DIGITIZING PRODUCTS:
CREATING DEMONSTRATORS
FOR FUTURE EDUCATION

Structural Health Monitoring

FI UBB

Resita, October 2022

Co-funded by the Erasmus+ Programme of the European Union

Project consortium

Dissemination level

Code	Access granted to
PU	Public

Legal Disclaimer

About the DigiDemo project

Environmental challenges and digital transformation are two of the main drivers changing the world and the way business will be done in the future. Therefore, it is essential to enable future employees to address these drivers. The skills and competencies needed to develop digitalized products and awareness of the environmental challenges are therefore crucial for the European workforce and industry to continue being competitive in a future green economy and to maintain jobs across Europe.

The DigiDemo project addresses these challenges by developing demonstrators especially for higher education allowing to improve mainly mechanical engineering studies by integrating skills and competences allowing them to understand, develop and commercialise connected products. The results will be publicly available and can be used by every institution interested in integrating this type of training in their cursus.

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Revision history

Version	Date	Author(s)	Description
1.0			Initial draft

Document status

Status description
For Information

Abbreviations

UCN	University College Nordjylland (Denmark)
FIV	Fagskolen I Viken (Norway)
FHV	Fachhochschule Vorarlberg (Austria)
ESTA	ESTA Belfort (France)
UBB	Babes-Bolyai University (Romania)

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1 Introduction

The project is proposed for courses in the 5th and 8th semesters of the Mechanical engineering program and the 6th semester of the Industrial informatics program at the Faculty of Engineering of UBB. A class has in the normal case between 10 and 15 students who work in small teams and have to fulfil different tasks. Typically, the students in a class belong to a unique study program but are equipped with transversal/interdisciplinary competencies. For extra-curricular activities such as research and publication of papers, students can collaborate in interdisciplinary teams.

Students from mechanical engineering will focus on aspects regarding the vibration of structures, damage assessment & prediction of remaining life, and the use of advanced materials or structures in building engineering structures. Associated with this knowledge, the students gain skills in measurement systems, signal processing, and using artificial intelligence (AI) in specific mechanical engineering applications.

Students from informatics focus on designing measurement systems and developing virtual instruments (VI). The acquired signals are processed involving Python programs made by the students. Particular attention will be paid to understanding physical phenomena and implementing AI techniques for real-world applications based on these phenomena.

The students' tasks are not limited to using the demonstrator, but also to setting up the demonstrator and adapting it for different types of tests. In normal case, students work in specialized groups, but working in interdisciplinary groups is also possible.

Figure 1: Overview of the demonstrator

Table 1: Specification of key properties of the focus project

Key Property	Value		
EQF level	6 (Bachelor)	6 (Bachelor)	6 (Bachelor)
Year of study	3	3	4
Domain	Mechanical engineering	Industrial informatics	Mechanical engineering
Workload	4 ECTS	5 ECTS	5 ECTS
Keywords	Vibration, Structural Health Monitoring, Sensor, IoT, Virtual instrument		

2 Description of the demonstrator

This demonstrator replicates industrial structures such as girder bridges, crane girders, frame elements, machine parts, etc. The structure is equipped with sensors and actuators, which are connected to an operating system via a Wi-Fi or Ethernet network. The demonstrator fulfills all functions requested by advanced monitoring systems existent in the industrial environment. Common functions include data acquisition for static and dynamic tests, data transmission, storage, and processing.

Figure 2: The demonstrator prepared for static experiments

Along with the mechanical stand presented in Figure 2, the proposed demonstrator involves a monitoring system consisting of two computers with specialized software, an acquisition system, and an excitation system. The components of the monitoring system can be replaced with an Arduino developer kit and associated sensors. The use of such components has the advantage of reduced price but involves competencies that are not common for mechanical engineering students. Therefore, these components can be used just by students from informatics classes.

2.1 The mechanical part of the stand

The mechanical part of the stand, see Fig. 3, is composed by:

- a solid and stable frame (1)
- two bearings, each one composed of
    - guiding element (3)
    - U profile (4)
    - lower plate (5)
    - upper plate (6)
- screws

The specimen (2) is supported by one or two bearings and is used to test the static and/or dynamic behaviour of structures. These laboratory-scale structures are beams with various cross-sectional areas, girders, or trusses. The material of the specimens can be metal, timber, or composite. The specimens are fixed using bearings that permit simulating boundary conditions of different types.

