Erasmus+ Programme

KA2 STRATEGIC PARTNERSHIP PROJECT
„Contemporary Approach to the Development of Spatial Comprehension through Augmented Reality Content"
SPACAR
N° 2019-1-LT01-KA202-060471

DEVELOPMENT OF TEACHING MATERIALS METHODOLOGY
14/11/21

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1. Introduction

From an academic standpoint, the development of 3D spatial skills has been cited and recognized by many authors as a key factor in many scientific and technical disciplines (Metz et al., 2012; Wai et al., 2009). Studies have consistently shown that proper spatial skills are directly related to academic success in science, technology, engineering, and mathematics (Adanez & Velasco, 2002; Sorby, 1990; Strong & Smith, 2001; Xiao et al., 2018).

Although many instructors still rely primarily on lectures and traditional teaching practices and laboratory sessions, the growing body of empirical research shows that didactic lectures do not necessarily succeed in eliciting comprehension of complex concepts (Terenzini & Pascareua, 1994) and that learning can be improved when instructors incorporate teaching strategies that are interactive (Arafeh & Levin, 2003), student-centred, and take advantage of the existing technology (Kolb, 2014). As stated by Millar (2003), good teaching demands ongoing creative effort. In this regard, Augmented Reality (AR) technology provides an attractive and engaging resource to complement and enhance traditional teaching materials, usually based on pen and paper exercises, while promoting the development of visualization, self-assessment, and self-directed learning skills (Chen et al., 2011; Martín-Gutiérrez et al., 2010)

2. Spatial Ability

Spatial ability as one of the main components of human intelligence is a well-studied topic in Psychology. This means that different approaches and classifications can be found in the literature to analyse it. Some authors (Linn & Petersen, 1985; Lohman & Kyllonen, 1983) classify the spatial ability in several sub-abilities, each referring to different aspects: “Spatial Relation” refers to tasks that require the mental rotation of simple two-dimensional or three-dimensional objects (Thurstone, 1938); “Spatial Visualization” is related to the ability to manipulate complex spatial information when several stages are needed to produce the correct solution; “Spatial Orientation” refers to tasks in which a given object or an array of objects has to be imagined from another perspective.

Other authors (Olkun, 2003; Pellegrino et al., 1984) simplify this classification by limiting it to only two categories: “Spatial Relations” that includes spatial relation and spatial orientation previously described and “Spatial Visualization” as the mental manipulation and integration of stimuli consisting of more than one part or movable parts, where usually there is movement among the internal parts of a complex configuration and/or the folding and unfolding of flat patterns.

Following the latest approaches within the field of research on human intelligence, from a psychometric perspective, spatial ability is identified as a second-order factor called **Visual Processing (Gv)**, whose subfactor structure is presented in Figure 1.

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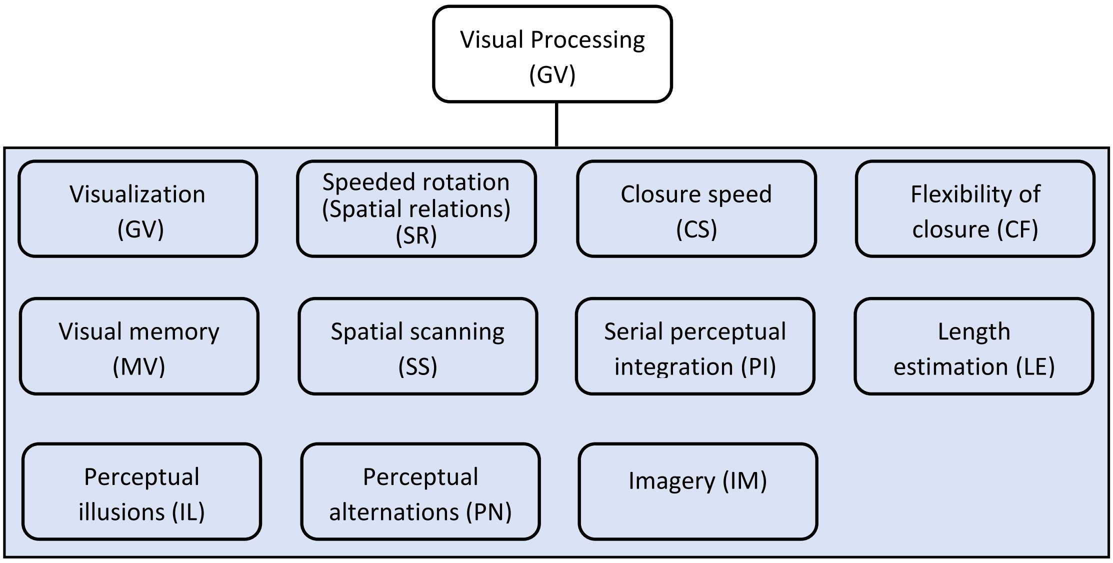

Figure 1. Factor structure for Visual Processing in the CHC theory (Buckley et al., 2019)

The Cattell-Horn-Carroll Model (CHC) model of intelligence (Schneider & McGrew, 2012) defines **Visual Processing (Gv)** as the ability to make use of simulated mental imagery (often in conjunction with currently perceived images) to solve problems. Its detailed subfactor structure is presented on Table 1.

Table 1. Subfactor structure for visual processing (Gv) (Schneider & McGrew, 2012)

Subfactor	**Definition**
Visualisation (Vz)	The ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g. rotated, changed in size, partially obscured)
Speeded rotation (spatial relations) (SR)	The ability to solve problems quickly by using mental rotation of simple images
Closure speed (CS)	The ability to quickly identify a familiar and meaningful visual object from incomplete (e.g. vague, partially obscured, disconnected) visual stimuli, without knowing in advance what the object is
Flexibility of closure (CF)	The ability to identify a visual figure or pattern embedded in a complex distracting or disguised visual pattern or array, when one knows in advance what the pattern is
Visual memory (MV)	The ability to remember complex images over short periods of time (less than 30 seconds)
Spatial scanning (SS)	The ability to visualise a path out of a maze or a field with many obstacles
Serial perceptual integration (PI)	The ability to recognise an object after only parts of it are shown in rapid succession
Length estimation (LE)	The ability to visually estimate the length of objects
Perceptual illusions (IL)	The ability to not be fooled by visual illusions
Perceptual alternations (PN)	Consistency in the rate of alternating between different visual perceptions
Imagery (IM)	The ability to mentally produce very vivid images

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Other researchers in the last years have added moving or dynamic stimuli when considering the analysis of spatial ability. Besides, in Table 2 there is a list of other potential subfactors considered by other researchers relate to visual processing (Gv) not included in the CHC theory, organized graphically in

Figure 2.

Table 2. Subfactors not represented within the CHC theory (Schneider & McGrew, 2012)

Subfactor	Definition
Spatial relations	The ability to solve problems by using mental rotation of complex images in a relatively untimed situation
Spatial orientation	The comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude to remain unconfused by the changing orientations in which a spatial configuration may be presented, and an ability to determine spatial orientation with respect to one's body (McGee, 1979)
Imagery quality	The ability to generate a mental image, add and/or subtract detail from the image, rotate, maintain, and transform the image in specified ways (Burton & Fogarty, 2003)
Imagery speed	The efficiency of those processes involved in the generation, maintenance, and transformation of mental representations (Burton & Fogarty, 2003)
Shape and direction illusions	The ability to not to be fooled by distortions in apparent shape, parallelism, and collinearity such as the Poggendorff, Wundt, and Zoellner illusions (Coren et al., 1976)
Size contrast illusions	The ability to not to be fooled by distortions in which the apparent size of an element appears to be affected by the size of other elements that surround it, or form its context such as the Delboeuf, Ebbinghaus, Jastrow, and Ponzo illusions (Coren et al., 1976)
Overestimation illusions	The ability to not be affected by illusions of overestimations of linear extents, such as the Mueller-Lyer illusion and both parts of the Baldwin illusion (Coren et al., 1976)
Underestimation illusions	The ability to not be affected by illusions of underestimations of linear extent such as the apparently shorter segment of the Oppel-Kundt illusion (Coren et al., 1976)
Frame of reference illusions	The ability to not be affected by frame of reference illusions like the rod-and-frame illusion (Coren et al., 1976)
Directional judgement	The ability related to performance of tasks involving prediction of directions (Colom et al., 2002)
Speed judgement	The ability related to performance of tasks involving prediction of arrival times of moving objects (Colom et al., 2002)
Movement detection	The ability to detect barely visible movement of an object and to determine the direction of this movement (Roff, 1953)
Dynamic visual memory	The ability to remember complex dynamic images over short periods of time (less than 30
Dynamic serial perceptual integration	The ability to recognise a dynamic object after only parts of it are shown in rapid succession
Dynamic spatial scanning	The ability to visualise a path out of a dynamic maze or a field with many obstacles

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Dynamic perceptual alternations	Consistency in the rate of alternating between different visual perceptions of a dynamic stimulus

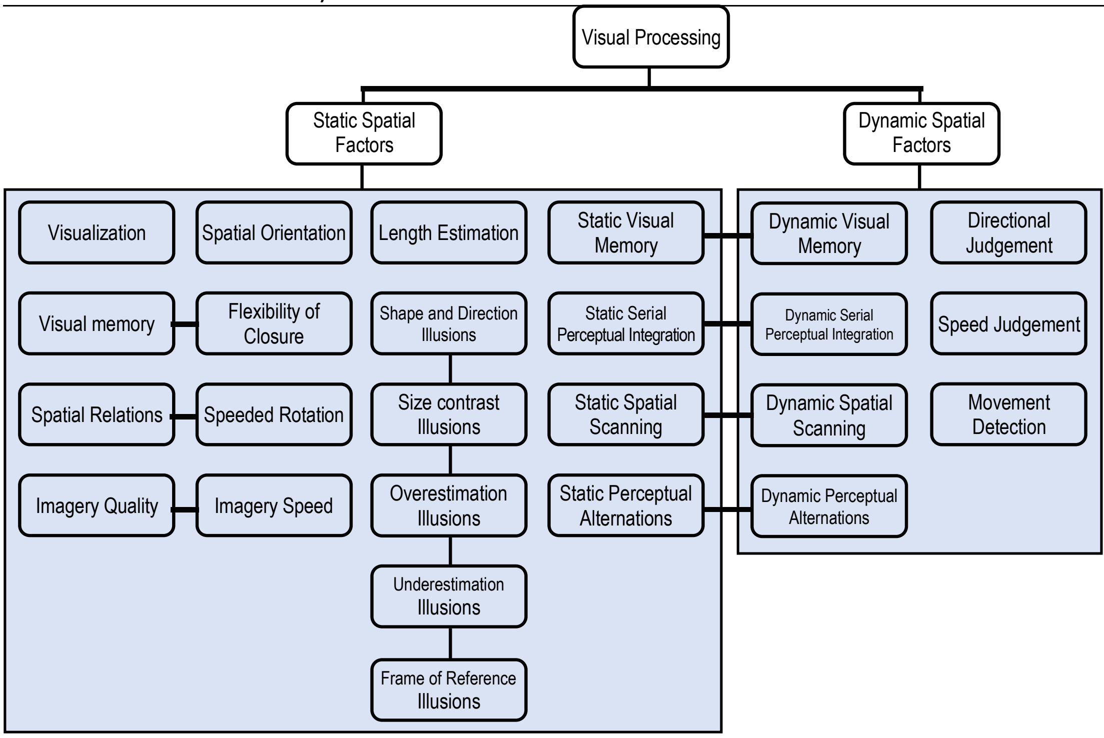

Figure 2. Extended subfactor structure of Visual Processing (Gv) (Buckley et al., 2019)

Regarding the context of the SPACAR project, the resources to be developed will support the improvement of static factors. Inside of these, the potential benefit provided by training/learning activities will influence the subfactors listed in Table 3.

Table 3. Subfactors potentially to be improved through by SPACAR exercises

Subfactor	Definition
Visualisation	The ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g. rotated, changed in size, partially obscured)
Speeded rotation	The ability to solve problems quickly by using mental rotation of simple images
Closure speed	The ability to quickly identify a familiar and meaningful visual object from incomplete (e.g. vague, partially obscured, disconnected) visual stimuli, without knowing in advance what the object is
Visual memory	The ability to remember complex images over short periods of time (less than 30 seconds)
Spatial scanning	The ability to visualise a path out of a maze or a field with many obstacles
Spatial relations	The ability to solve problems by using mental rotation of complex images in a relatively untimed situation
Spatial orientation	The comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude to remain unconfused by the changing orientations in which a spatial configuration may be presented, and an ability to determine spatial orientation with respect to one's body (McGee, 1979)
Imagery quality	The ability to generate a mental image, add and/or subtract detail from the image, rotate, maintain, and transform the image in specified ways (Burton & Fogarty, 2003)

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Imagery speed	The efficiency of those processes involved in the generation, maintenance, and transformation of mental representations (Burton & Fogarty, 2003)

3. Measuring Spatial Abilities

The measurement of spatial abilities is standardized by international tests, that have been extensively analysed in the last 20 years (Nagy-Kondor, 2017). In this section, the most used instruments related to studies about the development of spatial abilities in engineering students will be described (Marunić & Glažar, 2014).

