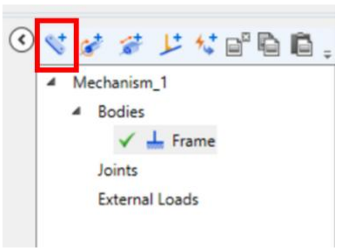
	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	196,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500



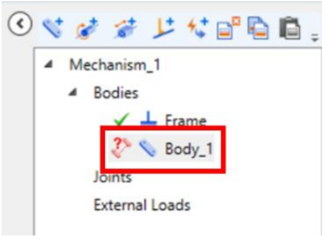
128) Now, add another node, rename it as “B” and assign its proper coordinates



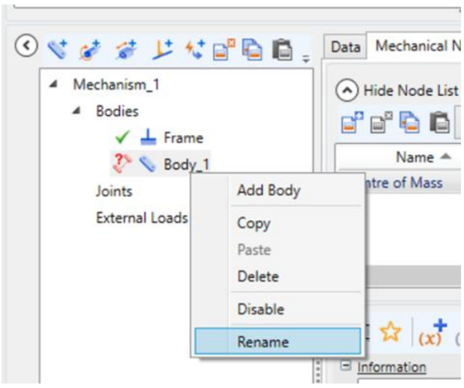
129) Results. The 2 nodes are shown on the mechanism viewer



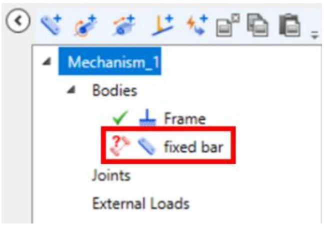
130) The next step is to add the first body: the fixed bar. So, click “Add body”



131) Result

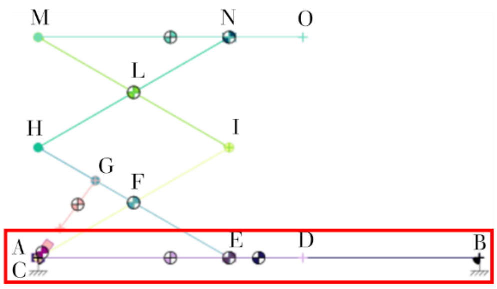


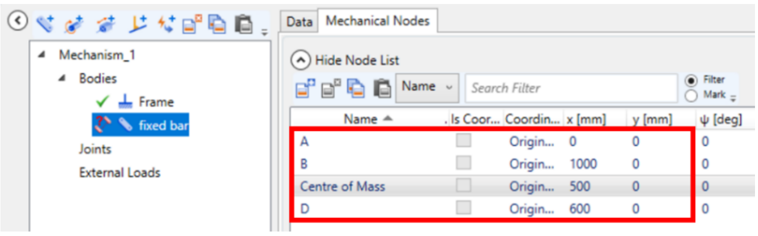
132) Change the name of the body into "fixed bar": right click on body_1 and rename.



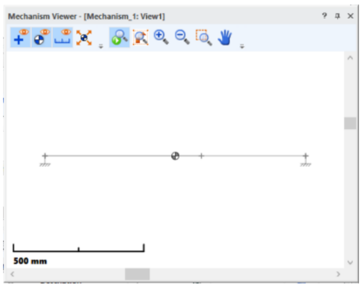
133) Result

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

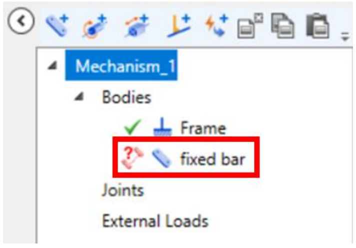




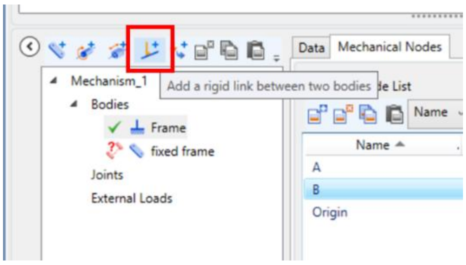
134) The fixed bar involves points A and B (to clamp itself to the fixed frame) and D (to create the sliding movement for the mobile base).
Point E and C are not involved in this body.
Add points A, B and D and assign to the centre of mass the coordinates that positions it in the middle (500;0)



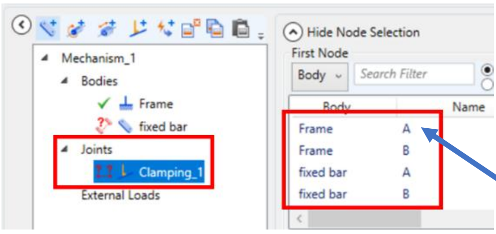
135) Result. It is possible to see the fixed bar, its nodes and the centre of mass in the mechanism viewer



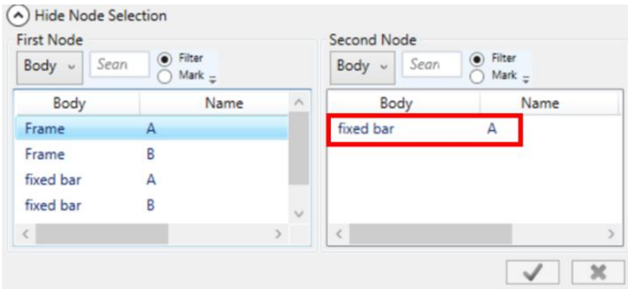
136) The question mark left to the body indicates that the body is not fixed or jointed. In fact, it needs to be clamped with the fixed frame



137) Click on "Add a rigid link between two bodies"

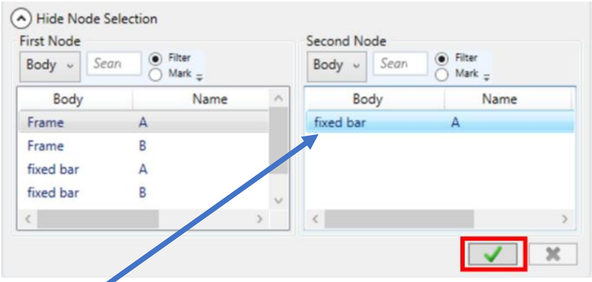


138) Result. It appears the Clamping_1 in the new joint list and the list of possible nodes that can be used for this type of joint (First node). Select the node A of the Frame

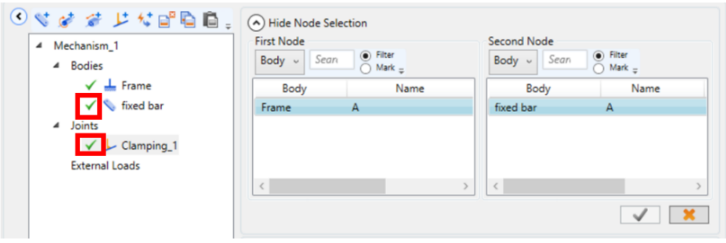


139) Result. By selecting the first node, the list of possible other nodes that can be joined with the first one becomes visible. In this case only the node A of the fixed bar

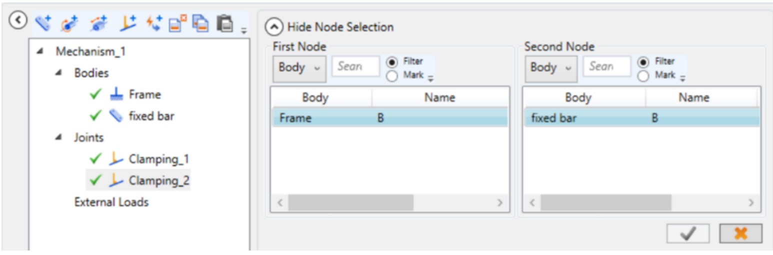
can be joined with the node A of the fixed frame because they have the same coordinates



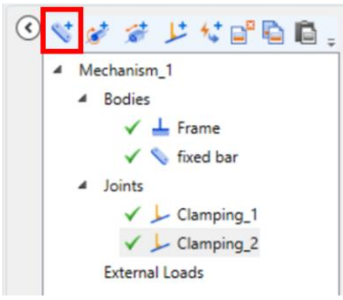
140) Select the node A of the fixed bar as the second node and confirm



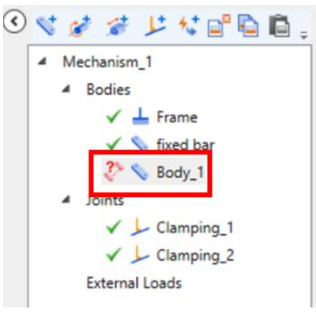
141) Result. The fixed bar is clamped and the green tik is set left to the body and to the joint



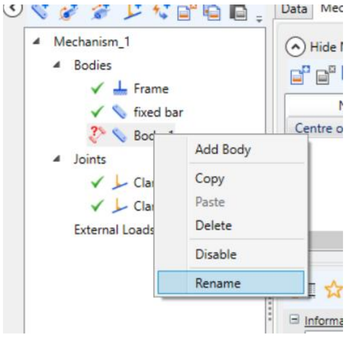
142) For completeness clamp also the point B repeating these last steps



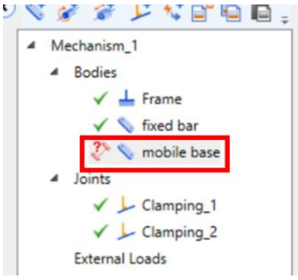
143) The next step is to add the next body: the mobile base. So, click “Add body”



144) Results

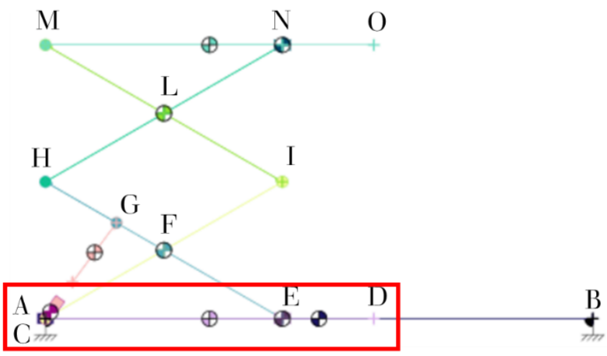


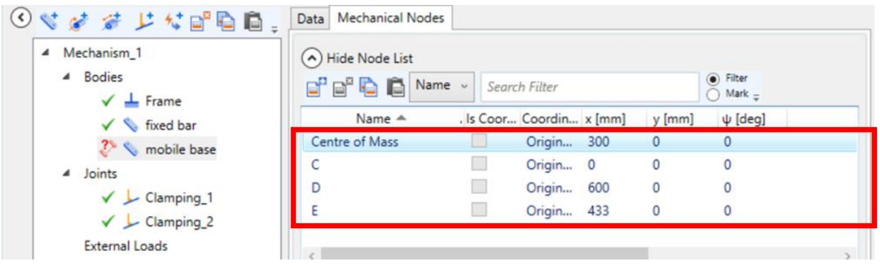
145) Change the name of the body into “mobile base”: right click on body_1 and rename.



146) Result

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

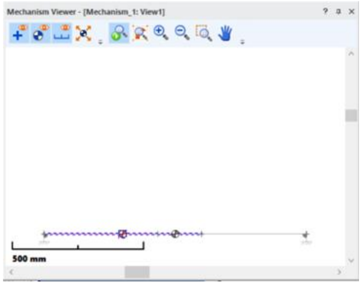




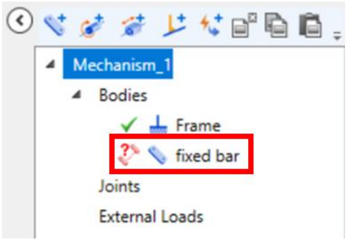
147) The mobile base involves points C (pivot joints with the narrow boom and with the cylinder), D (to create the sliding movement along the fixed bar) and E (to create the sliding movement for the trolley).

Point A is not involved in this body.

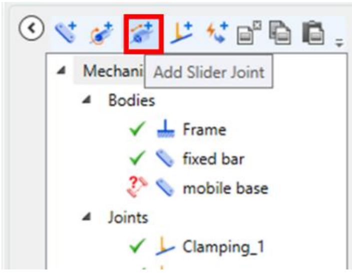
Add points C, D and E and assign to the centre of mass the coordinates that positions it in the middle (300;0)



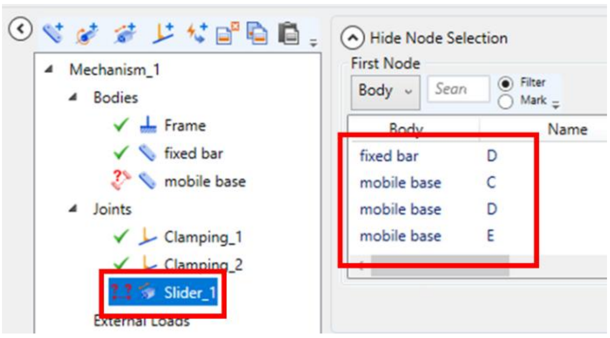
148) Result



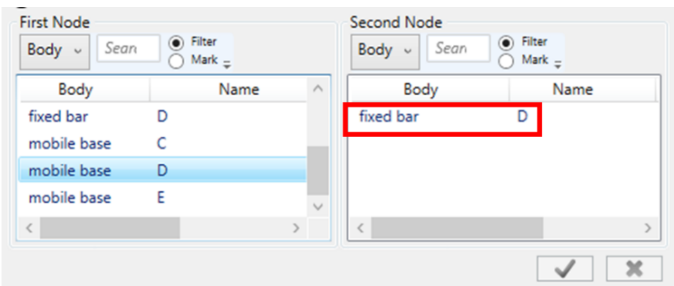
149) Even in this case, the question mark is present. It is needed to create the <u>sliding</u> constraint between the mobile base and the fixed bar.



150) Click on "Add Slider Joint"

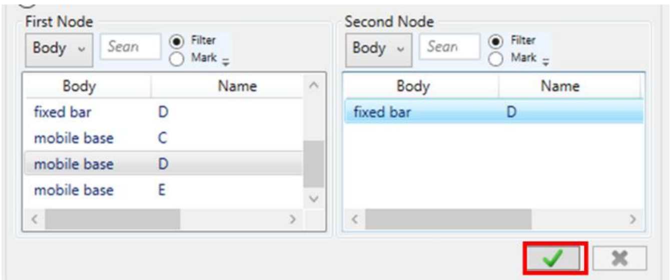


151) Select the node D of the mobile frame as the first node

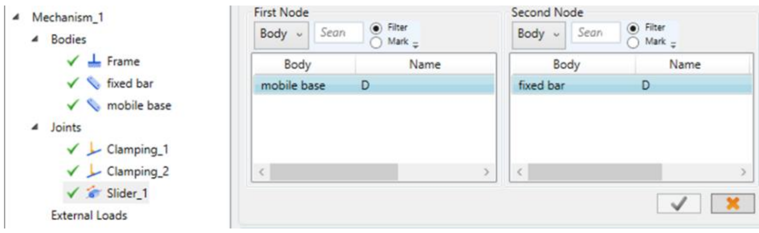


152) Result. As before, by selecting the first node, the list of possible other nodes that can be joined with the first one becomes visible. In this case only the node D of the

fixed bar can be joined with the node D of the fixed frame because they have the same coordinates

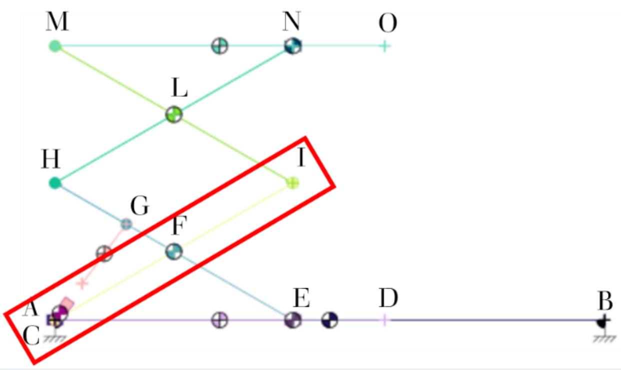


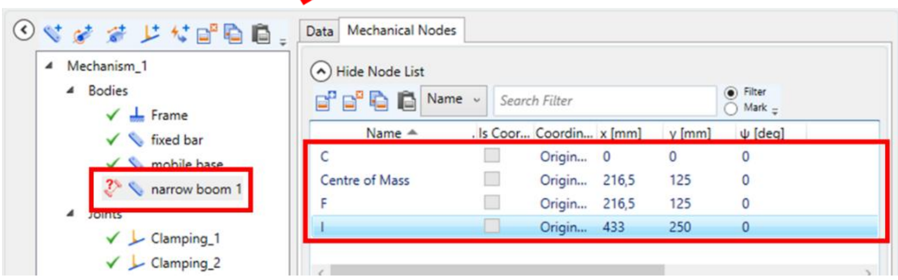
153) Select the node D of the fixed bar as the second node and confirm



154) Results

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500



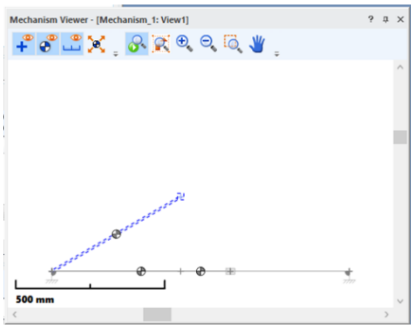


155) The next step is to add the next body: the first narrow boom.

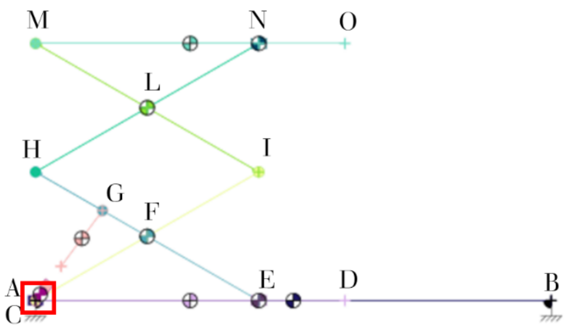
The first narrow boom involves points C (pivot joints with the mobile base and with the cylinder), F (to create the joint movement around the middle pin of the boom with rod attachment) and I (to create the joint movement around the bottom pin of the large boom).

Point A is not involved in this body.

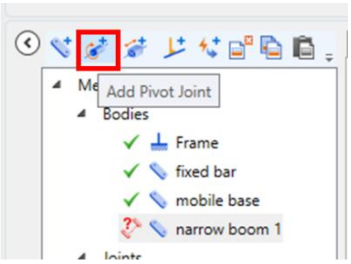
Add the body; rename it; add points C, F and I and assign to the centre of mass the coordinates that positions it in the middle (216,5 ; 125)



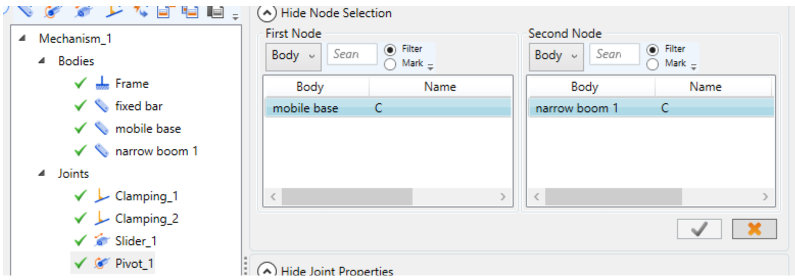
156) Result



157) Now it is needed to create the <u>pivot</u> joint in C (with the mobile base). Joint F and I cannot be created now because the other bodies don't exist yet.

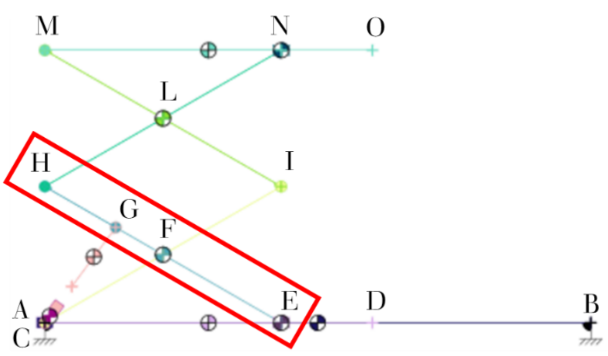


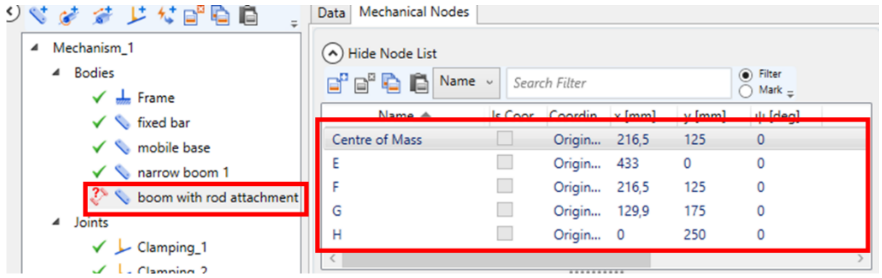
158) Click on "Add Pivot Joint"



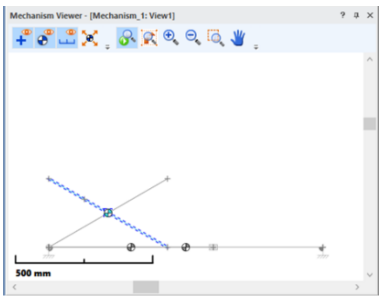
159) Create the pivot joint in C between the mobile base and the narrow boom

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

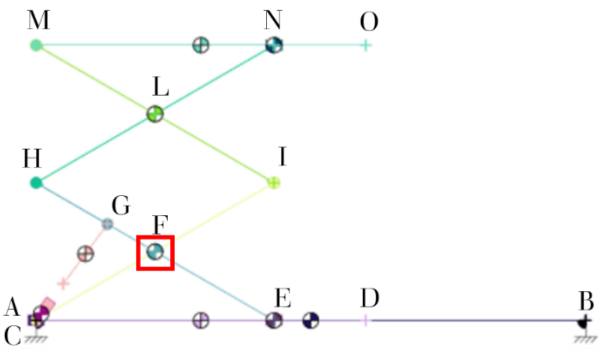




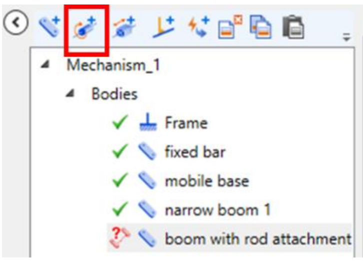
160) The next step is to add the next body: the boom with rod attachment. This body involves points E (pivot joints with the trolley), F (joint movement around the middle pin of the narrow boom 1), G (joint movement around the rod fixture of the actuator) and H (joint movement around the bottom pin of the second narrow boom). Add the body; rename it; add points E, F, G and H and assign to the centre of mass the coordinates that positions it in the middle (216,5; 125)



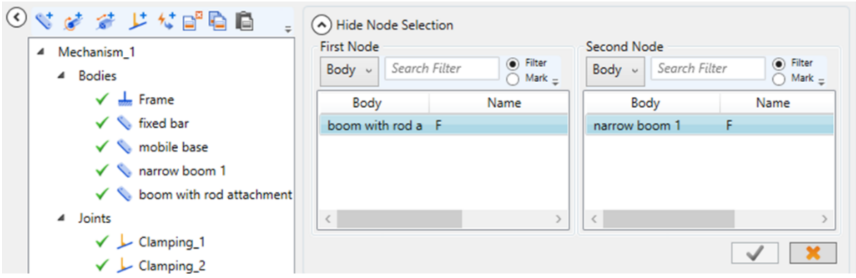
161) Result



162) Now it is need to create the <u>pivot</u> joint in F (with the narrow boom 1). Joint E, G and H cannot be created now because the other bodies don't exist yet.

