Erasmus+

digiVET

Digitally enriched curriculum

bridging formal and non-formal VET

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Introduction

This publication was developed in the framework of a project Digitally enriched curriculum bridging formal and non-formal VET co-funded by the Erasmus+ programme. The key issue that we addressed in the project is how to bridge the gap between formal vocational education of young people and their engagement in extracurricular activities with a view to offering new learning experiences relevant for their vocational careers. The research that we conducted for the project in Poland, Greece and Italy clearly shows that schools and out-of-school learning environments rarely come together to develop a programme that would cross their borders. This results from different agendas pursued by the formal and non-formal education sectors. School programmes are driven by national curricula giving teachers little time to go beyond the particular content of their course and its predefined schedule. On the other side of the scene there are non-formal education providers offering a range of courses which can be adapted to needs and interests of learners in a particular context and time.

The area in which we are particularly interested is young people's progression towards digital competence. We have discovered that those who acquired proficient digital skills helping them move to higher education and employment followed a characteristic learning pathway:

- Mastering digital skills was to a large extent conducted in out-of school settings: at home, online or in peer interest groups.

- Most of the young people interviewed by us presented their autonomous learning paths in sharp contrast to IT classes in schools which they found lagging behind new developments in digital technology.

- The most successful of them in their school years participated in a diverse range of learning experiences, which encompassed not only technical skill acquisition but also development of more generic transversal skills such as communication, teamwork, problem-solving and creativity.

- Participation in informal interest communities acted as an essential motivation factor for them to engage in intense learning and an opportunity to discover how their interests might relate to the job market.

The above findings suggest that in order to support young people in developing their digital competence, essential in many vocational careers, we need to look at the whole “ecology of learning” which goes beyond a narrow view of formal education towards a holistic perspective embracing school, online learning practices and out-of-school activities. In other words we need to bridge formal and non-formal education environments to support young people to develop digital competences relevant for their vocational careers.

The learning activities that we organised in the framework of the project involved young people in initial vocational education and training from Poland, Italy and Greece. They were all preparing for occupations in which competent use of digital technologies is important. On the other hand they had limited opportunities to participate in extracurricular enrichment programmes due to their distant location, price, etc. Thus our workshops aiming at developing competences essential for employment was welcomed as interesting and relevant.

This publication includes learning scenarios that were developed for the above workshops and then validated in the course of their implementation. It is addressed to VET teachers and trainers working in schools or non-formal education organisations open to innovation at the interface of initial VET, lifelong learning and youth work, particularly those who seek new opportunities to extend or improve their programmes in the field of digital education. It can also be of interest to decision makers in the VET field in charge of planning courses as well as local/regional authorities deciding on financial support to non-formal learning programmes.

The project partners cooperated closely in the process of writing the publication. In each country we developed different learning scenarios that correspond to our fields of expertise.

Chapter One on 3D design was developed by Centro Machiavelli from Florence, Italy in cooperation with two other Florentine vocational institutions, Metallo Nobile and European Centre of Restoration. It explores the applicability of new 3D modeling technologies in areas where manual/hand processing is still predominant, and the support of 3D techniques is still at an early stage: jewelry making and restoration of cultural heritage (furniture and sculpture).

Chapter Two on digital prototyping was developed by two Polish organisations: Education Centre EST and Centre for Continuous and Vocational Education from Wadowice, Poland. It outlines a programme of workshop activities for VET students of building construction, carpentry and electronics leading them how to progress from manual to digital prototyping of objects relevant for their fields.

Chapters Three and Four were brought together by the Computer Technology Institute from Patras, Greece. The adapted material presented in these chapters aims to acquaint VET students with the technology behind intelligent spaces and precision farming. They are based on and inspired by the educational materials created in the context of three successful projects: GAIA whose goal was to increase awareness about energy savings and sustainability, Introduction to Arduino - a guide on the use of Arduinos and IoT for use by Greek schools and Skills for Future Farmers addressed to VET students in agriculture programs.

Chapter One: 3D Modeling

The 3D modeling process in the field of 3D computer graphics, allows to define a three-dimensional shape in a virtual space created on a computer. To create these forms, called **3D models**, are used certain software called 3D modelers or, more simply, **3D software.**

3D modeling technique is recent, it was created around 1959 When General Motors, in cooperation with IBM, developed one of the first CAD systems called DAC. Initially it was linked to the industry field, as a support to design, but over the years the areas of application have enormously expanded, embracing That many applications can be grouped into two large macro-categories.

Scientific and Technical applications

- Mathematical, physical and natural sciences (biology, physics, mathematics, astronomy, etc.)
- Study of the territory (Geology, Seismology, meteorology, etc.)
- Historical sciences (archeology, paleontology, paleoanthropology etc.)
- Applied Sciences
- Medicine (Forensic, reconstructive, diagnostic investigations, etc.)
- CIVThe engineering
- Industrial engineering
- Architecture
- Industrial design
- Design of mechanical parts

Artistic applications

- Film and television industry
- Video games and gaming applications
- Advertising graphics
- Editorial publications
- Web Design
- Multimedia applications
- Artistic production

Therefore, today 3D modeling techniques and virtual graphics have entered the labor world and found numerous fields of application, and more and more are the requests of 3D modelers specialized in specific areas.

Going further into what said above, the seminars planned by ***Centro Machiavelli*** are aimed to address training objectives that allows to explore the applicability of the new 3D modeling technologies in areas where manual / hand processing is still predominant, and the support of 3D techniques is still at an early stage: jewelry design and sculpture restoration. These seminars have been planned and implemented in cooperation with "ERC European Restoration Center" - Building School and with "Metal Noble", School of jewelry technique and design, both of Florence.

Analyzing the programs of the two institutes, it has been possible to verify how the organization of 3D modeling seminars can be a valid tool that can be integrated with existing courses and benefit both students and professionals who work in these fields.

To make the seminars compatible with existing courses, the program includes a common part concerning the introduction to 3D modeling and specific parts:

- for goldsmiths, the creation of a goldsmith product with the support of 3D technology
- for the restoration of a sculptural element, the intervention with the support of 3D technology on a plaster model that presents deficiencies of material
- for the restoration of antique furniture, the replica of metallic decorative elements

In all the cases, a comparison is made with the traditional work method, analyzing the benefits and difficulties. The use of specific examples has been considered necessary to analyze in a practical and tangible way the differences between the two processes to facilitate understanding how these methodologies can be taken up and adapted in different contexts.

The expected learning outcomes of this module are the following:

- to know how the virtual space is defined and how it works
- to know the different ways of creating a virtual three-dimensional form
- to have an overview of the 3D modeling software and their features, to be able to opt for the one that best suits your needs
- to be able to model example forms

As mentioned, the process of creating three-dimensional shapes within virtual spaces was born within the industrial sector. Initially as a support to the design, then, with time, with the advent of new techniques and new more sophisticated software, the fields of application of the 3D modeling have considerably increased, expanding into many working and non-working environments. In the world of 3D computer graphics emerged figures such as CAD Designer, 3D Modeler, 3D Animator and 3D Rendering Expert, who require specific preparation and reflect extremely wide and complex fields.

Our seminars focus on the figures of the 3D Modeler, who designs virtual models, geometric or organic, to support other professional figures who will use them in their specific fields.

3D modeling can be divided in two different typologies:

- ***organic modeling*** Which is the typical modeling used to make humans or creatures, animals or humanoids. It is used for all "*natural*" subjects, such as rocks, plants, trees and for the territory in general, In these cases the models are the more the more successful they are rich in details.

- ***geometric modeling is*** the less recent type of modeling, it is used to make technical or mechanical objects, or in any case for anything that has an artificial nature, and that does not fall into the previous category. Generally the complexity of the models created with this kind of modeling is much lower, if we look at the external appearance of the individual forms, but not if we consider aspects linked to the precision and correspondence of the parts.

Naturally the same object can contain both organic and geometric modeling, or it can be formed by a set of parts containing both organic and geometric models.

The seminars also cover various types of modeling: the procedural one will be mentioned, and the focus is on the manual one and the one coming from real models (3D scan). We explain the differences between solid, surface and volumetric 3D modeling so that the students can analyze their own needs and have a clear idea of what they want to request from a software.

There are a myriad of 3D modeling software, specific to different types of modeling, which essentially can be divided into commercial and free. In this phase an overview of the programmes is made, analyzing their features to understand their possible use in one's field of work.

The choice of software to be used in the seminars will then be decided by the teacher based on the students' needs. In particular, they focus is on open source and free programs:

- Tinker CAD: This software runs directly in the web browser and uses boolean modeling to create objects. In practice, one form is added to or subtracted from another to create increasingly complex objects. Easy to learn and free. Very useful for 3D modeling those approaching for the first time.

- Free CAD: Open source and multi-platform software for 2D and 3D CAD modeling. Very simple to use and with numerous tutorials and a very large community network.

- Blender: One of the most comprehensive open source multi platform 3D modeling software, whose features compete with the most famous commercial software. For this reason it is one of the most used programs. The documentation that can be found on the web and as paper manuals is very wide, but perhaps, given its characteristics, even among the most difficult to learn.

- Sculptris: Very simple and intuitive program to approach the world of digital sculpture. From the same Z-Brush software house.

Among the commercial programs:

- Rhinoceros Commercial 3D modeling and design software. It is used in various fields among the one in which design where it has become a standard stands out. Characterized by an easy-to-learn interface and a fairly affordable price, it is possible to use the trial version for 90 days, enough time to learn it and to evaluate the eventual purchase.

- Zbrush: One of the most widespread software in the world for digital sculpture. Not particularly easy to learn however at an affordable price.

- 3DCoat**:** A very affordable professional software that allows you to create organic forms and sculpture 3D models through digital tools and polygonal constructions. Equal to ZBrush features.

Although the seminars focus on 3D modeling, the various 3D printing techniques will be also mentioned. The following topics provide content for this part:

- From 2d to 3d printing: 3D printing as an evolution of 2D printing
- Subtractive printing techniques, also known as a "traditional" technique that is obtained by cutting or digging the material from a larger initial piece. the most common technologies of this type are the cutters numerically controlled (CNC) and the laser cutters
- Additional printing techniques, which created an object through the superposition of multiple layers of material and thin. The existing additive techniques differ according to functional the way the layers are deposited and the material that can be used
- Advantages and disadvantages of the two procedures
- Rapid prototyping for finished products
- 3D printing for indirect production: realization of tools and / or equipment necessary for the realization of finished elements
- Additive printing technologies: extrusion, digital light processing, fusion of granular material, laminar structure
- Materials
- Fields of application

I. Modelling of a ring: phases of the seminar

Regarding the jewellery field we proceed to the realization of a ring by analysing all the phases that characterize both the traditional process, and the one involving the use of software and 3D printers. The final product will be an object in metal combined with precious stones.

In this case, the student whether he is already a goldsmith or a novice, will be able to:

- Know the stages of conception and design of a goldsmith's artefact
- Know its components and technical features
- Analyse the various viable processes
- Shape the object
- Evaluate the use of a professional program or open source
- Analyse the finished product and evaluate the benefits and weaknesses of the traditional process and the process with the aid of 3D modelling software

1. Stages of conception and design of a goldsmith's artefact

The design steps of a jewel can be summarized as:

Analysis and observation of the real world: In this phase you get information.

- It identifies the user that the product is targeted to (Who?)
- It analyses the users' needs (when will the product be worn? Where? How? Why?)
- Fashion, trends, and people's inspirations are considered
- From these analyses and from the answers resulting from the observation of reality, we arrive at the definition of the type of product to be designed

Research: At this point market surveys are carried out:

- What demand is there for these objects?
- Are there similar objects?
- What are the currently most sold items?
- What are the trends for the next year?
- For what reasons the product can differentiate or improve existing products?

Project Brief: From this preliminary phase we obtain what is called "project brief", that is the guidelines to follow when designing. The designer streamlines the information reported in the brief and integrates them by first defining the themes and then the lines of the collection.

Planning: In this step the resources available are evaluated, and then activities, times, costs, people who intervene in the process are organised.

Planning phase: In this phase we begin with the development of the collection project in the first part called ***"Vision"***. The designer applies his creativity to find an idea that responds to the requests indicated in the brief. It starts with a series of sketches, views, snapshots of projects and ideas. You work freely focusing on research for the idea, the drawings don't necessarily have to be connected. Sketches, notes, phrases, words, pictures, symbols are drawn up to sketch an idea. All the material is then collected, sorted and processed, then a re-examination is carried out, only a part of the material is selected, the one that best responds to the requests of the brief. These works are organized in the form of a ***"Concept"***.

The concept, that represents the idea that you want to follow, should be defined graphically and must be equipped with documentation that makes it clear:

- Colours
- Materials
- Shapes
- Finishes

In **"Concept"**, formal, functional and technical choices are defined:

- How many parts is it composed of?
- Is it possible to simplify it in view of assembly in production?
- What are the best materials to use?
- What technology is more appropriate to use?
- How strong and durable will the object be?
- What is the degree of comfort?
- What are the production costs?
- What impact will it have on the environment?