3.1 Mental Cutting Test (MCT)

The standard MCT (CEEB, 1939) consists of 25 items. In each item (see Figure 3 for an example) presents a perspective on an object and a cutting plane. The subject must choose the correct figure that represents the resulting section. Some of the items have relatively unusual shapes and in some case is very difficult to recognize the relative position of the cutting plane respect to the object (Tsutsumi, 2004). The MCT takes 20 minutes to complete, and the result is a numerical score out of 25.

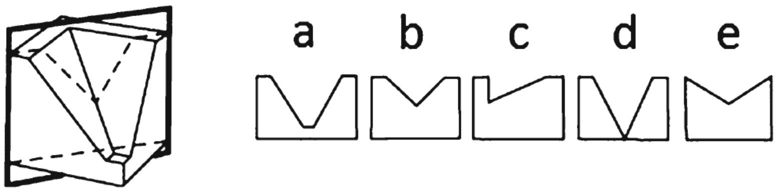

Figure 3. Example item in MCT

3.2 Mental Rotation Test (MRT)

MRT (Vandenberg & Kuse, 1978) consists of 20 items (see Figure 4 for an example), divided into two equal sets, with a three minute limit for the completion of each set. Each item consists of five stimuli, which include a target that consists of three-dimensional cubes and four alternatives (two correct alternatives and two incorrect alternatives). Correct alternatives are structurally identical to the target but shown in a rotated position. The participants are asked to find the two correct alternatives. Two points are awarded for each item with two correct choices. One point is received if only one of the options is chosen and that it is correct and no points are scored if one of the two alternatives is correct but the other is not, or if the two are incorrect. The maximum score that can be obtained is 40.

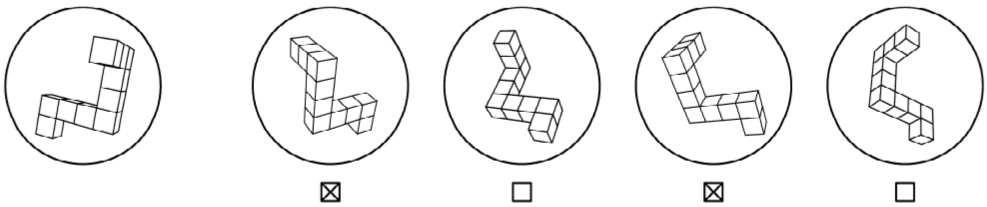

Figure 4. Example item in MRT

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3.3 Differential Aptitude Test: Space Relations (DAT: SR)

DAT:SR (Bennet et al., 1956) consists of 50 items (see Figure 5 for an example) and the task is to select an appropriate 3D object among four alternatives that would be obtained from folding the given unfolded shape. The DAT:SR test takes 20 minutes to complete, and the result is a numerical score out of 50.

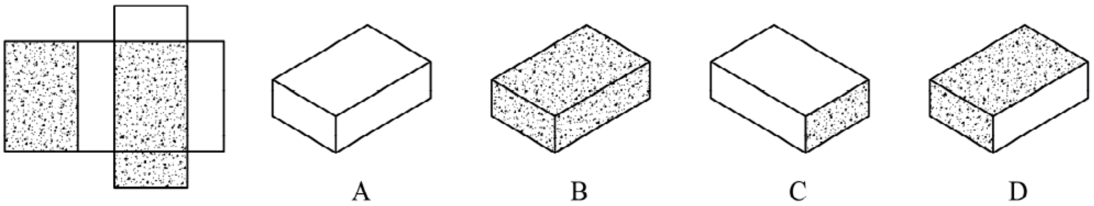

Figure 5. Example item in DAR:SR

3.4 Purdue Spatial Visualization Tests: Rotations (PSVT: R) and its revised version

PSVT: R (Guay, 1977) consists of 30 items and takes 20 minutes to complete. For each item, a given object is rotated in space. Then a set of five choices a presented that show a rotated version of a second object. Subjects have to select that choice where the second object would be rotated by the same amount in space as the first object was (see Figure 6 for an example).

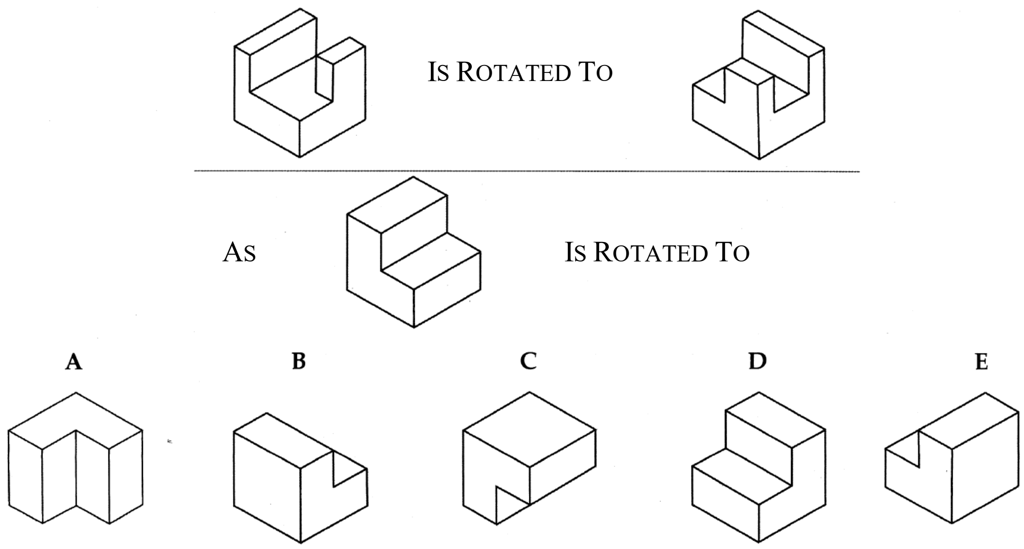

Figure 6. Example item in PSVT:R

The Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R) (Yoon, 2011) is a revised version of the PSVT:R. The instrument has 2 practice items followed by 30 test items that consist of 13 symmetrical and 17 asymmetrical figures of 3-D objects, which are drawn in isometric perspective. In the revised version, figures are rescaled, and items are reordered from easy to difficult.

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3.5 Purdue Spatial Visualization Tests: Visualization (PSVT: V)

PSVT: V (Guay, 1977) consists of 30 items. Participants must visualize an object framed in a clear box from a specific corner marked with a dot. Five alternatives are offered. Just one is correct.

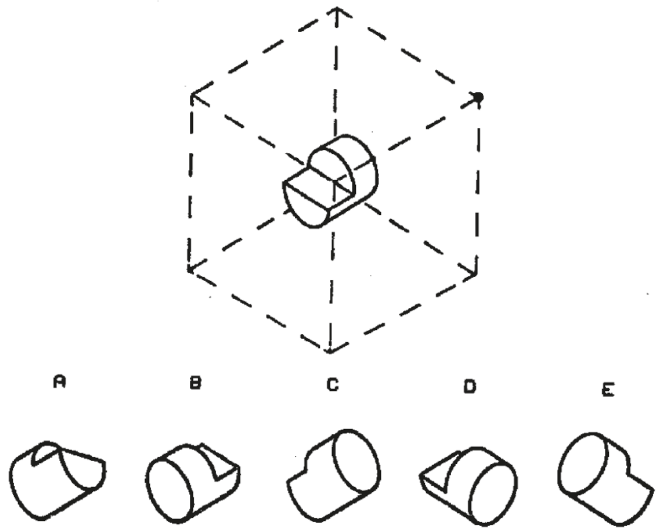

Figure 7. Example item in PSVT: V

3.5 Purdue Spatial Visualization Tests: Development (PSVT: D)

PSVT: R (Guay, 1977) consists of 30 items where the development of an object is presented. Participants must choose between 5 options, which is the object, presented by its axonometric projection, whose development is shown. Just one alternative is correct.

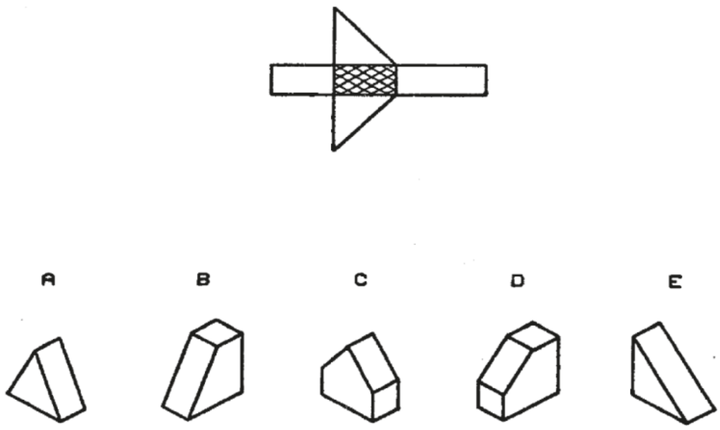

Figure 8. Example item in PSVT: D

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3.6 Spatial Orientation Test (SOT)

The Spatial Orientation Test (Hegarty & Waller, 2005) consists of 12 items. Seven objects are drawn on the top half sheet of paper corresponding to each item (see Figure 9). Participants are asked to imagine being at the position of one object (the station point) facing another object and then try are asked to indicate the direction to a third object (target). Participants provide their response using a circle that is drawn in the bottom half of the page. For example, if the imagined station point is the flower sign and the object defining the heading is the tree. If the target object is the cat, the participant should draw the dotted line, as indicated in Figure 9 to provide a correct response.

The score for each item is obtained measuring the absolute deviation in degrees between the participant's response and the correct direction to the target (absolute directional error). The participant's total score is calculated as the average deviation across all attempted items.

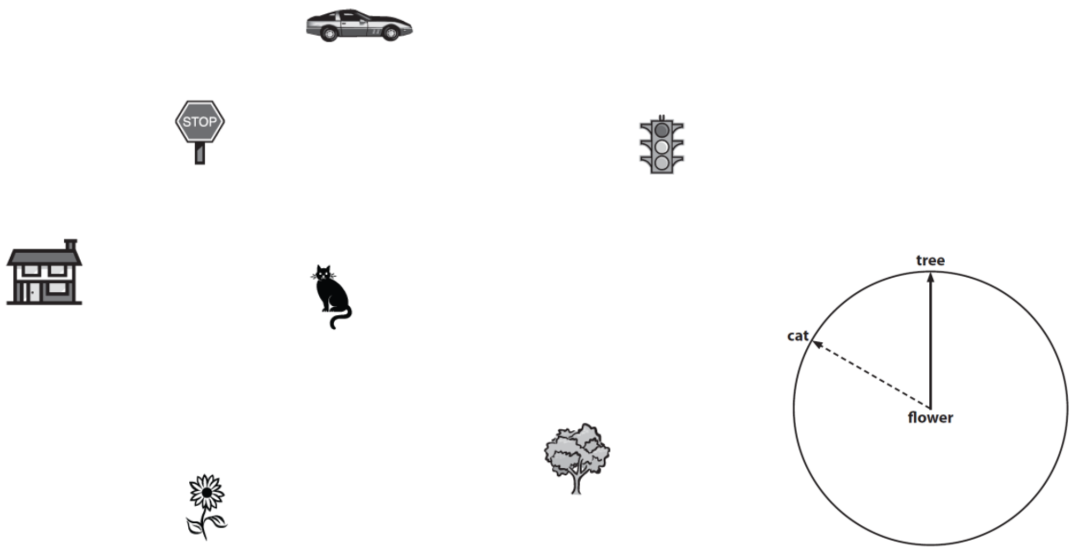

Figure 9. Test item in Spatial Orientation Test

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4. Pedagogical Framework

The engineering graphics discipline offers many alternatives to create specific didactic content to train spatial skills. One of the main sources of exercises is the geometric operations (projection + section) that connect a 3D object with its representation on 2D. Geometrical transformations such as rotation and symmetry also provide good training activities. 3D CAD modelling also is a good source of ideas for exercises, considering that the modelling process requires specific skills to identify the set of form features that combined by the proper Boolean operators produce a correct 3D model that offers a virtual representation of a physical 3D part.