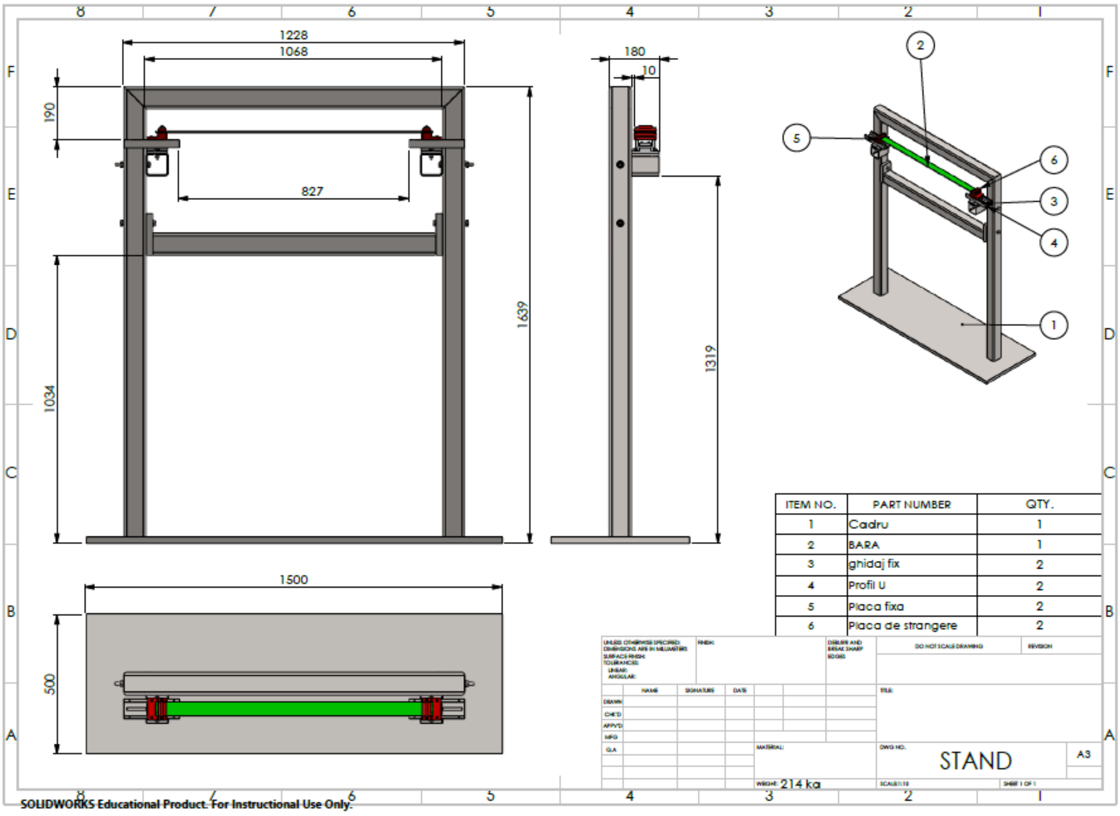


Figure 3: Overview of the mechanical stand detailing the individual components

2.1.1 The frame

The frame is made of steel elements welded together, except the intermediate girder which is fixed by screws on the vertical frame components. The main dimensions and the geometry of the frame are presented in Figure 3, and the technical drawing of the assembly and the components is given in Annex B. The role of the frame is to sustain the bearings and the specimen, ensuring a horizontal position to the latter.

Any other type of frame can be used, but it should be stable and natural frequencies close to that of the specimens must be avoided.

2.1.2 The bearings

The bearings consist of a series of elements that permit fixing the specimen at one or two of its ends. The bearing elements, listed at the start of this sub-section 2.1, are represented in Figure 4 as an assembly. One of the features of this bearing system is that it permits adjusting the distance between the two restraining points, i.e., the length of the specimen.

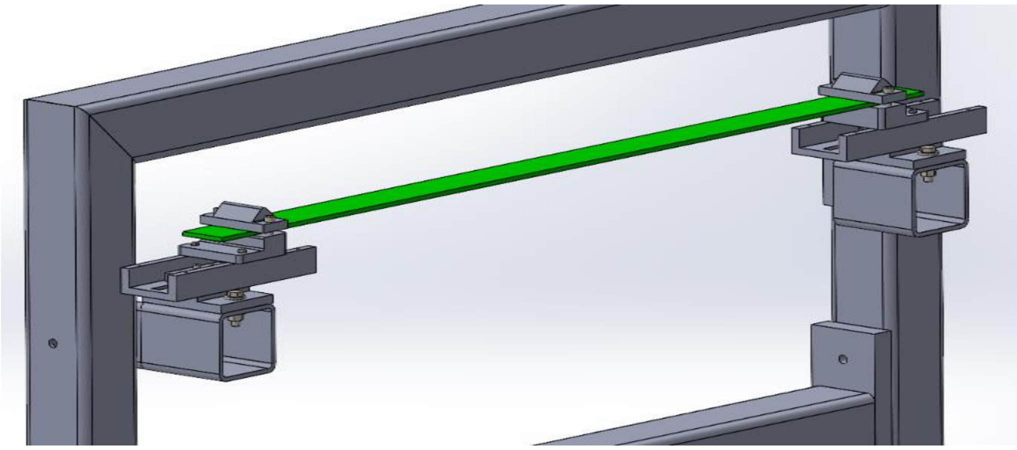
The guiding element is fixed on the frame with two screws. The lower plate can be fixed on different positions on the U-profile, which in turn can move on the guiding element. In this way, the operator can set different distances between the edges of the two lower plates, adjusting accordingly the useful length of the specimen. Obviously, in the test phase, all elements of the bearings are fixed with screws and no relative displacement between these elements is permitted. Finally, the upper plate is mounted on the lower plate. There are two possibilities to fix the specimen via the two plates, namely:

A. Clamping: when the displacement and the rotation in the vertical plane are restricted. In this case, the specimen is fixed between the lower and the upper plate.