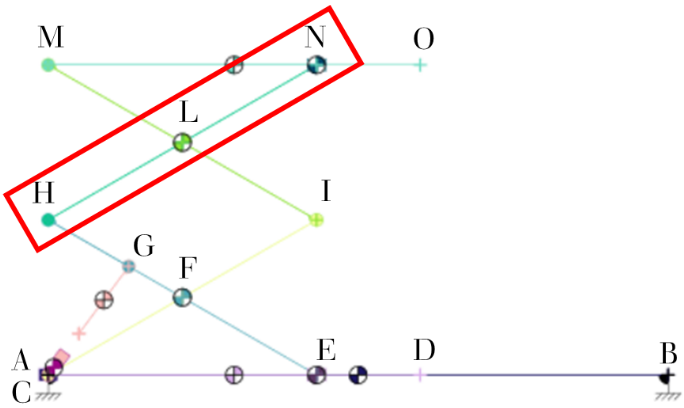


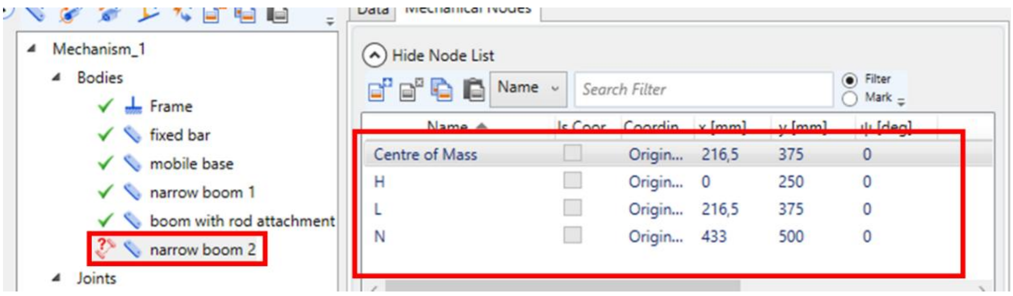
163) Click on “Add Pivot Joint”



164) Create the pivot joint in F between the boom with rod attachment and the narrow boom

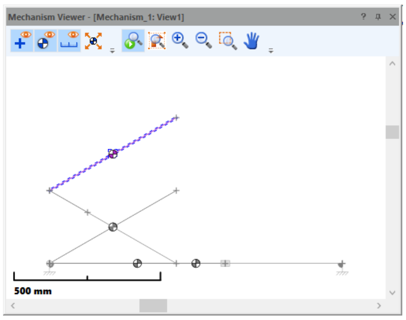
	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500



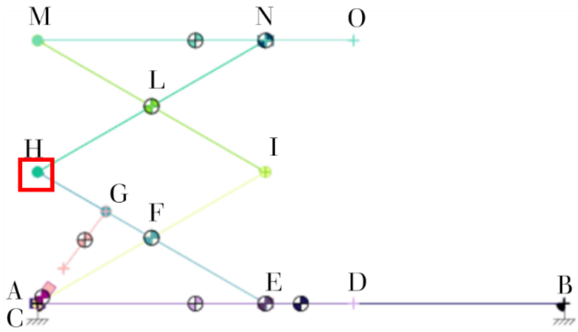


165) The next step is to add the next body: the second narrow boom. This body involves points H (pivot joints with boom with rod attachment), L (joint movement around the middle pin of the large boom), N (joint movement around the trolley) .

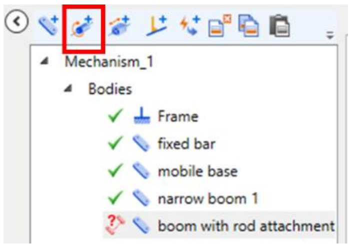
Add the body; rename it; add points H, L, N and assign to the centre of mass the coordinates that positions it in the middle (216,5 ; 375)



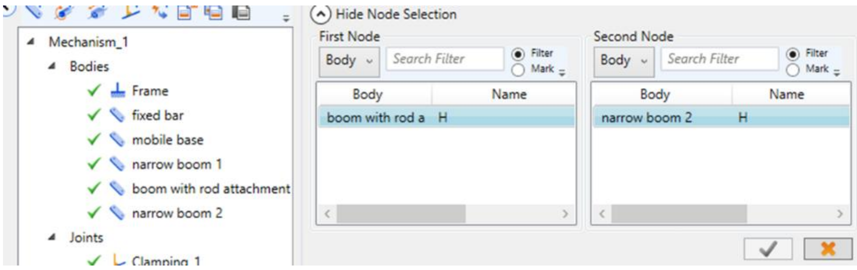
166) Result



167) Now it is need to create the <u>pivot</u> joint in H (with the boom with rod attachment). Joint L and N cannot be created now because the other bodies don't exist yet.

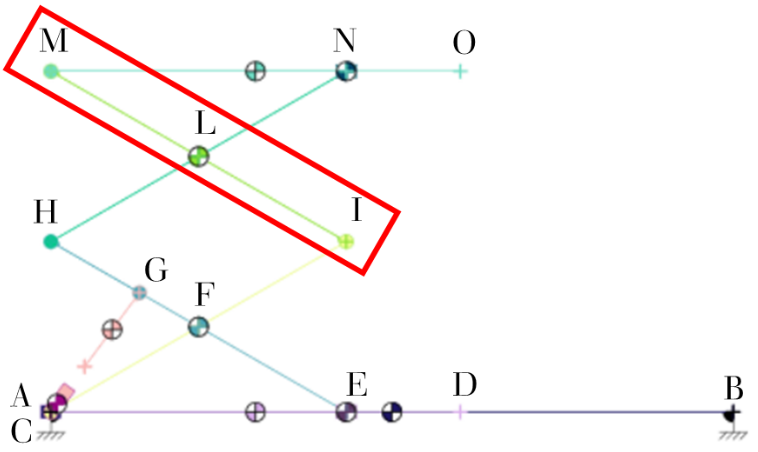


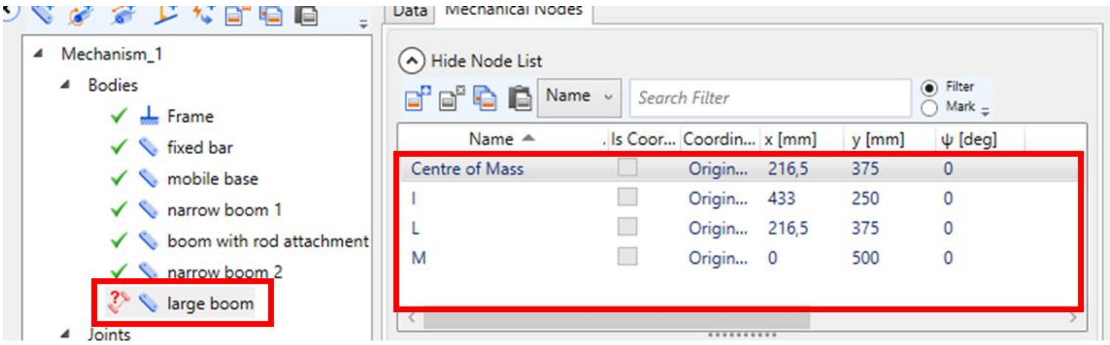
168) Click on "Add Pivot Joint"



169) Create the pivot joint in H between the boom with rod attachment and the narrow boom 2

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

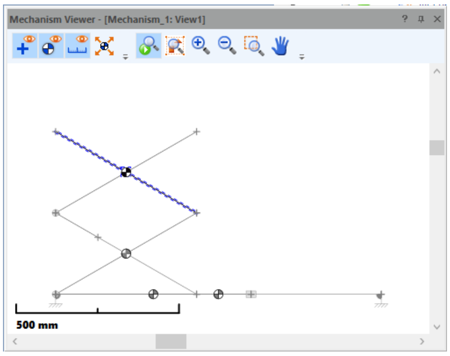




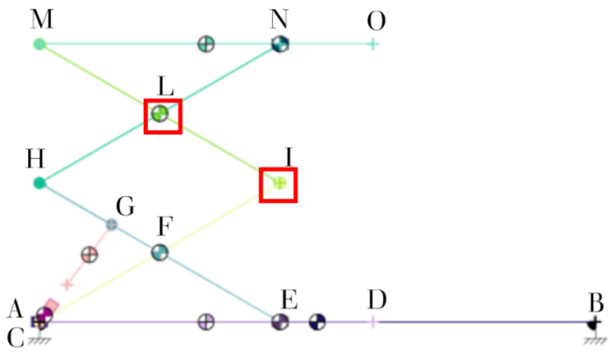
170) The next step is to add the next body: the large boom.

This body involves points I (pivot joints with narrow boom 1), L (joint movement around the middle narrow boom 2), M (joint movement around the pin of the workbench) .

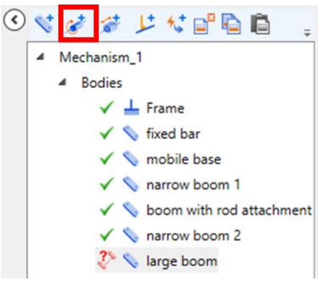
Add the body; rename it; add points I, L, M and assign to the centre of mass the coordinates that positions it in the middle (216,5 ; 375)



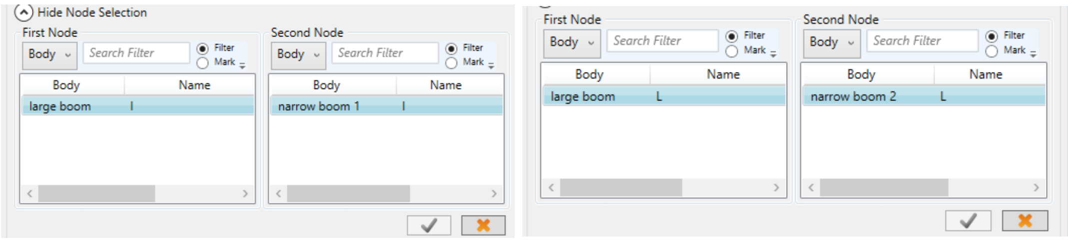
171) Result



172) Now it is need to create the pivot joints in I (with the narrow boom 1) and in L (with the narrow boom 2). Joint M cannot be created now because the other body doesn't exist yet.

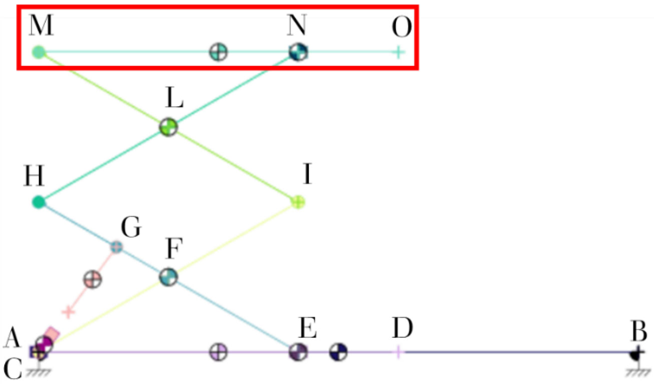


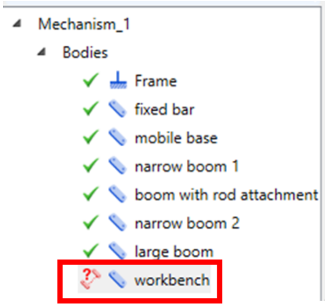
173) Click on "Add Pivot Joint"

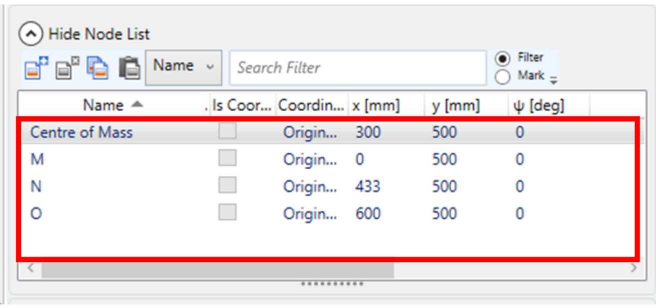


174) Create the pivot joints in I, between the large boom and the narrow boom 1, and in L between the large boom and the narrow boom 2

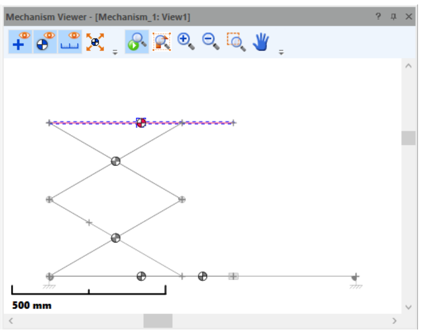
	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500



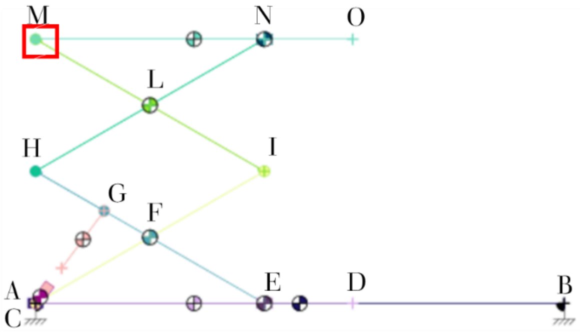




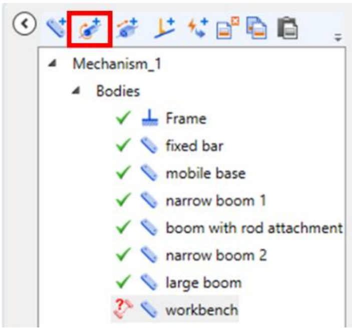
175) The next step is to add the next body: the workbench.
This body involves points M (pivot joints with the large boom), N (joint movement around the trolley), O (end of the workbench) .
Add the body; rename it; add points M, N, O and assign to the centre of mass the coordinates that positions it in the middle (300 ; 500)



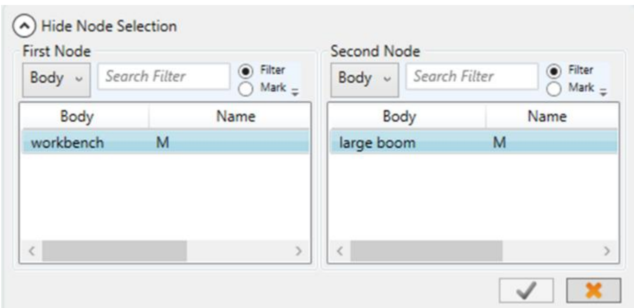
176) Result



177) Now it is needed to create the <u>pivot</u> joint in M (with the large boom). Joint N cannot be created now because the other body (the trolley) doesn't exist yet.

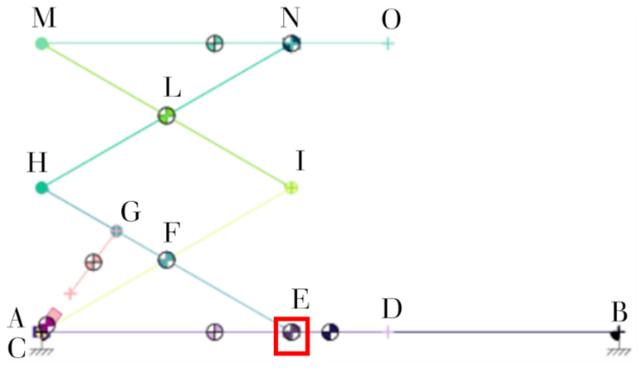


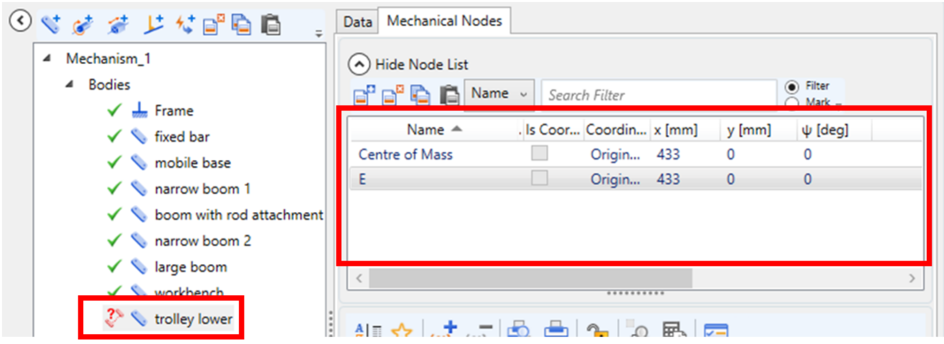
178) Click on "Add Pivot Joint"



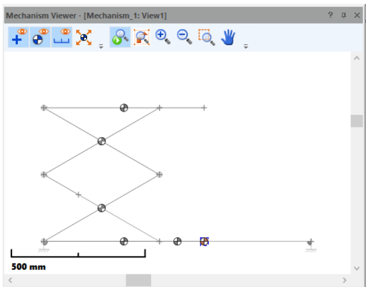
179) Create the pivot joint in M, between the workbench and the large boom

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

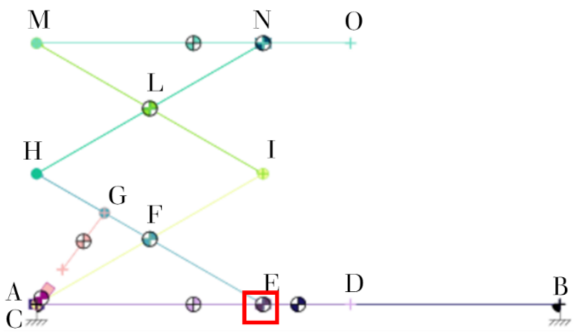




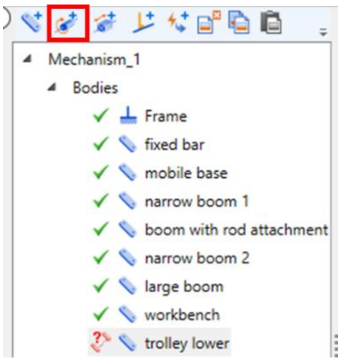
180) The next step is to add the next body: the lower trolley.
This body involves only the point E (pivot joints with the large boom and slider joint with the mobile base).
Add the body; rename it; add the point E and assign to the centre of mass the coordinates equal to the ones of the E point (433 ; 0)



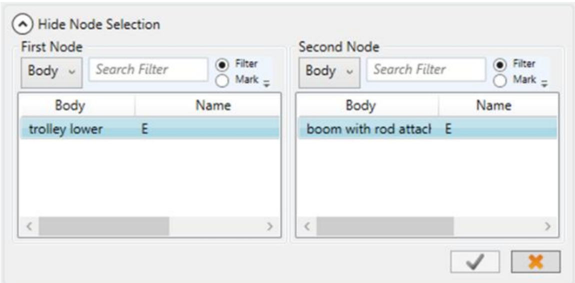
181) Result



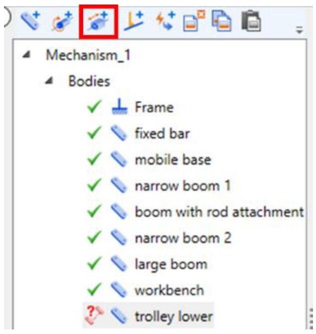
182) Now it is needed to create the <u>pivot</u> joint in E (with the boom with rod attachment) and the <u>slider</u> joint in E (with the mobile base).



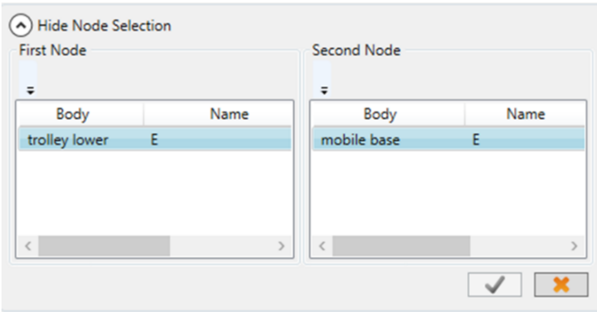
183) Click on “Add Pivot Joint”



184) Create the pivot joint in E, between the lower trolley and the boom with rod attachment

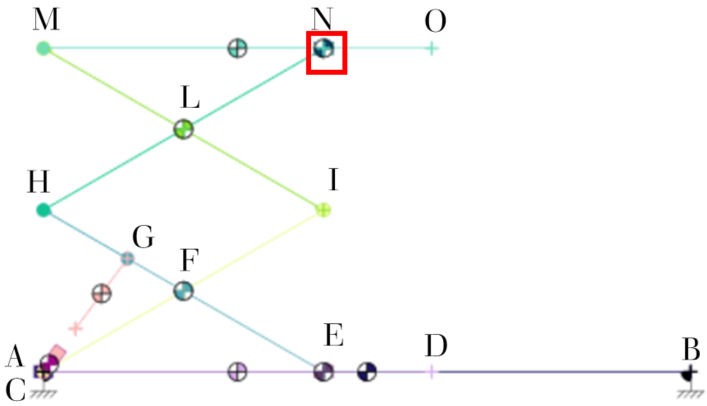


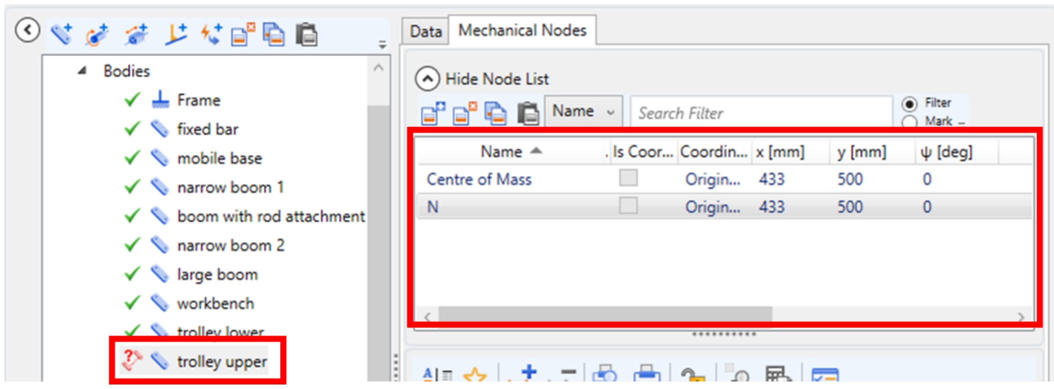
185) Click on “Add Slider Joint”



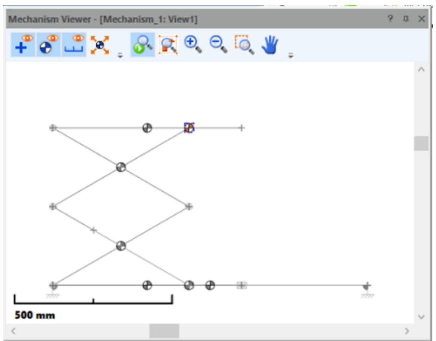
186) Create the slider joint in E, between the lower trolley and the mobile base

	X	Y
A	0	0
B	1000	0
C	0	0
D	600	0
E	433	0
F	216,5	125
G	129,9	175
H	0	250
I	433	250
L	216,5	375
M	0	500
N	433	500
O	600	500

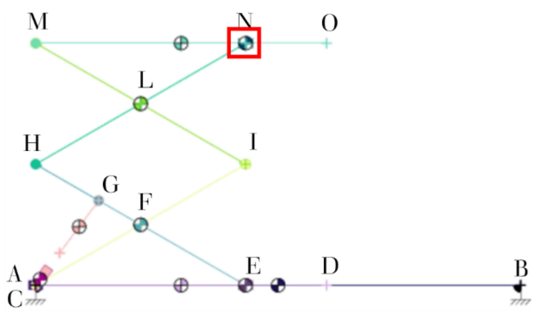




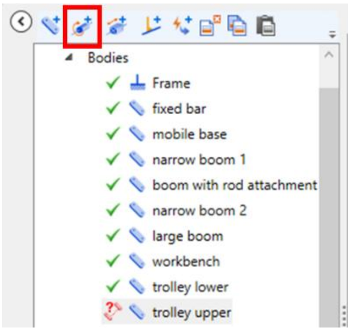
187) The next step is to add the next body: the upper trolley.
This body involves only the point N (pivot joints with the narrow boom 2, and slider joint with the workbench).
Add the body; rename it; add the point N and assign to the centre of mass the coordinates equal to the ones of the N point (433 ; 500)



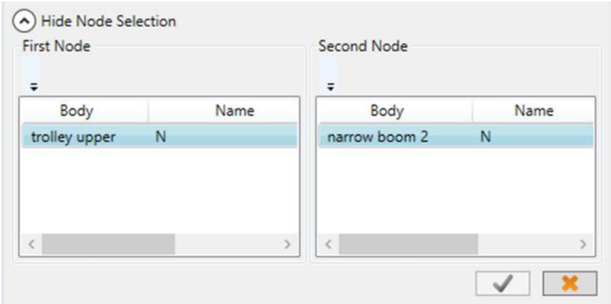
188) Result



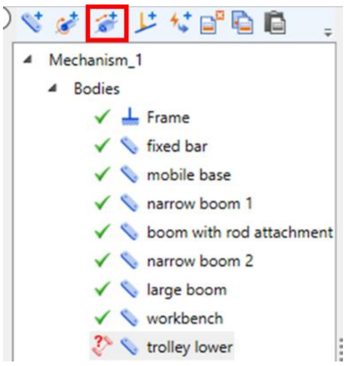
189) Now it is needed to create the pivot joint in N (with the narrow boom 2) and the slider joint in N (with the workbench).