Answers to conceptual questions will also be evaluated:

- What impact will it have on the body?
- What emotions does it arouse?
- What values does it transmit?
- What story does it tell?
- Is it possible to recognise in it the brand?

The concept is displayed in plan, elevation and section and listed with the respective measures by elaborating ***technical tables.***

From technical tables we proceed to the creation of a first ***two-dimensional model*** and ***two-dimensional renderings*** are developed to better evaluate the object in its volumetric and material development.

At the end of this step the ***three-dimensional modelling*** (CAD) phase, the ***three-dimensional rendering*** of the model and the ***prototyping*** (CAM) will follow to verify the correctness of the design setting and its technical feasibility through the creation of a ***prototype*** (master).

The testing of the prototype is of fundamental importance, because it is the product of all phases described above and at the same time the starting point of the production phase. It is the object of definitive assessment among all the components that participate in the process and determines whether it is necessary to make corrections, or if the object can go into production. In fact, after this verification phase, with the creation of one or more prototypes and any necessary corrections, you can move on to the production phase thus ending the design process.

In the production stage we will proceed with other types of decisions, such as, materials, quantities, use of semi-finished products, production methods and cost containment, production through third parties etc. Once the production is done, we will then move on to marketing for the sale.

2. Technical characteristics of the product

To proceed to the design of a ring is important to know some technical features regarding the product under consideration.

Types: there is a wide variety of types of rings. The following are some of the best known types.

Wedding band: It is the classic wedding ring, the more widely used. It is characterized by a smooth metal, most often yellow gold. The width is variable, as well as the possibility to engrave inside the wedding date, a name. This kind of ring is generally worn on the left hand on the ring finger, while in Central-Eastern Europe, and also in the Iberian Peninsula (except Catalonia), it is customary to wear it on the right.

Solitaire ring: It is the most widespread and appreciated engagement ring: it has a diamond mounted on its own, with no other stones around. Symbolic meaning: one diamond, one love. The stem can be in gold, most often white, or platinum.

Trilogy: ring with three stones, usually diamonds.

Eternity or Riviera ring: Ring with a metal band (generally White gold) with a row of gems, usually diamonds, which goes around the finger.

Trinity: Ring developed by Cartier in 1924: it consists of three different bands of different metals (white gold, pink gold, yellow gold) that intersect.

Signet ring (shield) or Chevalier: ring of very ancient origins (dates back to Egyptian era) it is characterized by a bezel on which a symbol is engraved. It was used both for ornamental purposes and for practical needs as to oppose one's "signature" on wax tablets.

Halo: Ring with a diamond or other central stone and a halo of smaller gems around it. It serves to increase the visual impact without having to resort to a larger and more expensive stone.

Pave ring: ring characterized by a paved frame of generally small stones.

Measurement

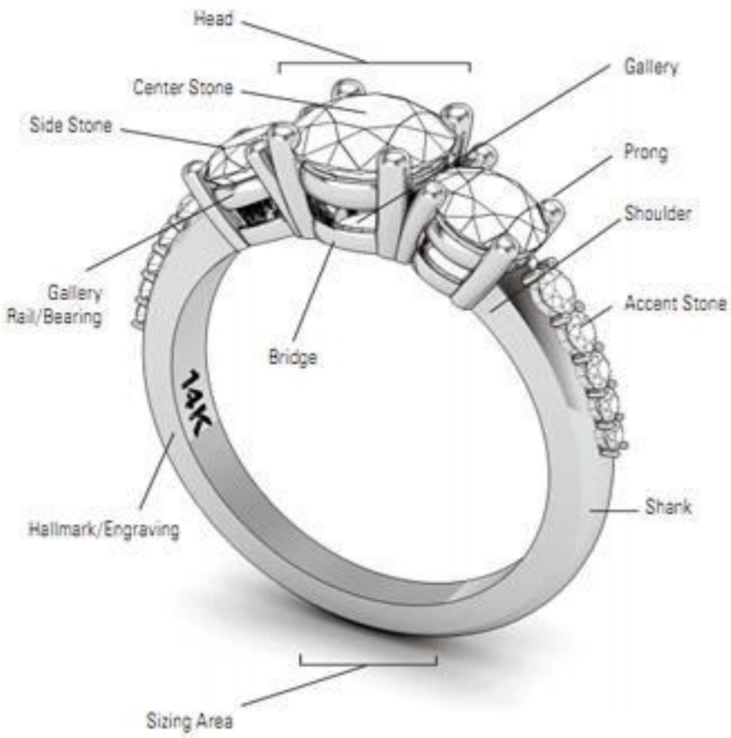
The size of a ring is defined by sizes that vary from country to country. Each measurement corresponds to the diameter (or circumference) of the finger. Below is a table of the main measures:

Standard				Diametro	Circonferenza
Inglese	Francese	USA	Italiano	cm.	cm.
D	41,5	2	2	1,33	4,18
D	42		2	1,33	4,18
E	42,75	2,5	2,5	1,35	4,24
	43		3	1,36	4,27
F	44	3	4	1,4	4,4
	45		5	1,43	4,49
G	45,5	3,5	5,5	1,45	4,55
H	46		6	1,46	4,58
H-1/2	46,75	4	6,75	1,47	4,62
I	47		7	1,49	4,68
I-1/2	48	4,5	8	1,53	4,8
J	49		9	1,56	4,9
J-1/2	49,25	5	9,5	1,58	4,96
K	50		10	1,6	5,02
L	50,5	5,5	10,5	1,61	5,06
L-1/2	51		11	1,62	5,09
M	51,5	6	11,5	1,63	5,12
	52		12	1,65	5,18
	52,5		12,5	1,66	5,21
N	53	6,5	13	1,68	5,28
	53,5		13,5	1,7	5,34
	54		14	1,72	5,4
O	54,5	7	14,5	1,73	5,43
	55		15	1,74	5,46
	55,5		15,5	1,76	5,53
P	56	7,5	16	1,78	5,59
	56,5		16,5	1,8	5,65

Standard				Diametro	Circonferenza
Inglese	Francese	USA	Italiano	cm.	cm.
Q	57	8	17	1,81	5,68
	57,5		17,5	1,83	5,75
	58		18	1,85	5,81
	58,5	8,5	18,5	1,86	5,84
R	59		19	1,88	5,9
	59,75	9	19,5	1,9	5,97
S	60		20	1,92	6,03
	60,5		20,5	1,93	6,06
	61	9,5	21	1,95	6,12
T	61,5		21,5	1,96	6,15
T-1/2	62	10	22	1,98	6,22
U	62,5		22,5	1,99	6,25
	63		23	2	6,28
U-1/2	63,5	10,5	23,5	2,02	6,34
V	64		24	2,04	6,41
	64,5		24,5	2,05	6,44
W	65	11	25	2,06	6,47
	65,5		25,5	2,08	6,53
X	66		26	2,1	6,59
	66,25	11,5	26,5	2,11	6,63
	67		27	2,12	6,66
Y	67,5	12	27,5	2,13	6,69
	68		28	2,15	6,75
Z	68,75	12,5	28,5	2,17	6,81
	69		29	2,19	6,88
	69,5		29,5	2,2	6,91
1	70	13	30	2,22	6,97

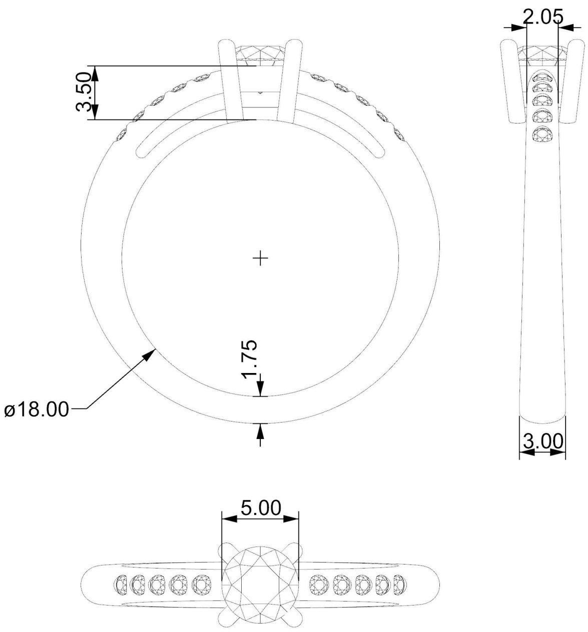
Components

The parts which form a ring generally depend on the type and can be indicated in:
shank or band
head
center stone
claws or prongs
side stones
shoulders
gallery
bridge



3. Examination of example ring made with traditional method

As a case study for the seminar we take as an example a classic style ring with 5mm central stone mounted on a claw setting and 1pt side stones

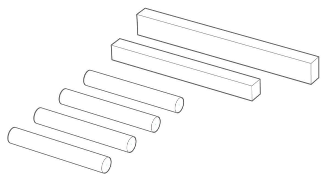


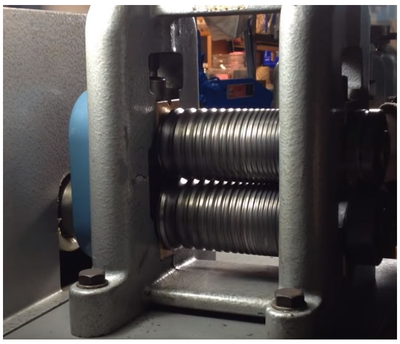
At this stage we illustrate how the goldsmith artefact taken into consideration is realized in the classical way:

Metal Preparation - casting - modelling - model preparation
(cutting-marking-drilling-welding) - embedding - engraving - polishing

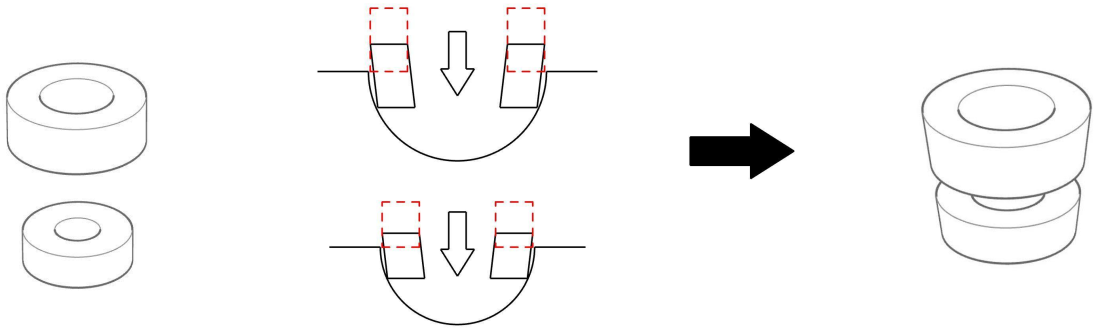
First we identify the parts to be made:
the claw bezel and the ring shank on which the bezel will be positioned

Preparation of the claw bezel
Through the preparation of the metal and the drawing, two bars with a rectangular section and four with a circular section of the dimensions necessary for the creation of the bezel and the prongs are made.

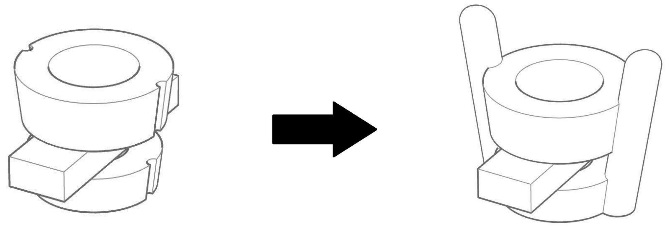




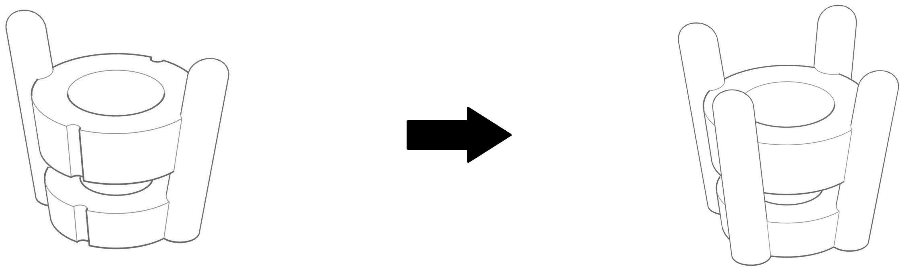
The two rectangular section bars are folded and welded to form two rings. The two rings are then formed on a dapping block to assume a cone-shaped form.



The two rings are superimposed using a spacer and engraved laterally to the right and left. These incisions serve as guides for soldering the first 2 prongs.