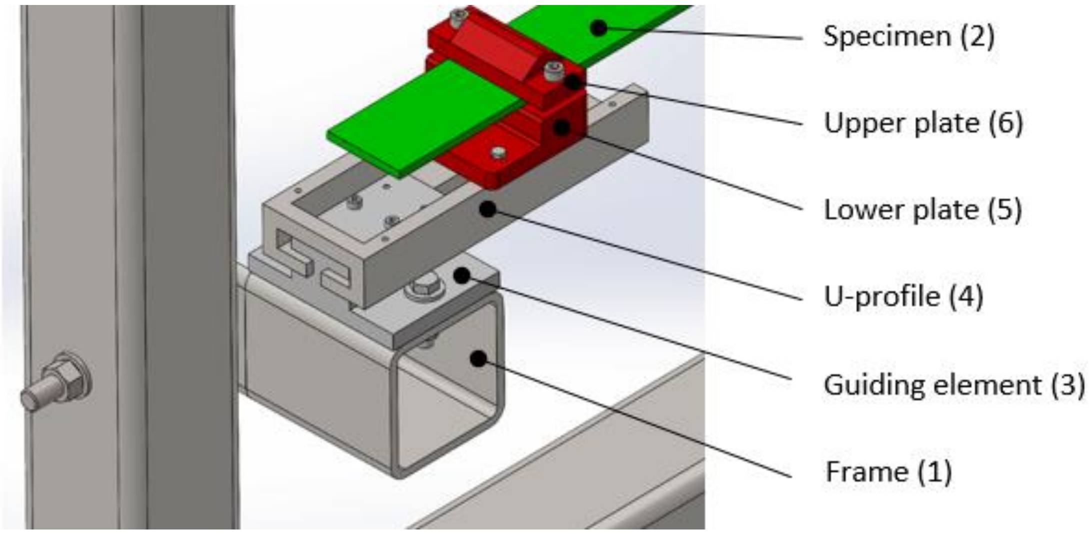
B. Hinging: when displacement in the vertical plane is restricted but rotation is permitted. In this case, the specimen rests on the top of the upper plate, on its sharp edge.

If for one end we use no bearing, we simulate the third case, namely:

C. Free end: when both displacement and rotation in the vertical plane are permitted.



a)



b)

Figure 4: The bearing fixed on the frame: a) the position of the two bearings; b) detail on a bearing set for simulating the clamping condition

2.1.3 Calibrated weights

The experiments can be performed with the specimen, i.e. considering only the dad mass, or we can add different masses to the specimen. To this aim, we need a set of calibrated weights that are attachable to the specimen.

2.2 The monitoring system

Several measurements are necessary during experiments. One set of data to be acquired is the distance, namely the displacement of the structure at different points. To this aim, we use analogue devices (mechanical comparators). Instead of an analogue system, it is also possible using digital devices to measure and record distances.

A second set of data that is acquired is the acceleration of the structure in various cases of edge support. To this aim, we use a complex measurement system composed of accelerometers, an analogue-to-digital converter, an amplifier, and a computer that has installed dedicated software. In the laboratory of the Faculty of Engineering of UBB we involve specialized laboratory equipment, but an alternative is to build a measurement system involving cheap sensors and a development platform like Arduino. This approach fit the requests of students in informatics.

2.2.1 Mechanical comparator

Measuring displacements is necessary to identify the initial state of the structure and the deflection after applying a concentrated mass. A typical mechanical comparator is presented in Figure 5. The precision of the comparator is p = 0.01mm and the measurement range should de r = 0-10mm.

Figure 5: Mechanical comparator

Due to its magnetic support, the comparator can be fixed at any location on the intermediate transverse bar of the frame.

2.2.2 Accelerometers

Several accelerometers are used to acquire vibration signals, their number being defined by the studied problem. The frequency range is f = 4-1500Hz and the maximum allowed acceleration is a_{max} = 10g. The accelerator is connected to the Analog-to-Digital converter by a cable. It is recommended to employ accelerometers with TEDS, in order to avoid calibration before each set of measurements.

Figure 6: Kistler accelerometer

The accelerometer is fixed at the desired location on the specimen using a special wax. This permits a facile fixing and removal.

2.2.3 Analog-to-Digital converter

The analogue signal is converted in a digital signal by the NI 9234 module. The connection to the computer via a chassis and a USB cable.

Figure 7: Four-channel dynamic vibration signal acquisition module NI 9234 mounted in a NI USB-chassis

2.2.4 The computer

To ensure mobility, a laptop is used to receive, process, and store data. It has installed LabVIEW for acquisition of data and Python for processing the acquired data. Python can be linked directly to LabVIEW via a dedicated node.