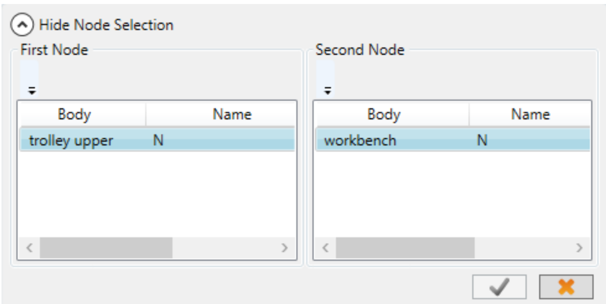
190) Click on "Add Pivot Joint"



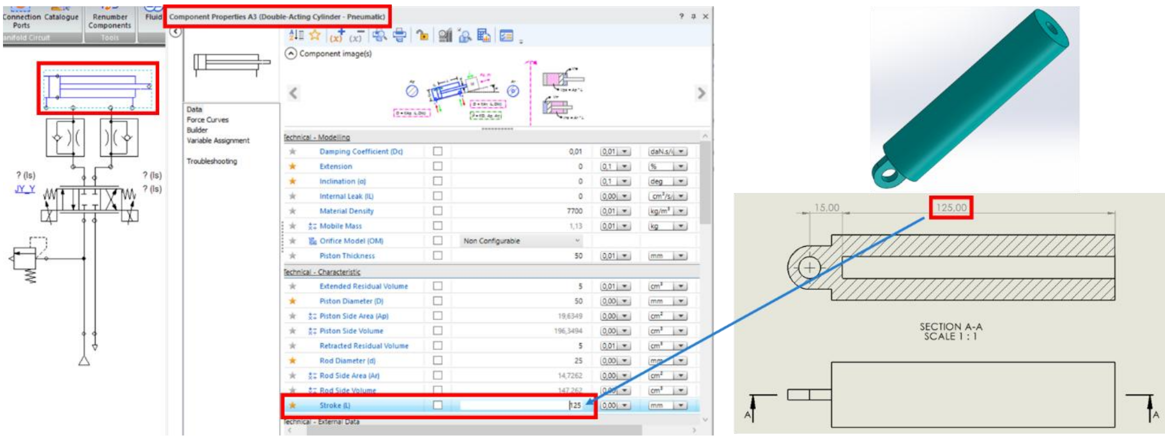
191) Create the pivot joint in N, between the upper trolley and the narrow boom 2



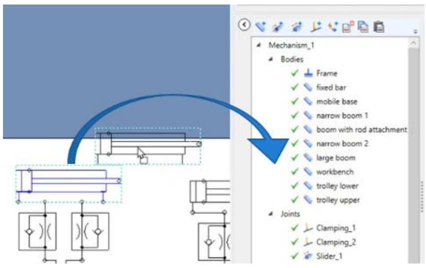
192) Click on "Add Slider Joint"



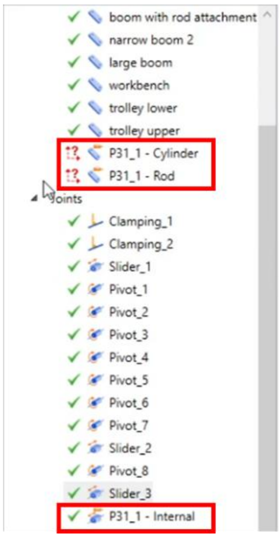
193) Create the slider joint in N, between the upper trolley and the workbench



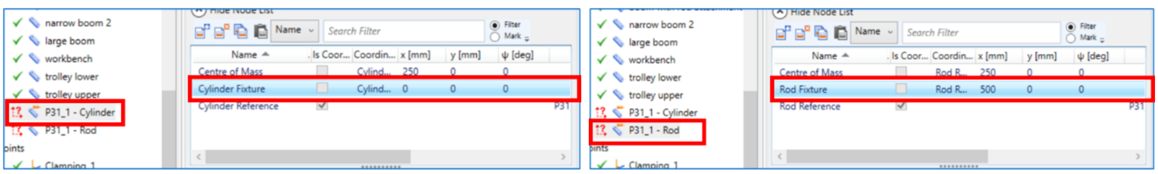
194) The next step is to add the first actuator, responsible for the vertical movements, in the mechanism manager. Before to do this, remember to assign the correct value of its stroke on the Component Properties, so 125 mm. (it will no longer be possible to change the value of the stroke once the actuator is involved on the mechanism manager)



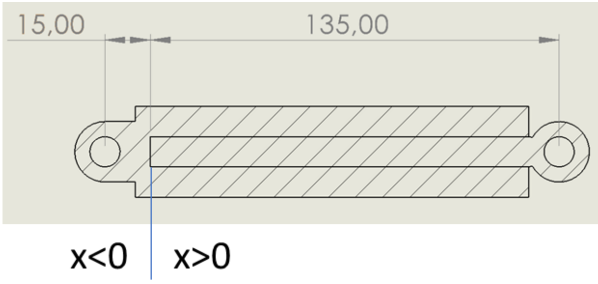
195) Drag and drop the actuator from the fluid scheme into the bodies list of the Mechanism_1



196) Results. The bodies Cylinder and Rod are created, as well as the internal constraint

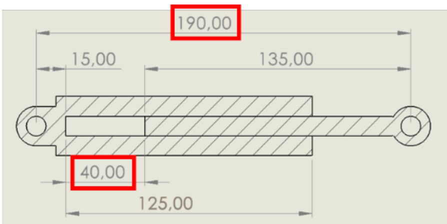


197) By default. The bodies Cylinder and Rod have a node called Cylinder/Rod Fixture that are the points in which this 2 bodies will be jointed to the mechanism

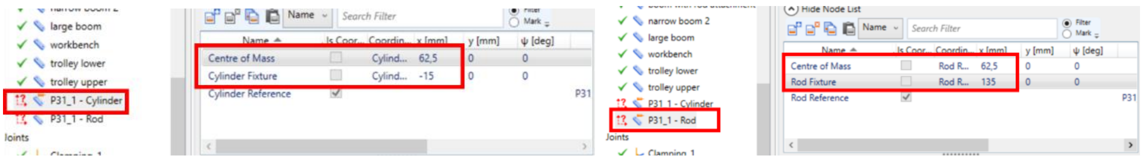


198) The coordinates of the Cylinder and Rod fixture are evaluated from the actuator reference as shown on the left, in which:

- The actuator is horizontal (leading to X coordinates of fixtures)
- The rod is on its instroke position
- Cylinder fixture has a negative value from the reference in this configuration (-15 mm)
- Rod fixture has a positive value from the reference in this configuration (135 mm)

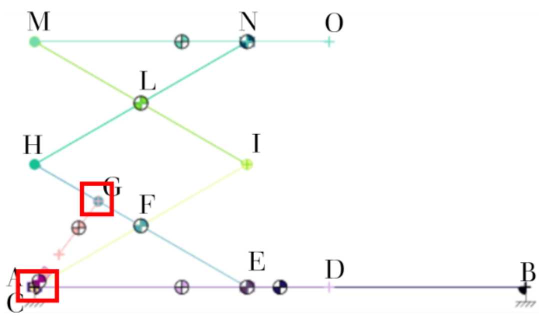


Note: when the these 2 nodes will be joined to other 2 nodes of the mechanism (both related to the external reference) the software will evaluate the stroke in the starting position, as it knows the distance between the 2 external nodes.

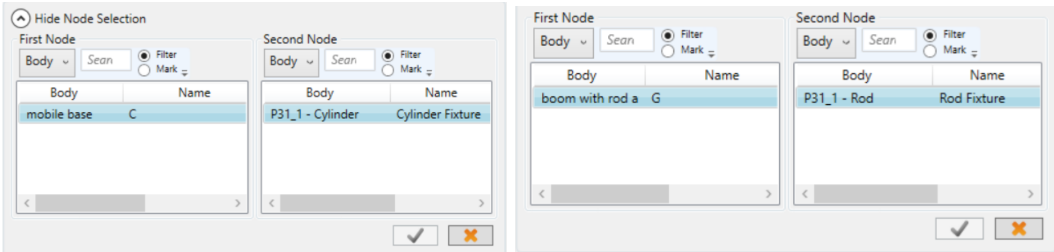


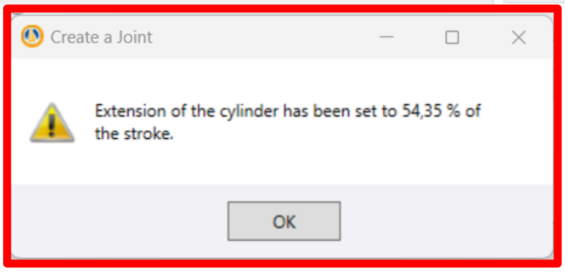
199) Assign the correct value of the X coordinates of the Cylinder Fixture (-15 mm) and of the Rod Fixture (135 mm).

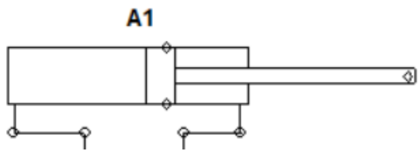
For simplicity assign the X coordinates of the centre of mass for both bodies equal to 125/2=62,5 (middle stroke)



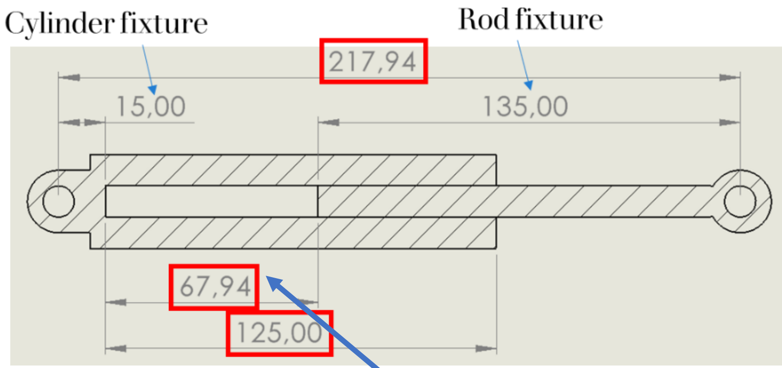
200) Now, the cylinder must to be jointed with the mobile base (node C) and the rod with the boom with rod attachment (node G)



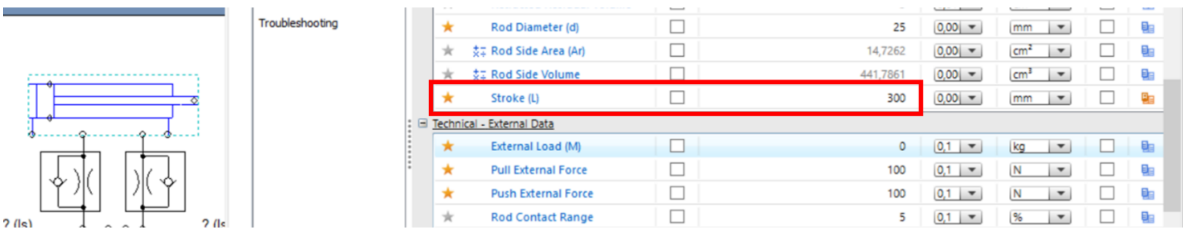




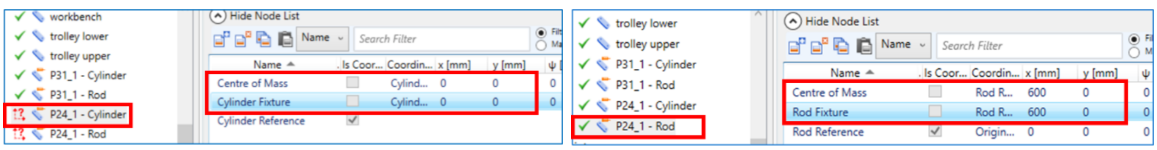
201) Create the 2 pivot joints mentioned before. As a result, a message appears indicating the extension evaluated (the value of the stroke in the starting position in percentage)



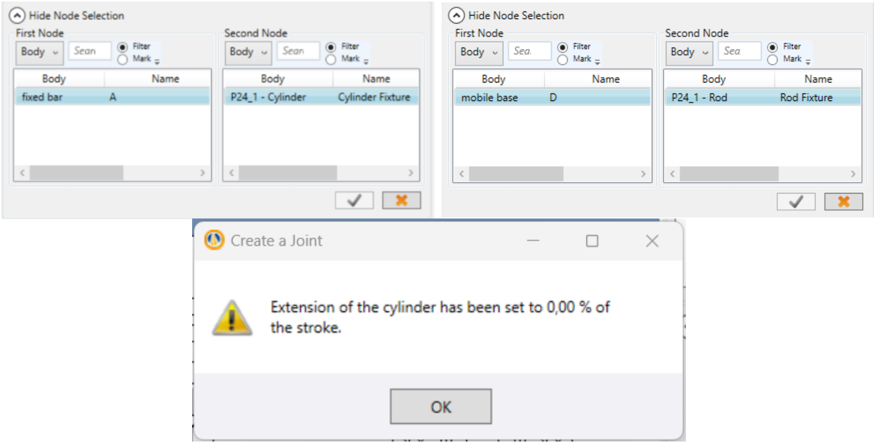
202) In this configuration, the distance between the node C and the node G is 217,94 mm. So, the software find the initial stroke length equal to 67,94 mm and the extension equal to 67,94/125 in percentage



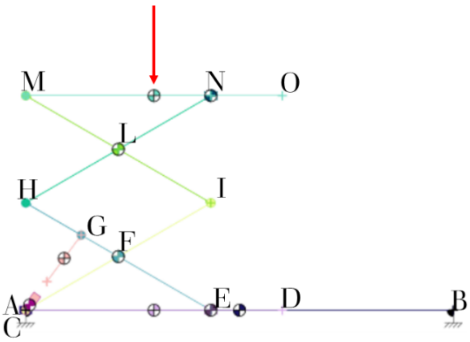
203) The next step is to add the second actuator, responsible for the horizontal movements, in the mechanism manager. Before to do this, assign it stroke value at 300 mm on the component characteristic.

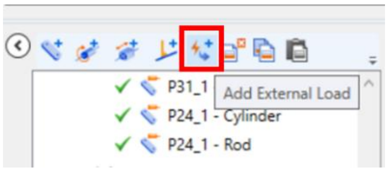


204) Put it inside the mechanism manager, as the step 195, and assign x=0 to all nodes of the cylinder and x=600 to all nodes of the rod

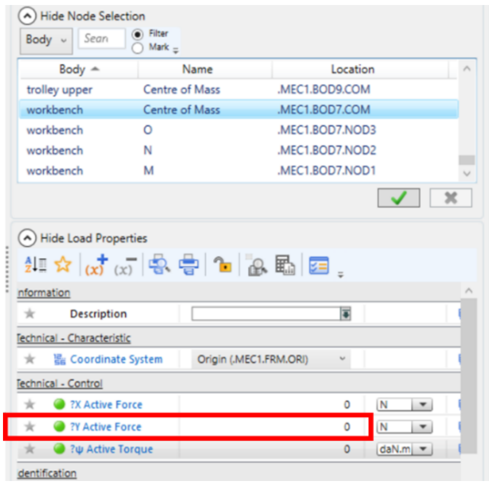


205) Then connect the Cylinder fixture to the node A of the fixed bar and the Rod fixture to the node D of the mobile base, both with pivot joint. The extension will be 0%





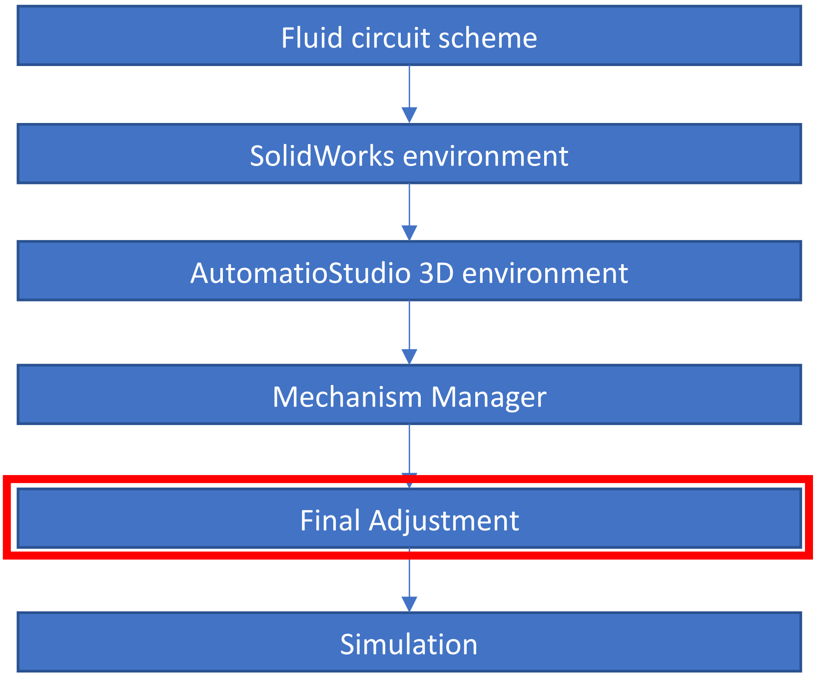
206) The last step for the mechanism manager is to add a vertical load applied to the centre of mass of the workbench. Click on "Add External Load"



207) It becomes visible the list of possible nodes in which it is possible to apply a load. Select the Centre of the mass of the workbench

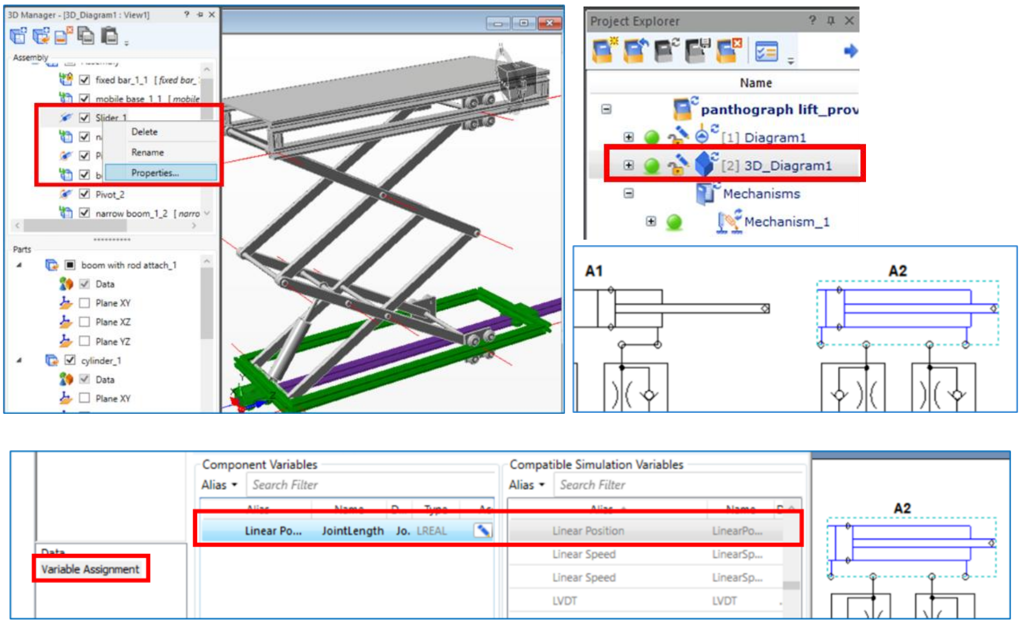
Note: it is possible to assign a constant value to the force in a specific direction (negative Y means that it is facing downward) or to link the variable "?Y Active Force" to a knob in order to change the force during the simulation. See after

4.3.10. Steps

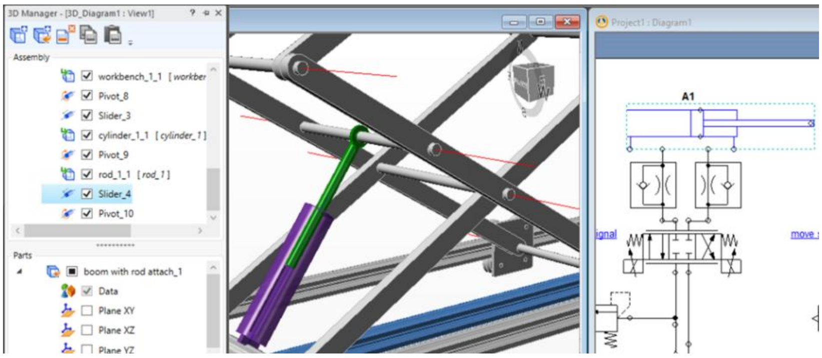


4.3.11. Final Adjustment

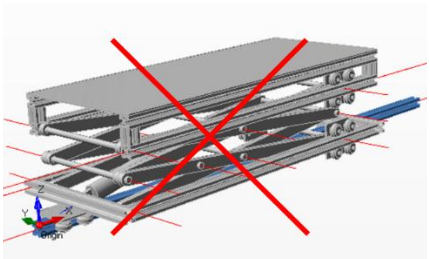
LINK BETWEEN THE SLIDING VARIABLE AND THE PISTON STROKE



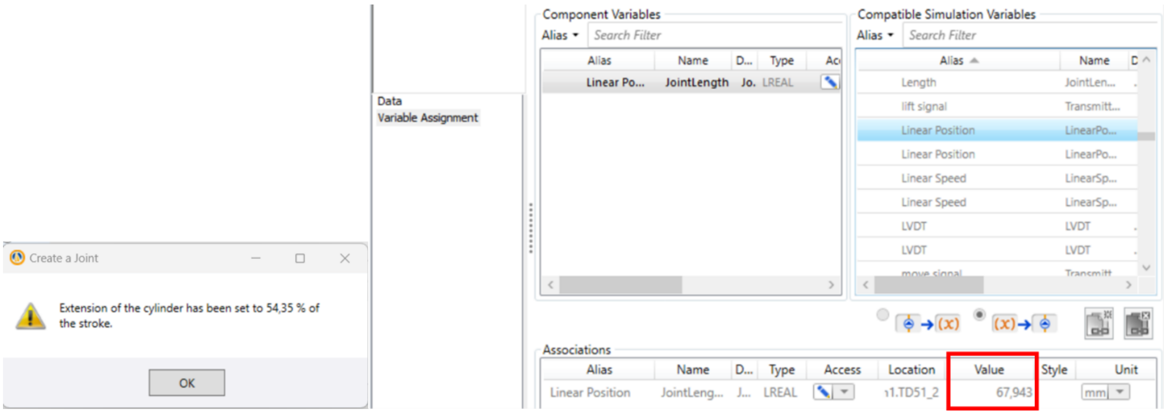
208) In order to link the sliding variable of the mobile base along the fixed bar, right click on the slider_1 on the 3D diagram and select “Properties…”. Then, on the Variable assignment, link the linear position of the joint to the linear position of the component A2



209) The next step is to link the linear position of the Slider_4 to the linear position of the component A1