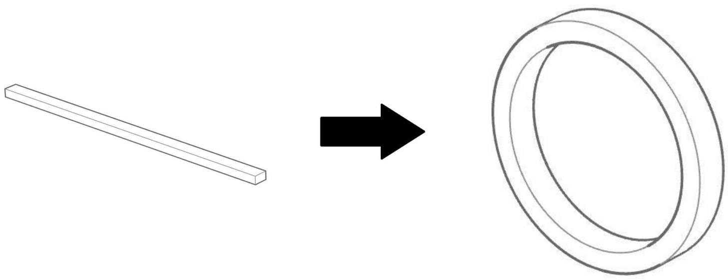


At this point, the spacer is eliminated, the two rings in front and behind are engraved to create two more guides and the other two prongs are welded: the bezel is completed.

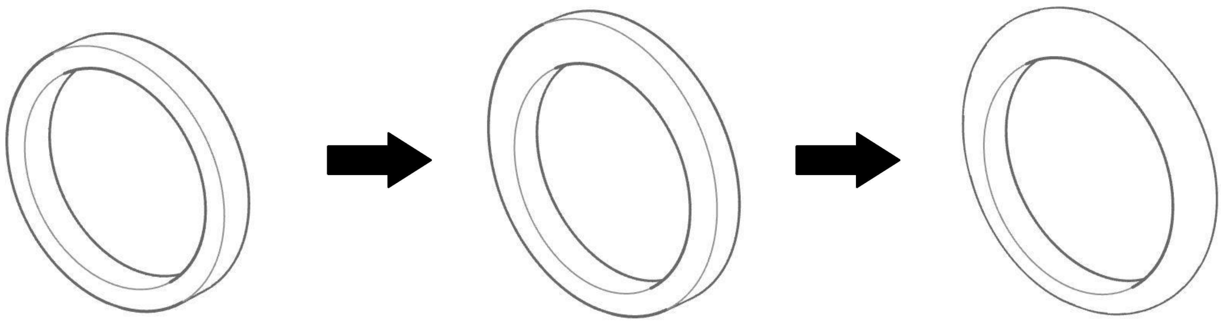


Realization of the shank

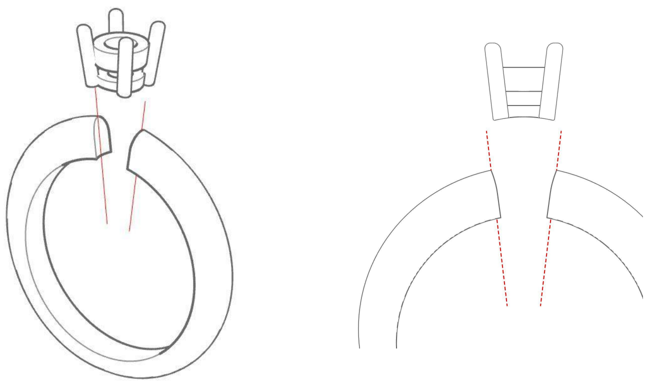
Through the preparation of the metal and the drawing, a rectangular-section bar of suitable dimensions for the creation of the stem is made. This bar is then bent to form a ring.



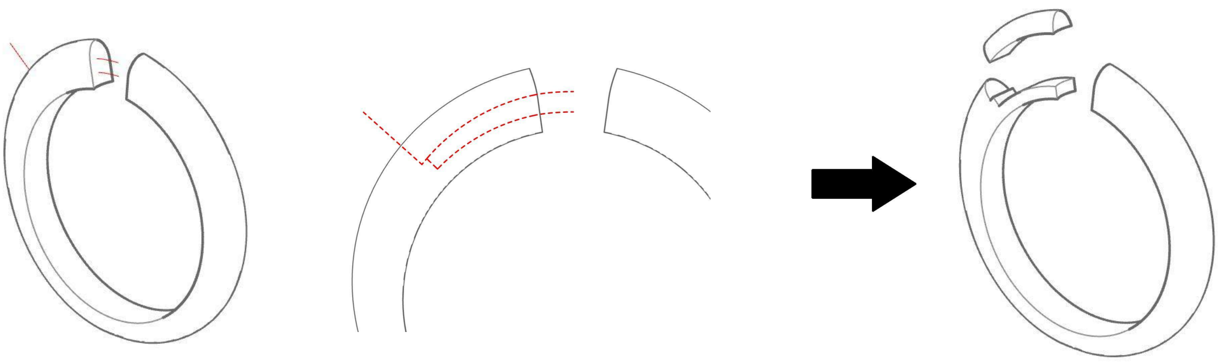
The ring is beaten until the desired shape is obtained.



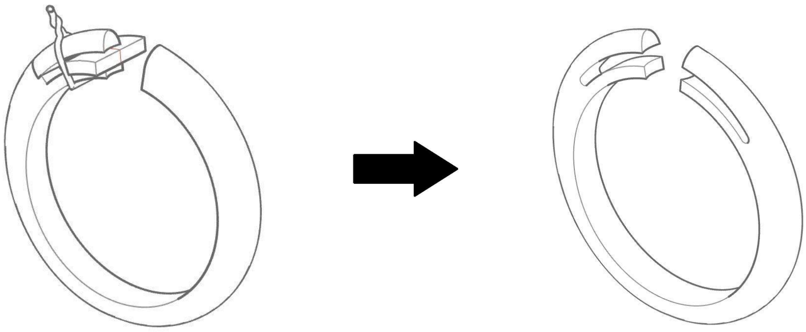
A cut is made in the upper part to ensure that the bezel can be inserted.



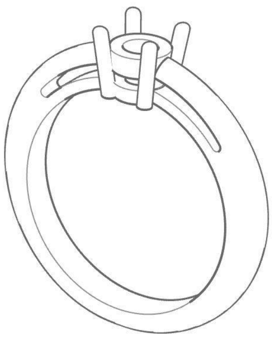
At this point, we proceed with the construction of the bridge and the shoulders, and then of the gallery, cutting the right and the left side of the ring.



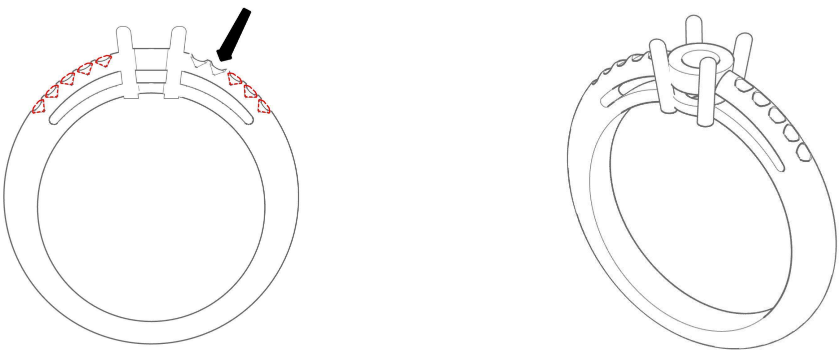
The two shoulders are welded to the shank with the help of a spacer completing this second phase.



The claw bezel is inserted into the shank and welded.



The positions of the stones are marked on the shoulders and the holes are prepared with a cutter.



After this stage the ring is ready to be set by the setter.

4. Ring construction using assisted modelling software

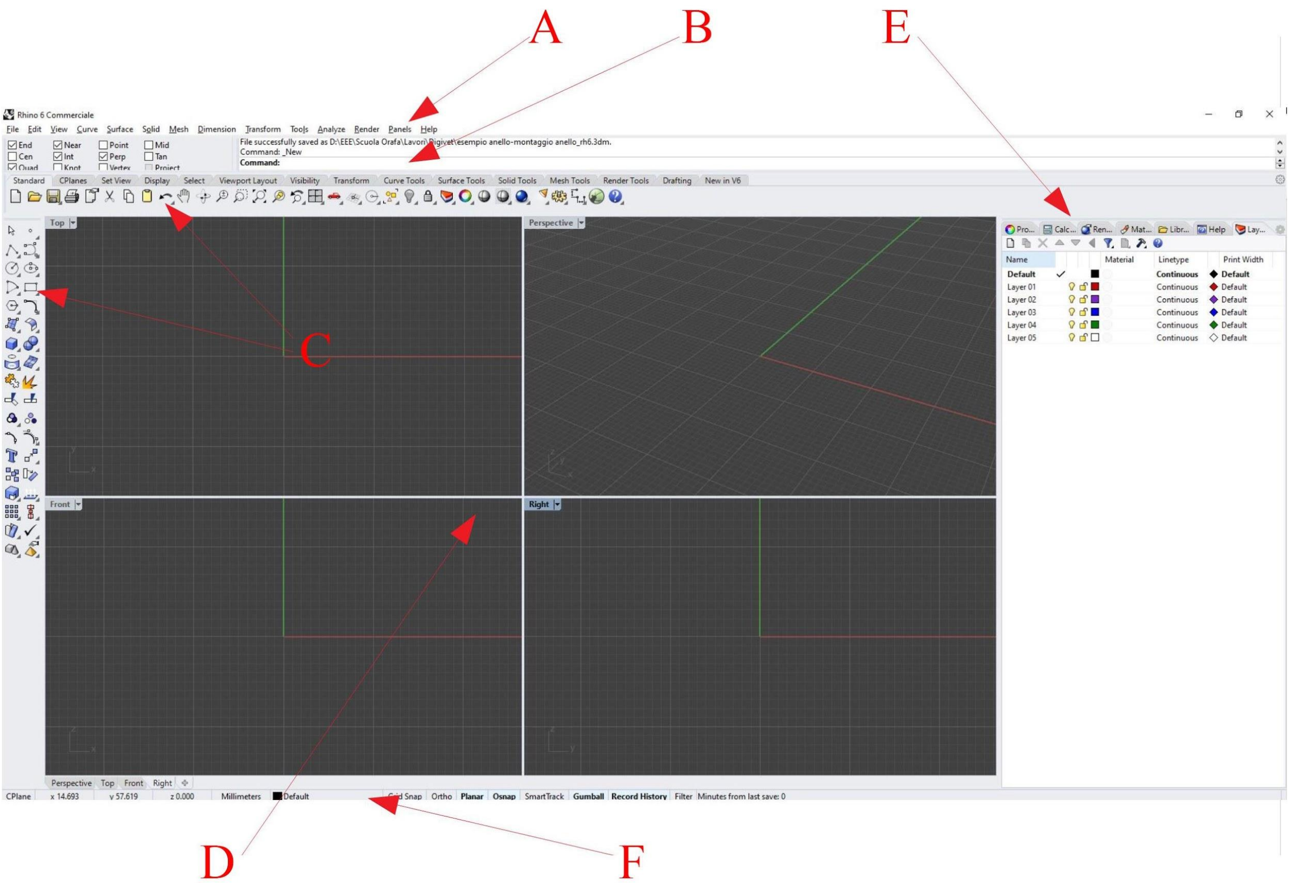
In this phase we proceed to the modelling of the ring previously observed in its manual realization, using the computer and 3d printing. It is possible to use any 3D modelling software, on the market there are many that differ a lot both in terms of address, type of modelling and cost. In this seminar Rhinoceros and FreeCAD are considered, the first is commercial software, the second product of an open source project, precisely because they are targeted for mechanical engineering and product design.

4.1 Introduction to Rhinoceros

Rhinoceros, made by *Robert McNeel & Associates*, is normally used for industrial design, architecture, naval design, jewellery design, automotive design, CAD/CAM, for rapid prototyping, *Reverse engineering* and for communication design. In design and goldsmithing it has become a standard. This growing popularity is based on its diversity, multidisciplinary features, low learning curve and on its relatively low cost.

Rhinoceros meets all the needs of a goldsmith modeller: It is a free form NURBS surface modeller. With this software it is possible to create, edit, analyse and translate NURBS[1] curves, surfaces and solids in Windows or Mac environments. There are no limitations on the complexity, degree or size of the model to be designed. It is also the software on which many of the plug-in used in jewellery design laboratories around the world are based, such as Matrix, RhinoGold, RhinoPRO-J or Rhinojewel. Finally, as already mentioned, it is possible to use a trial version for a period of 90 days, useful time to evaluate and learn it.

The Rhinoceros Interface is basically divided into:
A - the menu bar, where you can give commands to the software through the items shown in the menus organized in different areas of work
B - the command line, where you can interact with the software through commands typed via the keyboard
C - The tabbed toolbar (also including the side toolbar), where the inputs in this case, are given via buttons grouped into tabs
D - the graphic area divided into windows, in which the virtual 3D space with models is displayed
E - the area of the tabbed panels, where it is possible to graphically operate on different properties of the model
F - the status bar, where the cursor coordinates, units, drawing aids and various other properties are displayed



With Rhinoceros it is possible to create points, curves, surfaces and solids. For this reason it is used both in two-dimensional technical drawing, with the elaboration of technical tables and drawings on paper, in the drawing of paths, and in 3D modelling aimed at creating 3D objects or rendering.