To employ artificial intelligence algorithms, necessary to accurately estimate the natural frequencies or find the damage type, position and severity, one can use Python or MATLAB.

2.3 The specimens

Different types of beams and trusses are used for experimentation. The specimens are real- or laboratory-scale industrial systems or structural elements.

The specimens can be:

- uniform beams
- beams with variable cross-sections
    - tapered beams
    - beams with holes
    - beams consisting of FGM
- trusses.

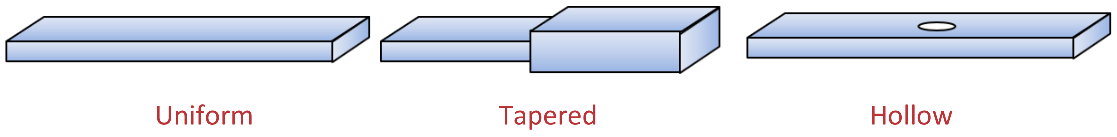


Figure 8: Different types of beams

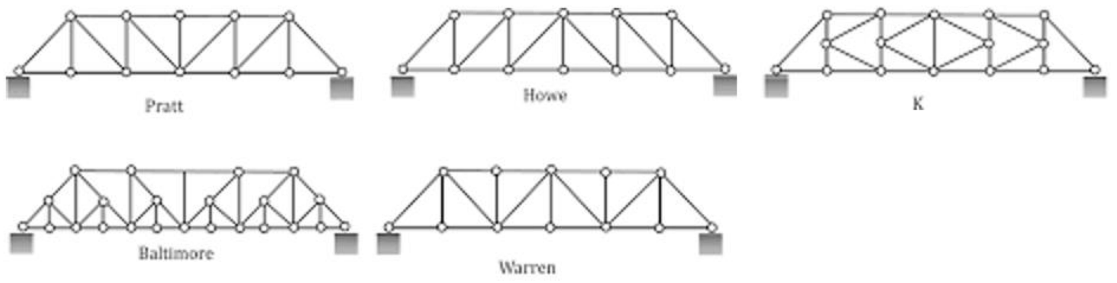


Figure 9: Different types of trusses

The beams are made of steel, plastic, or composite materials (multilayer or fiber-reinforced). The trusses can be manufactured involving circular or square-shaped pipes, profiles, or flat bars. The trusses can have welded joints that are simpler to be manufactured, but it is preferable to connect the bars with screws. The latter option allows studying the problem of weak joints. Another option is to realize the truss elements involving the additive manufacturing technology.

The length of a specimen is calculated in respect with the frame design and the bearing types. When using beams, the slenderness must be considered when the theoretical model is selected.

3 Training tasks

Training is ensured for Mechanical engineering students and Industrial informatics students. The knowledge and skills to be acquired are similar, but the weight on the topics is different. Mainly, they have to understand how the engineering structures behave in various conditions and how this behaviour can be monitored and used to find abnormal functioning.

3.1 Issues for the Mechanical Engineering students

Study of the natural frequencies and mode shapes – The students calculate the natural frequencies of beams or perform FEM simulations to find the natural frequencies of trusses. Different types of structures and materials are involved. Afterward, they perform measurement on the real structures and compare the results. The aim of this application is to transmit knowledge about how the geometry and the material used influence the dynamic behaviour of structures.

Study of the deflection of structures - The students calculate the deflection of beams and find the deflections of trusses using the FEM in different location along the structure. Afterward, they add masses and calculate, respectively measure the deflections again. The aim of this application is to transmit knowledge about how the rigidity of a structure can be adjusted and how the different types of trusses behave when loaded with a mass.

Study of the effect of damage - The students create damage to the structures, by drilling, cutting, fatigue, screw loosening, corrosion, etc. The damage simulates damage that occurs in engineering structures. Analysing the healthy and the damaged specimens, the students identify the effect of specific damages on the behaviour (deflection, frequency, mode shape) of the real structure. Using the changing of parameters, the students identify the cause that created the damage and find the position and severity of the identified damage.

Additional issues - Design and 3D printing* of bearings to simulate different boundary conditions; design and printing of trusses to realize a desired dynamic behaviour with the lowest consumption of material; designing virtual instruments to acquire and process signals; design of acquisition and excitation systems; design and setting the acquisition system.
* *using existing printers in the laboratories*

3.2 Issues for the Industrial informatics students

Design and setting of the acquisition system – Students design the structure of the acquisition system and choose the appropriate devices (e.g. the accelerometer selection). Afterwards, they create virtual instruments in LabVIEW dedicated to measuring vibration signals and set the signal parameters in accordance with the sampling theory. Signals are stored in a database.

Frequency estimation - The students create an application in Python that allows the precise estimation of the natural frequencies of the structures. Interpolation methods, zero-padding, but also other estimators developed in the laboratory can be used, including using artificial intelligence. The original vibration signals are also analysed with the standard procedure (DFT) and the results are compared with those obtained after post-processing.