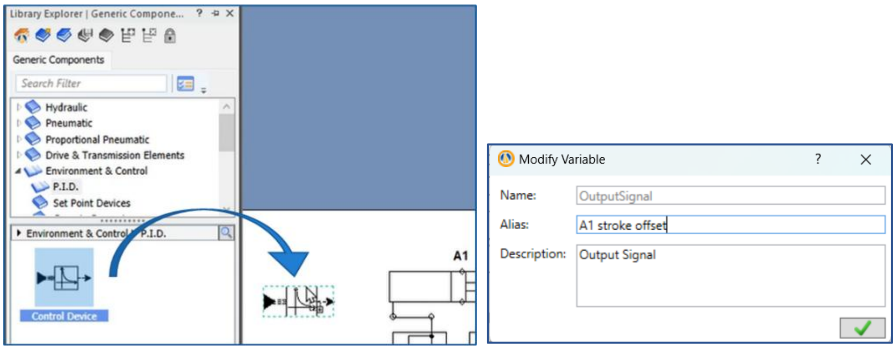


Problem! The Sliding variable of the Slider_4 is not considering the Extension of the piston A1. This means that the software considers the 0 position of the sliding variable (as it appears in the 3D drawing above) equal to the 0 position of the piston stroke (and not equal to the value of the extended stroke). The stroke cannot assume negative values, this means that the pantograph lift could not reach the configuration shown on the right → <u>an offset between the 2 variables is needed</u>

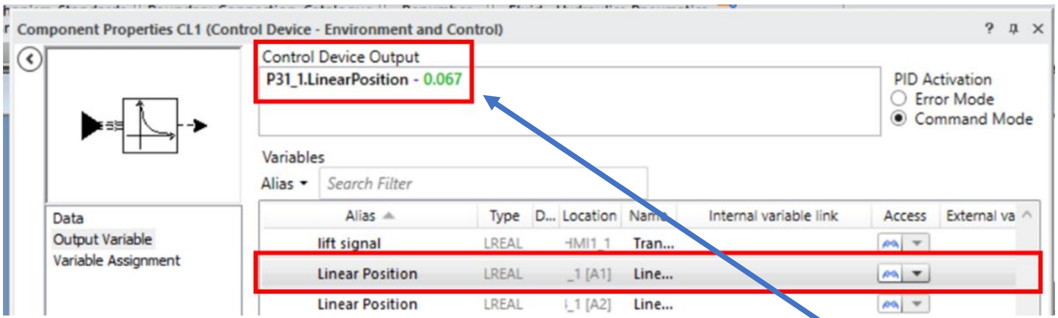


2 possible way to find the value of the offset to impose:

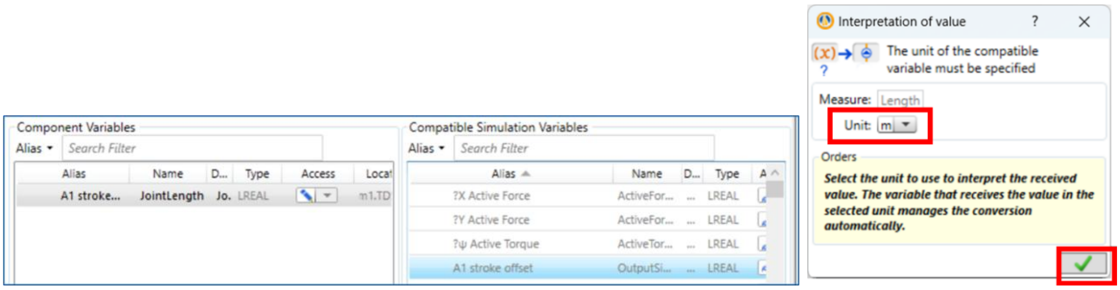
- Multiply the value of the total stroke (125 mm) with the value of the extension found at the step…
- Trying to link the Slider_4 variable to the linear position of the component A1 as the step 208, It appears the initial value that will be the opposite of the offset. Remember to delete the link then



210) To create the offset it is possible to use the “Control Device” of the P.I.D. library. Drag and Drop it inside the scheme and assign the Alias name of the new variable created.

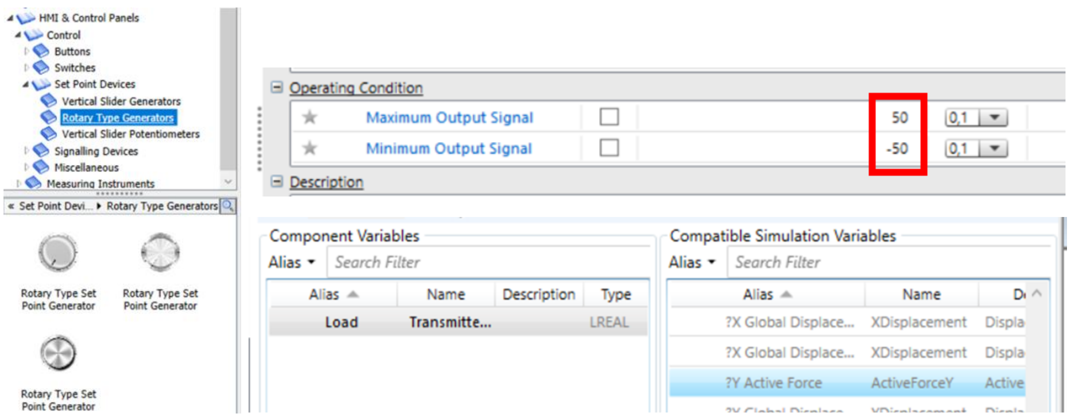


211) In the Control Device Output window writhe the equation: double click on the linear position variable of the component A1 and digit the negative offset (in meters) manually. Then confirm



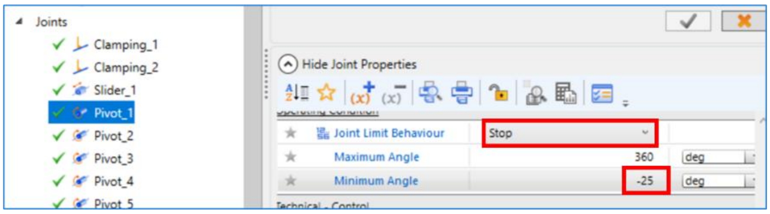
212) Now return on the 3D environment and link the Slider_4 variable to the new one created. Assign the unit in [m] and confirm

LINK BETWEEN FORCE AND KNOB



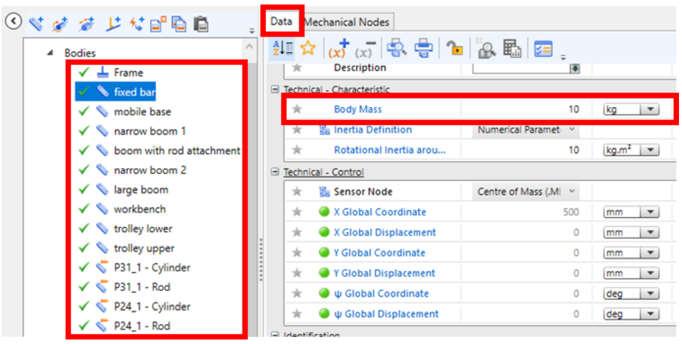
213) In order to change the load during the simulation, add a knob from the HMI library to the scheme and link to it the variable related to the load of the mechanism manager (?Y Active Force). In the operating condition of the knob assign a 50 as maximum and -50 as minimum values

JOINT ROTATION CONSTRAINT



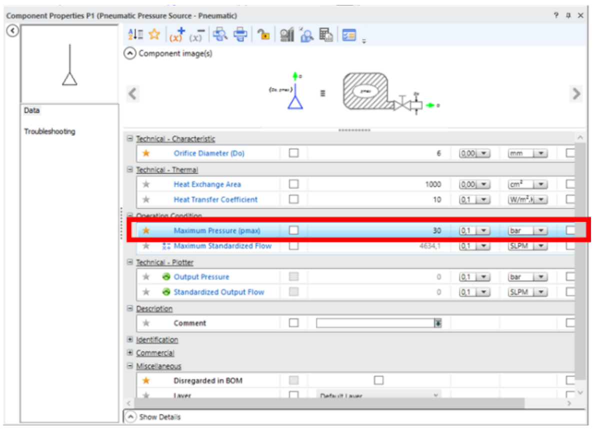
214) In order to avoid a wrong position of the pantograph lift, it is needed to limit the rotation of the pivot joint that link the first narrow boom to the mobile base. Return on the mechanism manager, select the pivot 1, impose its Joint Limit Behaviour as “Stop” and assign -25 degree as Minimum angle

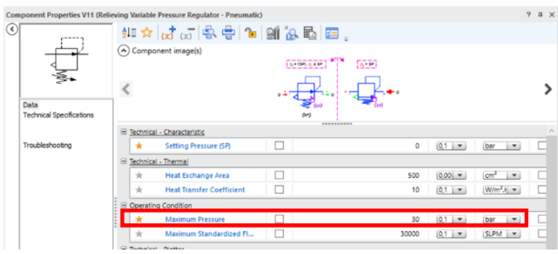
BODIES MASS



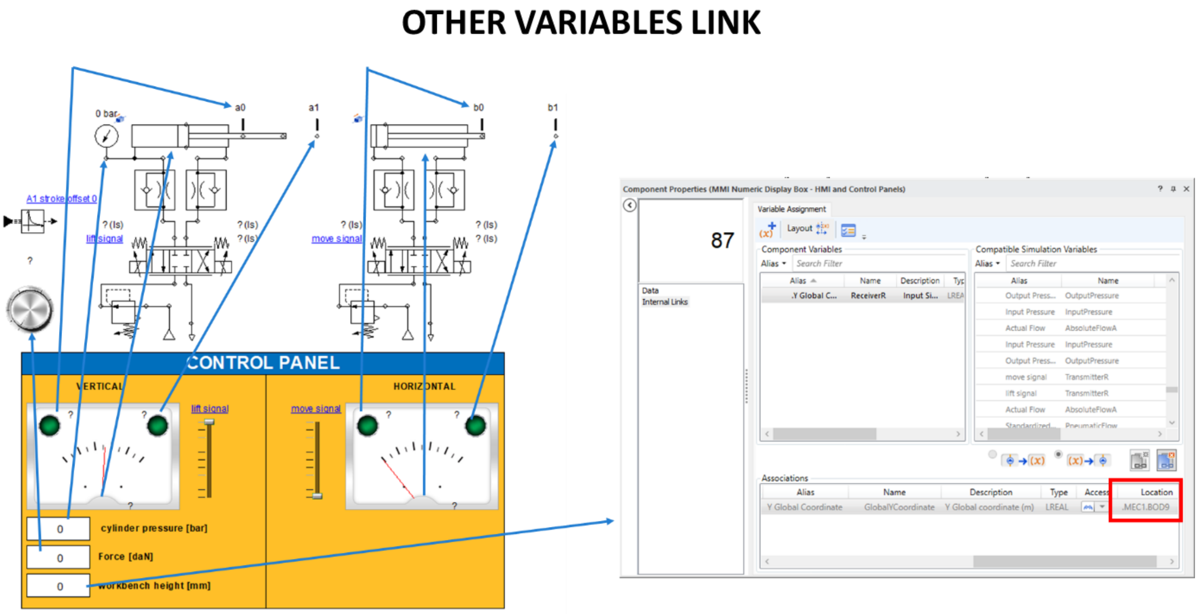
215) By default, the mechanism manager assigns to each body a mass value of 10 kg (and it doesn’t allow to impose a 0 value). In this case the total weight is: 14 bodies x 10 kg = 140kg, that is too much. In order to reduce the total weight (and so, the working pressure of the lift actuator), impose a mass of 0,2 kg to each body

WORKING PRESSURE

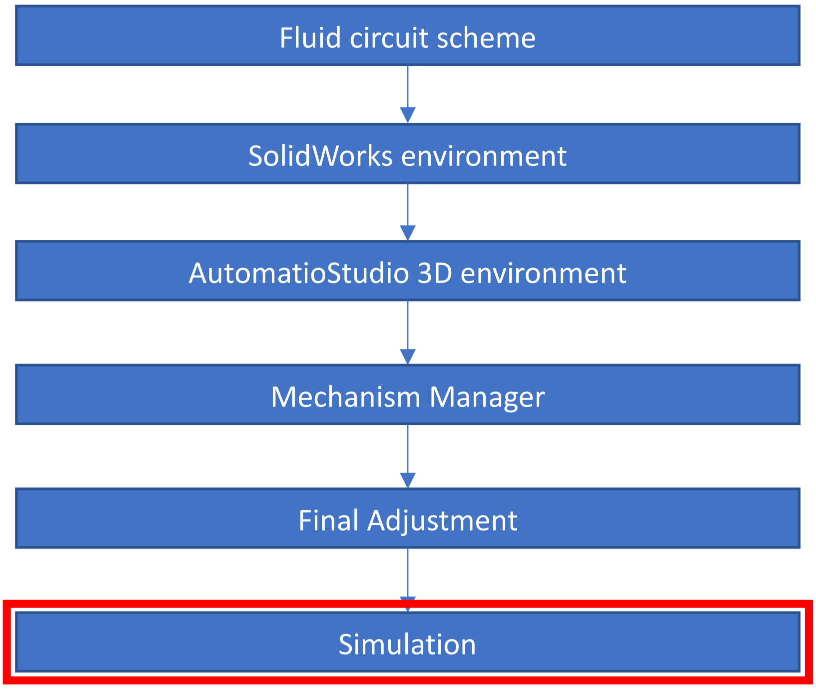




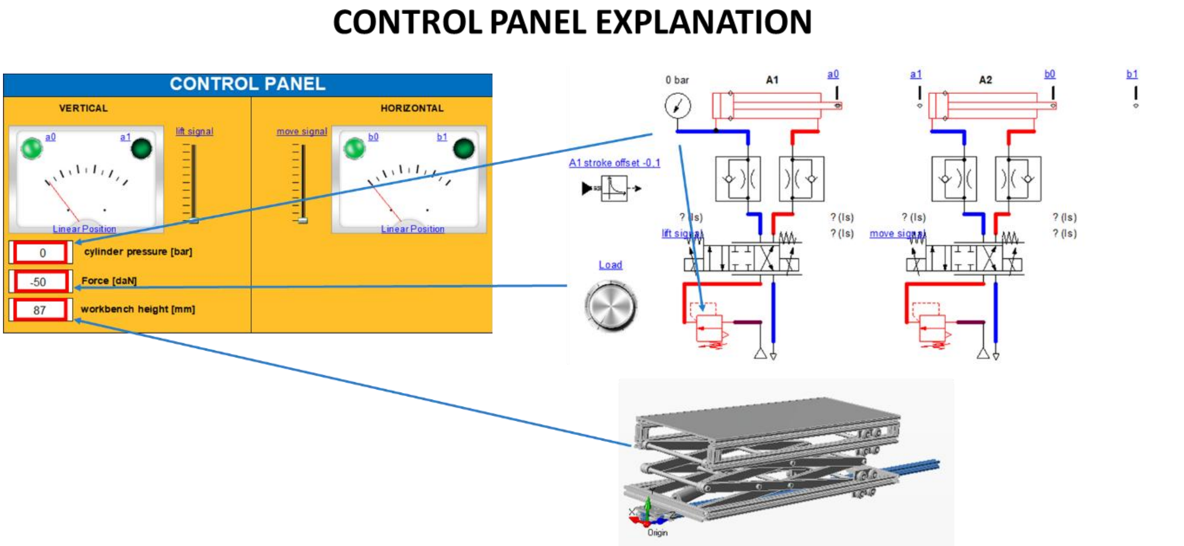
216) Impose a working pressure limit of 30 bar to the pressure source and the pressure regulator



4.3.12. Step

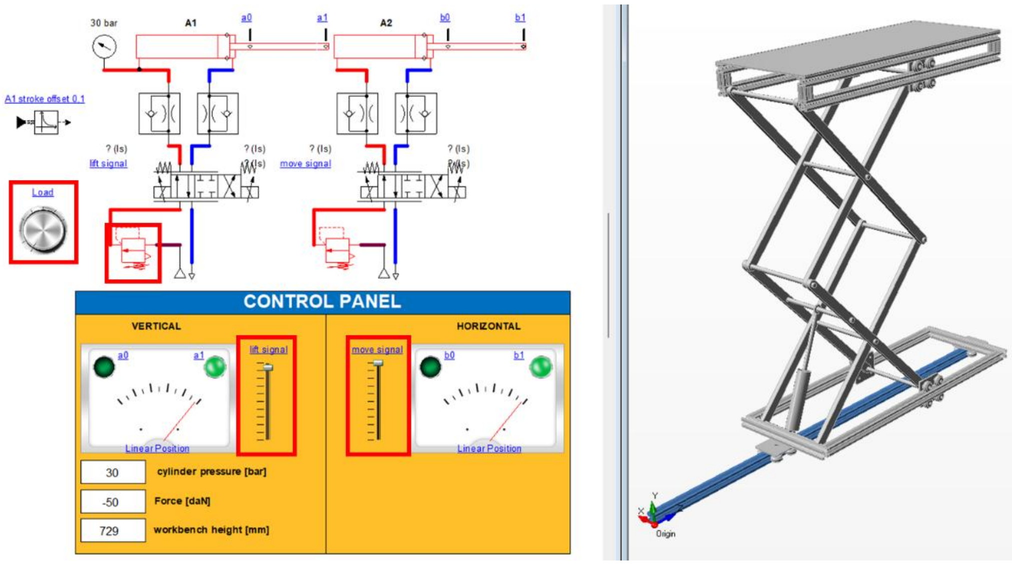


4.3.13. Simulation



217) The last step before to start the simulation is to adjust the HMI. In this tutorial the left side of the control panel, related to the vertical movement, includes 3 display indicating:

- The load entity (controllable using the knob)
- The pressure needed to lift the load (controllable by changing the pressure reducing valve)
- The workbench height (the Y position of its origin)



218) During the simulation try to play with the knob, the pressure reducing valve and the 2 cursors in order to move and lift the pantograph, while evaluating the pressure needed to lift the load.

Note:

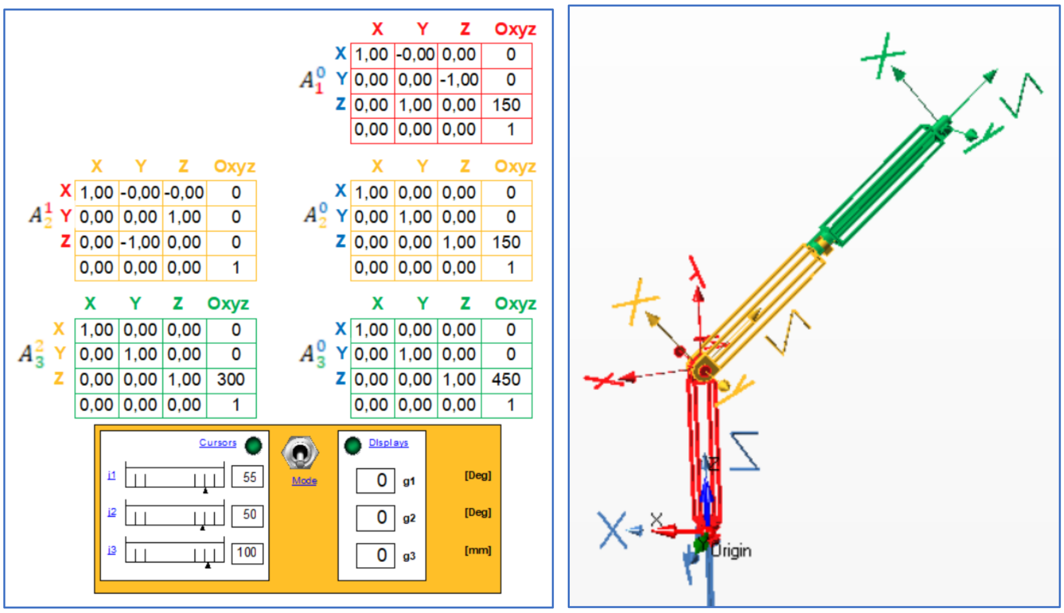
- positive value of the Force means that it is facing upwards
- negative value of the Force means that it is facing downward

!! THANK YOU !!

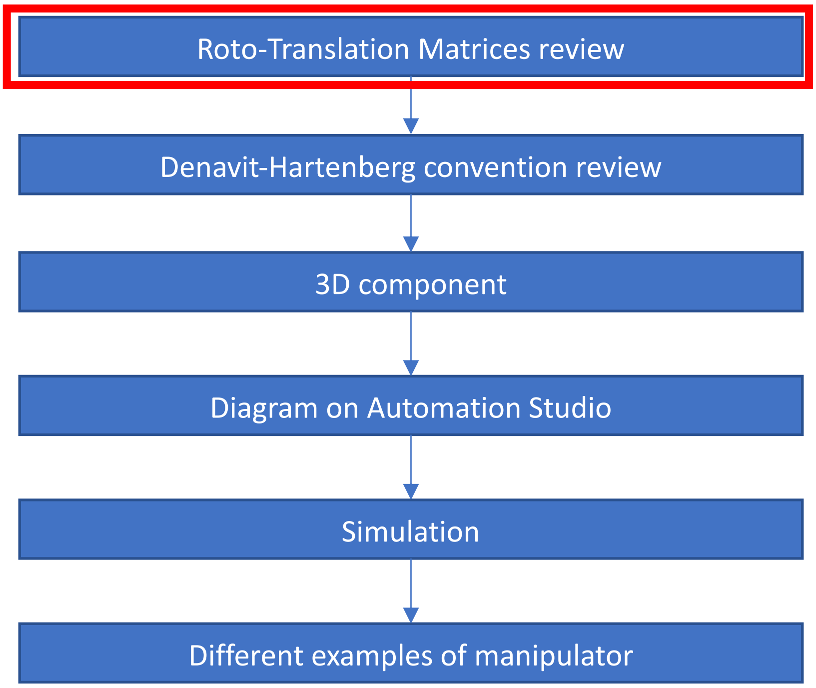
4.4. Project 3: Denavit-Hartenberg convention explanation

4.4.1. Introduction

This is a simple exercise aimed to help students to improve knowledges about the Denhavit-Hartenberg convention and the rotation matrix of each frame in a robotic chain, thanks to the usage of AutomationStudio.
The file is composed by: 1 x diagram; 1 x 3D diagram and 3 x SFC which are useful only to compute the value of each cell of the rotation matrices, thanks to structured texts.
The user will play, on the diagram, with the joint variables and observe the values inside each rotation matrix and the manipulator (which includes each frame) moving on the 3D environment



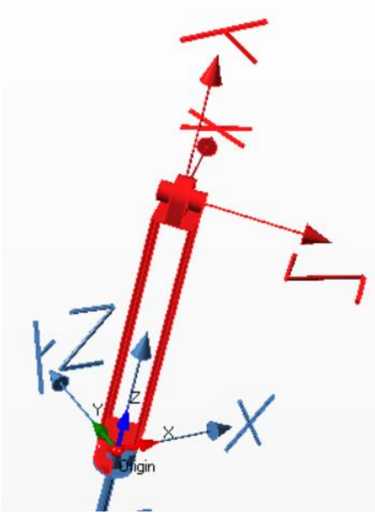
4.4.2. Steps



4.4.3. Roto-Translation Matrices review

A_1^0

	X	Y	Z	Oxyz
X	0,71	-0,00	0,71	0
Y	0,71	0,00	-0,71	0
Z	0,00	1,00	0,00	150
	0,00	0,00	0,00	1



45	g1	[Deg]

Joint angle, around Z

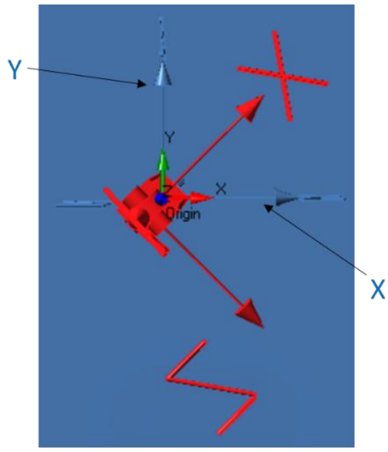
The roto-translation matrix is a 4x4 matrix that describe the rotation and position of a frame with respect to another one. On the example below, the matrix describes the rotation and position of the red frame with respect to the blue one

A_1^0

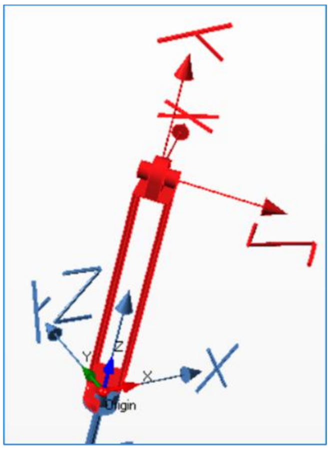
	X	Y	Z	Oxyz
X	0,71	-0,00	0,71	0
Y	0,71	0,00	-0,71	0
Z	0,00	1,00	0,00	150
	0,00	0,00	0,00	1

45	g1	[Deg]

Joint angle, around Z



Top view



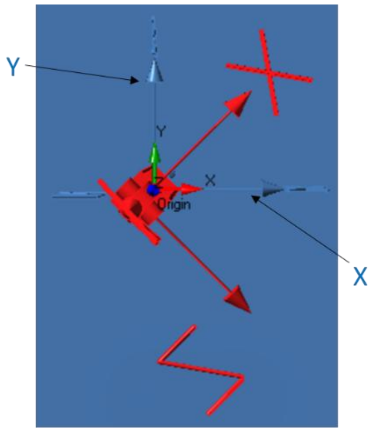
Axonometric view

The first column of the matrix represents the projection of the X axes on the X,Y,Z axes in this configuration (45 degrees joint angle around Z). From the top view it is possible to see that, effectively, the X axes has a component along X equal to 0,71 (cosine of 45 degrees) and a component along Y equal to 0,071 (sine of 45 degrees). From the axonometric view (even if it is more clear from the front view) it is possible to see that X axes has null component along Z axes.