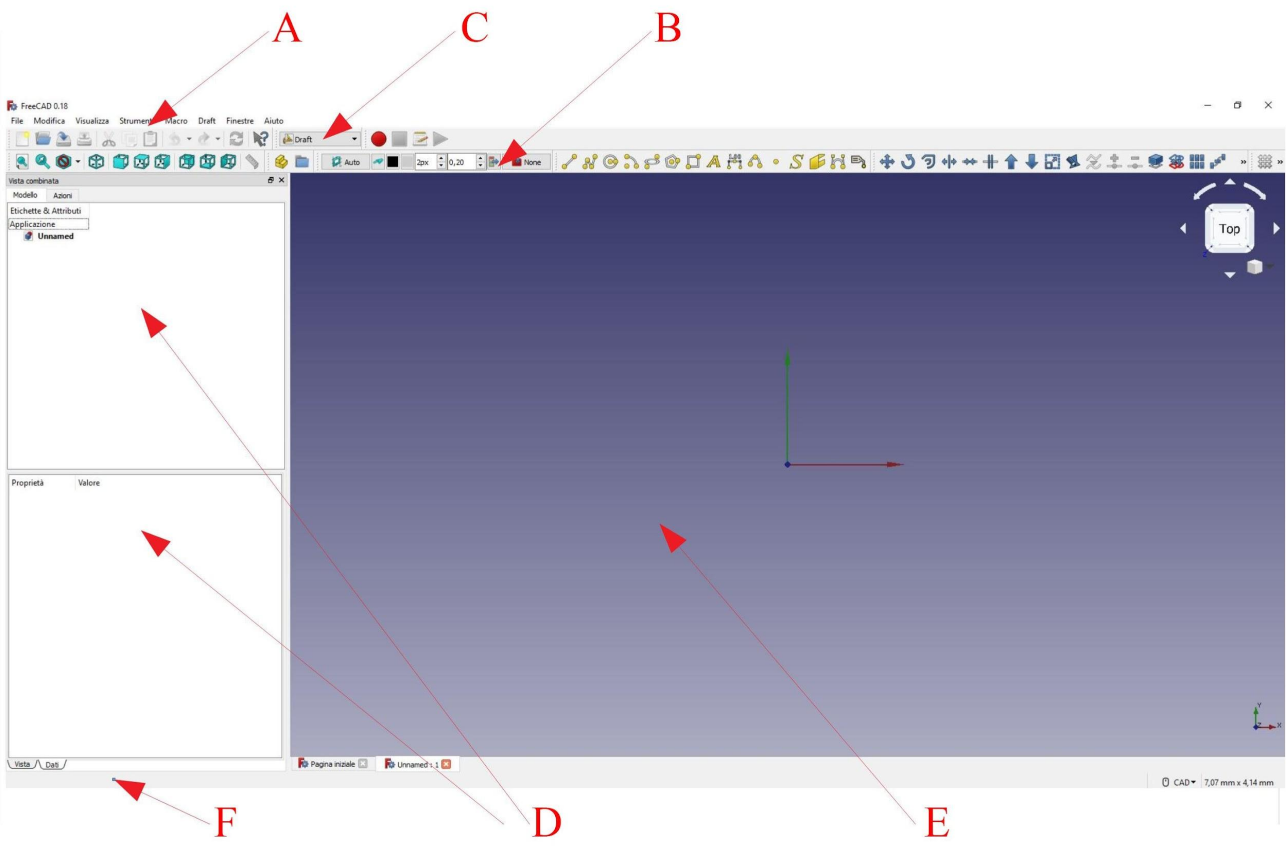
4.2 Introduction to FreeCAD

FreeCAD is a parametric 3D modeller that is part of an open source project started in 2001 by Jürgen Riegel. It is essentially a 3D parametric solid modeller that makes use of other open source libraries: in fact it is based on Open CASCADE, a software development platform consisting of libraries, components and services used for the development of most free CAD / CAE programs, Coin3D (an Open Inventor creation), the Qt Framework graphics libraries (GUI), and Python, a popular scripting/programming language. FreeCAD itself can also be used as a software library by other CAD / CAE programs.

It is mainly aimed at mechanical engineering, but it is also used in other areas such as architecture and design.

The FreeCAD interface is essentially divided into:

A - The standard menu where you can perform basic program operations
B - The toolbar area organised into buttons for commands
C - The workbench selector selector
D - The combo view area, which includes: the tree view with the hierarchy and the history of the objects, the task panel that is activated when a tool that requires user input (text, points, coordinates, characteristics of a shape etc.) is activated, the property editor of the selected objects
E - The 3D view that displays the workspace and geometric objects of the document
F - The status bar, which is a ribbon that displays messages and informations



The operation of FreeCAD is based on the division into workbenches, where there are the tools necessary to perform a certain type of task. From this point of view it appears a little less user-friendly than a software like Rhinoceros, but at the same time is logically well structured.

[The workbenches](#) are:

- **Std Base**: this is not really a workbench, but this category is used to collect all the "standard"commands and tools of the system that can be used in all workbenches
- **Arch Workbench**: for working with architectural elements
- **Draft Workbench**: contains 2D tools and basic 2D and 3D CAD operations
- **FEM Workbench**: provides Finite Element Analysis (FEA) workflow
- **Image Workbench**: for working with bitmap images (matrix)
- **Inspection Workbench**: provides specific tools for examining shapes. It is still in development
- **Mesh Workbench**: for working with triangulated mesh
- **OpenSCAD Workbench**: to interact with OpenSCAD and repairing constructive solid geometry (CSG) model history
- **Part Workbench**: to work with CAD objects (3D Part type)
- **Part Design Workbench**: to build Part shapes using sketches
- **Path Workbench:** to produce G-Code instructions. It is still in an early stage of development
- **Plot Workbench**: to edit and save output plots created from other modules and tools (under development)
- **Points Workbench**: for working with point clouds
- **Raytracing Workbench**: for rendering with ray-tracing
- **Reverse Engineering Workbench**: provides specific tools to convert shapes / solid / meshes into parametric FreeCad-compatible features. It is still in development.
- **Robot Workbench**: to study the robot movements
- **Ship Workbench**: FreeCAD-Ship works over Ship entities, that must be created on top of provided geometry
- **Sketcher Workbench**: for working with geometrically constrained sketches
- **Spreadsheet Workbench**: to create and manipulate spreadsheet data
- **Start Center Workbench**: allows you to quickly switch to one of the most common workbench
- **Surface Workbench**: provides tools for creating and modifying surfaces. It is similar to the Part Shape builder Face from edges.
- **TechDraw Workbench**: it is used to produce basic technical drawings from 3D models created with another work environment such as Part, PartDesign, or Arch, or imported from other applications.
- **Test Framework Workbench**: for debugging FreeCAD
- **Web Workbench**: offers a browser window instead of the 3D View within FreeCAD

It is possible to switch from one workbench to another through the workbench selector (C).

Like many CAD modellers, there are numerous 2D tools for two-dimensional technical drawing, it is possible to work with meshes, to create solid for rendering or 3D printing. It is mainly made for mechanical design, but it is also useful in all cases where it is necessary to model 3D objects with precision.

5. The modelling of the ring

In this phase we proceed with the modelling of the ring and to its preparation for printing with the use of 3D software. The steps are the following:

- Analysis of the model in its parts and design of their construction
- 2D model drawing in its front and side views
- 3D modelling of individual parts
- Assembly
- Print preparation: analysis of the minimum points, creation of the supports, creation of the .stl file
- Printing of the model

The procedure is identical using both Rhinoceros and FreeCAD.

Analysis of the object to be modelled

The ring is made up of 2 parts: the shank and the claw bezel.
The shank has a gallery formed by the shoulders and the bridge.
On the shoulders there are holes for embedding the 1pt stones.
The bezel is formed by two superimposed rings and by four cylindrical prongs.

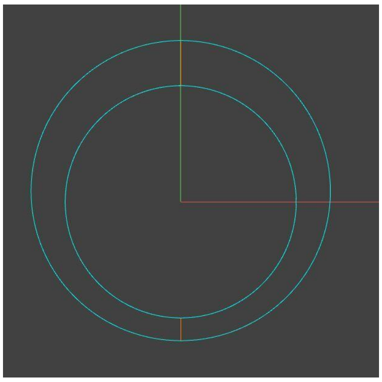
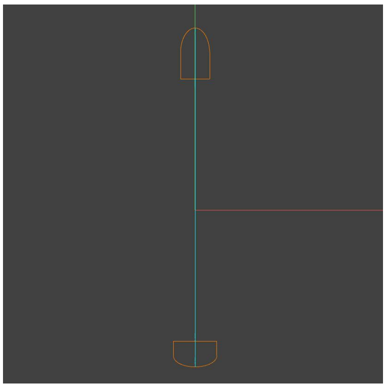
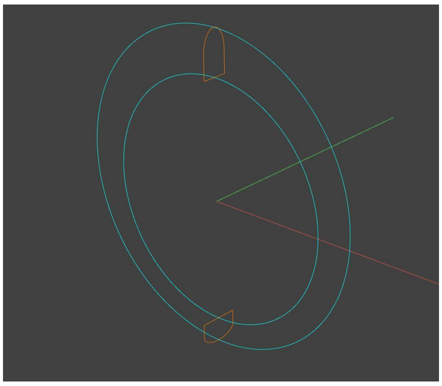
Design of the creation of the 3D objects in its individual parts

In modelling, by generalizing, it is possible to create 3D objects through the processes of extrusion, revolve and additive and subtractive modeling (boolean). After an analysis of the possible routes passable, it can be imagined that:

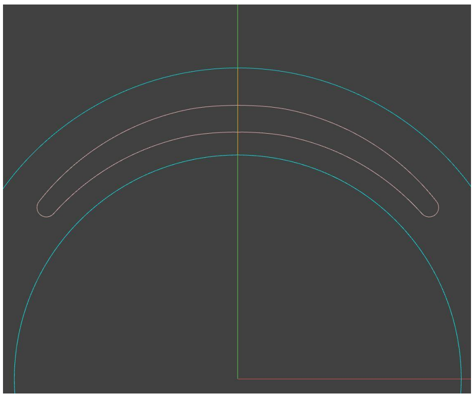
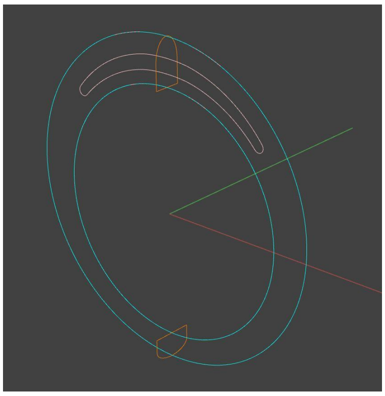
- The shank will be created through a specific extrusion (sweep), the bezel compartment by a subtraction of the overall volume of the bezel, the gallery by the subtraction of a corresponding volume (obtained by extrusion).
- The holes on the shoulders for the stones will be created by subtracting the overall volume of the stones (obtained by revolution).
- The bezel will be created by revolving the two sections of the two rings that make up the bezel itself.
- The prongs will be realized through the creation of a cylinder (pipe), which is then copied and rotated four times around the bezel.

Two-dimensional drawing

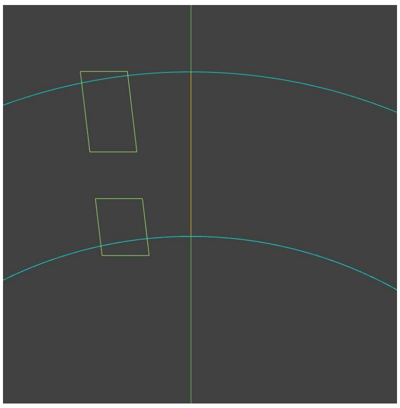
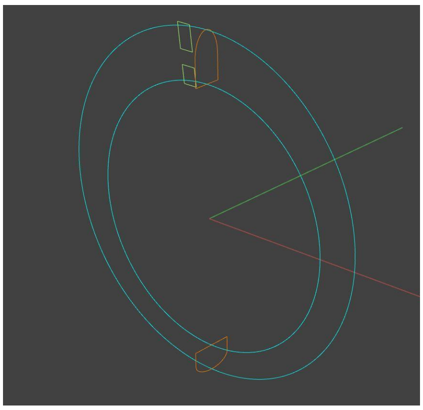
A. A circle is drawn, which represents the finger size and the sections of the features that the ring must have.