Damage classification and assessment - Students take the modal parameters related to the vibration measurement results and create a database used as INPUT for artificial neural networks. To learn the network, the position and severity of the fault is used as TARGET. By creating networks with different metadata, students determine the efficiency and computing power required for each set of metadata and compare the results in order to choose the most appropriate network.

Additional issues - Performing measurements with analogue and digital instrumentation; creation of relational databases for managing vibration signals; analysis of the behaviour of mechanical structures and identifying modal parameters.

4 Description of the fulfilment of demonstrator characteristics for the focus project

Table 2: Description of the fulfilment of demonstrator characteristics for the focus project

Characteristic	Description
Teaching improvement	The demonstrator allows students to better understand the vibration behaviour of engineering structures and design structural elements with the desired behaviour. Students go through the entire process of developing a monitoring system, starting with requirements, and continuing with design, implementation, and integration. Programming and using the software for practical applications enhances the understanding of the subject. Teamwork is also supported; sometimes interdisciplinary teams can be involved.
Sustainability awareness	Students are trained to compare the mechanical behaviour of structures made from different materials and to choose those that are less aggressive to nature. Also, by assessing the damage, the students can decide on the need for maintenance or replacement of parts, avoiding the failure of the entire structure.
Replicability	The demonstrator is implemented using common materials and components. Several computers and measurement devices, respective computer programs generally existing in universities are requested. The demonstrator can be easily replicated.
Industry needs	The demonstrator can be used for teaching different measurement techniques, programming, and procedures to estimate the remaining life of engineering structures.
Interdisciplinarity	The demonstrator requires competencies both in mechanical engineering and informatics. Mechanical engineering students go deeper through programming and the use of artificial intelligence since industrial informatics students design systems and create programs for real-world applications.

5 Classification according to the dimensions

Table 3: Classification of the focus project according to the dimensions

Dimension	Property	Value
Value chain	development	☑
	production	☐
	sales	☐
	after-sales-support	☑
	end-of-life	☐
Chain of technology	mechanical structure	☑
	sensors	☑
	electronic circuits	☐
	edge device	☐
	data transmission	☑
	cloud	☐
Sustainability	energy reduction	☐
	material reduction	☑
	better materials	☑
	better production	☐
	repairability	☑
	recycling	☐
Physicality	physical setup	☑
	simulation	☑
Degree of student freedom	guided	☐
	coached	☑
	autonomous	☐
Transportability	fixed	☐
	transportable	☑
	portable	☐
Costs (implementation)	EUR	2.000
Costs (operation)	EUR	10
Workload (implementation)	Hours	150h
Workload (operation)	Hours	16h

Dimension	Property	Value
Size	m	1.5 x 0.2 x 1.5
Weight	kg	214
Special requests	no/yes, if yes: which	no

6 Technology and prices

Table 4: Equipment description and prices

No.	Name	M.U.	Quantity	Cost
1	Square tube 80x80x4mm	m	12	60.00 €
2	Steel plate	m^2	1	10.00 €
3	Guiding element	pcs	2	5.00 €
4	U profile	pcs	2	30.00 €
5	Upper plate	pcs	2	15.00 €
6	Lower plate	pcs	2	120.00 €
7	Screw M8x40mm	pcs	40	15.00 €
8	Nut and washer M8	pcs	80	10.00 €
9	Flat steel 50x5mm*	m	20	20.00 €
10	Flat steel 40x4mm*	m	20	18.00 €
11	Plastic plate 2x2m*	pcs	1	20.00 €
12	Fibre reinforced plate 2x2m*	pcs	1	35.00 €
13	Sandwich plate 2x2m*	pcs	1	35.00 €
14	Laptop with operating system	pcs	1	2,000.00 €
15	LabVIEW student edition	pcs	1	50.00 €
16	MATLAB student edition	pcs	1	50.00 €
17	Kistler accelerometer 10g	pcs	1	150.00 €
18	Four-channel NI module	pcs	1	1,000.00 €
19	NI USB-Chassis	pcs	1	1,000.00 €
20	Python	pcs	1	0.00 €
21	Mechanical comparator with magnetic support	pcs	1	100.00 €
			Total	**4,743.00 €**