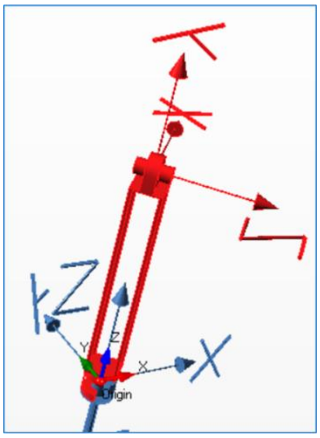
A_1^0	X	Y	Z	Oxyz
X	0,71	-0,00	0,71	0
Y	0,71	0,00	-0,71	0
Z	0,00	1,00	0,00	150
	0,00	0,00	0,00	1

45 g1 [Deg]

Joint angle, around Z



Top view



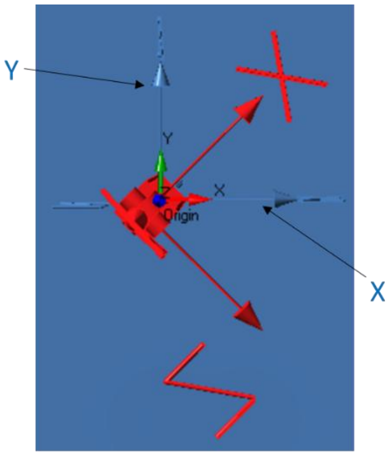
Axonometric view

The second column of the matrix represents the projection of the Y axes on the X,Y,Z axes with this angle joint (45 degrees) around Z. From the top view it is possible to see that, effectively, the Y axes has null component along X and Y. From the axonometric view (even if it is more clear from the front view) it is possible to see that Y axes has the component along Z axes equal to 1 (perfectly in that direction).

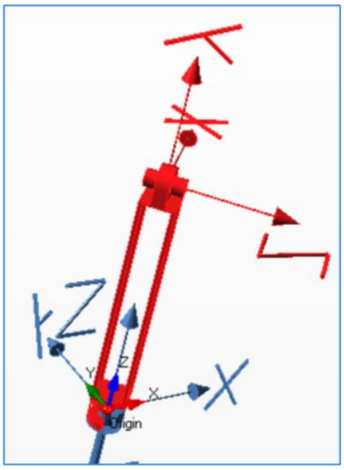
A_1^0	X	Y	Z	Oxyz
X	0,71	-0,00	0,71	0
Y	0,71	0,00	-0,71	0
Z	0,00	1,00	0,00	150
	0,00	0,00	0,00	1

45 g1 [Deg]

Joint angle, around Z

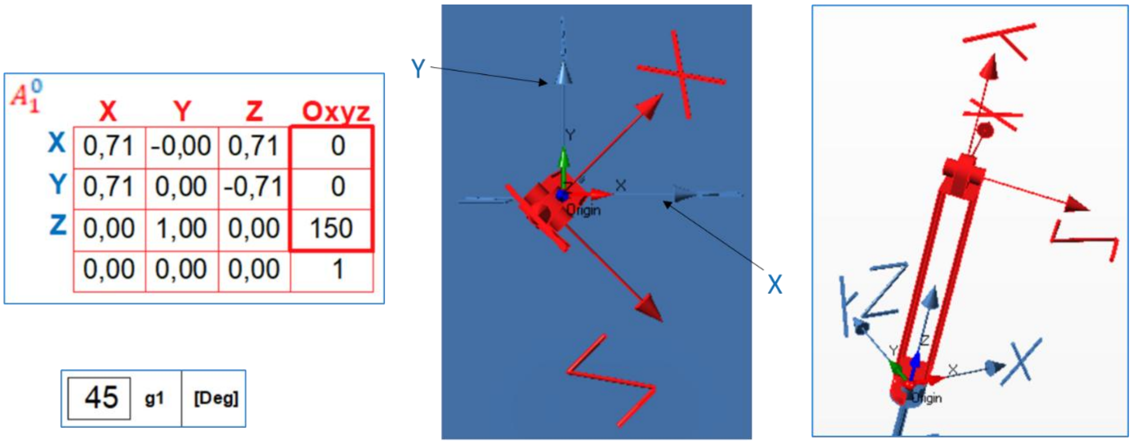


Top view



Axonometric view

Similar to the first column, The third column of the matrix represents the projection of the Z axes on the X,Y,Z axes with this angle joint (45 degrees) around Z. In this case (top view) the only difference with the first column is the <u>negative</u> projection of the Z axes along Y.



Joint angle, around Z — Top view — Axonometric view

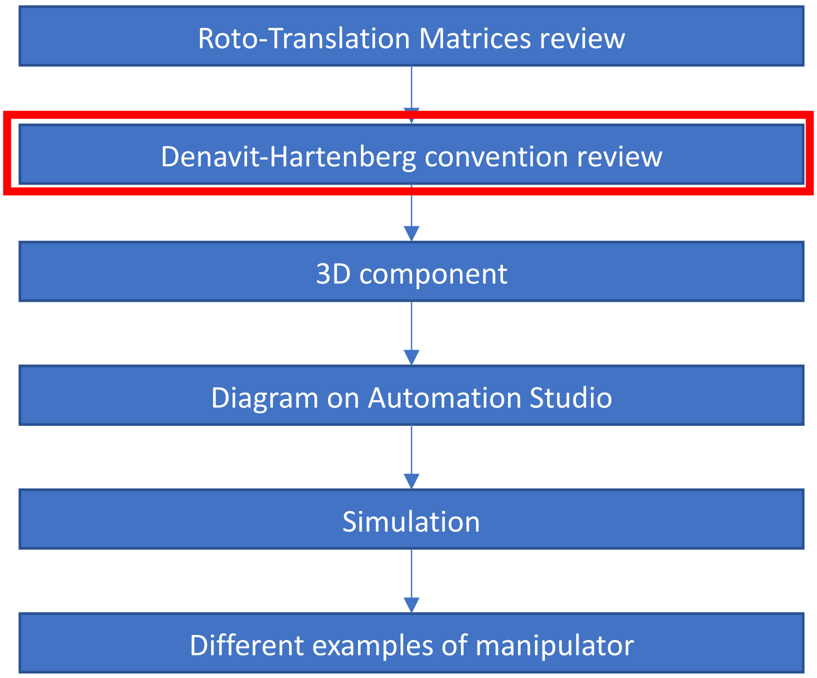
The fourth column of the matrix represents the position of the origin O of the red frame along X,Y,Z. In this case O is positioned on the top of the arm (where is possible to attach another joint) at 150 mm along Z axes (no component along X and Y axes)

A_1^0

	X	Y	Z	Oxyz
X	0,71	-0,00	0,71	0
Y	0,71	0,00	-0,71	0
Z	0,00	1,00	0,00	150
	0,00	0,00	0,00	1

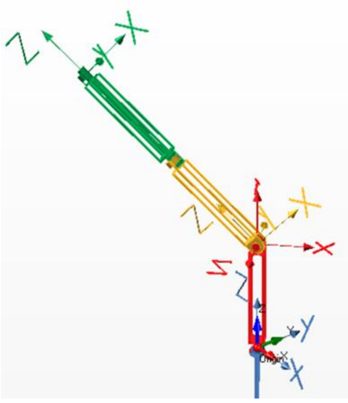
The last remaining raw is constant for all roto-translation matrices

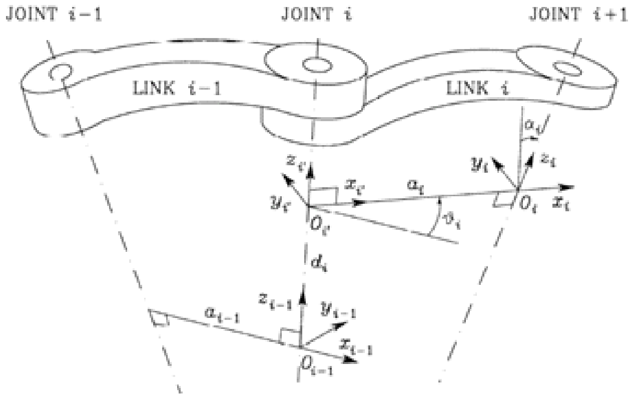
4.4.4. Steps



4.4.5. Denavit-Hartenberg convention review

The Denavit-Hartenberg (DH) convention is a standardized method to describe the kinematic chains of robotic manipulators. It provides a systematic way to assign coordinate frames to the links of a robot and to describe the relative positions and orientations of these frames

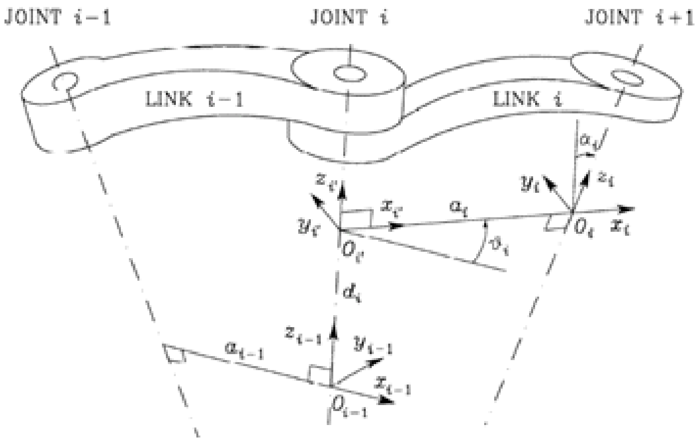




Coordinate Frames: Each link of the robot is assigned a coordinate frame. The position and orientation of these frames are described relative to each other.

$$A_i^{i-1}(q_i) = A^{i-1} A^{i} = \begin{bmatrix} c_{\vartheta_i} & -s_{\vartheta_i} c_{\alpha_i} & s_{\vartheta_i} s_{\alpha_i} & a_i c_{\vartheta_i} \\ s_{\vartheta_i} & c_{\vartheta_i} c_{\alpha_i} & -c_{\vartheta_i} s_{\alpha_i} & a_i s_{\vartheta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformations: The D-H convention uses a series of transformations to describe how one coordinate frame is related to the next. These transformations are represented by homogeneous transformation matrices



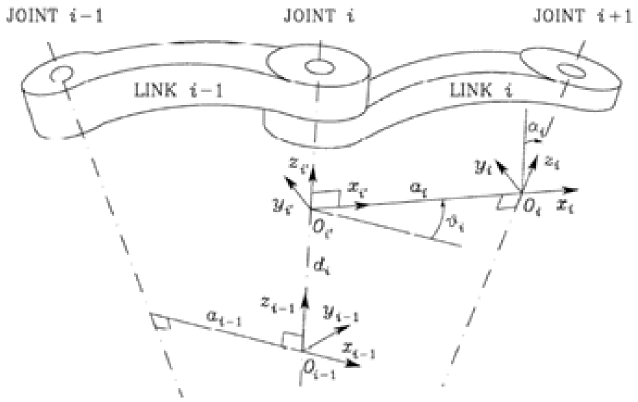
Parameters: Four parameters are used to describe the transformation between two coordinate frames:

- **θ**: Joint angle, which represents the rotation (from xi-1 to xi) around the “i-1” z-axis.
- **d**: Joint offset, which represents the distance (from Oi-1 to Oi’) along the “i-1” z-axis.
- **a**: Link length, which represents the distance (from Oi’ to Oi) along the “i” x-axis.

- **α**: Link twist, which represents the angle (from zi-1 to zi) around the “i” x-axis.

$$A_i^{i-1}(q_i) = A_{i'}^{i-1} A_i^{i'} = \begin{bmatrix} c_{\vartheta_i} & -s_{\vartheta_i} c_{\alpha_i} & s_{\vartheta_i} s_{\alpha_i} & a_i c_{\vartheta_i} \\ s_{\vartheta_i} & c_{\vartheta_i} c_{\alpha_i} & -c_{\vartheta_i} s_{\alpha_i} & a_i s_{\vartheta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The matrix is not constant, but depends on the configuration. In particular, it depends on the single joint variable qi (θi for revolute joint or di for sliding joint)

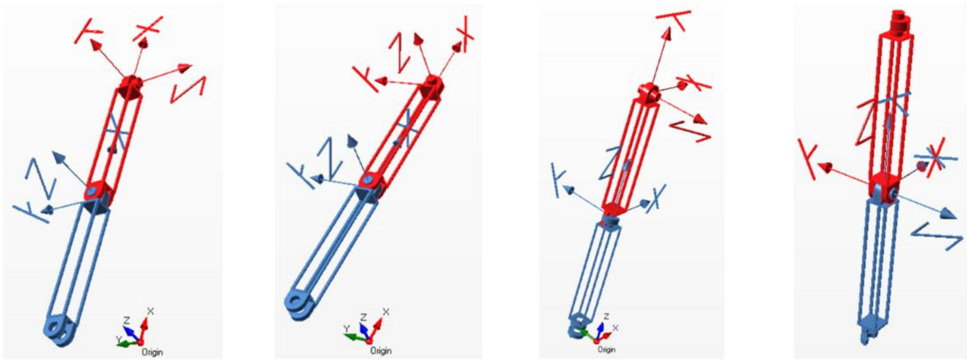


With reference to the figure, we assume that axis I is the joint axis that connects link i-1 (fixed) to link i and will proceed as follows:

- Choose axis zi along the axis of joint i+1
- Locate origin Oi at the intersection of axis zi with the common normal to axes zi-1 and zi.
- Also, locate Oi’ at the intersection of the common normal with axis z
- The common normal between two lines is the line containing the minimum distance segment between them
- Choose axis xi along the common normal, directed from joint i to joint i+1
- Choose axis yi to complete a right-handed frame

The DH convention provides a nonunique link frame in the following cases:

- For frame 0, only the direction z0 is specified. The origin O0 and the direction of x0 cannot be univocally chosen, since O-1 does not exist, and consequently the common normal 0->1 is undefined. O0 and x0 can be arbitrarily chosen
- For frame n, since there is no joint n+1, axis zn is not univocally determined, while xn has to be normal to axis zn-1. Typically, joint n is revolute, thus zn is chosen to be aligned to z
- When to consecutive axes are parallel, the common normal is undetermined, and so is the related frame
- When two consecutive axes intersect, the common normal collapses in a point. Thus, the direction of axis xi can be arbitrarily chosen

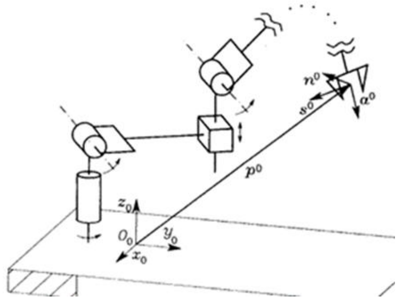


1) 2) 3) (d≠0) 3) (d=0)

In order to set up frame i it is necessary to consider three cases:

1) zi−1 and zi are not coplanar: there exists a unique common normal that defines xi, and the point where this line intersects zi is the origin Oi.
2) zi−1 is parallel to zi: there are infinitely many common normal so, in this case, we are free to choose the origin Oi anywhere along zi. The best choice is to position the origin where "d" results as equal to 0 (best for computation)
3) zi−1 intersects zi: In this case xi is chosen normal to the plane formed by zi and zi−1. The positive direction of xi is arbitrary. The most natural choice for the origin Oi in this case is at the point of intersection of zi and zi−1 (d=0). However, any convenient point along the axis zi suffices (d≠0). Note that, in this case, the parameter "ai" is always equals to 0.

$$T_n^0(q) = A_1^0(q_1)A_2^1(q_2)\dots A_n^{n-1}(q_n)$$

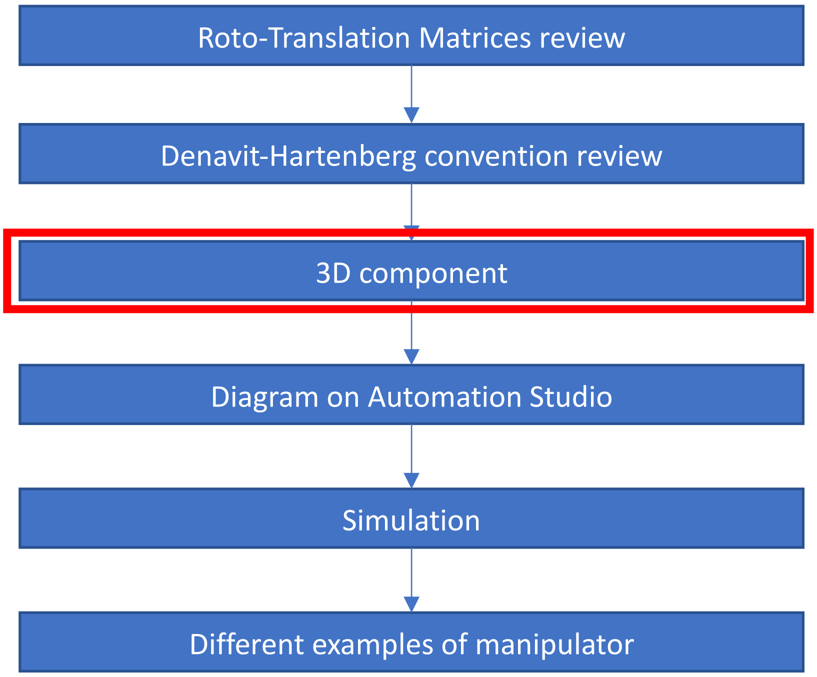


Once obtained all the transformation matrix between each frames, it is enough to apply the matrix product to obtain the position and the orientation of the end-effector (or each frame, eventually) from the origin

$$A_i^{i-1}(q_i) = A_i^{i-1}A_i^{i'} = \begin{bmatrix} c_{\vartheta_i} & -s_{\vartheta_i}c_{\alpha_i} & s_{\vartheta_i}s_{\alpha_i} & a_i c_{\vartheta_i} \\ s_{\vartheta_i} & c_{\vartheta_i}c_{\alpha_i} & -c_{\vartheta_i}s_{\alpha_i} & a_i s_{\vartheta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

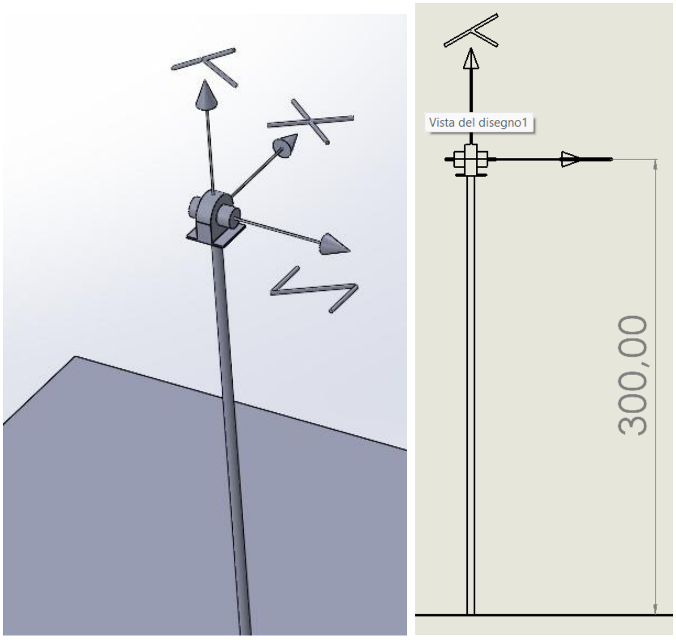
<u>REMEMBER</u>: the choice of position and orientation of each frame is done personally. It is only important, once a frame is placed, to recognize correctly the 4 DH parameter, in order to use the standard matrix below

4.4.6. Step

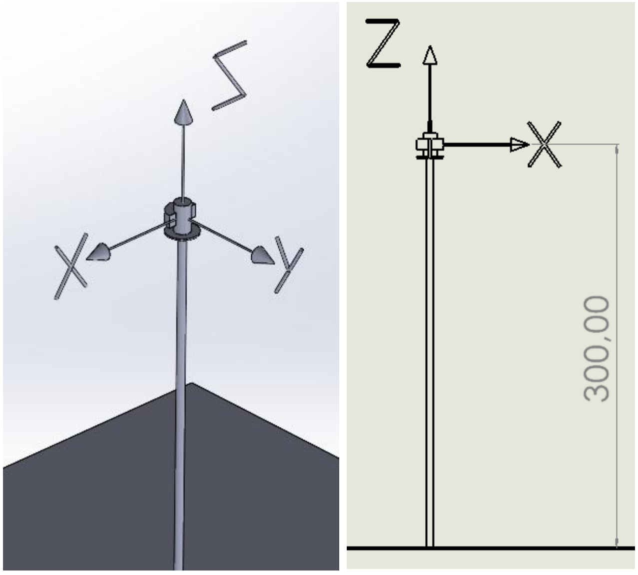


4.4.7. 3D component

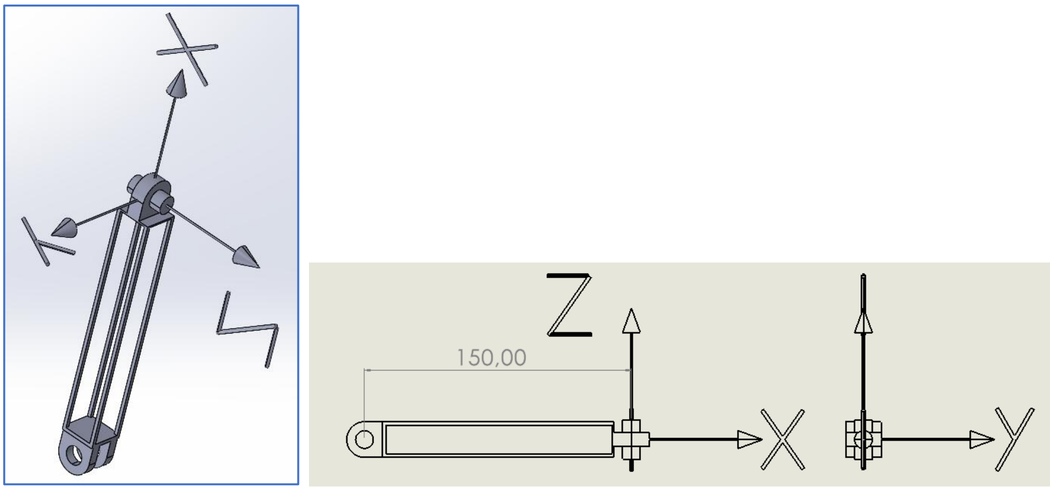
The 3D components (.STEP format) have been realized in order to show their frame while moving as best, but they have not a real application.