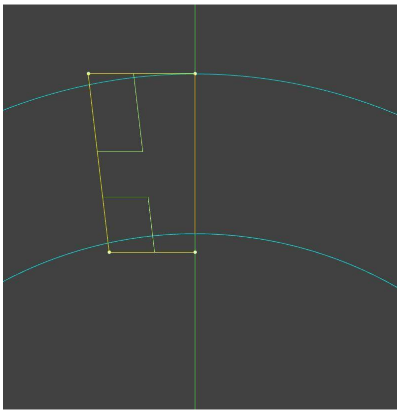
B. A closed curve is drawn which represents the gallery area.

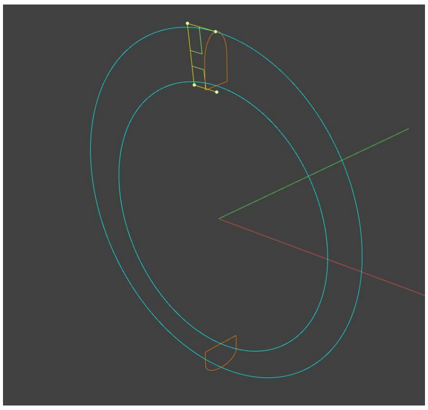



C. The sections of the bezel are drawn considering that it is formed by two rings.

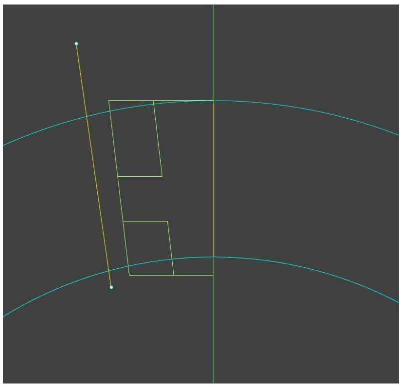



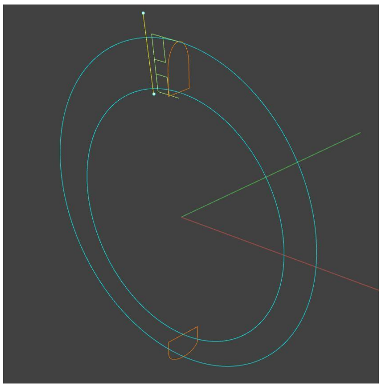
D. the profile that will create the overall volume of the bezel needed to create the space for inserting the bezel on the ring is drawn.



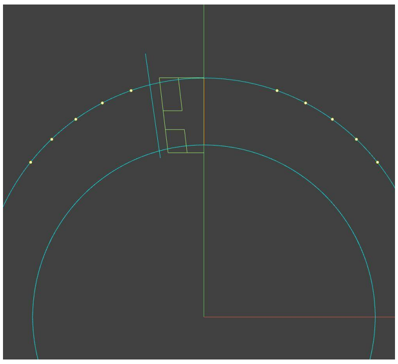


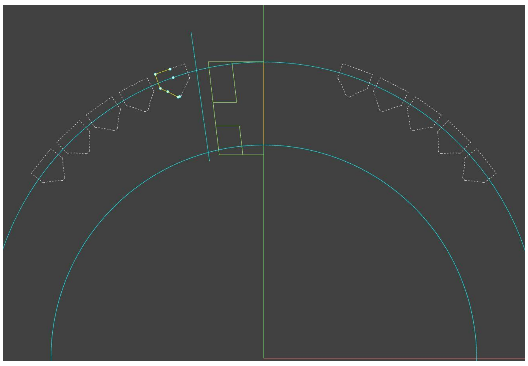
E. A line is drawn that represents the central axis of one of the prongs.





F. The phase of the two-dimensional drawing is completed by indicating the position of the stones to be inserted and drawing the profiles necessary for the creation of the overall volumes of the stones.

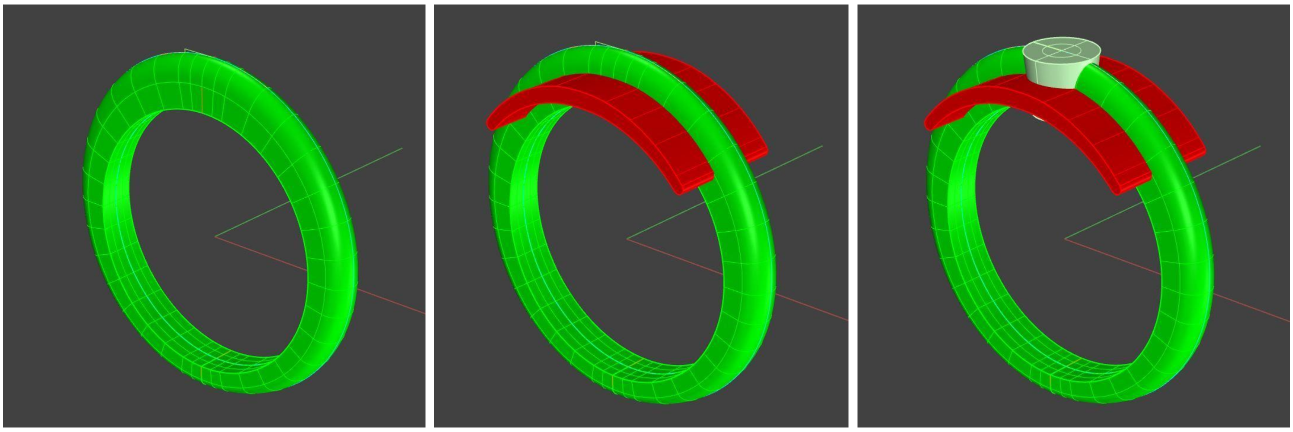




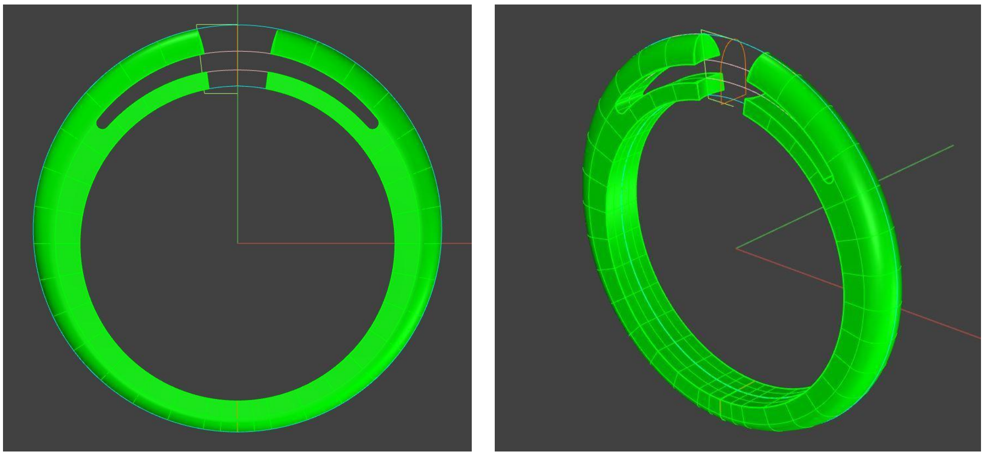
Three-dimensional modelling

Once the two-dimensional drawing part is completed, we move on to modelling the solids starting from the curves just drawn.

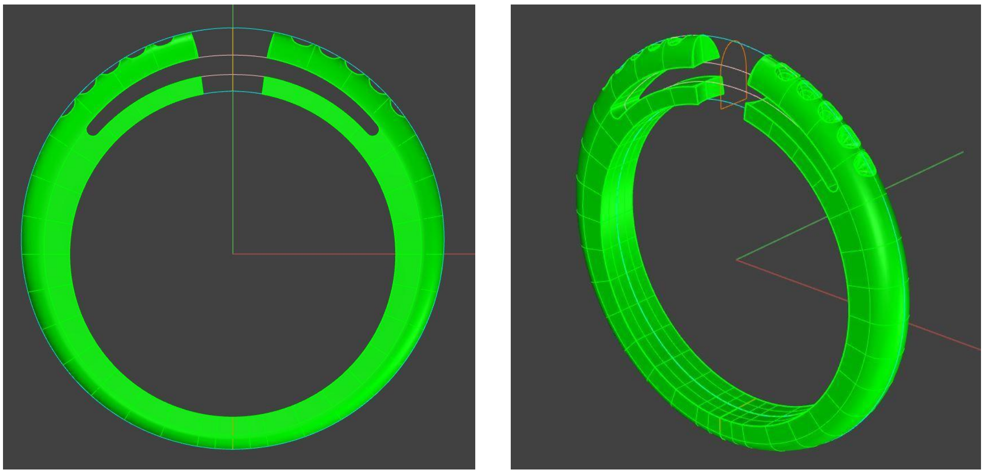
A. the volumes of the shank (through a sweep), the gallery (extrusion) and the volume of the bezel (revolve) are created.



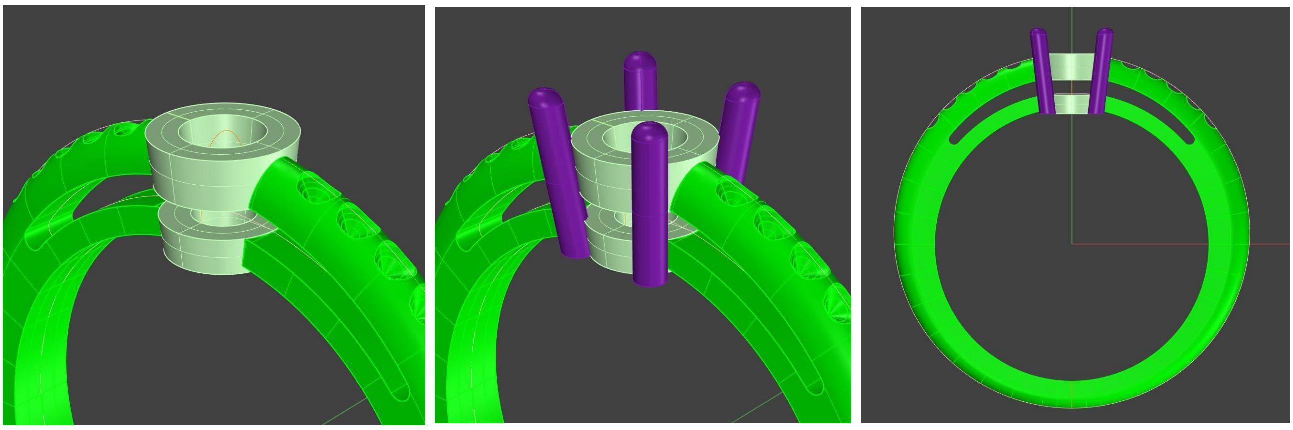
B. A boolean subtraction is carried out to obtain the gallery and the space for the claw bezel.



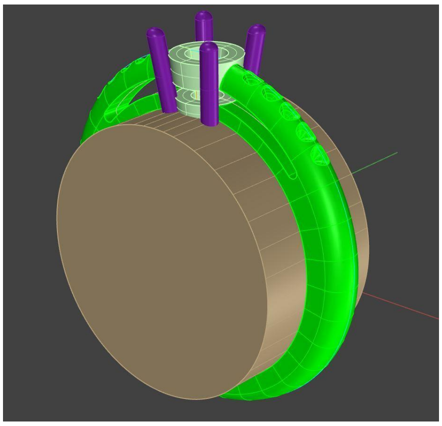
C. The overall volume of the 1 pt stone is created by revolve, and is replicated in the points where the insertion of the stones is foreseen. These are then subtracted by the volume of the ring. We then move on to create the volumes of the bezel.

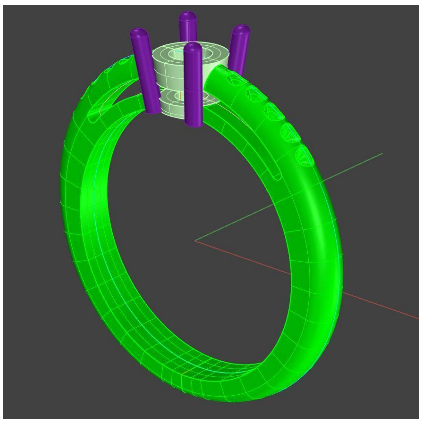


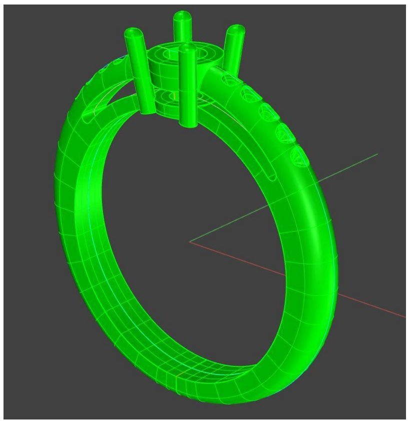
D. the two rings of the bezel are created by revolve and then we create the first prong. After that, this prong is then rotated to the correct position and subsequently replicated 4 times around the bezel.