In order to organize the didactic content in a meaningful way, Bloom's taxonomy is going to be deployed (Bloom et al., 1956) to arrange the training activities. Although there are some new proposals (Krathwohl, 2002) revising the original taxonomy, taking into account the widespread use of the original one and previous works connecting it to the engineering graphics field (Violante et al., 2020), the original taxonomy will be followed in this document as detailed in Table 4.

Table 4. Structure of the original Bloom's taxonomy in the cognitive domain

Levels	Sublevels	
1. Knowledge		
	1.1 Knowledge of specifics	
		1.11 Knowledge of terminology
		1.12 Knowledge of specific facts
	1.2 Knowledge of ways and means of dealing with specifics	
		1.21 Knowledge of conventions
		1.22 Knowledge of trends and sequences
		1.23 Knowledge of classifications and categories
		1.24 Knowledge of criteria
		1.25 Knowledge of methodology
	1.3 Knowledge of universals and abstractions in a field	
		1.31 Knowledge of principles and generalizations
		1.32 Knowledge of theories and structures
2. Comprehension		
	2.1 Translation	
	2.2 Interpretation	
	2.3 Extrapolation	
3. Application		
4. Analysis		
	4.1 Analysis of elements	
	4.2 Analysis of relationships	
	4.3 Analysis of organizational principles	
5. Synthesis		
	5.1 Production of a unique communication	
	5.2 Production of a plan, or proposed set of operations	
	5.3 Derivation of a set of abstract relations	
6. Evaluation		
	6.1 Evaluation in terms of internal evidence	
	6.2 Judgments in terms of external criteria	

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Table 5. Bloom's taxonomy in engineering technical drawing (Violante et al., 2020)

Levels	**Description**	**Keywords**	**Sample questions about orthographic projection methods**
1. Knowledge	Exhibits memory of previously learned material by recalling fundamental terms, facts, methods, procedures, concepts	cite, define, identify, label, list, match, name, recognise, reproduce, select, state	1. Letter the names of each of the standard views in a sketch 2. List the main types of projection methods 3. Match the right symbol with the corresponding projection method
2. Comprehension	Understand the uses and implications of given Information (terms, facts, methods, procedures, concepts)	classify, convert, describe, distinguish between, explain, extend, give examples, illustrate, interpret, paraphrase, summarise, translate	1. In the first angle projection method, the view seen from left is placed on (a) Above front view (b) Right of front view (c) Above top view (d) Below front view 2. Which of the following projection methods does not use projectors perpendicular to the projection plane: (a) Isometric (b) orthographic (c) oblique (d) axonometric?
3. Application	Use strategies, concepts, principles, and theories in concrete situations. Solve problems. Practice theory	apply, arrange, calculate, carry out, construct, demonstrate, discover, execute, implement, modify, operate, predict, prepare, produce, relate, show, solve, use	1. In each lettered cell shown, the circle represents the location of a missing view. Select the correct view from the views proposed 2. For each row shown, select the pictorial view of the object that will produce the orthographic views that are given
4. Analysis	Breaking information into its component elements to explore relationships	analyse, associate, determine, diagram, differentiate, discriminate, distinguish, compare, estimate, infer, order, outline, point out, separate, subdivide	1. Compare 1st angle method of projection and 3rd angle method of projection
5. Synthesis	Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions	combine, compile, compose, construct, create, design, develop, devise, formulate, integrate, invent, modify, organise, plan, produce, propose, rearrange, reorganise, revise, rewrite	1. Formulate the right number of views needed to fully describe an object in 1st angle method of projection
6. Evaluation	Judge the value of ideas, materials and methods by developing and applying standards and criteria	appraise, assess, check, conclude, contrast, criticise, evaluate, hypothesise, judge, justify, support, test	1. Check if projections of the drawing, provided in the figures, have been used in an appropriate way

In section 2 of this document, Visual Processing (Gv) was defined as the ability to make use of simulated mental imagery (often in conjunction with currently perceived images) to solve problems. The goal of the SPACAR project is to develop a series of intellectual outputs to provoke the use of mental imagery to solve problems linked to the engineering graphics discipline. To guide the development of these exercises, Table 5 provides some examples in the context of technical graphics to understand the hierarchical levels of the Bloom's taxonomy. Choosing the exercises according to their associated Bloom's level will allow teachers to adapt them to different educational levels and contexts. The role of augmented reality will be to provide both support to understand the exercise (input) and the solution or steps needed to solve it (output).

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4.1 Design principles

The intellectual output of the project (exercises) will follow the next principles:

1. Main goal of the exercises is improving spatial abilities on students using these resources.
2. Exercises will operate on Bloom's levels 2-6 and will be provided to students according to their "prior" knowledge.
3. Exercises will provide a progression on difficulty. For each Bloom's level will be developed sets of exercises with a growing level of difficulty. An objective metric, such as the complexity of the geometry involved in the exercise should be used to measure the level of difficulty.
4. Exercises will be provided to students in a progressive way, beginning will Bloom's level 2 and finishing with level 6.
5. As far as possible, sketching activities should will be integrated as part of the exercises, considering that they also contribute to develop spatial abilities (Mohler & Miller, 2008).
6. Tasks in the spatial ability tests used in the validation study described in section 6 of this document should not be included in any of the exercises.

4.2 Taxonomy of exercises

Aimed to help participants in the project in the elaboration of the intellectual outputs, this section provides some examples of activities that are organized according to their cognitive level in the Bloom's taxonomy. This is not an exhaustive list and can be extended in future versions of this document.

Comprehension level (2)

Some activities suitable for this level are:

- Identification of surfaces and vertexes in both orthographic and axonometric views of a three-dimensional virtual object provided as an input.
- Identification of orthographic views from a virtual three-dimensional model used as input.
- Identification of the geometry of a solid of revolution defined by section, axis, and angle.
- Identification of the result of a Boolean operation applied to several objects.
- Isometric sketching of block-structured objects defined by a codification (Connolly et al., 2009).

Application level (3)

Some activities suitable for this level are:

- Creation of orthographic views (with and without hidden line representation) from perspective: object of growing difficulty level: block-based, single and double inclined planes, cylindrical surfaces.

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- Identification of the rotated version of an object (chain of rotations).
- Identification and sketching of a symmetrical version of an object.

Analysis level (4)

Some activities suitable for this level are:

- Part identification and numbering in assembly drawing.
- Prism identification when used as building blocks in parts.
- Identification of developments of objects.

Synthesis level (5)

Some activities suitable for this level are:

- Definition of the constructive solid geometry (CSG) steps to build a 3D model.
- Creation of perspectives from orthographic views.
- Interpretation of topographic maps.
- Identification of an object from its development.
- Creation of the BIM model of a building or infrastructure project using its drawings as an input.

Evaluation level (6)

Some activities suitable for this level are:

- Assembly part compatibility on exploded views.
- Feasibility of a CSG tree to represent a model.
- Assessment of correctness of the number y content of cuts, sections and views to define an object.

4.3 Alignment with the proposed structure of intellectual outputs

Intellectual outputs of the SPACAR project are organized in five main blocks:

- O1: Cutting geometrical solids with planes.
- O2: Intersections of geometrical surfaces.
- O3: Orthographic projections.
- O4: Construction of elements of machine parts.
- O5: Architectural and construction drawing.

Each of the five blocks offer many opportunities to apply the different types of exercises listed in section 4.2. Due to the greater complexity in the topics covered by O3, O4 and O5, this type of outputs can be covered by all the cognitive levels in Bloom's taxonomy.

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5. Format of Exercises

Each exercise should at least include the following information:

- Intellectual output identification.
- Exercise identification/number.
- Title
- Description.
- Digital files.
- Result.
- Prior knowledge required to solve the exercise.
- Description of the augmented reality content.

3D content to be displayed using augmented reality should delivered using FBX or OBJ file formats. A Word template to deliver the exercises has been developed. An example of exercise using this template is presented on Appendix 1.

6. Validation Framework

To evaluate the effectivity of the intellectual outputs of the project it is recommended to apply a quasi-experimental design (Campbell & Stanley, 2015), due to the difficulty of applying a random assignment of subjects (students) to the experimental or control group. Some of the universities and vocational centres that participate in the SPACAR project, or other centres identified through the dissemination activities of the project could provide the students for the experimental study.

In Figure 10, a block diagram with the experimental design is presented. Regarding pre-test and post-test to be used, considering the most used tests in previous studies connecting spatial ability development and engineering education, it is recommended to use:

- Revised Purdue Spatial Visualization Tests: Rotations (Revised PSVT: R).
- Differential Aptitude Test: Space Relations (DAT: SR).
- Spatial Orientation Test (SOT).

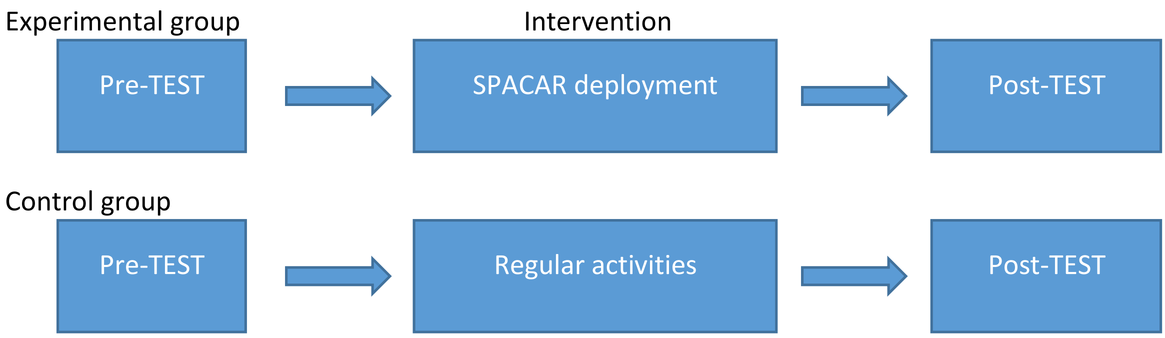

Figure 10. Experimental design

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To analyse the impact of SPACAR outputs on students' motivation, it is recommended to conduct the Instructional Materials Motivation Survey (IMMS) at the same time that the post-tests. IMMS is based on the ARCS (Attention, Relevance, Confidence and Satisfaction) model (Keller, 2010). The IMMS has 36 items. The Relevance and Confidence subscales both have 9 items, the Satisfaction subscale has 6, and the Attention subscale has 12. Both experimental and control group would receive the IMMS.

To collect the subjective feedback from students about the augment reality app (experimental group) it is recommended to use the Handheld Augmented Reality Usability Scale (HARUS) (Santos et al., 2015).

The results obtained through the validation studies will improve the visibility and impact of the SPACAR project, providing an additional dissemination path for the project outputs though scientific conferences and journals.

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Appendix 1. Examples of exercises

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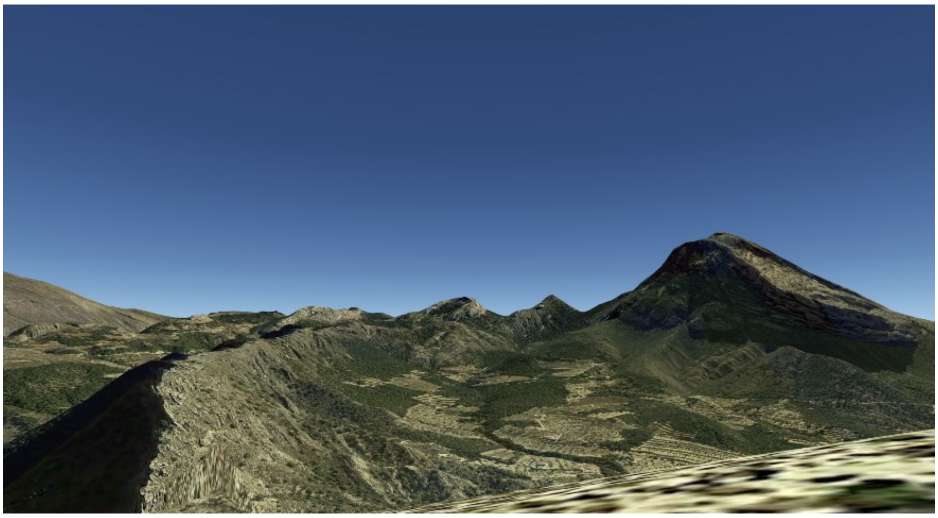
Example Exercise 1

Title: Identification of point of view on a topographic map

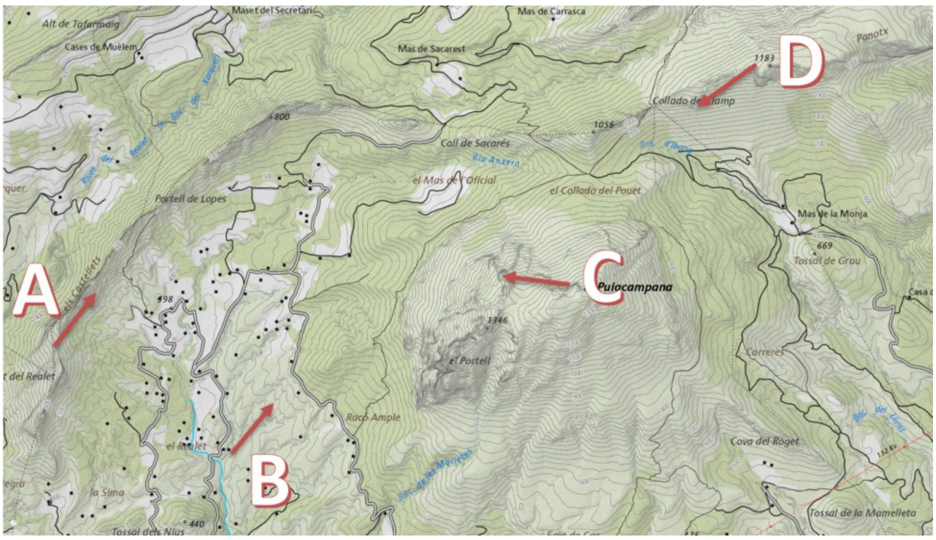
Description: Imagine you are on top of a mountain, and you see the landscape presented in the image. You must identify what is your position on the corresponding topographic map. Select the response that indicates where and which direction you think you are located.