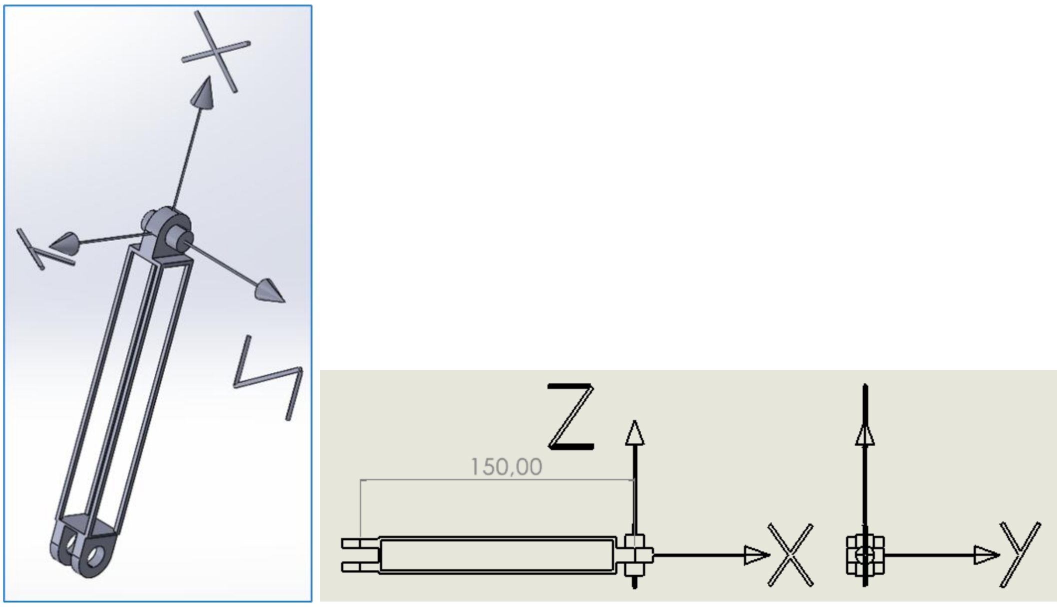
Fixed plane + fixed bar: z-axis horizontal



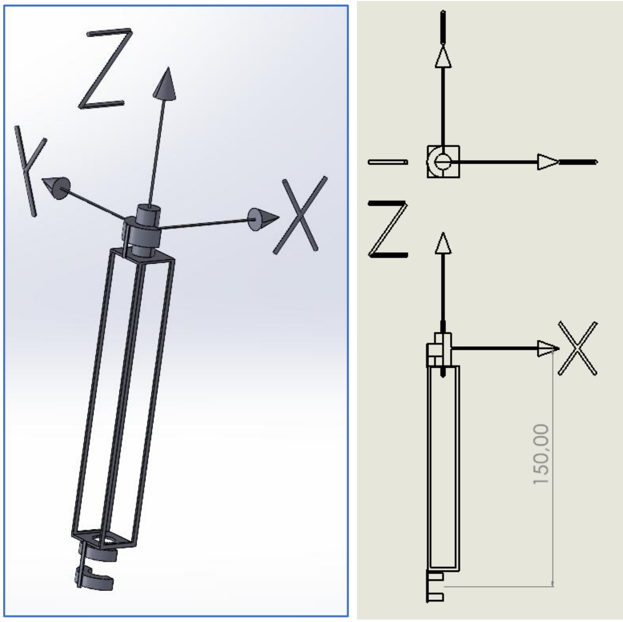
Fixed plane + fixed bar: z-axis vertical



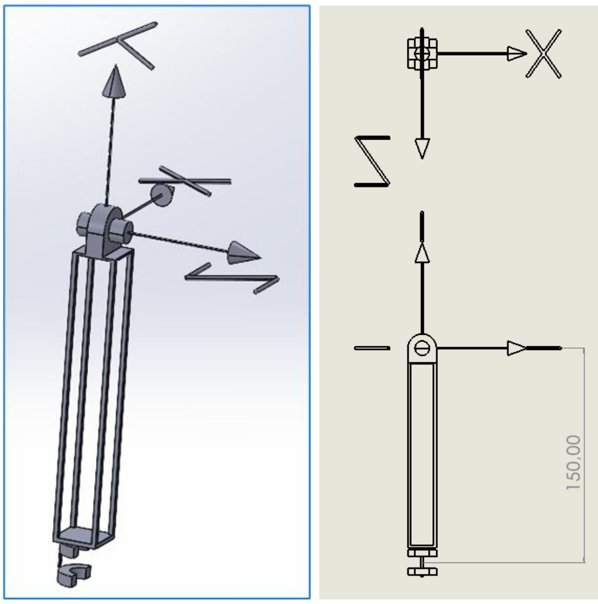
Revolute joint: z-axes not coplanar (1st case)



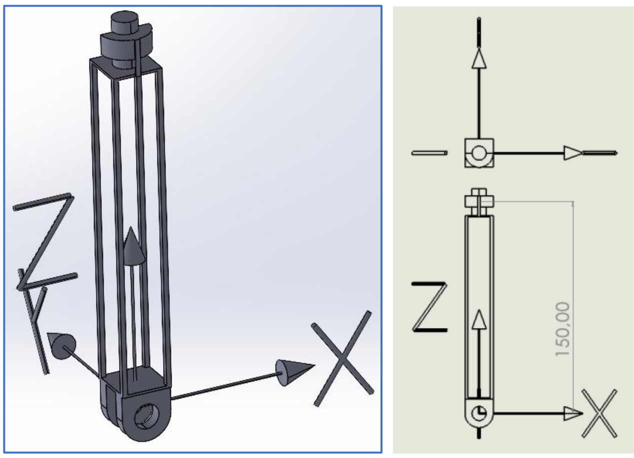
Revolute joint: z-axes parallel (2nd case)



Revolute joint: z-axes collinear (combination of 2nd and 3rd case with d≠0)

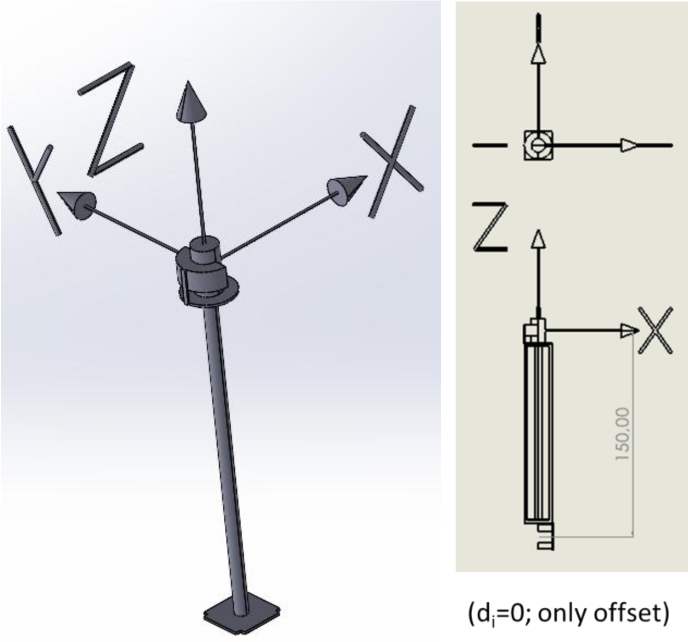


Revolute joint: z-axes intersect with d ≠0

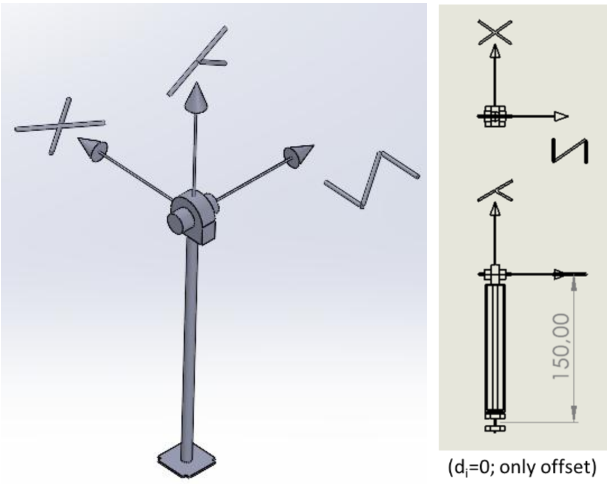


Revolute joint: z-axes intersect with d =0

<u>Sliding joint - fixed part</u>



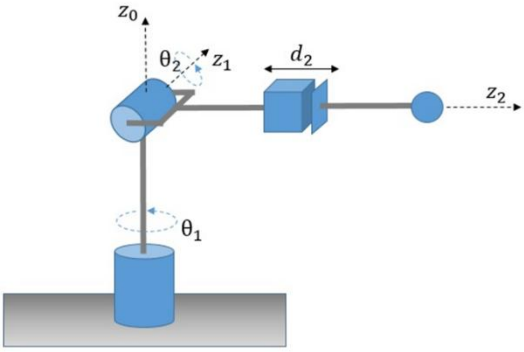
Sliding joint - moving part: z-axes collinear

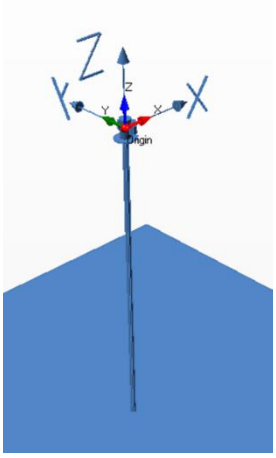


<u>Sliding joint - moving part</u>: z-axes coincident with d $\neq 0$

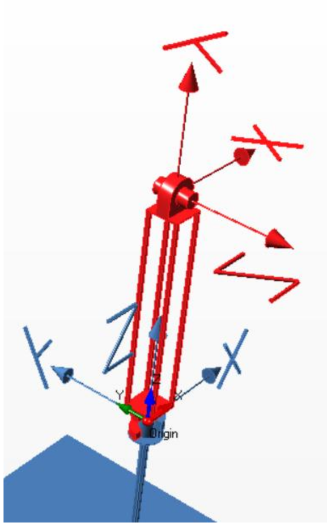
Note: for sliding joint it is impossible to obtain z-axes intersecting with “d” always equal to 0, as “di” is its joint variables and the previous Z axes is always along the sliding direction (no need to place the frame coincident to the previous one)

<u>RRP – Spherical manipulator example</u>





The choice of the first fixed frame "0" is concerning only the Z axis (along the next joint (1) direction, vertically), as mentioned at the slide 13



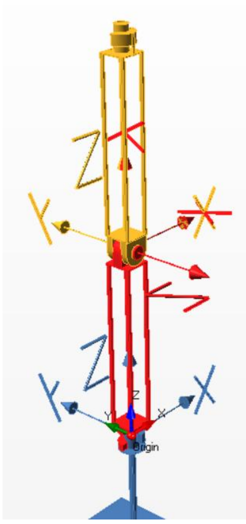
The choice of the frame "1" is done considering that:

- Z has to be oriented along the joint 2,
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d1 exist (150 mm) because the origin Oxyz is directed (and remain constant) along Z axis
- Once Z and Oxyz are placed, it is enough to perform the cross product between Z and Z to obtain the X direction. As it is possible to choose the orientation of X axis, it is

convenient to choose the same orientation of X (remember that the joint variable θ1 is evaluated between X and X)

- Z results to be rotated around X axis of 90 degrees (α, twist)
- So the 4 DH parameters are defined as:

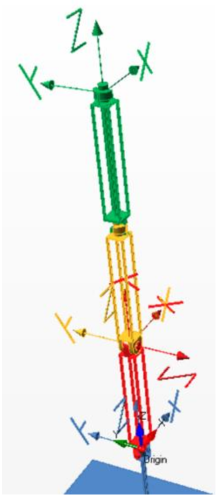
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150	q1_i



The choice of the frame "2" is done considering that:

- Z has to be oriented along the joint 3,
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d1 doesn't exist because the origin Oxyz must be positioned along Z axis. In this case both a2 and d2 are null, so the origin Oxyz must be coincident to Oxyz
- Once Z and Oxyz are placed, it enough to perform the cross product between Z and Z to obtain the X direction. Even in this case, it is convenient to choose the orientation of X as the same of X.
- Z results to be rotated around X axis of -90 degrees (α, twist)
- So the 4 DH parameters are now defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 2	0	-90	0	q2_i



The choice of the frame "3" is done considering that:

- Z has to be oriented along the end-effector (assuming it is fixed on the frame 3)

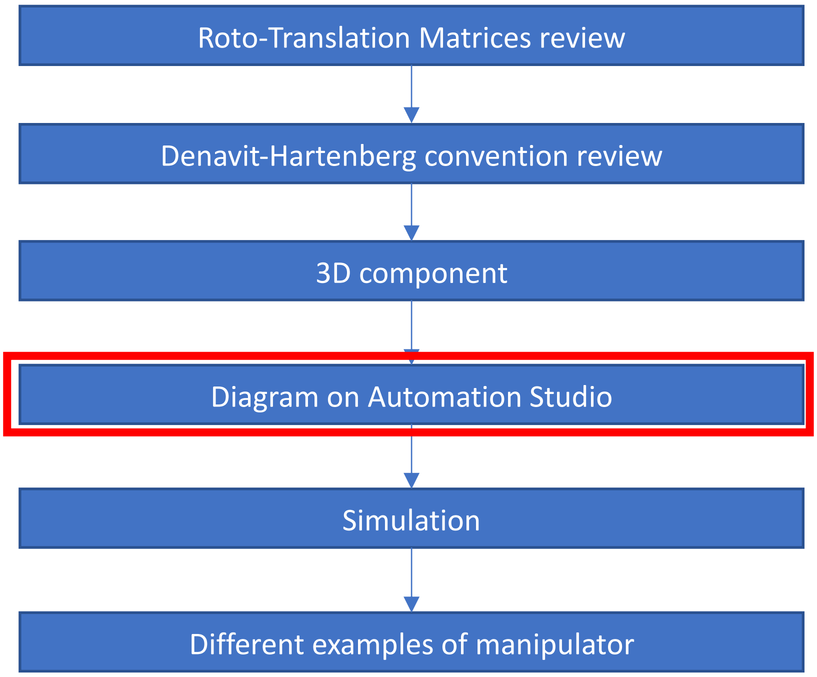
- As a consequence, **zi−1 and zi are collinear**, so a3 is null and it is possible to place Oxyz wherever along Z axis and it is convenient to place it where the end effector is attached to.
- Once Z and Oxyz are placed, it is convenient to choose the X and Y orientations equal to the previous ones,
- The joint variable for the sliding joint is d (not θ) that is along Z axes. In this direction are also present the 2 offsets related to the length of the 2nd and 3rd component (150+150 mm)
- Z results not to be rotated around X axis (α, twist)
- So the 4 DH parameters are now defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 3	0	0	300+q3_i	0

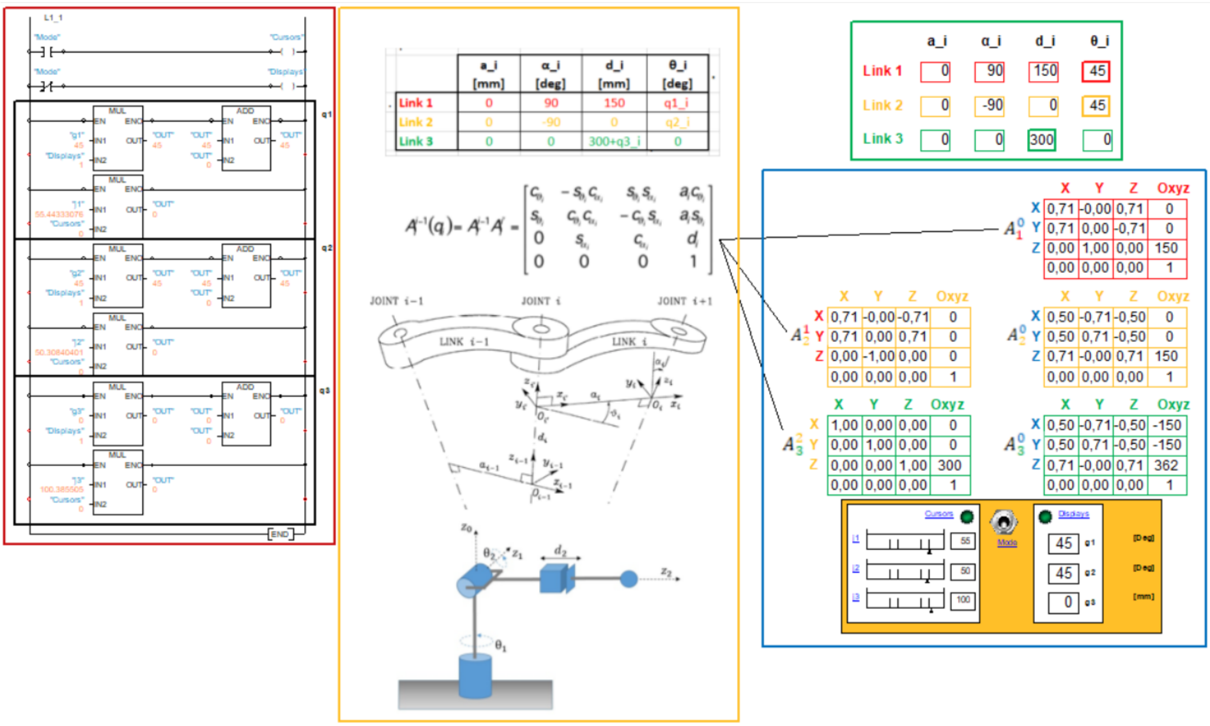
At the end, the resulting DH table (including all the 4 parameter for each joint) is:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150	q1_i
Link 2	0	-90	0	q2_i
Link 3	0	0	300+q3_i	0

4.4.8. Steps



4.4.9. Diagram on Automation Studio

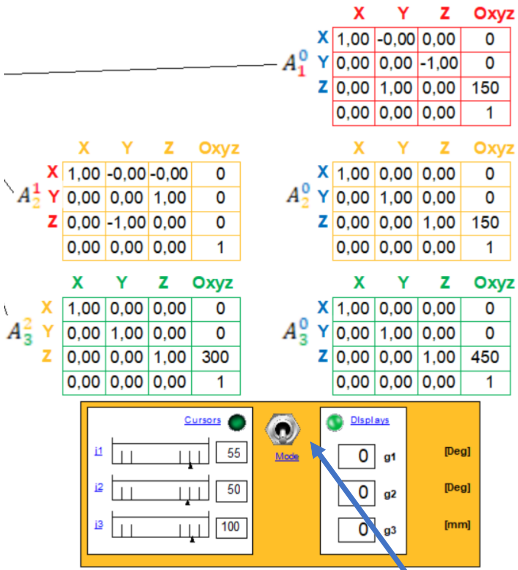


The Diagram is divided in 4 parts:

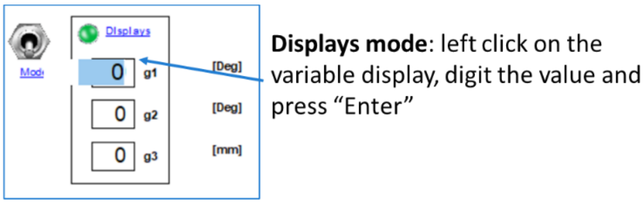
- The HMI, in which the user can manage the joint variables (Li or gi, accordingly to the "Mode" switches selected from the panel) and watch the matrices changing.
- A ladder evaluating the output for each joint variables, according to the Mode selected: it perform the operation

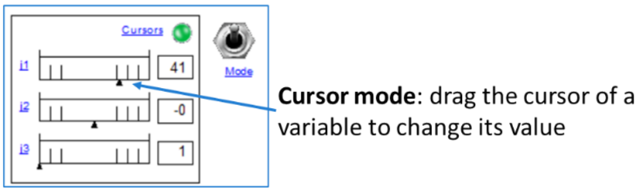
  qi=Li*Mode+gi*NOT(Mode)
- A table in which it is possible to change the 4 DH parameters (except for the joint variable coming from the ladder as outputs: in this case θ1, θ2 and d3)

- Pictures showing how the 3 A_i^$(i-1)$ matrices are been evaluated from the SFC files (according to DH parameter from the table)



On the HMI, the user can decide to change the joint variables playing with the Displays or with the Cursors, according to the Mode switch





On the HMI, the user can decide to change the joint variables playing with the Displays or with the Cursors, according to the Mode switch

The SFC diagrams evaluate the value of each cell of all matrices, by using structured text

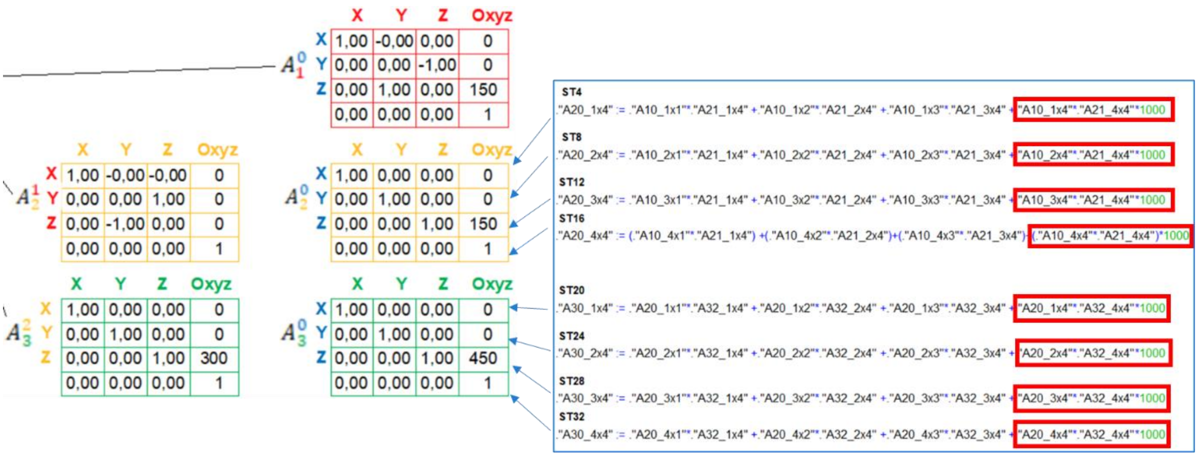
For each cell, a variable is dedicated and it is computed by a single structured text. For example, the variable A10_1x1 (matrix A_1^0; raw 1; column 1) is computed by ST1. The structured text need values compatible with the standard international units, so all angles must be converted into "radiant" and all length in "meter".