E. by means of a cylinder (extrusion) corresponding to the volume of the finger, the lower part of the bezel is finished with a boolean difference. Uniting (boolean) all the pieces we obtain the final model.







Preparing for 3D printing

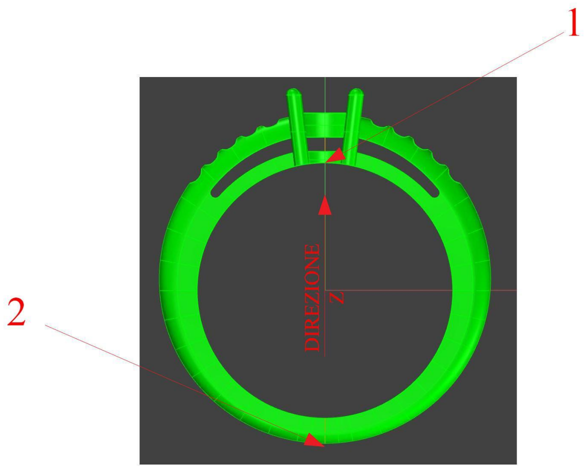
For the model obtained, the most appropriate printing process is that of rapid prototyping. The first thing to check is that the object is closed, a solid without holes. Secondly, depending on the printer you are using, it may or may not be necessary to insert supports or buttresses to the piece.

In our case we use a 3D printing process through rapid prototyping that requires supports (most common case). These supports are generally small cylinders or cones positioned in correspondence with the minimum points of the object.

The minimum points are the parts of the model that are not in direct contact with the plate of the printer in the Z direction. If the supports are not inserted at these points, the print will present shortcomings or, at worst, the printing process will not function.

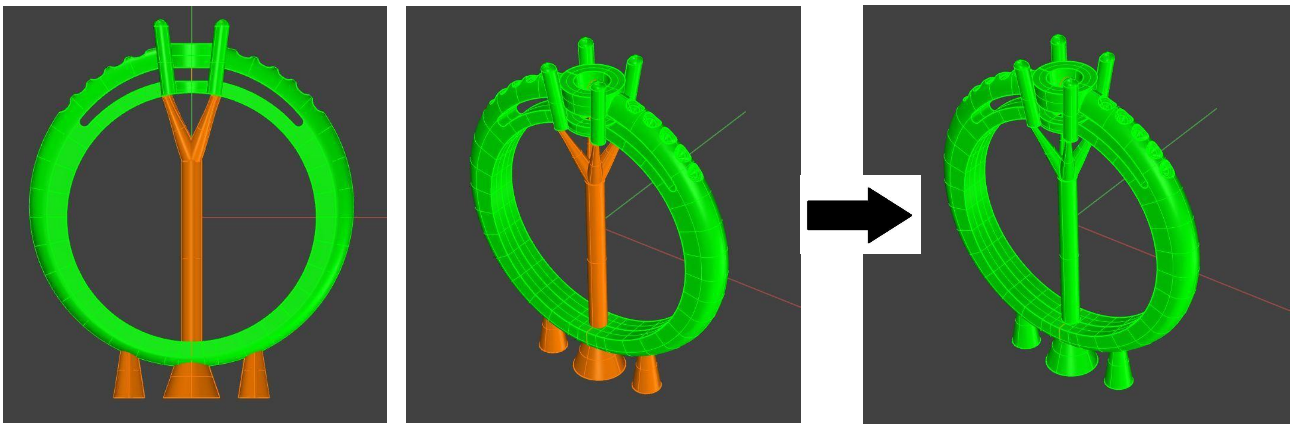
Normally, all printers are equipped with software that allows the insertion, manual or automatic, of printing supports. There is also software specifically designed for this purpose. Another way is to insert them directly into the 3D modelling phase.

In this case, therefore, once the object is obtained, the presence of minimum points will be analysed and the necessary supports will be inserted.



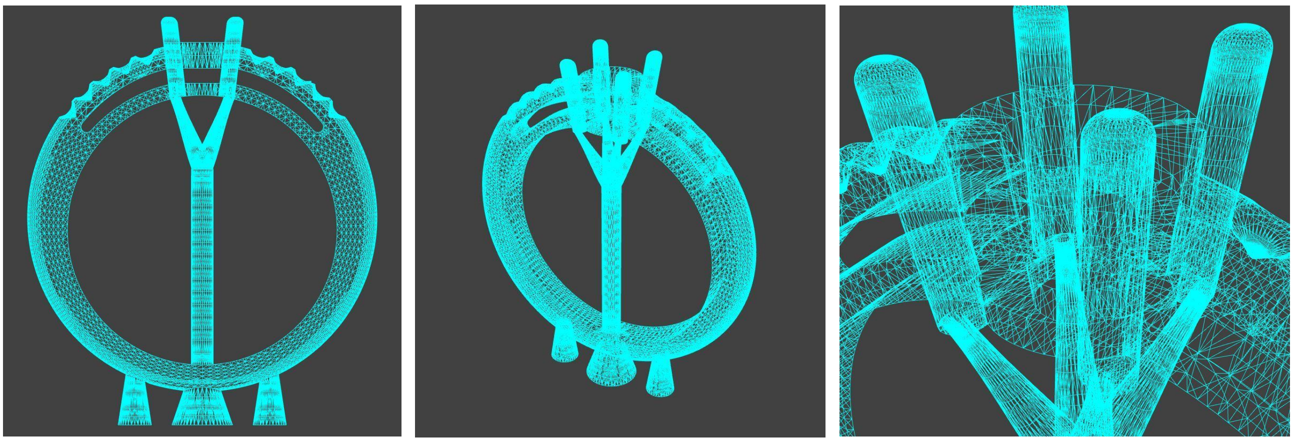
The points that need the supports, given the simplicity of the model, are only two. However, even when there are horizontal or almost horizontal surfaces, it is good practice inserting supports.

Once the minimum points are covered with supports and everything is joined by a boolean union, the model is ready for printing.

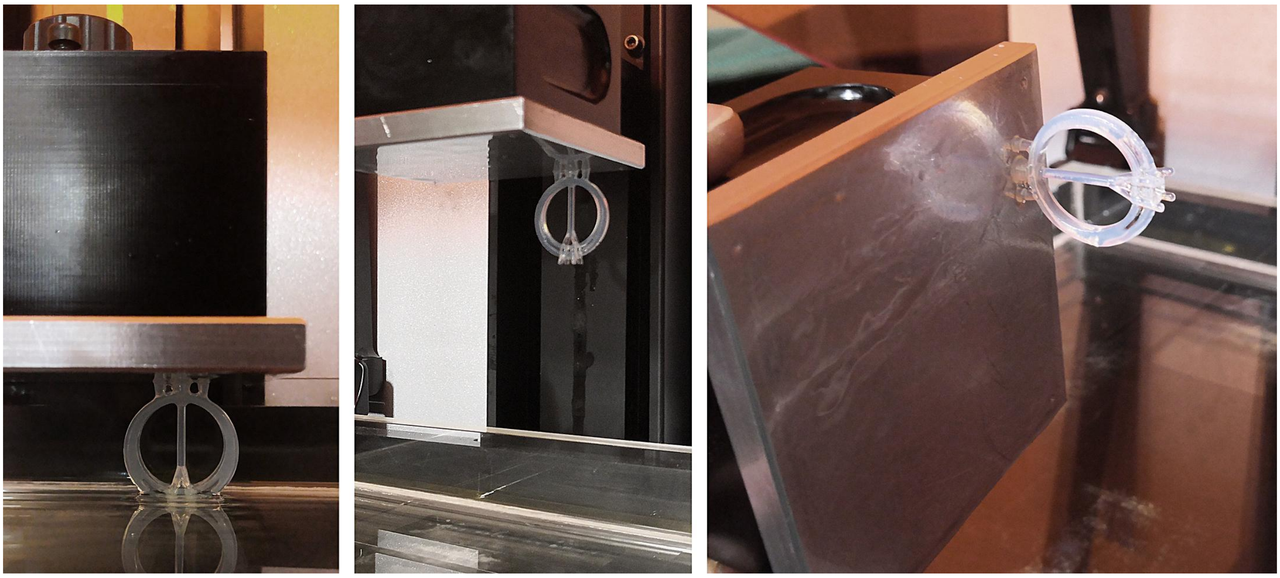


To make the printer read the model it is necessary to create a .STL file. The .STL file (Standard Triangulation Language To Layer) is a graphic standard that describes the object by decomposing the surfaces that make it into triangles. In practice, the surfaces of the piece are made of mesh with triangular elements. Approximately increasing the number of triangles the definition of the surface improves.

In practice, the .STL file consists of the X, Y and Z coordinates repeated for each of the three vertices of each triangle, with a vector to describe the orientation of the normal of the surface.



The real model, printed in a meltable material such as resin or wax, is finally cast in metal through the lost wax casting process and, after a phase of finishing the workpiece, is ready to be set by the setter.



Ring 3D printing phases

6. Verification and conclusions

The resin molds and cast metal models are observed and analyzed.

All the steps carried out both with the traditional method and with 3D modeling are also compared. All aspects are analyzed in terms of quality, timing, costs in order to have a clear idea of the benefits that computer-aided processing can bring to the field of artisan goldsmith production.

What is clear is that the processing times of a goldsmith's item are significantly reduced, while also allowing for the possibility of increasing production and extending the range of design solutions that can be tackled. Elements, generally impossible to make completely manually, can be taken into consideration and the attention of both the craftsman and the designer can focus on more specialized aspects following the simplification of the process of making the raw object. It should also be noted that for both the goldsmith and the designer, they both grow their technical capacity and knowledge of their specializations.

It has also proven that, even at a technical level, the objects made are more accurate in several areas, as certain critical steps and points in the manual processing which require precision are performed with the help of computers and machinery.

The production costs, while considering the additional work costs of the designer, machinery, printing and casting, are consequently significantly reduced.

However, in the context examined, that is the artistic goldsmith workmanship, the manual workmanship remains absolutely necessary and predominant. The work of the CAD designer must be considered complementary and supportive to craftsmanship, since the specific and predominant characteristics of the manufactured products, speaking of artistic craftsmanship, can only be manual.

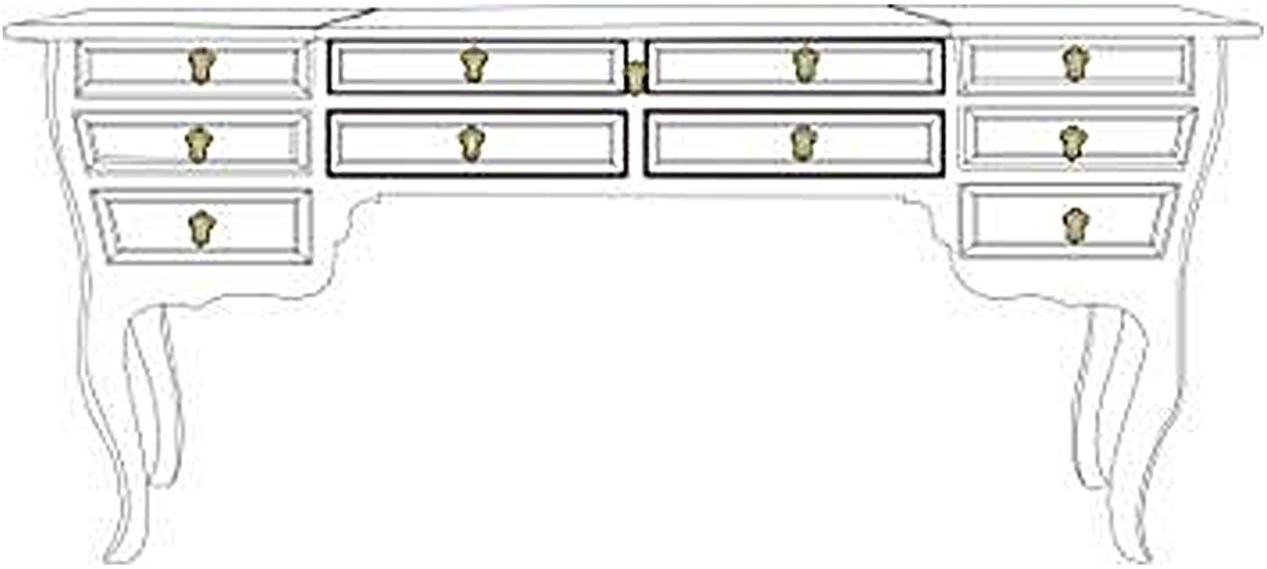
II. Reproduction of 2 bronze elements in the restoration of a Florentine desk: phases of the seminar

As for the restoration of an antique piece of furniture, we are looking at a Florentine desk from the Museo degli Argenti in Florence, dating back to the mid-18th century.

It is a desk dating from 1750 to 1766, in Rococo style that can be recognized by the slightly rounded sides, by the thin and curved legs and in the bronzes. It is a center desk because it also has a decoration on the back that follows the drawers on the front.