Digital files:

IO5-11-a.png: Image file corresponding the landscape view



IO5-11-b.png: Image file corresponding the topographic map



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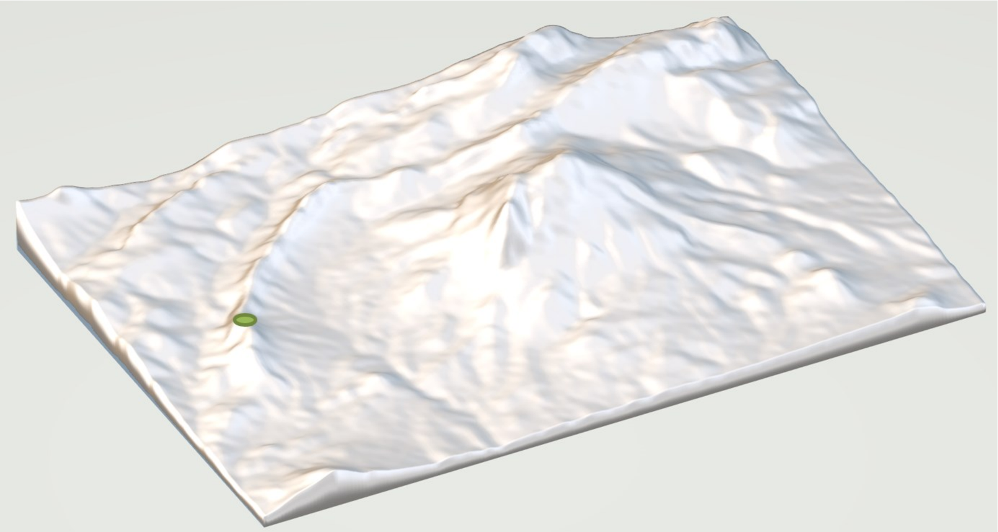
IO5-11-c.fbx: digital elevation model format corresponding to the area covered by the topographic map. The green area represents the solution of the exercise



Result: The correct answer is A. This location is represented by a green area on the 3D digital model.

Augmented reality content: A 3D model of the terrain with the solution of the exercise.

Prior knowledge: Reading of topographic maps.

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Example Exercise 2

Title: The Farnsworth House

Description: The Farnsworth House, designed and built between 1946 and 1951 by architect Mies van der Rohe, is recognized as an iconic masterpiece of the architecture. It is located at Plano, Illinois, 58 miles southwest Chicago. Create a 3D structural model of the building using the building drawings that are freely available at the Library of Congress at: https://www.loc.gov/resource/hhh.il0323.sheet

Digital files:

IO5-20-a.png: Picture of building by Grigas, V. (Photographer, 2013)

IO5-20-b.fbx: 3D model of the structure

Result: A 3D model of the building structure

Augmented reality content: The result of the exercise (3D model of the structure)

Prior knowledge: interpretation of architectural drawings and 3D modelling.

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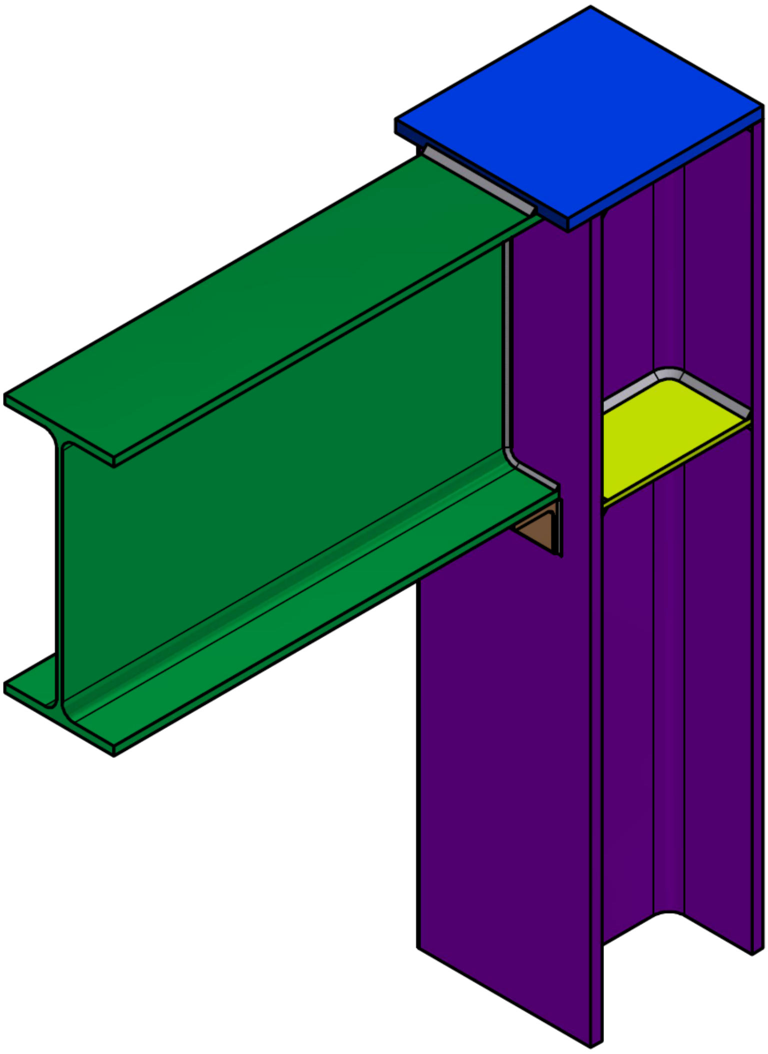
Example Exercise 3

Title: Metal constructions. Semi-rigid joint of an IPE beam with a HEB column on the top floor

Description: Using as input a 3D model the joint, add the welding symbols to the drawing views representing the joint. Consider an effective throat thickness of 10 mm for all the welds (only fillet welds are used). All welds are made on field except those corresponding to the angular support.

Digital files:

IO5-07-a.fbx: 3D model of the joint



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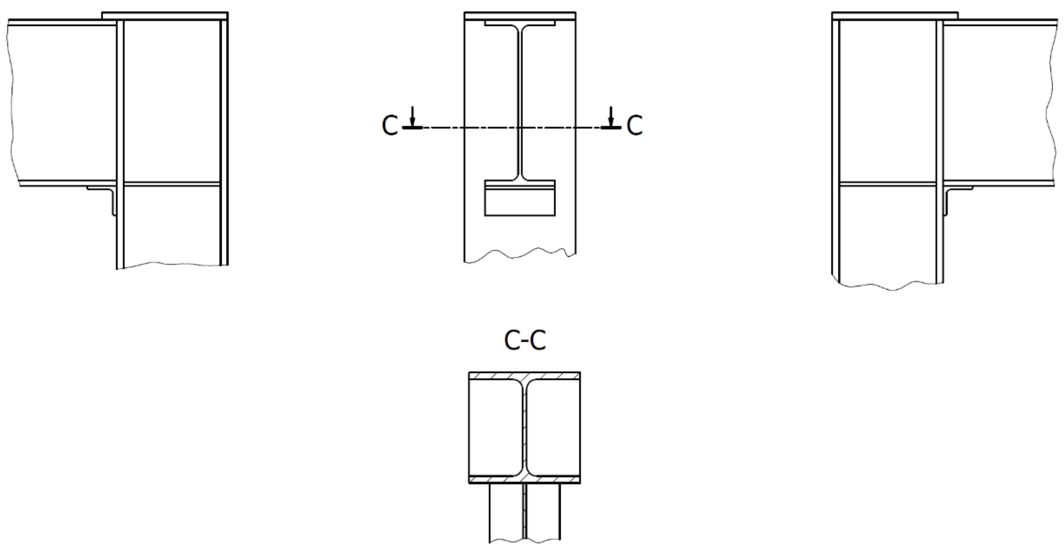
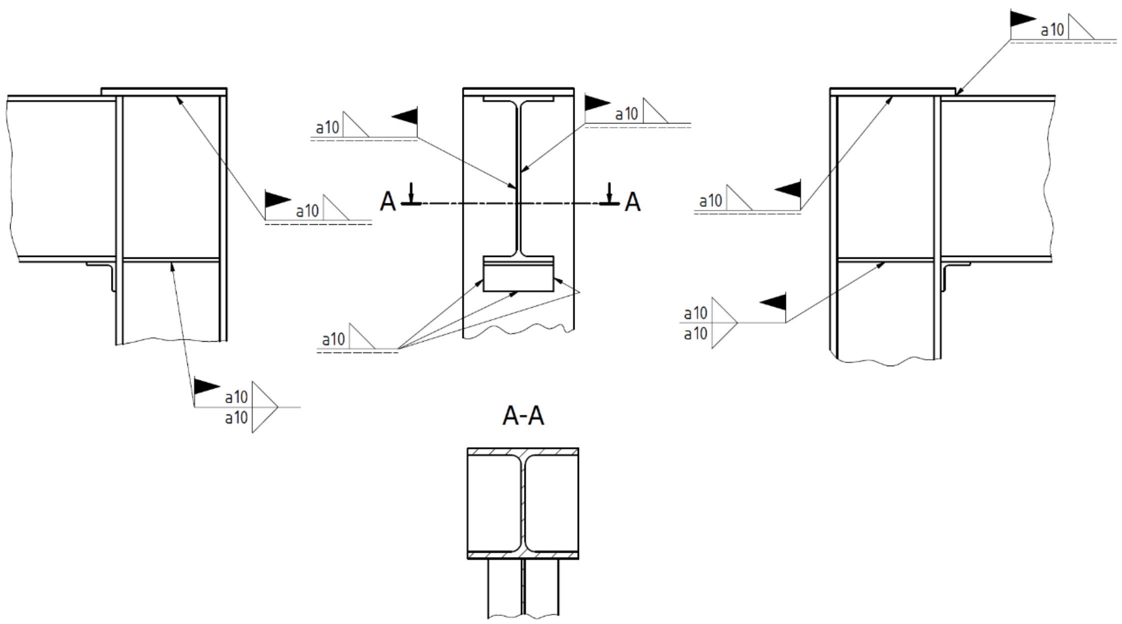
IO5-07-b.png: drawing views of the joint



IO5-07-c.png: drawing with the solution



Result: The answer is presented in IO5-07-c.png.

Augmented reality content: A 3D model of the joint.

Prior knowledge: Welding annotations in technical drawings.