A_1^0

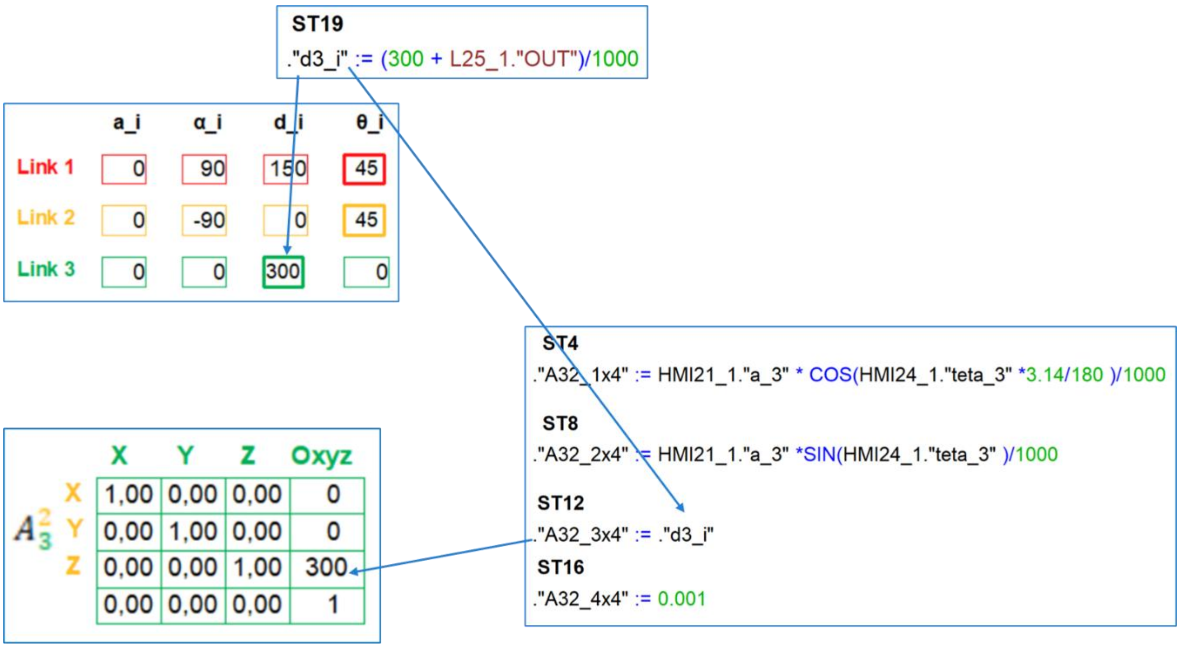
1,00	-0,00	0,00	0
0,00	0,00	-1,00	0
0,00	1,00	0,00	150
0,00	0,00	0,00	1

At the end, the variables inside a matrix are expressed as:

- [Percentage], for the first 3 column (sine and cosine may change from 0 to 1)
- [mm], for the fourth column



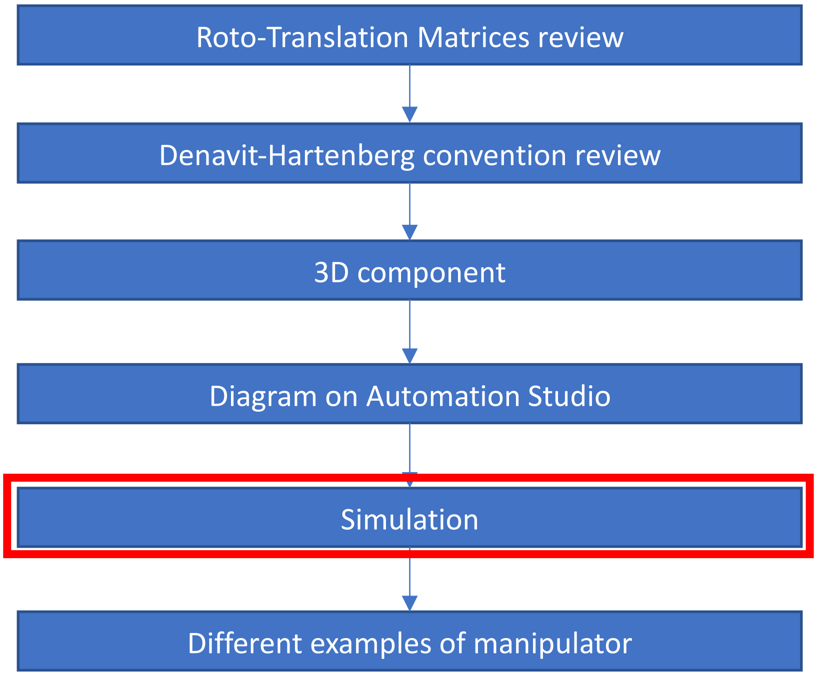
The matrices A_2^0 and A_3^0 are obtained thanks to the matrix product done on SFC3 (in which the last columns must be multiply by 1000, because the product performs the conversion from [mm] to [m] 2 times)



In the case in which a variable is affected by offset (like on the third joint variable in this case), another variable has been created on the "SFC2 diagram" to add this offset.

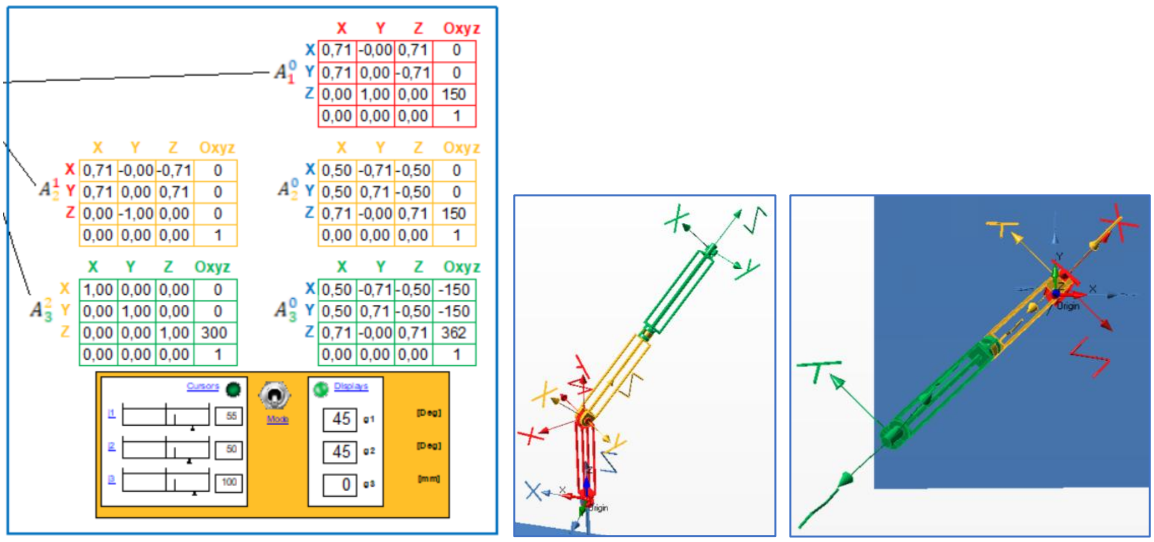
In this case, the variable d3_i add 300 (offset) to the variable coming from the ladder as an output (which should be “d3”).
This new variable already considers the conversion from [m] to [mm], in order to be shown correctly on the DH table (expressed in [mm]), so it is no more needed on the computation of the cell (matrix A_3^2; raw 3; column 4)

4.4.10. Step



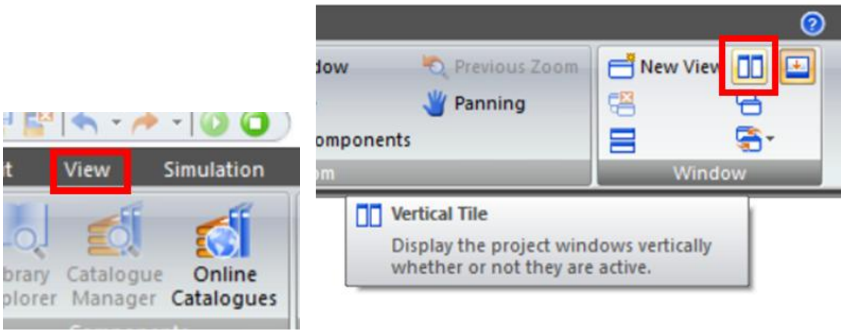
4.4.11. Simulation

RRP – Spherical manipulator example

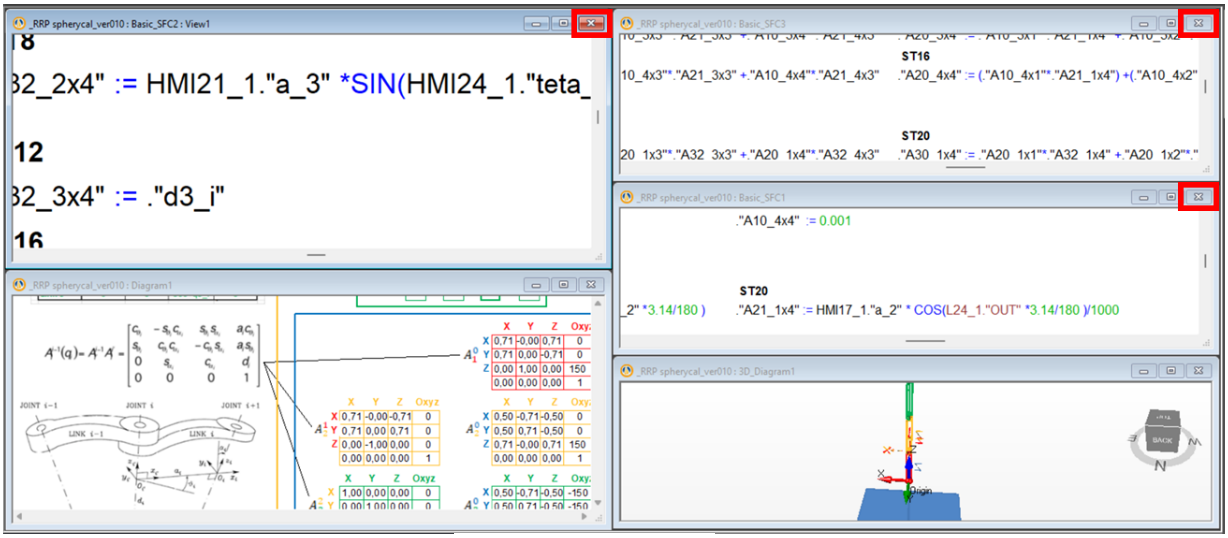


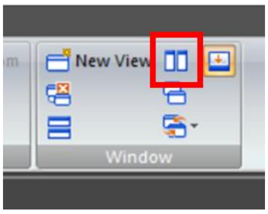
Run the simulation and assign 45 degrees rotation for the first 2 angle variable (for example). Then watch the matrices and the 3D drawing.

In this case X axes has an X component equal to 0,71 (cosine 45 degrees $=\frac{\sqrt{2}}{2}$), and X has components along X and Y equal to 0,71 (cosine and sine of 45 degrees $= \frac{\sqrt{2}}{2}$). The cross product returns that X axes has component equal to 0,5 along X and Y, and it is correct because $\frac{\sqrt{2}}{2} * \frac{\sqrt{2}}{2} = \frac{1}{2}$

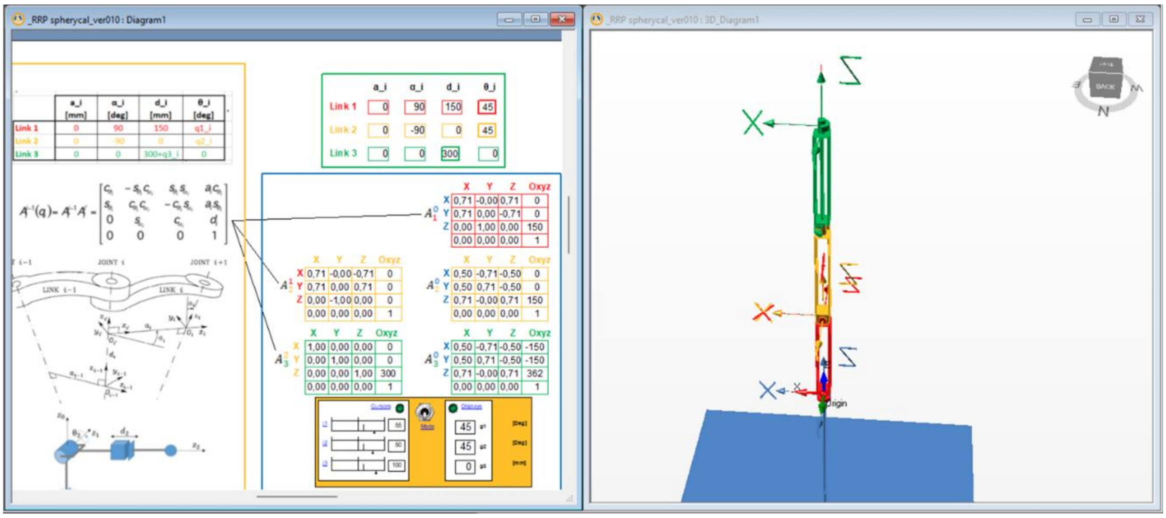


During the simulation, click on "Vertical Tile" on "View" window to display all files



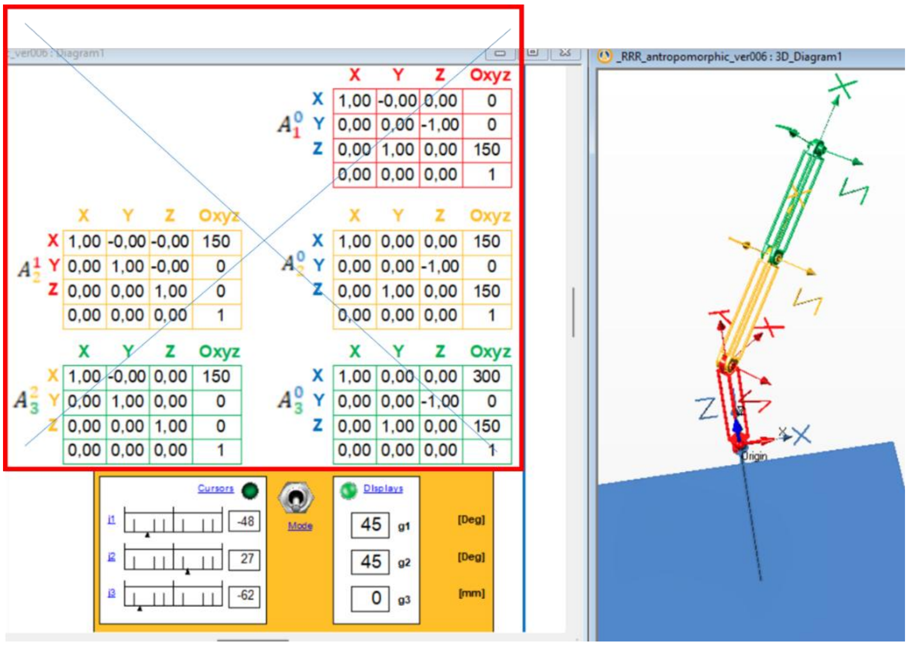


Then, close all the 3 SFC diagram and click again on "Vertical Tile"



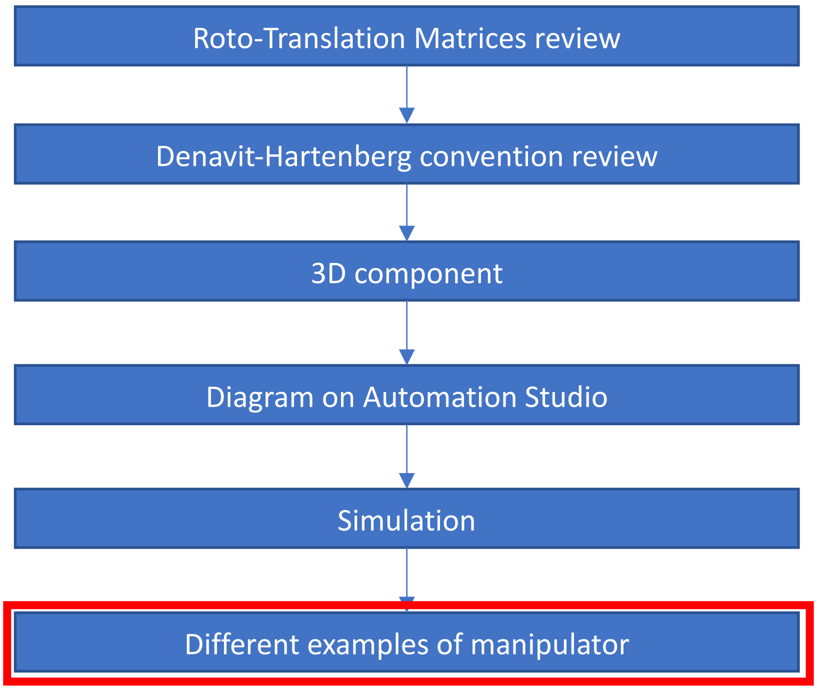
Result: only the 2 interesting parts remain opened and perfectly divided

PAY ATTENTION!



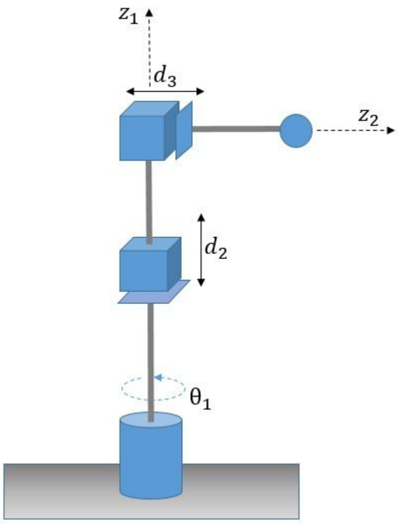
Sometimes it happens that the matrices don't work (maybe it's a problem only for my PC, I hope). In that case stop the simulation and run it again.

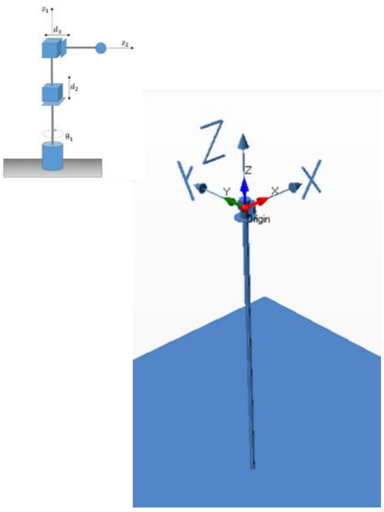
4.4.12. Steps



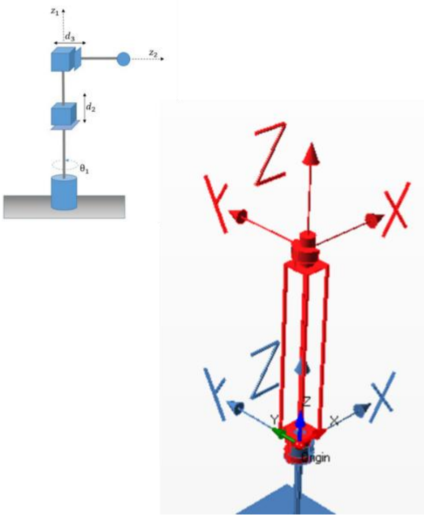
4.4.13. Different examples of manipulator

RPP – Cylindrical manipulator example





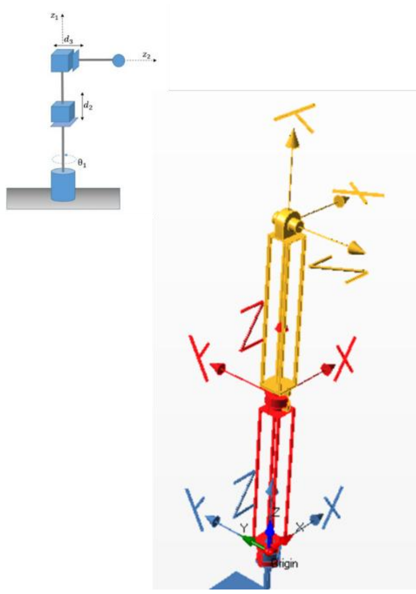
The choice of the first fixed frame “0” is concerning only the Z axis (along the next joint (1) direction, vertically), as mentioned on the slide 13



The choice of the frame “1” is done considering that:

- Z has to be oriented along the joint 2
- As a consequence, **zi−1 and zi are collinear**, so a2 is null and it is possible to place Oxyz wherever along Z axis and it is convenient to place it where the next component is attached to (150 mm offset).
- Once Z and Oxyz are placed, it is convenient to choose the X and Y orientations equal to the previous ones
- Z results not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

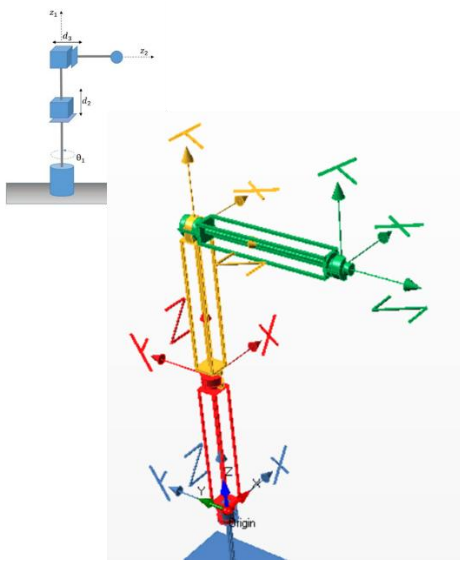
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	0	150	q1_i



The choice of the frame “2” is done considering that:

- Z has to be oriented along the joint 3
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d2 exist (joint variable + offset 150 mm) because the origin Oxyz is directed along Z axis.
- Once Z and Oxyz are placed, it enough to perform the cross product between Z and Z to obtain the X direction.
- X axis result <u>not</u> to be rotated around Z axis (θ, joint angle)
- Z axis result to be rotated around X axis of 90 degrees (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 2	0	90	150+q2_i	0



The choice of the frame “3” is done considering that:

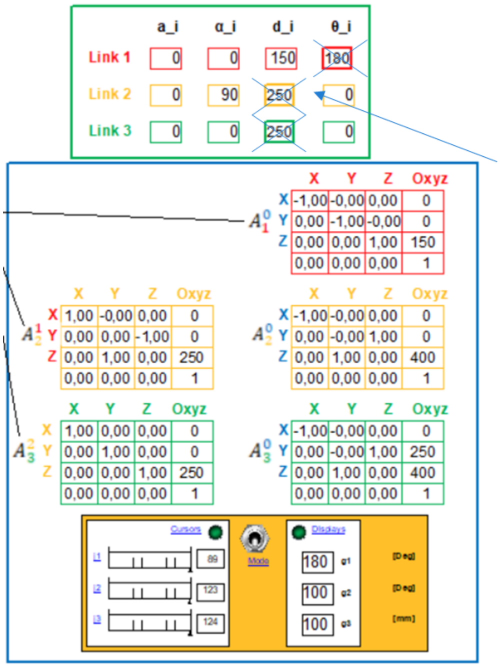
- Z has to be oriented along the end-effector
- As a consequence, **zi−1 and zi are collinear**(3rd case) in the situation in which d3 exist (joint variable + offset 150mm) because the origin Oxyz is directed along Z axis
- Once Z and Oxyz are placed, it is convenient to choose the X and Y orientations equal to the previous ones

- X axis result not to be rotated around Z axis (θ, joint angle)
- Z axis result not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 3	0	0	150+q3_i	0

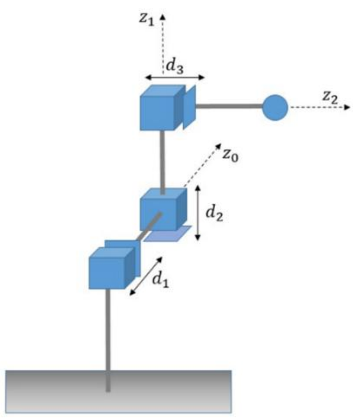
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	0	150	q1_i
Link 2	0	90	150+q2_i	0
Link 3	0	0	150+q3_i	0

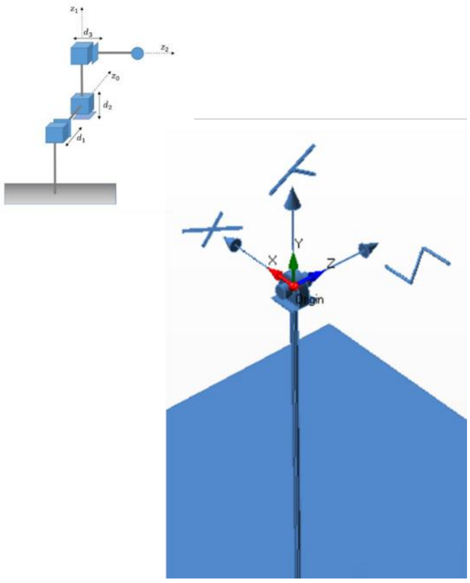
At the end, the resulting DH table (including all the 4 parameter for each joint)