The central plane can be raised and this movement, by means of a mechanism, raises an internal one. When the central floor is lowered, the desk can be closed with a key.

The dimensions are 160cm wide, 80cm deep and 85cm high.
The structure is made from poplar and the parts that need greater resistance are in walnut.
The perfectly symmetrical side structures are composed of three drawers of different size and shape as they follow the wavy profile of the sides.
In the central part of the desk, four fake drawers are designed with wooden games, arranged two by two; these exactly reflect the lines of the six true drawers located in the lateral bodies. In the same way, ten fake drawers are designed on the back of the desk in order to obtain an identical effect to the front.
The furniture is entirely laminated with hardwoods: bois de violette, bois de rose, rosewood rio, olive and olive briar-root; while some parts are in solid walnut.



There are a total of seven locks, six for the drawers and one for closing the top. The system that allows the internal plane to be raised and lowered is operated by means of a crank that fits into a square pivot protruding under the central lock on the front of the desk.

There are also elements in gilded bronze, characteristic of Florentine rococo style furniture: four feet with ebony wheels, two handles, nineteen nozzles (eleven in the front and 8 in the back), two rear plates that cover the hooks that allow the movement of the central plane, the guides embedded in the openable plane, the internal plate to the central front band which encloses the lock and the pin that connects the mechanism to the external crank.


In this case, the use of 3D modeling was chosen for the creation of a copy of one of the two handles and one of 19 nozzles present in the cabinet.

1. **The lost wax casting method**

Bronze is a material that can be processed by casting, and with traditional methods, copies of small-sized models such as those examined can be made, through the use of special rubber molds and the "lost-wax casting" technique.

A mold is built starting from the existing model, through this a wax copy is created, which is transformed into metal through the casting process.

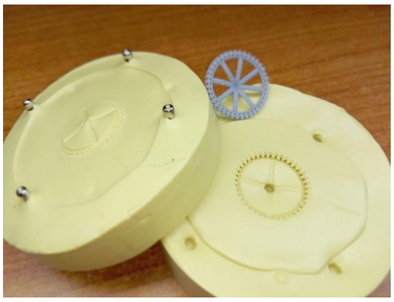
The hot rubber mold

For making copies, it is possible to use casts of the original model in a special rubber which, after being applied to the model, is subjected to a heat treatment, called vulcanization, which causes it softening first and then hardening. The rubbers used can be conventional, i.e. with a high content of natural rubber, or silicone.

The types of rubber obtained through the vulcanization process can be of two types: "Tear-off" or "whole". In the "tear-off" type, the model is inserted between two layers of rubber sprinkled with a veil of talc or with a special spray, so that its surfaces do not go together in a single block. In addition to the model, pins are inserted to allow correct reclosing. In the "whole" type, the model is simply inserted between two layers of rubber.

Once the preparation is finished, the rubber is inserted and compressed between two metal plates which are blocked. This bracket is inserted into the vulcanizer which carries out the heat treatment at a temperature generally between 140 ° C and 180 ° C and a time between 30 and 75 minutes, depending on the type of rubber and its thickness.

Once cooled, the die is opened to extract the model, simply by opening it in the case of "tear-off" rubber, or by cutting it in two by means of a scalpel in the "whole" rubber case. In the latter case, the cut must be made non-linear to allow for correct reclosure before the injection of the wax for the creation of the copies.


tear-off rubber mold


whole rubber cutting

The cold rubber mold

"Hot" rubber molds require the use of metal objects. For the use of other materials, which are affected by high temperatures, such as, for example, for wax models, "cold" molds are used which use another type of rubber. These are liquid silicone rubbers which, mixed in specific doses with a catalyst, a substance that accelerates polymerization, are able to harden at room temperature within 24-48 hours.

Special rubbers can be heat-treated at a low temperature and in this case the hardening time reduces to tens of minutes. Characteristics of these rubbers are the high definition in the details, due to the high fluidity of the mix, the absence of dimensional deformations (present in the hot rubbers due to the temperature variation), the anti-adhesiveness (without the need to use talc), robustness and durability. For this type of rubber molds only the "whole" type is possible.

To make a rubber you start with the preparation of the liquid rubber by mixing the parts of silicone base and catalyst. The mixture is put in a vacuum machine to eliminate any air bubbles. Once the process is completed, the liquid mixture is poured into a bracket containing the model to be gummed which, in order to avoid its sinking into the liquid, is generally held by an iron wire resting on the top of the bracket. Then the stirrup with its contents is placed under vacuum to eliminate the air bubbles generated during the pouring and, from time to time, topped up. At the end of this phase the mold is left to rest until the rubber has completely hardened. At the end, the matrix is opened with the help of the scalpel.

Cold rubber production

Wax injection

Once the rubber mold is obtained, to obtain one or more copies of the original object, a hot wax is injected into the mold. Before the injection, the inside of the mold is sprinkled with a veil of talc or a special spray to facilitate the detachment of the wax at the end of the process. In this phase, special waxes are used which allow the perfect reproduction of the model and which have the property of dissolving, during casting, without leaving residues or impurities, and machines called "injectors". The wax is injected into the rubber mold, which must be tightly closed, through an injector nozzle. In the mold, it is also necessary to provide vent channels that allow the wax to be optimally distributed within the mold. This will involve a finishing phase of the model after the process. The most modern injectors are also equipped with an air intake system to obtain a better distribution of the wax inside the rubber mold. In this case, the vent channels are not necessary. Once the wax is injected, it is left to cool and the mold is opened, thus obtaining the desired copy.

The melting

Once the wax model or models are obtained, the cylinder is prepared.
The wax pieces are placed in a tree structure whose trunk is a wax or metal rod. The pieces must be positioned in such a way that the column and the channels for feeding the waxes are positioned in the right dimensional ratio, and that these are fed correctly during the pouring of the molten metal so that it can solidify uniformly and gradually.
The structure must have dimensions such as to maintain a distance from the walls of the cylinder of 10-15mm and on the top of at least 13mm, before proceeding it is weighed in order to calculate the metal necessary for the casting.
Finally, the wax tree is immersed in a special liquid that eliminates impurities and reduces the surface tensions of the wax, facilitates the adhesion of the plaster thus eliminating the danger of air bubbles

Construction of the fusion tree

Once the preparation of the tree is finished, it is inserted into a cylinder for casting. Subsequently, a specific plaster mix for pouring is poured into the cylinder: this must be mixed correctly (38-40 ml of water per 100gr of powder), adding the powder to the water and never vice versa, obtaining a smooth and homogeneous mixture without lumps .
The cylinder with the dough is left to rest until the coating has completely hardened.



Lost wax casting cylinders, inserting the model, pouring the plaster mixture

Once hardened, the cylinder is placed in an oven which allows the melting of the wax that comes out of the cylinder through the hole in the column. When the wax has completely come out, the cylinder is inserted into a second oven which gradually cooks the plaster making it acquire the hardness necessary to resist the impact and heat of the molten metal. Times and methods vary according to the type of cylinder and the characteristics of the material and objects.

At this point the metal is melted and is poured into the cylinder. The melting of the metal can take place by means of flame heating, electromagnetic induction heating or electric resistance heating. The pouring of the molten metal in the cylinder must be done with extreme care. The air contained in the cylinder cavity and the gases that are formed during the contact of the molten metal and gypsum can hinder the flow of the metal or create surface microporosity or roughness.

Once the casting is complete, the cylinder is cooled to at least a temperature of 200 °C and the plaster casing is removed. To avoid deformations or distortions of the casting, a high-pressure water jet is used which disintegrates and dissolves the completely dehydrated and still lukewarm plaster, without damaging the enclosed metal piece. Once this is done, the metal model is immersed in a solution that eliminates surface oxidation. After a few hours, the tree is ready for part separation and finishing.

Limits of the traditional method

The lost wax casting method has very ancient origins, and allows the creation of objects with a high definition of details. However, it has dimensional shrinkage due to heat treatments during the processing phases: from those of the rubber mold, to that of the waxes and the casting.

The percentages of metal withdrawal during the melting phase of some materials are reported as follows:

Material	Small flow	Medium flow	Large flow
Gray cast iron	1	0,85	0,7
Steel	2	1,5	1,2
Aluminium	1,6	1,4	1,3
Bronze	1,4	1,2	1,2
Brass	1,8	1,6	1,4
Magnesium alloys	1,4	1,3	1,1

Percentage shrinkage coefficient of various materials

In the case under consideration, which consists in making copies from existing models, this problem is not negligible.

2. Reproduction of the handle and the nozzle through assisted modeling software

Through the use of the computer, any existing model can be reconstructed in a virtual environment. Being a virtual model, this can be modeled and modified, before its physical realization, depending on your needs. In the case examined, the models are reproduced respecting their formal and detailed characteristics, at the end the dimensions are increased taking into account the modifications that the models will undergo during the construction phases. In case there are deficiencies or damaged parts, these too can be fixed during the modeling phase.

The 3D modeling process intervenes only in the initial phase, allowing the creation of elements in meltable material (wax or resin). These pieces will then be made of metal using the same lost wax casting technique used in the traditional process previously described.

If a large number of copies of the original object were to be made, it is preferable to model elements with which to make molds. If only a piece or a few copies are needed, as in this case, it is preferable to create a resin model to be melted directly in metal, skipping the passage of the rubber mold, to minimize the loss of details and any deformations.

Analysis of the objects to be modeled





Analyzing the objects, one can see that the handle is a sculptural object, with organic characteristics, while the two attachment hinges and the nozzle are more geometric objects.

It can be understood that the main problem is that of correctly detecting the geometric and dimensional characteristics of the objects, since the nozzles and hinges are not perfectly geometric For this reason, it is necessary to resort to using a 3d scanner for the handle, so its modeling will be organic. For the nozzle however, being essentially a flat object, it is sufficient to acquire images using a normal two-dimensional scanner and proceed with its geometric modeling. For the hinges, also being geometric objects but with a profile that is difficult to measure, it is better to use a 3D scan that serves as a reference for geometric modeling.

As far as organic modeling is concerned, software that allows 3D sculpting modeling must be used. Among these, among the most important, we can mention ZBrush and 3d-Coat among the commercial programs, Blender among the open-source ones and Sculptris among the free ones.

In this case, the software is essentially used for finishing the 3d files acquired through a 3d scanner, so no particularly advanced software is needed. In this seminar 3d-Coat and Sculptris will be examined.

2.1 Introduction to 3d-Coat

3D-Coat is a commercial digital sculpting program from Pilgway designed to create free-form organic and hard surfaced 3D models from scratch, with tools which enable users to sculpt, add polygonal topology (automatically or manually), create UV maps (automatically or manually), texture the resulting models with natural painting tools, and render static images or animated movies.

The program can also be used to modify imported 3D models. Imported models can be converted into voxel objects for further refinement and for adding high resolution detail, complete UV unwrapping and mapping, as well as adding textures for displacement, bump maps, specular and diffuse color maps.

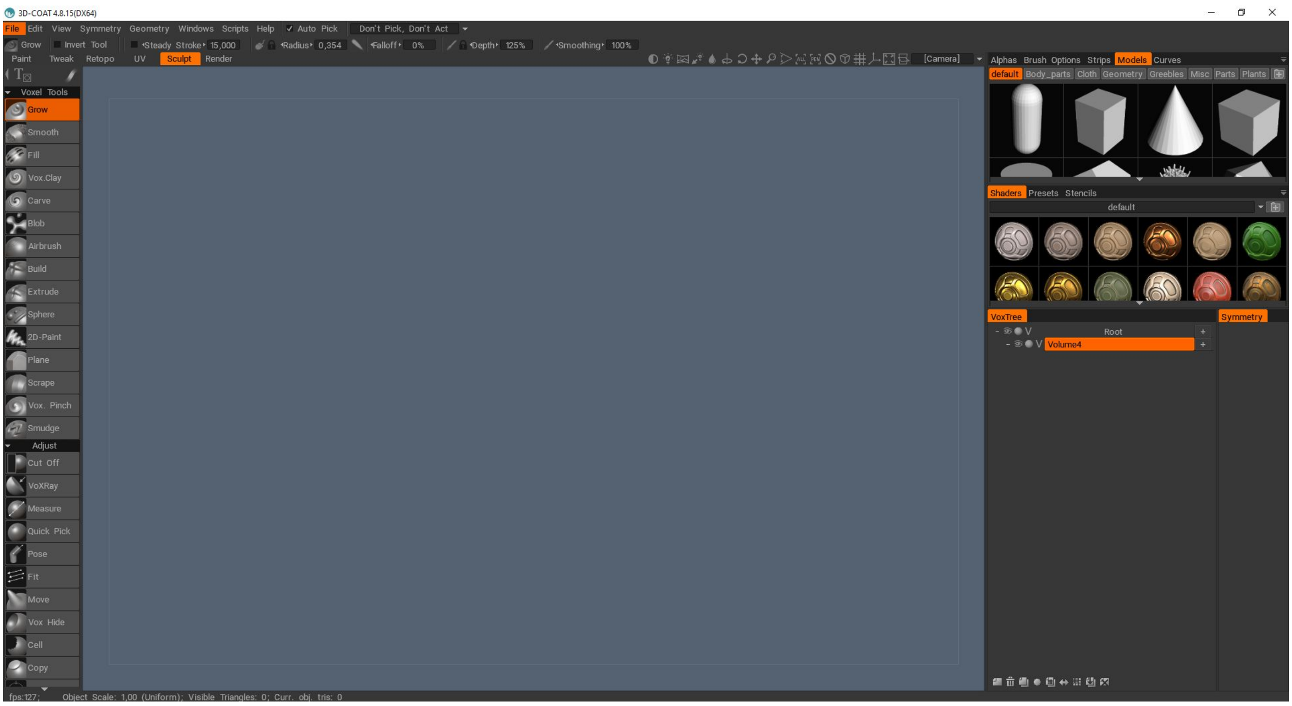
3D-Coat specializes in voxel sculpting and polygonal sculpting using dynamic patch tessellation technology and polygonal sculpting tools. The strength of the program is the retopology field in which it stands out for being one of the most complete software available on the market. In addition to providing a vast set of tools for manual retopology, it also incorporates an automatic remeshing system called Autopo.