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Appendix 2.
Practical guide for using the SPACAR platform and mobile app

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A2.1 Platform description

SPACAR project has developed a Web platform for the management of the courses by the teachers and project partners. The content of the courses is intended to be used through an app for mobiles phones, where different types of files can be visualized. 3D models can be visualized on augmented reality. In some cases, these 3D models are used as input for the exercises. In other cases, they are used to present the solution of the problem. The Web platform is available at: https://admin-spac-ar.azurewebsites.net

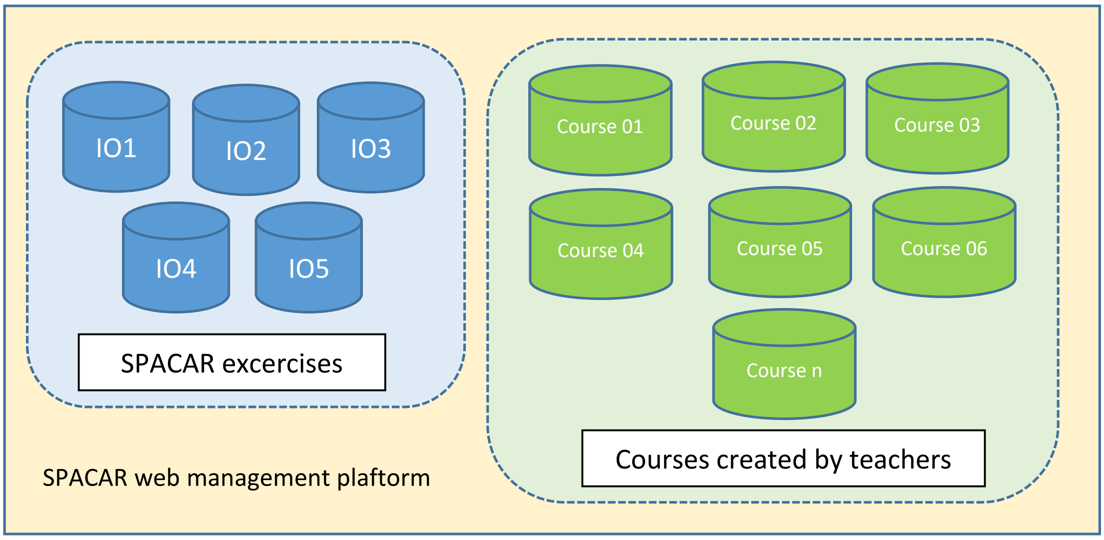

Figure 11. Course management in web platform

Intellectual outputs (IO) of SPACAR project provide a collection of exercises that are organized on 5 groups of intellectual outputs (IO):

- IO1: 1. Cutting Geometrical Solids with Planes.
- IO2: 2. Intersections of Geometrical Surfaces.
- IO3: 3. Orthographic projections.
- IO4: 4. Construction of Elements of Machine Parts.
- IO5: 5. Architectural und Construction Drawing.

The SPACAR web platform (login screen is presented on Figure 12) provides teachers with the proper administrative rights the possibility of creating their own courses. A course is a collection of exercises. These exercises can be copied from the IO developed by the SPACAR partners. They also can be created from scratch if the teachers want to extend them for a better adaptation to their regular course learning objectives. The language of the interface of the Web platform can be selected using the icon that appears on the upper right part of the screen (presented on Figure 13). It deploys the menu displayed on the right of Figure 12.

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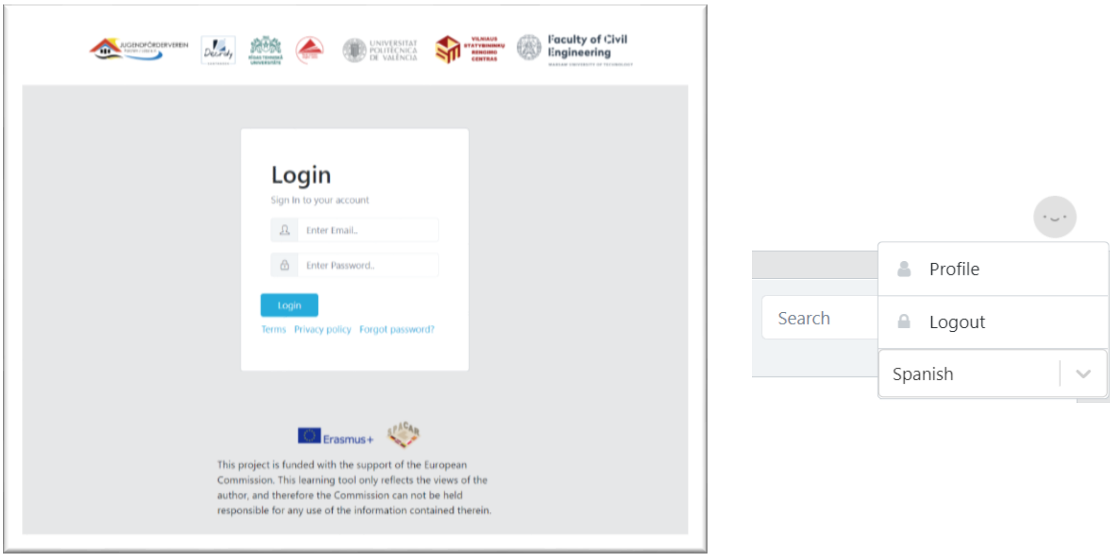

Figure 12. Login screen and menu for language selection

A2.2 Course management

For the course management the available functionality is:

- To view all courses, press "Courses" tab at the upper tab menu (Figure 13). Those courses corresponding to the original intellectual outputs developed in the project appear with the symbol ✅

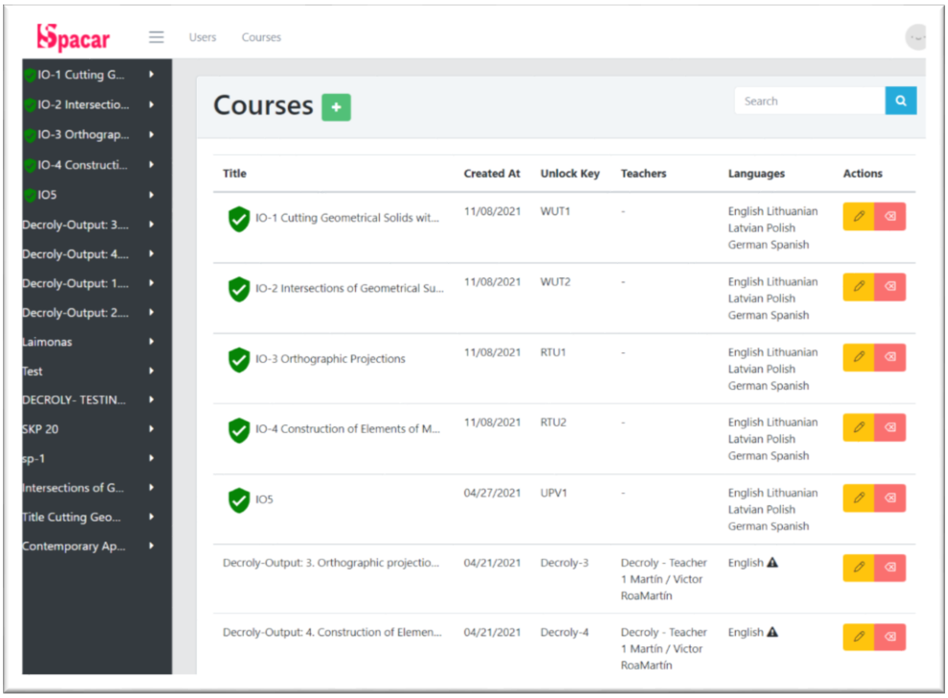

Figure 13. Courses on the platform

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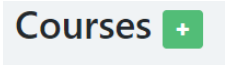
- To create a new course, press the + green button 

Fill the required fields and press "Submit" (Figure 14). To add a new language press + (plus) sign and select the language. Name and description are different for each language, unlock key and teachers are the same for the whole course.

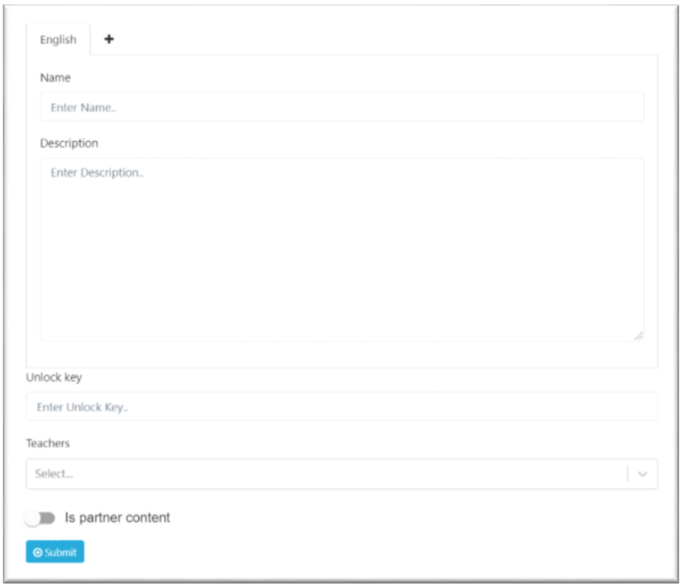


Figure 14. Data for course creation

- To edit course's information, click on its row in the list to deploy the Course info screen. Then press the orange button with a pencil icon (Figure 15). Edit fields and press "Submit". To remove a language from the course press x (cross) sign on the language tab (Figure 16)

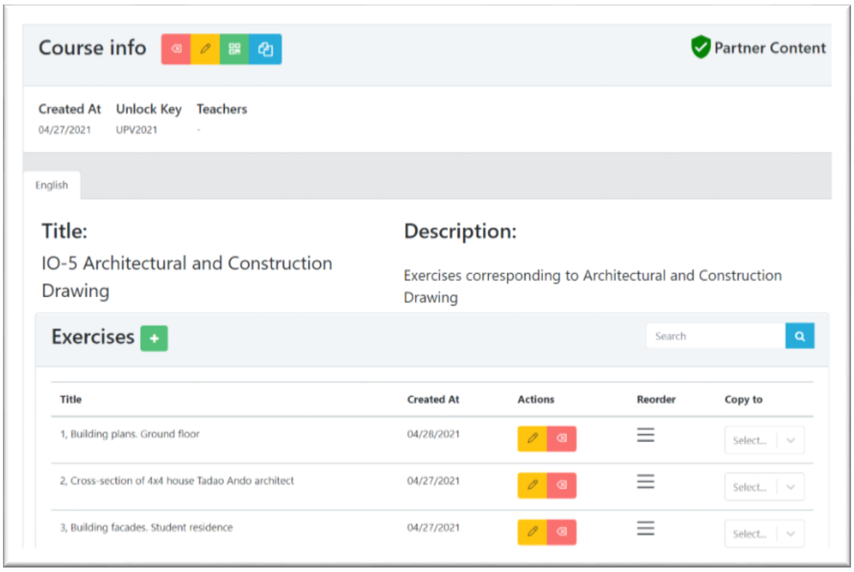


Figure 15. Edition of course data

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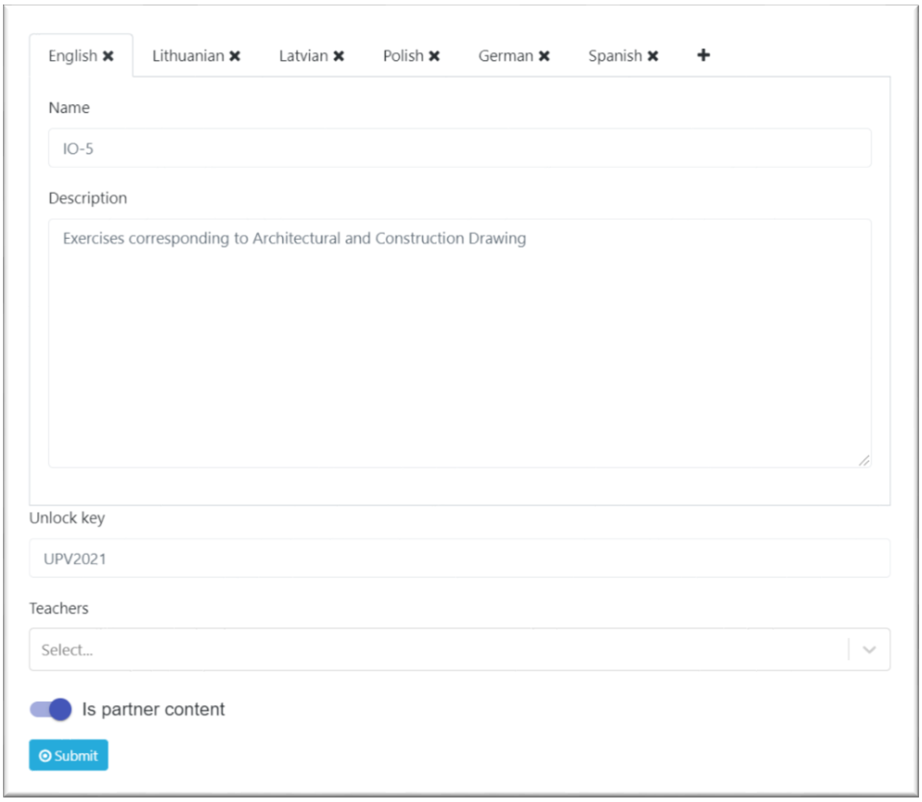
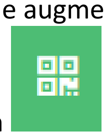


Figure 16. Edition of course data (II)

- To delete course, press the red button (Figure 15).
- To print the QR code to be used to visualize the augmented reality content using the SPCAR mobile app, click on the green icon  next to the "Course info" area on top of the window (Figure 15)
- To open course window, press on a course row in the courses table or in the sidebar (Figure 17).