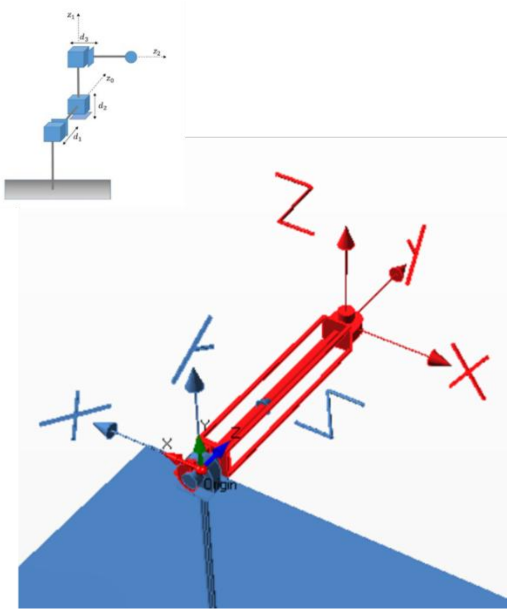
The diagram is practically the same of the RRP example. The only difference is the second joint variable (d2 instead of θ2)

PPP – Cartesian manipulator example





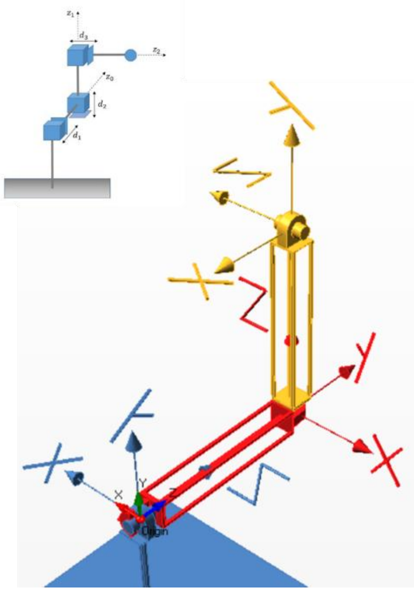
The choice of the first fixed frame “0” is concerning only the Z axis (along the next joint (1) direction, horizontally), as mentioned no the slide 13



The choice of the frame “1” is done considering that:

- Z has to be oriented along the joint 2
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d1 exist (joint variable + 150mm) because the origin Oxyz is directed along Z axis
- Once Z and Oxyz are placed, it enough to perform the cross product between Z and Z to obtain the X direction. As it is possible to choose the orientation of X axis, I have chosen it on the opposite direction of X (I just prefer Y exiting, it is not relevant)
- Z results to be rotated around X axis for 90 degrees (α, twist)
- X results to be rotated around Z axis for 180 degrees (θ, joint angle)
- So the 4 DH parameters are defined as:

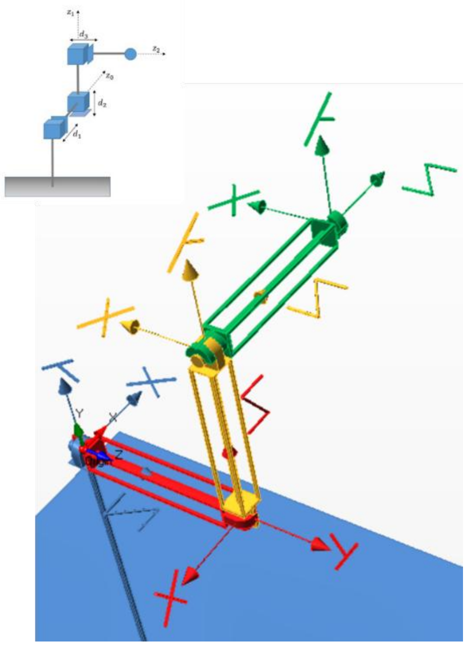
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150 + q1_i	180



The choice of the frame "2" is done considering that:

- Z has to be oriented along the joint 3
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d2 exist (joint variable + 150mm) because the origin Oxyz is directed along Z axis
- Once Z and Oxyz are placed, it enough to perform the cross product between Z and Z to obtain the X direction.
- X axis results to be rotated around Z axis of -90 degrees (θ, joint angle constant)
- Z axis results to be rotated around X axis of 90 degrees (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 2	0	90	150+q2_i	-90



The choice of the frame "3" is done considering that:

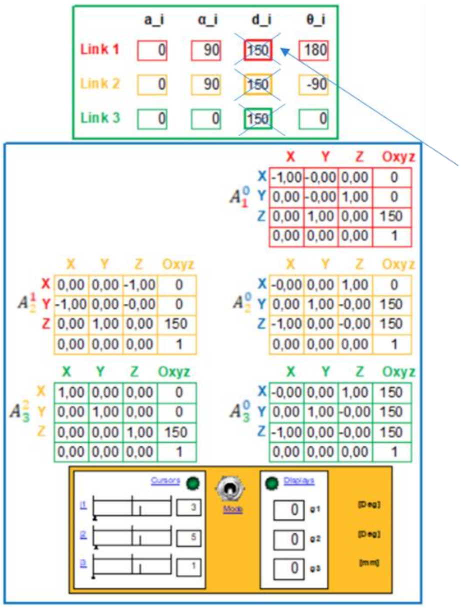
- Z has to be oriented along the end-effector
- As a consequence, **zi−1 and zi are collinear**(3rd case) in the situation in which d3 exist (joint variable + 150mm) because the origin Oxyz is directed along Z axis

- Once Z and Oxyz are placed, it is convenient to choose the X and Y orientations equal to the previous ones
- X axis result not to be rotated around Z axis (θ, joint angle)
- Z axis result not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 3	0	0	150+q3_i	0

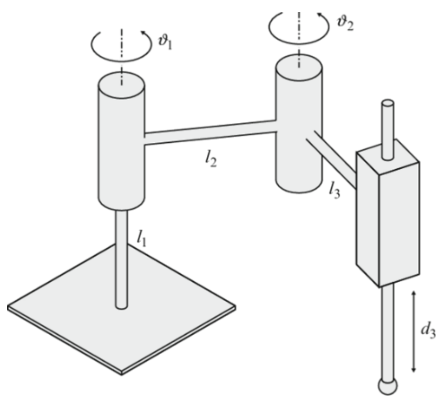
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150+q1_i	180
Link 2	0	90	150+q2_i	-90
Link 3	0	0	150+q3_i	0

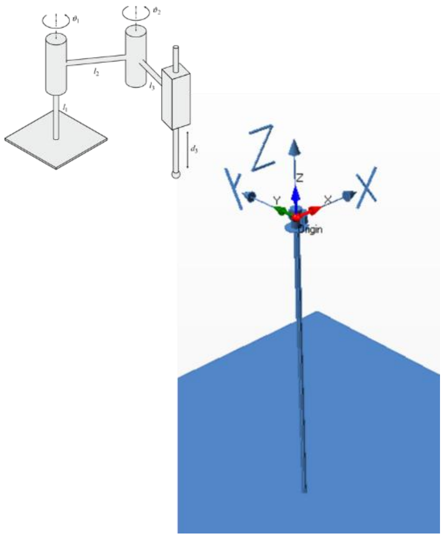
At the end, the resulting DH table (including all the 4 parameter for each joint)



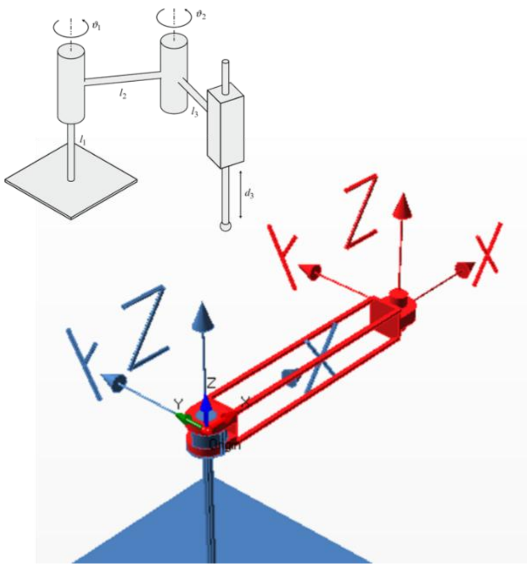
The diagram is practically the same of the RPP example. The only difference is the second joint variable (d1 instead of θ1)

RRP – SCARA manipulator example





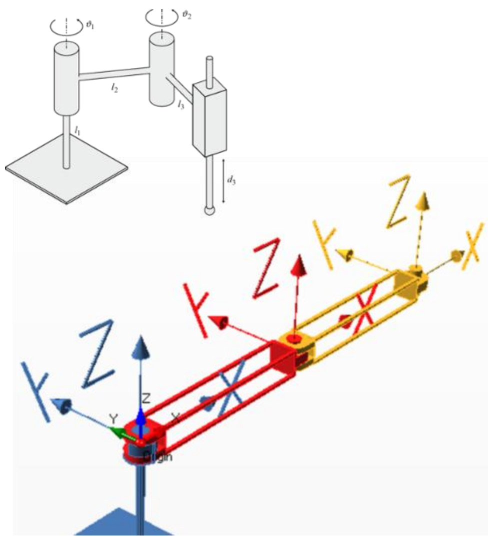
The choice of the first fixed frame "0" is concerning only the Z axis (along the next joint (1) direction, vertically), as mentioned on the slide 13



The choice of the frame "1" is done considering that:

- Z has to be oriented along the joint 2,
- As a consequence, **zi−1 is parallel to zi** (2nd case) and there are infinite common normal, so it is convenient to place the origin in a place in which d=0 and along X axis.
- Once Z and Oxyz are placed, it is enough to place the X axis along the common normal chosen (a≠0).
- Z axis result not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

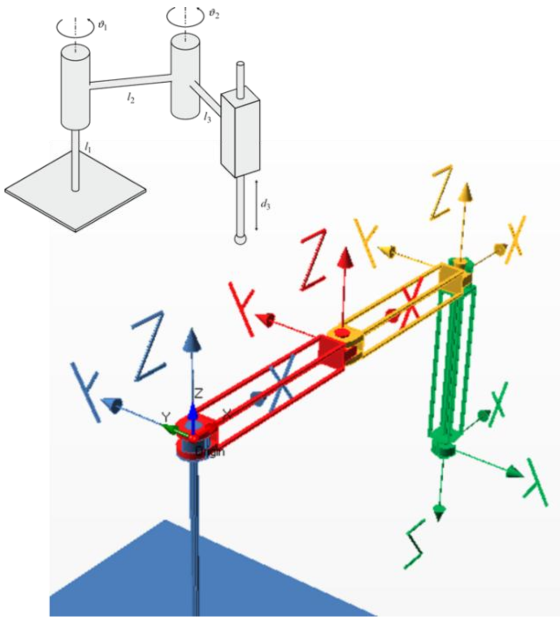
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	150	0	0	q1_i



The choice of the frame “2” is done considering that:

- Z has to be oriented along the joint 3,
- As a consequence, zi−1 is parallel to zi (2nd case) and there are infinite common normal, so it is convenient to place the origin in a place in which d=0 and along X axis.
- Once Z and Oxyz are placed, it is enough to place the X axis along the common normal chosen (a≠0).
- Z axis result not to be rotated around X axis (α, twist)
- So, the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 2	150	0	0	q2_i



The choice of the frame “3” is done considering that:

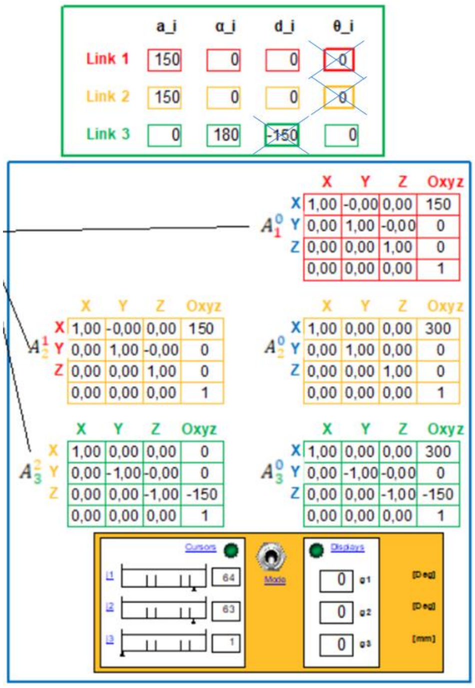
- Z has to be oriented along the end-effector
- As a consequence, zi−1 and zi are collinear(3rd case) in the situation in which d3 exist (joint variable + offset 150mm) because the origin Oxyz is directed along Z axis, but it is negative
- Once Z and Oxyz are placed, it is convenient to choose the X orientations equal to the previous ones

- X axis result not to be rotated around Z axis (θ, joint angle)
- Z axis result to be rotated around X axis of 180 degrees (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 3	0	180	-(150+q3_i)	0

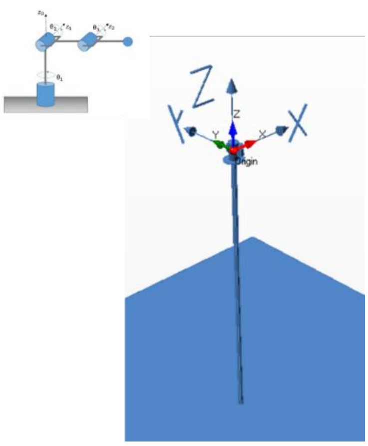
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	150	0	0	q1_i
Link 2	150	0	0	q2_i
Link 3	0	180	-(150+q3_i)	0

At the end, the resulting DH table (including all the 4 parameter for each joint)

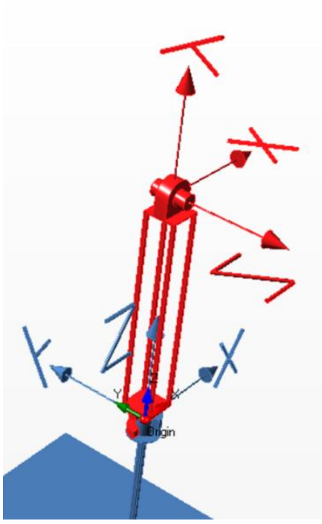


The diagram is the same of the RRP spherical manipulator example.

RRR – Anthropomorphic manipulator example



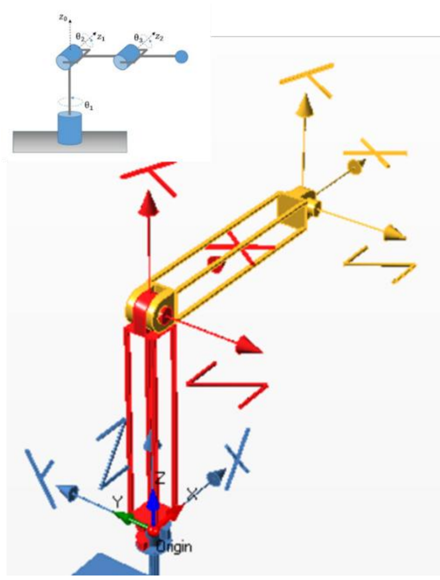
The choice of the first fixed frame “0” is concerning only the Z axis (along the next joint (1) direction, vertically), as mentioned on the slide 13



The choice of the frame “1” is done considering that:

- Z has to be oriented along the joint 2,
- As a consequence, **zi−1 intersects zi** (3rd case) in the situation in which d1 exist (150 mm) because the origin Oxyz is directed (and remain constant) along Z axis
- Once Z and Oxyz are placed, it enough to perform the cross product between Z and Z to obtain the X direction. As it is possible to choose the orientation of X axis, it is convenient to choose the same orientation of X (remember that the joint variable θ1 is evaluated between X and X)
- Z results to be rotated around X axis of 90 degrees (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150	q1_i

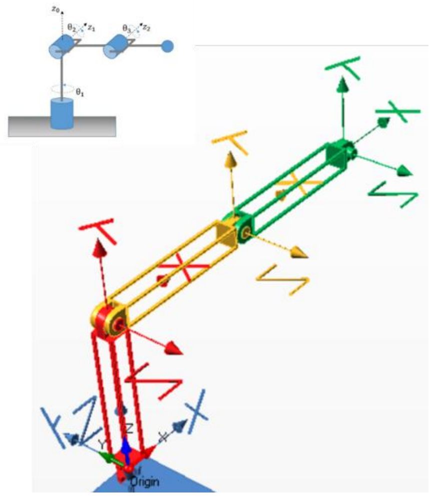


The choice of the frame “2” is done considering that:

- Z has to be oriented along the joint 3,

- As a consequence, **zi−1 is parallel to zi** (2rd case) and there are infinite common normal, so it is convenient to place the origin in a place in which d=0 and along X axis.
- Once Z and Oxyz are placed, it is enough to place the X axis along the common normal chosen (a ≠ 0) .
- Z results not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 2	150	0	0	q2_i



The choice of the frame “3” is done considering that:

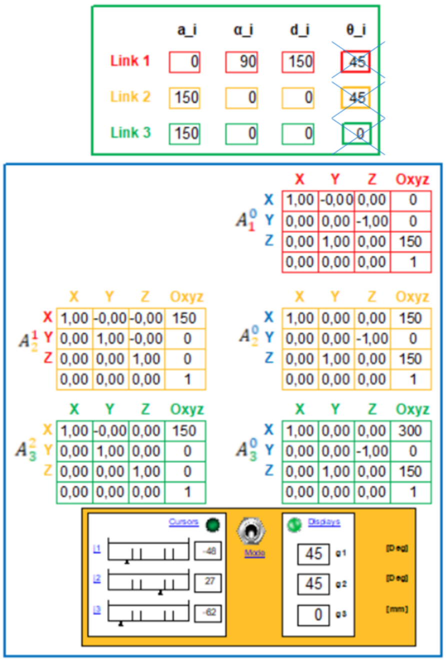
- Z has to be oriented along the end-effector
- As a consequence, **zi−1 is parallel zi** (2rd case) and there are infinite common normal, so it is convenient to place the origin in a place in which d=0 and along X axis..
- Once Z and Oxyz are placed, it enough to place the X axis along the common normal chosen (a ≠ 0) .
- Z results not to be rotated around X axis (α, twist)
- So the 4 DH parameters are defined as:

	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 3	150	0	0	q3_i

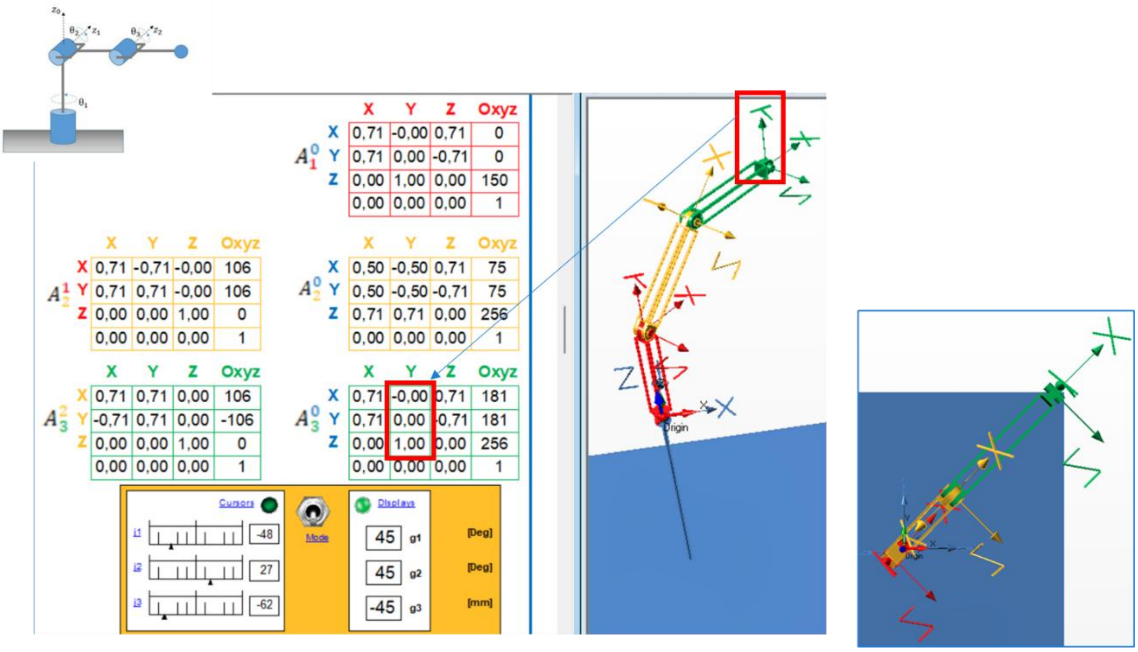
	a_i [mm]	α_i [deg]	d_i [mm]	θ_i [deg]
Link 1	0	90	150	q1_i
Link 2	150	0	0	q2_i
Link 3	150	0	0	q3_i

At the end, the resulting DH table (including all the 4 parameter for each link)

Note: I have chosen the end-effector oriented in this way, in this example, to avoid the frame 3 in the same position of the frame 2



The diagram is practically the same of the RRP example. The only difference is the third joint variable (θ3 instead of d3)



During the simulation, try to impose, for example: 45 degrees for the first joint; 45 degrees for the second joint and -45 degrees for the third one. Then, looking at the 3D drawing, check if the results obtained from the matrices make sense.

!! THANK YOU !!

5. Conclusion

This thesis has demonstrated the potential of Automation Studio as an educational tool for teaching mechatronics engineering, through the development and implementation of three practical tutorials. These tutorials focused on key areas such as: the simulation of pneumatic systems, PLC programming, and the movement of components in a 3D environment, all of which are crucial aspects of mechatronics engineering. By providing students with hands-on experience and realistic simulations, Automation Studio can help to easily reduce the gap between theory and practice, leading to a deeper understanding of engineering principles.

The first tutorial introduced the Mechanism Manager, a tool that allows students to simulate the kinematic and dynamic behaviour of mechanical systems. Through this tutorial, students learn how to create mechanical links between bodies and actuators, simulate the effects of loads and forces, and analyse the performance of a system which change its geometry dynamically. Thanks to the plotter and the dynamic excel file which include the formula used for the mechanical computation, they can change parameters (like the entity of the load, the pressure and the geometry of the mechanism) and to compare the results coming from the plotter to the results visible on the cells of the excel file. As the fluid circuit is pneumatic, they can also notice that oscillations happen.

The second tutorial focused on the 3D modelling capabilities of Automation Studio, guiding students through the process of importing 3D drawings, assembling components, and simulating their movements in a virtual environment, thanks to the variable association between the 3D components and the fluid circuit (affected by loads thanks to the mechanism manager, like in the first tutorial). This tutorial emphasized the importance of understanding spatial relationships and visualizing the behaviour of complex systems. Students can then use their proper creativity to realize different exercises.

The third tutorial study the application of the Denavit-Hartenberg convention for robotic arm kinematics, providing students with a practical understanding of coordinate frames, transformations, and rotation matrices. This kind of topic are usually studied on the paper, and it could be difficult to understand how they can reflect a real environment. This tutorial highlighted the power of Automation Studio in visualizing and analysing the movements of robotic systems.

The use of Automation Studio in an educational setting offers several benefits. Firstly, it allows students to visualize and interact with complex systems in a safe and controlled environment. This can be particularly helpful for understanding abstract concepts or those that are difficult to demonstrate physically. Secondly, Automation Studio provides a platform for students to develop and test their own designs, encouraging creativity and problem-solving skills. Finally, the software's user-friendly interface and extensive libraries make it accessible to students with varying levels of technical expertise.

While Automation Studio offers numerous benefits for educational purposes, there are also some limitations to consider:

- The cost of the software, which may be prohibitive for some institutions.
- The need for instructors to be adequately trained in using the software, which may require additional time and resources.

- The educational version of the software has a limit of the maximum number of components that can be used, as it is intended for simple projects

Despite these limitations, the potential benefits of Automation Studio for enhancing the learning experience in mechatronics engineering are significant.

The integration of Automation Studio into the mechatronics engineering curriculum can lead to a more engaging and effective learning experience. Moreover, Automation Studio can facilitate collaborative learning, as students can work together to design, simulate, and analyse complex systems.

6. References

- Famic website:
  https://www.famictech.com/en/
- Webinar mechanism manager:
  https://www.youtube.com/watch?v=UIzvbX7qIHQ&ab_channel=FamicTechnologies
- Fluid automation slides
- Robotic slides