* *for specimens*

Annex A: References

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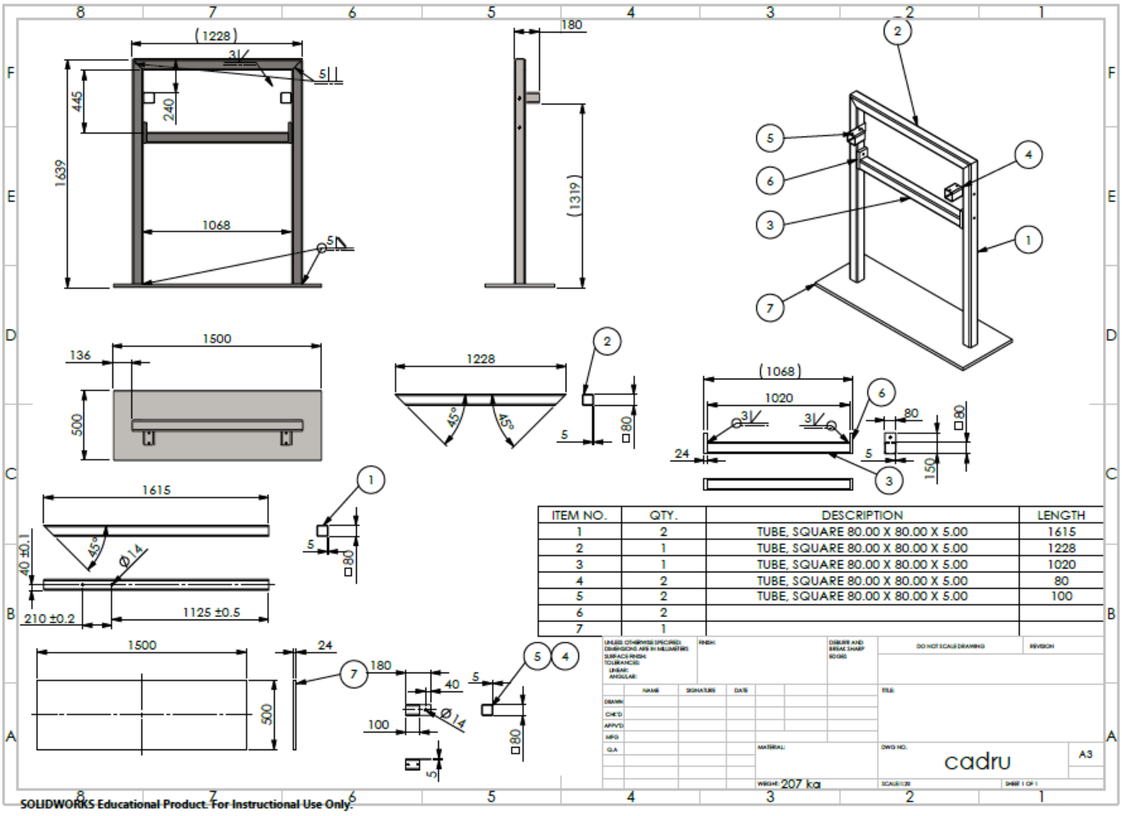
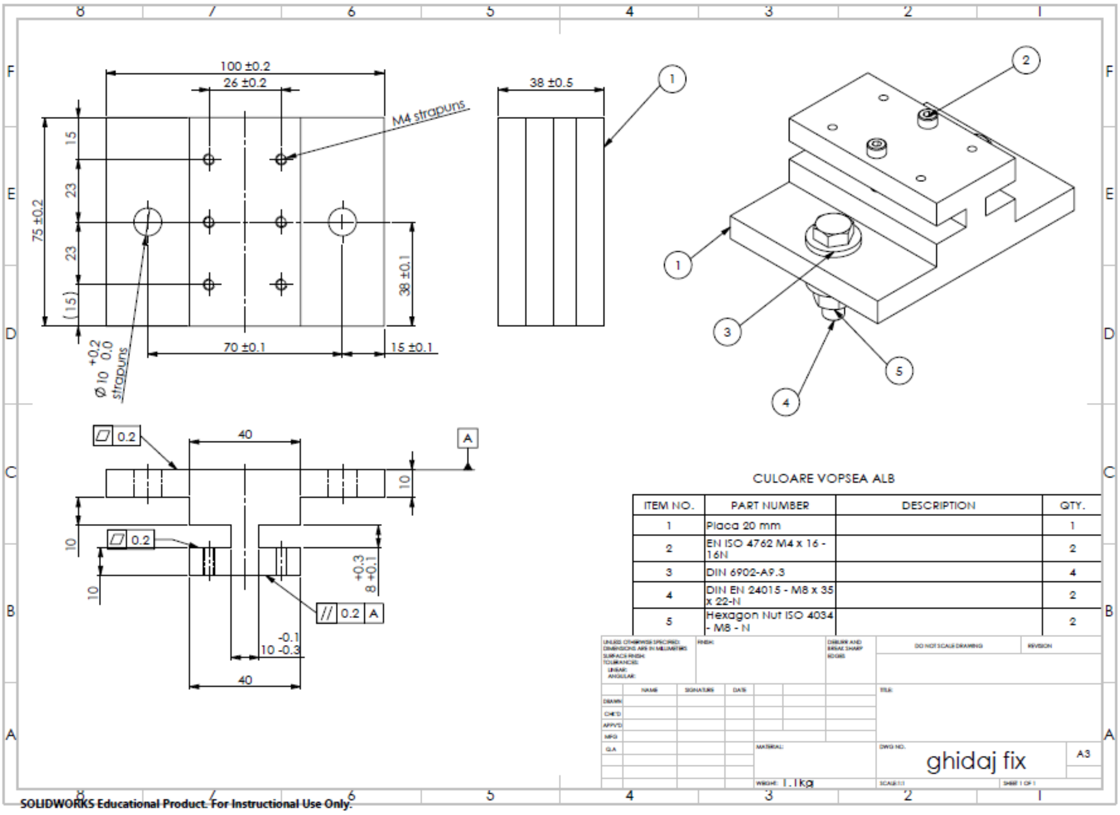
Annex B: Schematic of the frame