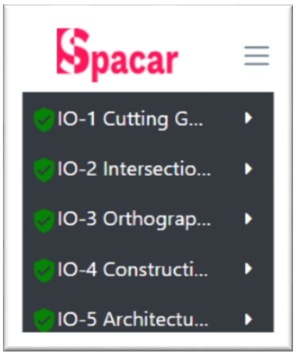


Figure 17. Part of the left sidebar

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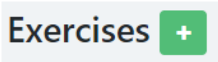
A2.3 Exercise management

- To view the course's exercises, press on a course row in the courses table or in the sidebar.
- To create a new exercise, press the green button with + (plus) sign 

. Fill the required fields and press "Submit" (Figure 18) Figure 9). If course has more languages, add a new exercise language by pressing the + (plus) sign and selecting the language.

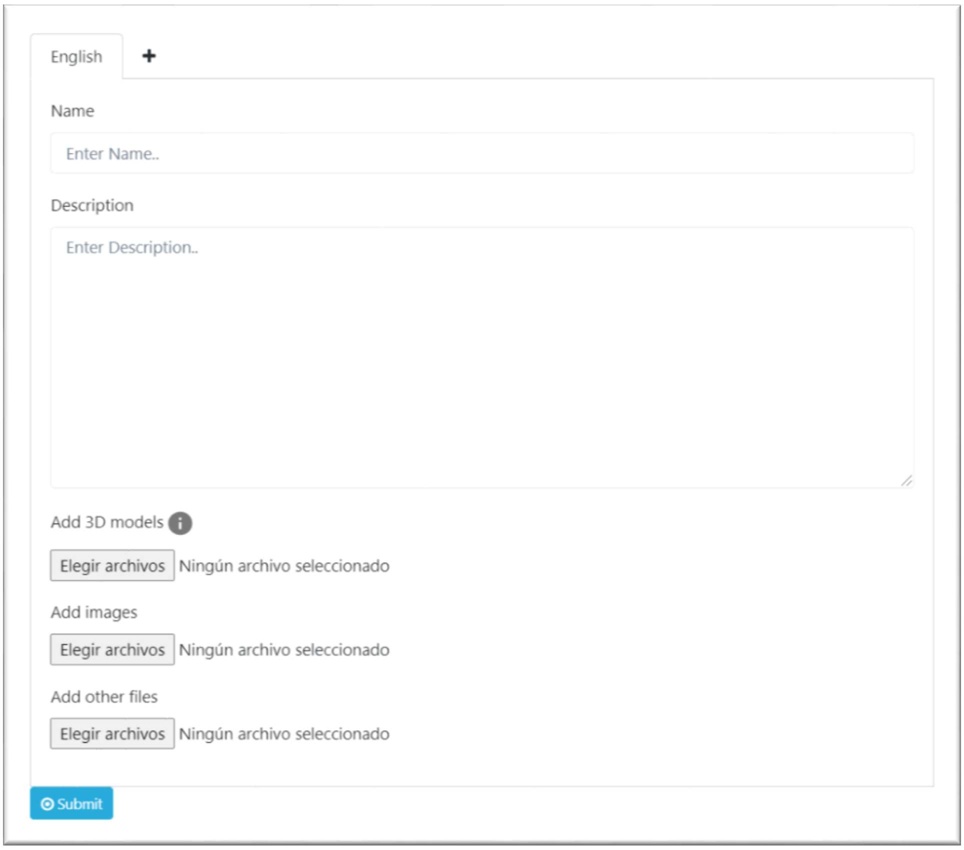


Figure 18. Exercise definition

- To edit exercise's information, press the orange button with a pencil icon in the "Actions" column (Figure 19). Edit fields and press "Submit" (Figure 20). To remove a language from the exercise press x (cross) sign on the language tab.

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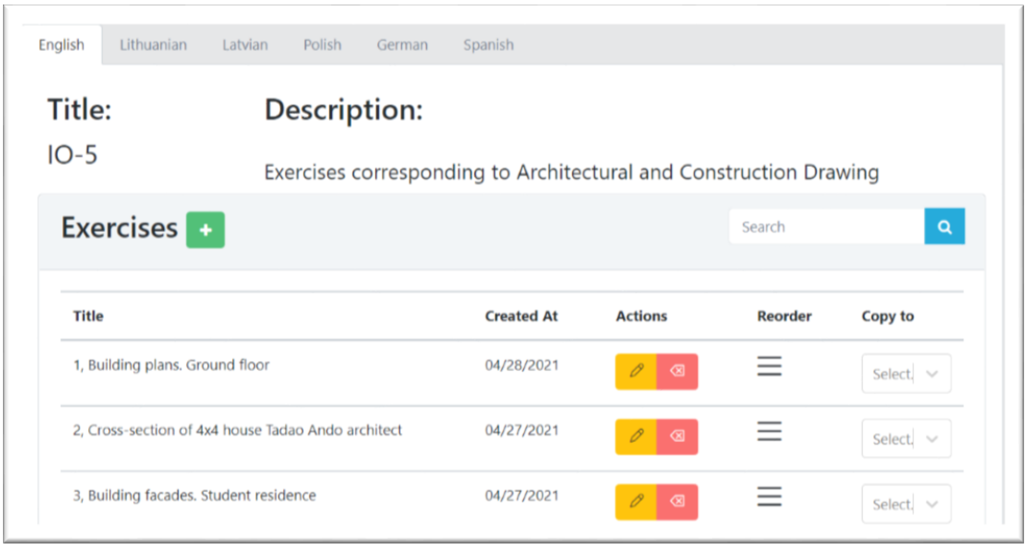

Figure 19. Edition of exercise information

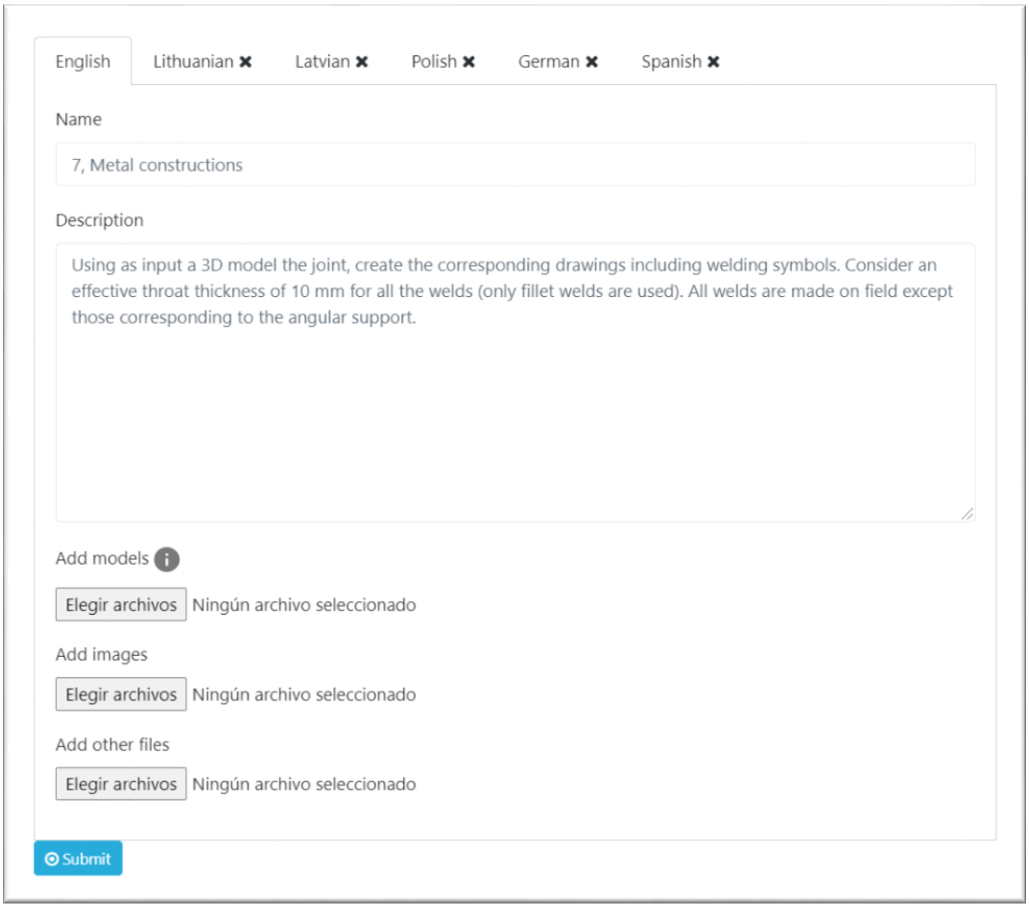

Figure 20. Description of an exercise

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- To delete exercise, press the red button in the "Action" column (Figure 19).
- To copy all exercises to another course, press the blue button and select the course to copy exercises to (Figure 15)
- To copy one exercise to another course, press the selection in the action column and select the course to copy exercises to (Figure 19).
- To reorder exercises, press and hold ☰ in the "Reorder" column and drag to the desired spot in the order.
- To open the exercise window, press on the exercise row in the exercises table or in the sidebar (Figure 19).
- To activate the visualization of a file linked to the exercise use the eye icon (Figure 21). User of the mobile app will have to refresh their course content.
- To delete a file linked to the exercise use the trash bin icon (Figure 21).

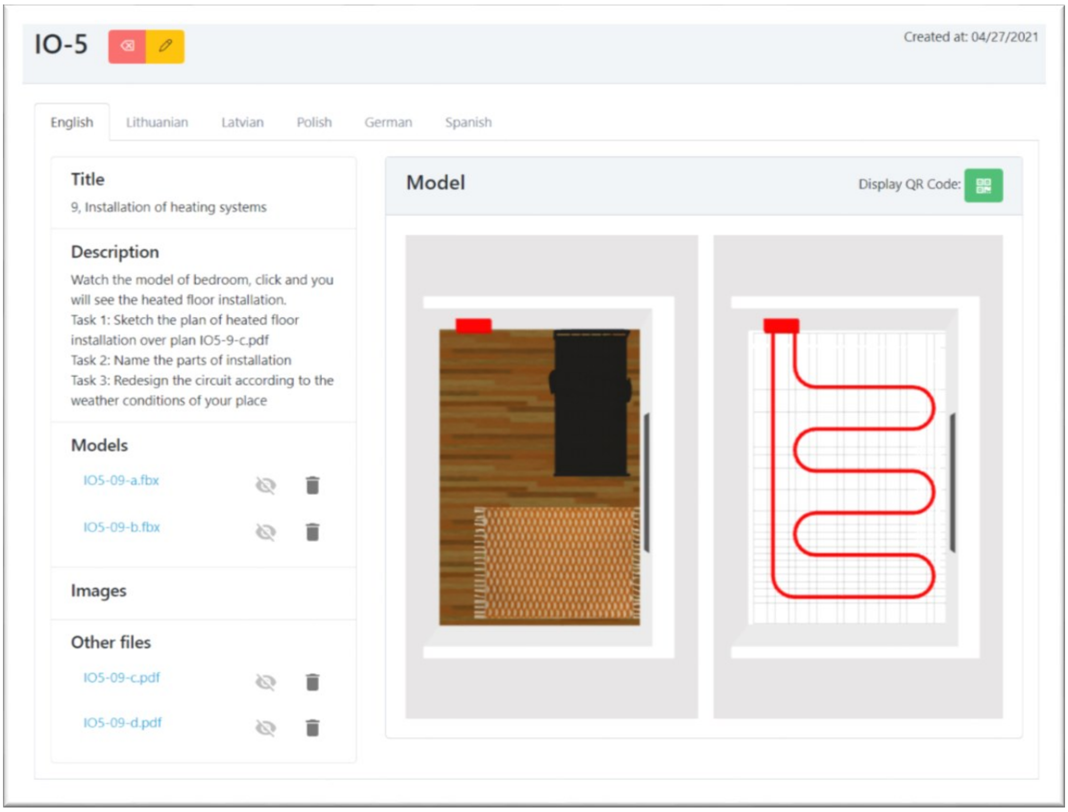

Figure 21 Control of attached files in exercise

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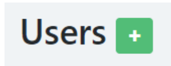
A2.4 User management

Only users with administrative privileges can do the following actions.

- To view all registered users, press “Users” tab at the upper tab menu (Figure 22).

Figure 22. Users‘ tab

- To create a new user, press the green button with + (plus) sign 

. Fill the required fields and press “Submit” (Figure 23).

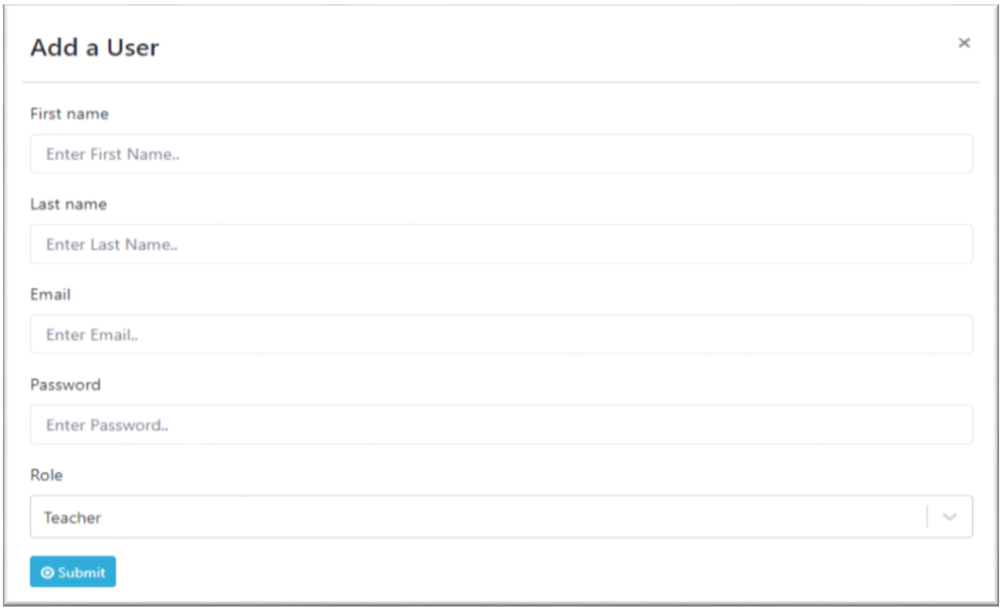


Figure 23. Window for user definition

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- To edit user’s information, press the orange button with a pencil icon in the “Action” column (Figure 24). Edit fields and press “Submit” (Figure 25).

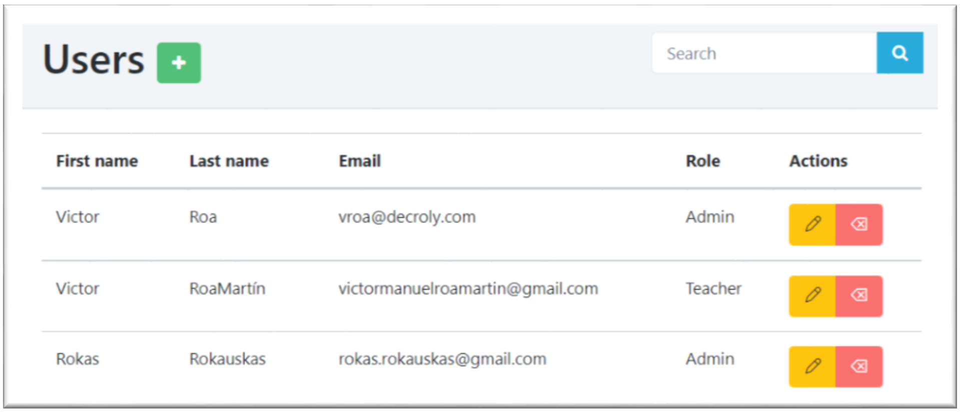

Figure 24. Actions on users

Figure 25. Edition of user data

- To delete a user, press the red button in the “Action” column (Figure 24).

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A2.5 User types

The platform supports three types of users as detailed in Table 6. They have different levels of permissions for the tasks supported by the platform.

Table 6. Types of users and their permissions

	Admin	Teacher	Student
Create, edit, delete other users	✔	✖	✖
View registered users	✔	✔ (only their students)	✖
Create, edit, delete courses	✔	✔ (only assigned)	✖
Create, edit, delete exercises	✔	✔	✖
View courses and exercises	✔	✔ (only assigned)	✔ (only unlocked)
Change default language	✔	✖	✖
Copy exercises	✔	✔	✖
Unlock courses	✖	✖	✔
View 3D models in Augmented Reality	✖	✖	✔
View exercise's image gallery	✖	✖	✔

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A2.6 Mobile application

The SPACAR app is the element to access the content of the developed courses for the students. In the initial screen (Figure 26) if the student is not registered in the system, clicking on the “Register” word, he/she can provide the email and password to create a new user in the system. Password must be at least 8 character long and contain at least one upper case character, one lower case character and one number or symbol.

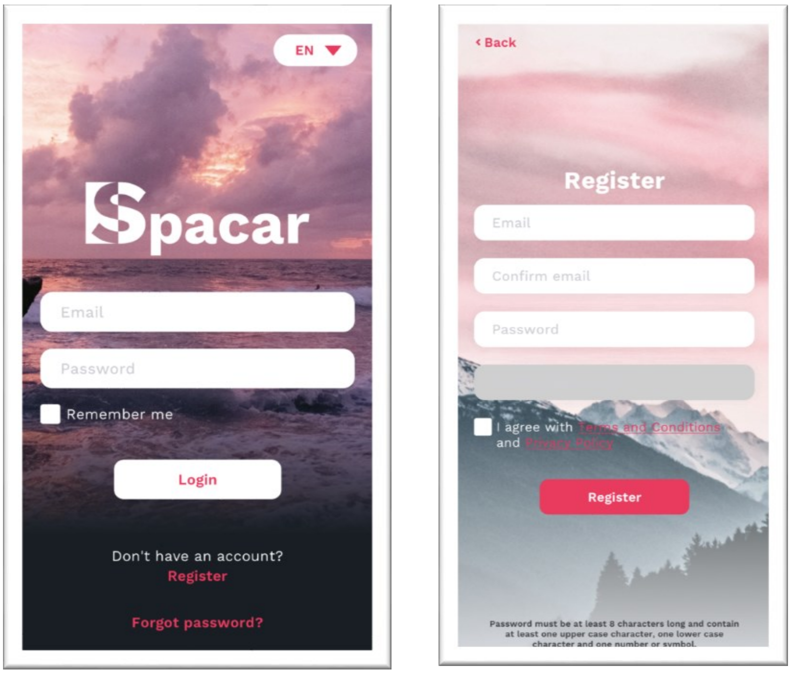

Figure 26. Initial screen and registration form

In the case of forgetting the password, this can be recovered clicking “Forgot password” to open the recover password screen (Figure 27).

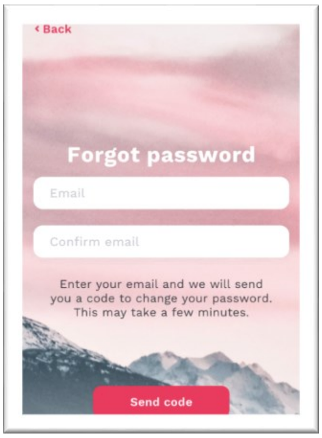

Figure 27. Password recovering

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Regarding the main functionality of the app. The more important aspects are:

- To change the displayed language, press the button  in the top right corner of the login screen or the preference screen and select the language (Figure 28).

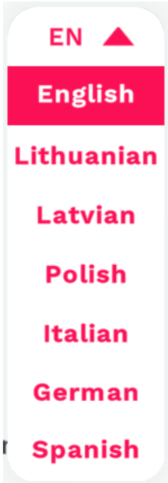

Figure 28. Language selection

- To unlock a course, press the plus button , type in the key and press "Unlock" (Figure 29).

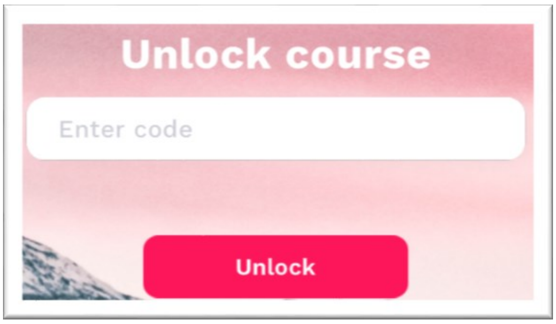

Figure 29. Unlocking a course

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- To open a course, press on the button with desired course's title. These buttons are added when the courses are unlocked (Figure 30).

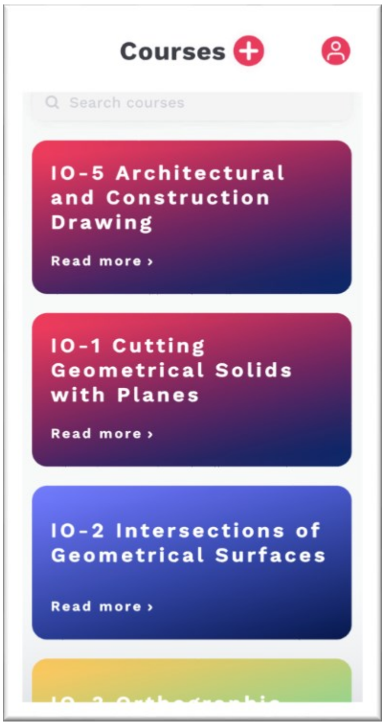

Figure 30. Opening a course

- To remove course, press on the **✕ Remove course** button at the bottom of a course and select "Remove" (Figure 31).

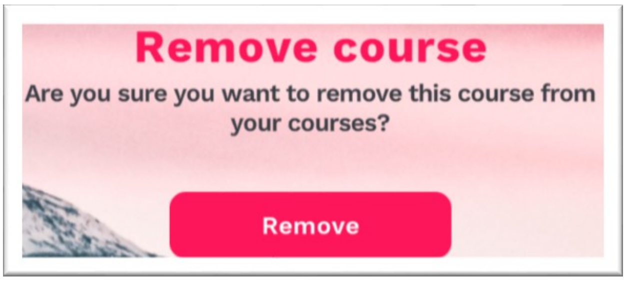

Figure 31. Removing a course

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- To open an exercise, press on the button with desired exercise's title (Figure 32). To view an image in the exercise's gallery, press on one of the buttons displaying an image.

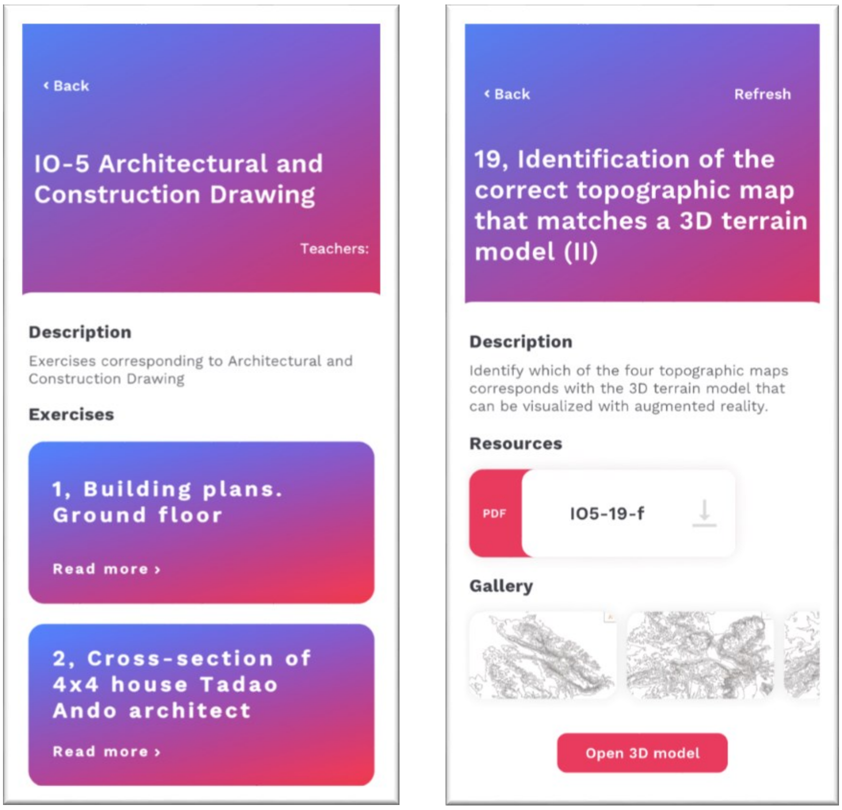

Figure 32. Exercise selection (left) and image gallery of one exercise (right)

- To download a file that is not an image or 3D model (they are listed as resources), press on the file's title (Figure 17).