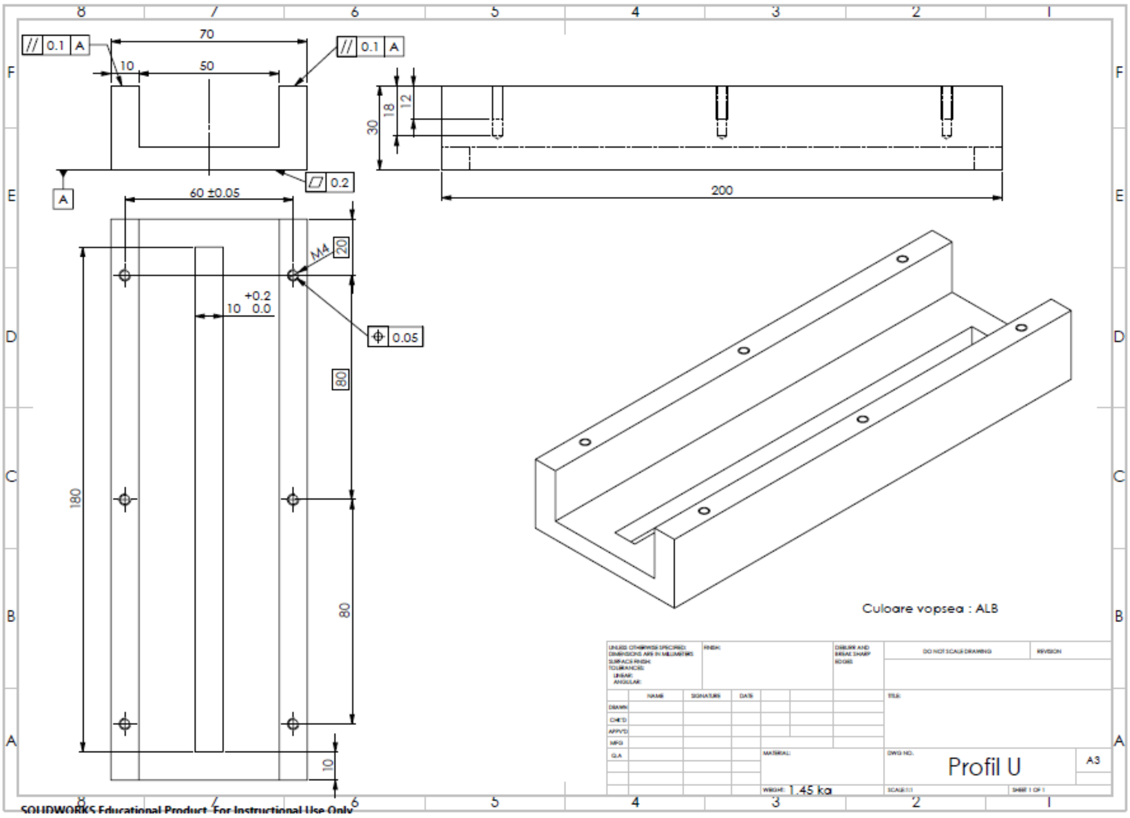


ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	2	TUBE, SQUARE 80.00 X 80.00 X 5.00	1615
2	1	TUBE, SQUARE 80.00 X 80.00 X 5.00	1228
3	1	TUBE, SQUARE 80.00 X 80.00 X 5.00	1020
4	2	TUBE, SQUARE 80.00 X 80.00 X 5.00	80
5	2	TUBE, SQUARE 80.00 X 80.00 X 5.00	100
6	2		
7	1		