Figure 33. Resource file

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- To view an image in the exercise's gallery, press on one of the buttons displaying an image (Figure 34)

Figure 34. Gallery

- To view the 3D model, press on the "Open 3D model" button [Open 3D model]. The 3D model is loaded and can be rotated and zoomed with the fingers (Figure 35)

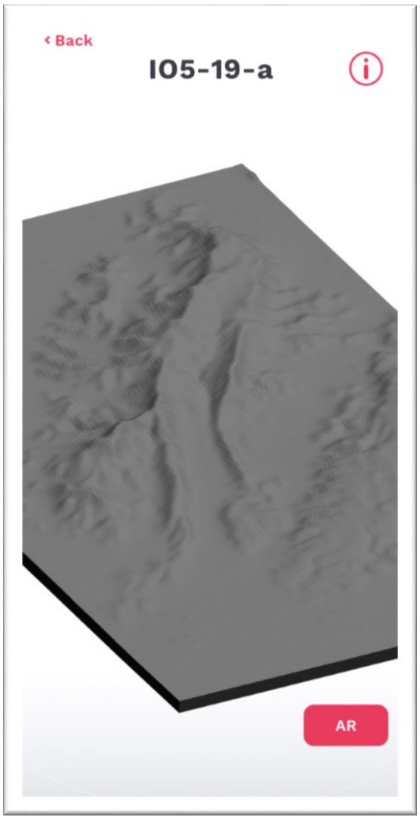

Figure 35. Example of 3D visualization

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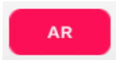
- To view the 3D model in augmented reality, press the “AR” button .

Figure 36. Augment reality visualization

To use the augmented reality visualization, a QR code (presented in Figure 37) must be printed. The camera on the mobile phone must be able to see the QR code to operate successfully.

Figure 37. QR code for all courses

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A2.7 Fixing 3D models

Sometimes 3D models look crooked and their shading seems wrong. This quick tutorial will help with fixing this issue using the open-source application **blender** that can be downloaded from https://www.blender.org.

In Figure 38 some examples of models before and after fixing are presented.

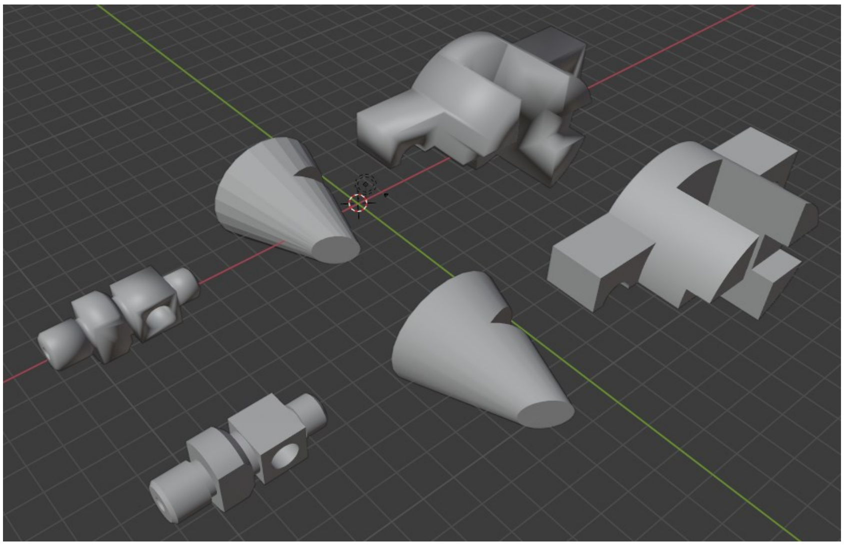

Figure 38. Sample parts for the tutorial.

1.- Firstly, import model into your blender scene (File -> Import -> select model's format -> select model) (Figure 39).

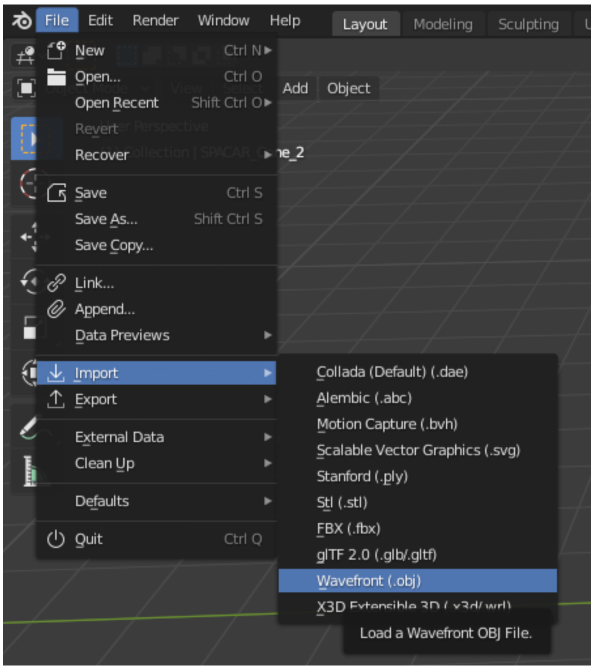

Figure 39. Importing a file in blender

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2.- Press left mouse button on the model.

3.- If it is too big, press "n" on the keyboard and change dimensions on the newly displayed "Transform" panel (Figure 40).

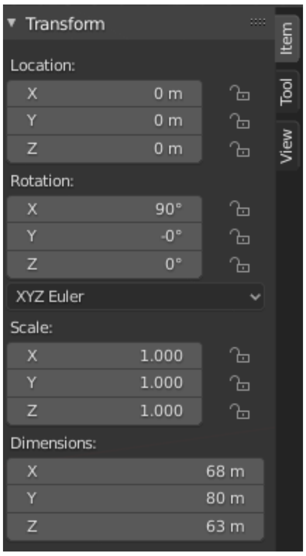

Figure 40. Transform panel in blender

4.- Press the “Object Data Properties” (green triangle) button, expand the “Normals” tab and select “Auto Smooth” (Figure 41).

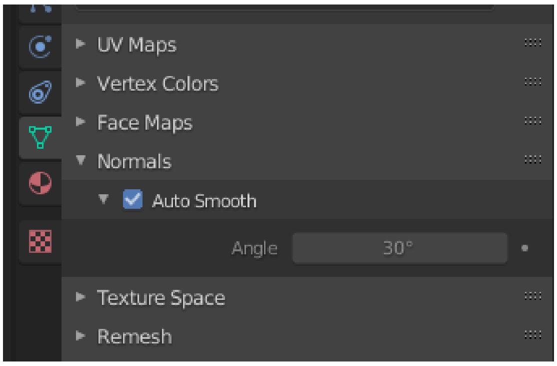

Figure 41. Object data properties in blender

5.- If “Auto Smooth” is already selected and you still need smoothing, unselect “Auto Smooth” and press “Tab” on your keyboard or select “Edit mode” in the top menu (Figure 42).

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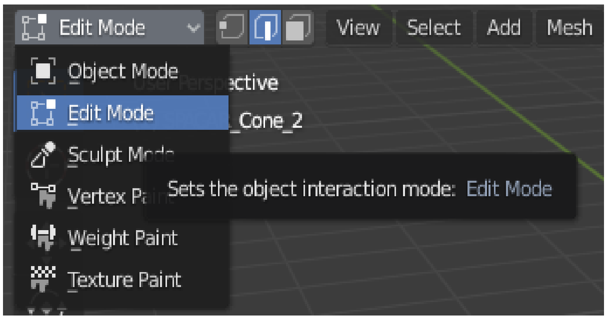
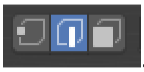
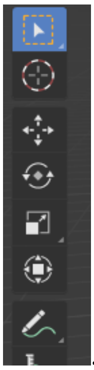


Figure 42. Choosing edit mode in blender

6.- Then press 2 on your keyboard (above the letters, not on the number pad) or select the middle option "Edge Select" - . Make sure that "Select Box" is selected on the side panel - .

7.- Then select the edges of the model with your mouse by drawing a selection box around them (or select them one by one) (Figure 43).

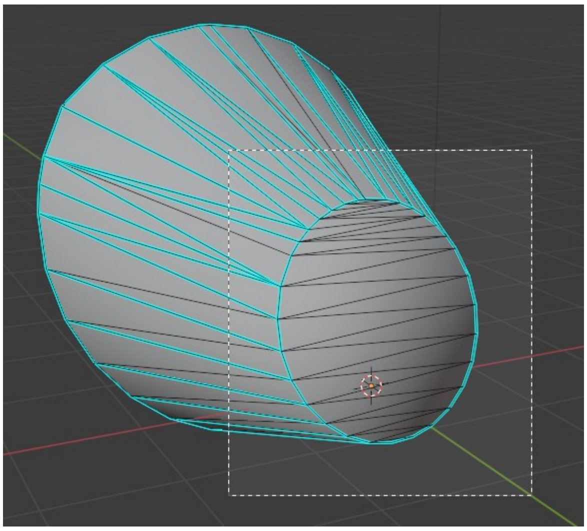


Figure 43. Edge selection

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8.-Make sure that only the sharp edges are selected (Figure 44).

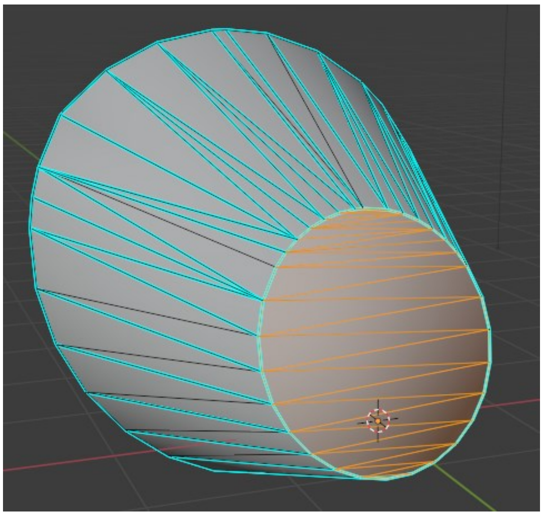

Figure 44. Selected edges

9.- Once the edges are selected, press right mouse button, and select "Edge Split" (Figure 45).

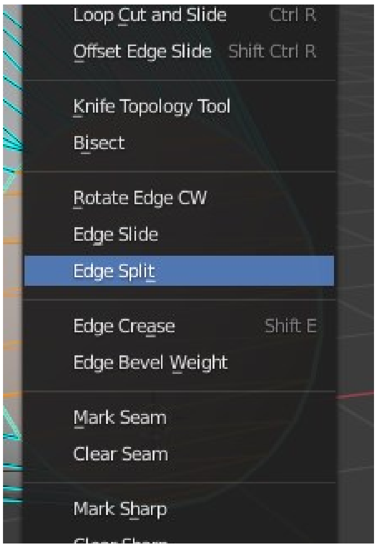

Figure 45. Edge split command

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10.- Repeat steps 7 – 9 for every flat side of the model (Figure 46).

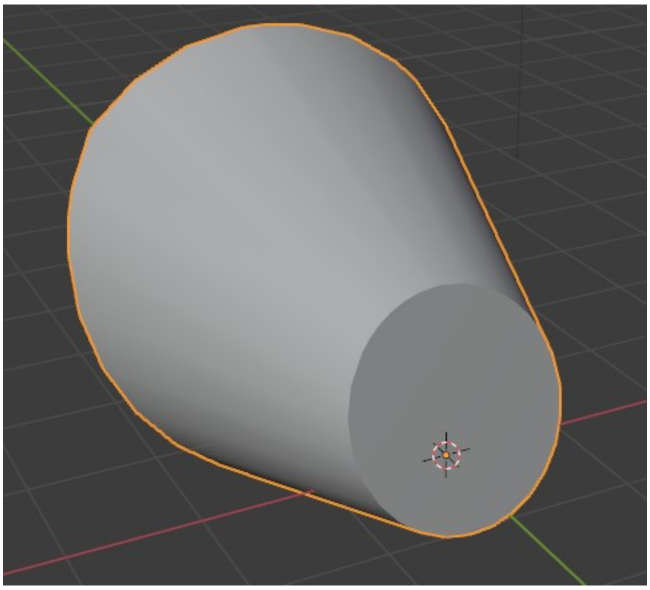

Figure 46. Fixed model

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