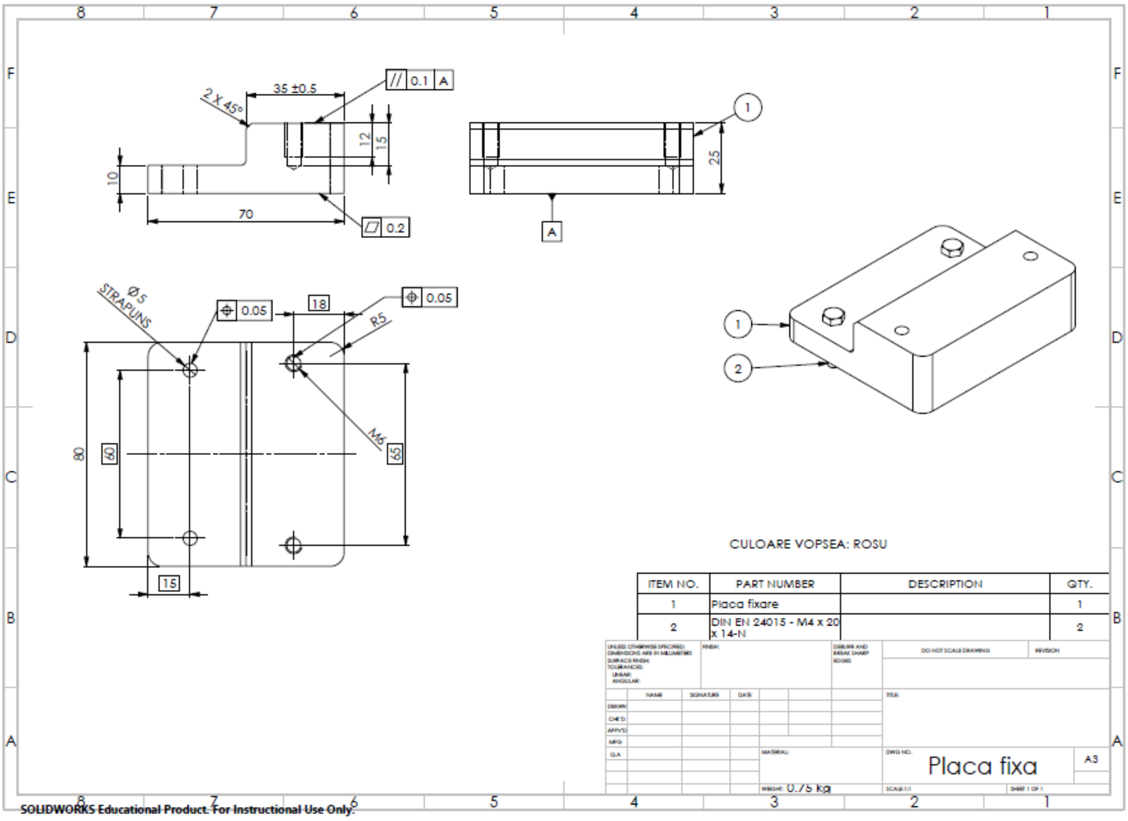
Annex C: Schematic of the bearing elements



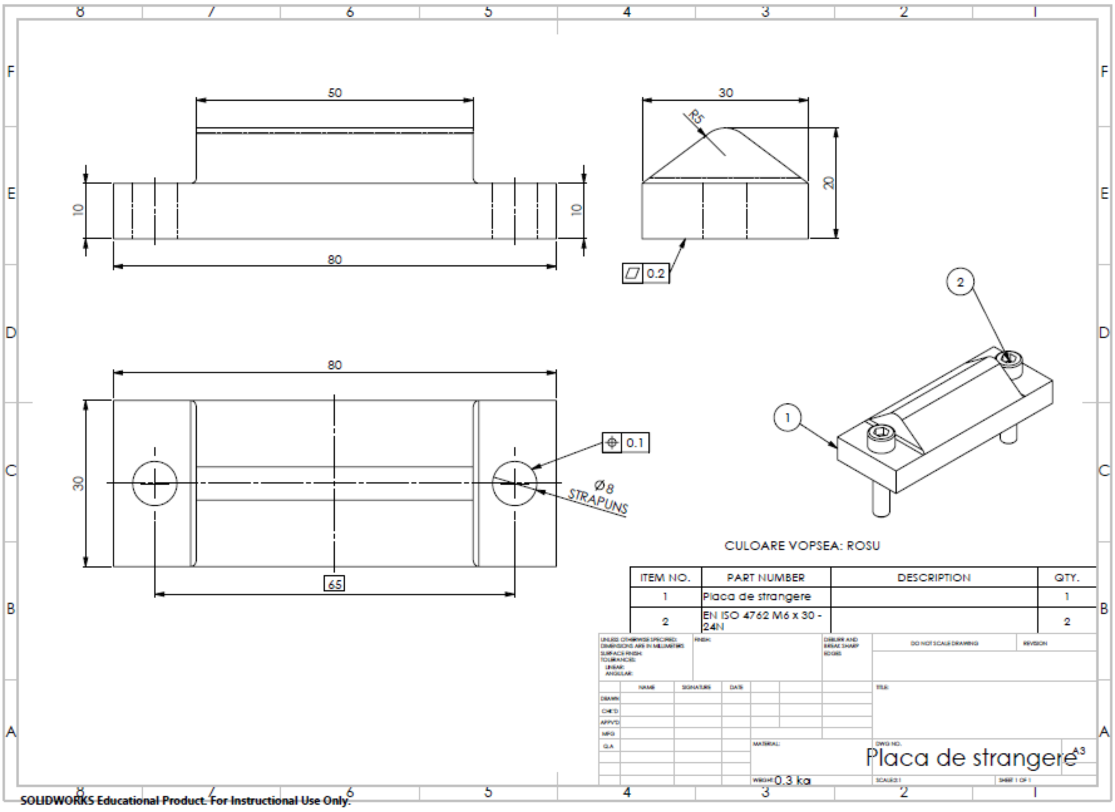
Guiding plate



U profile



Lower plate



Upper plate