Once the program is opened, a pop-up window appears that allows you to choose different starting points of the project: sculpting, retopology, painting, UV unwrapping etc.

Closing the pop-up you enter 3d-Coat. The interface is organized in environments called "Rooms":

- **Paint:** makes creating detailed textures for the model
- **Tweak:** where there are tools for editing mesh modifications, model poses and morph targets
- **Retopo:** in which we find all Topology creation and modification tools
- **UV:** where texturing is applied to the model
- **Sculpt:** contains a set of tools and functions that allow to construct detailed and elaborated organic and mechanical models
- **Render:** where you can test the model and its textures in an environment for creating photorealistic images or videos

For each room there are different windows, tools and options in the menus.



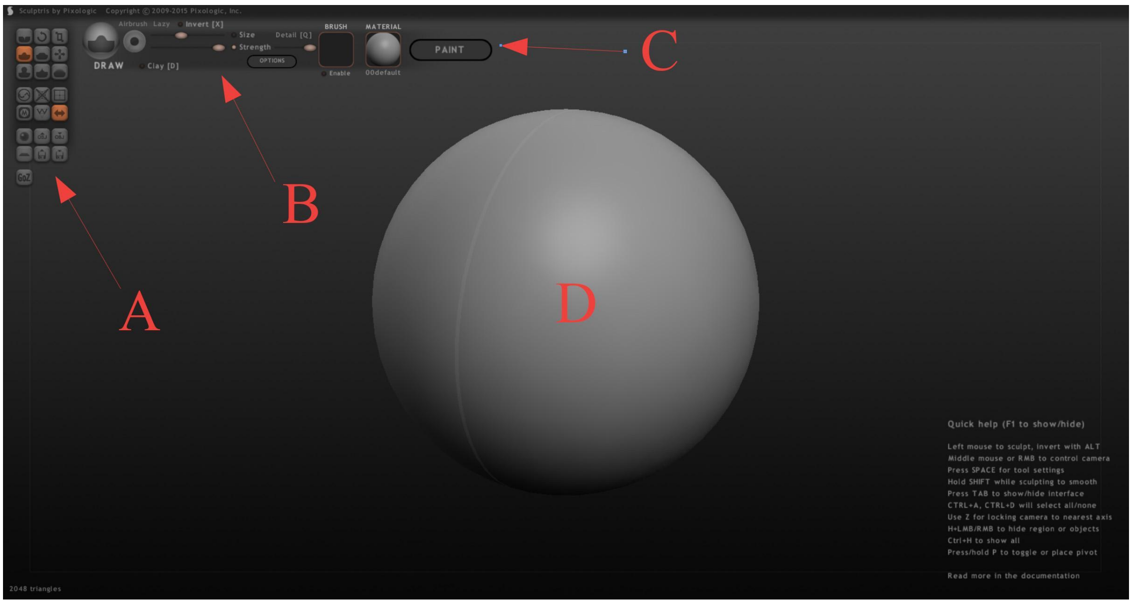
As for the seminar project, only the "Sculpt" room will be considered.

2.2 Introduction to Sculptris

Sculptris is a very simple 3D sculpture program focused on clay modeling.
Users can pull, push, pinch, and twist virtual clay.
It does not have the advanced software tools such as 3d-Coat, ZBrush or Blender, but still allows, with a little patience, to model highly complex objects as you can see from the following image.

The strength of this program is its immediacy and ease of learning. The few modeling tools present are more than enough to be able to finish a 3d model obtained by 3d scanning.

The interface is very basic and consists of four parts:
A – The main button bar for modeling, opening and saving files
B – The brush control bar
C – The button to switch to "Paint" mode for working on textures
D – The workspace or 3d view



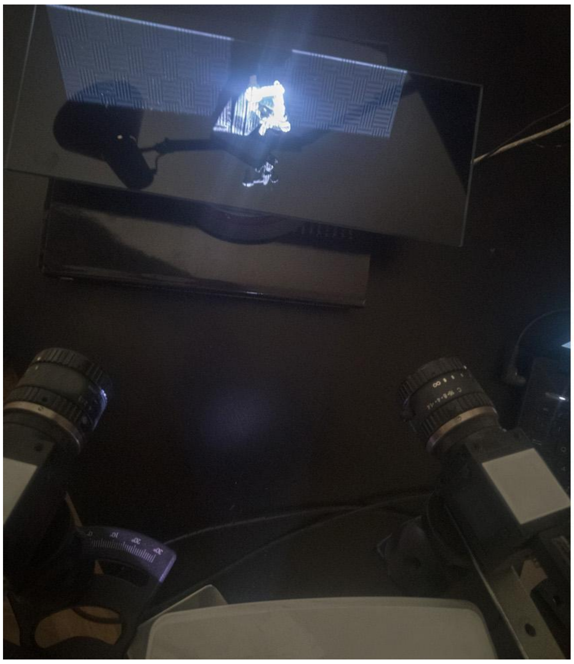
Handle 3D modeling

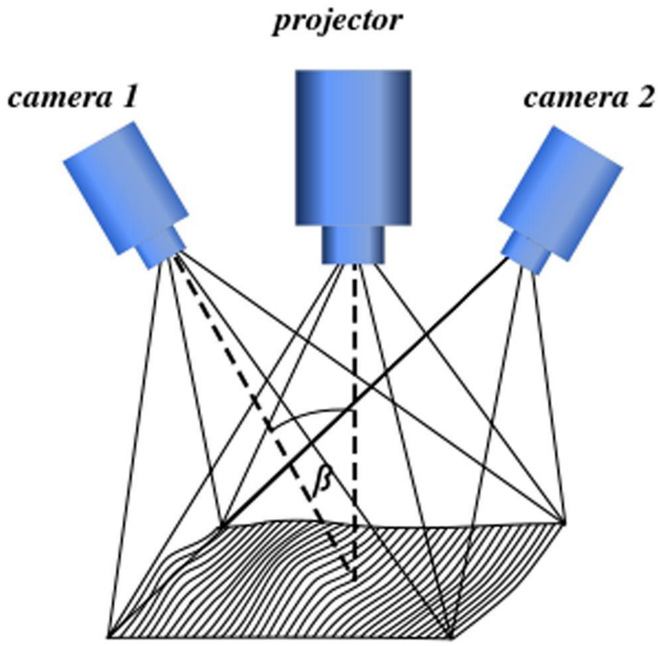
In order to scan an object it is good to ensure that it is clean and free of dirt or incrustations, because, if not removed, these are considered part of the model. An ultrasonic washer can be used for cleaning.

Before proceeding, it is useful to measure some rough dimensions of the object that will serve as verification during the process.

At this point it is possible to scan the model. It must be taken into account that the 3D scanner is not able to scan transparent, dark or reflective objects, so that the handle, being made of metal, must be covered with a thin layer of opacifying spray. In this way the laser line, or the optical pattern projected on the detail is visible and more defined to the instrument, allowing a cloud of points to be obtained, more responsive to the actual geometry to be detected. It is necessary to minimize the use of the spray because it could level the object's geometry.

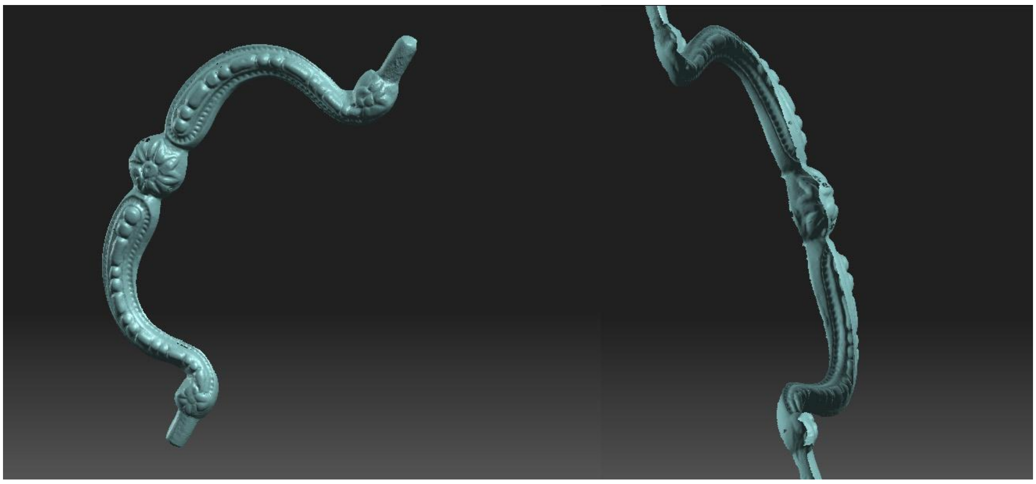
The scanning process takes place through a structured light scanner which uses, for its operation, the projection of a pattern, emitted by a projector, directly onto the surface of the object. Two stereo cameras store the images of the scanned part, and process them to produce stereo light-coding images, from which, by triangulation, a depth image is obtained. A depth image is a set of points where the 3d coordinates of the surface of the object are stored. These points define in the 3D space the portion of the object that has been framed and affected by the light patterns generated by the projector.



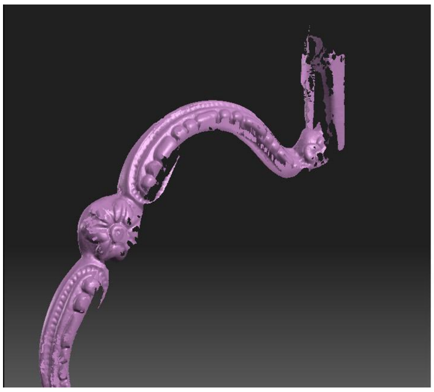


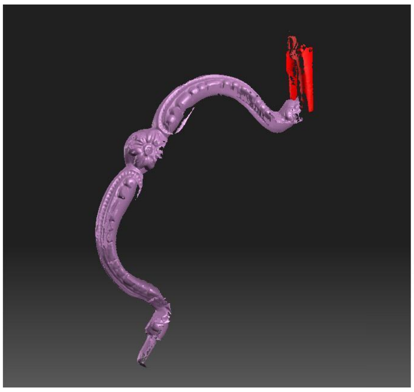
Structured light 3d scanner and operating scheme

The piece is positioned on a rotating platform that allows 360° rotation around the vertical axis of the platform during the scan. Each phase of the scan allows, in this way, to obtain a 360° overview of the object. Clearly, each overview shows in 3D only the portion of the object that was affected by the projection of the patterns. For this reason, multiple scan cycles are required.

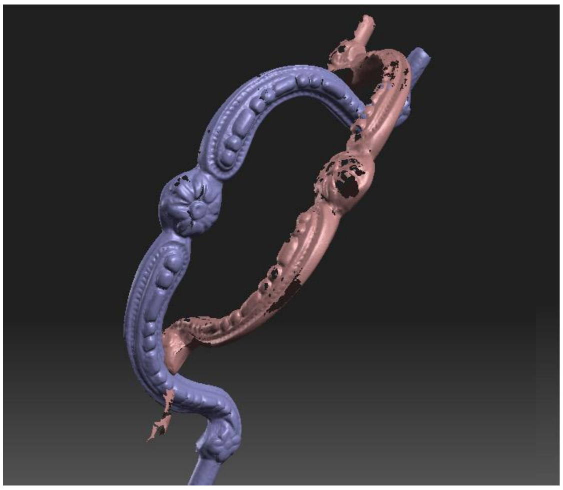


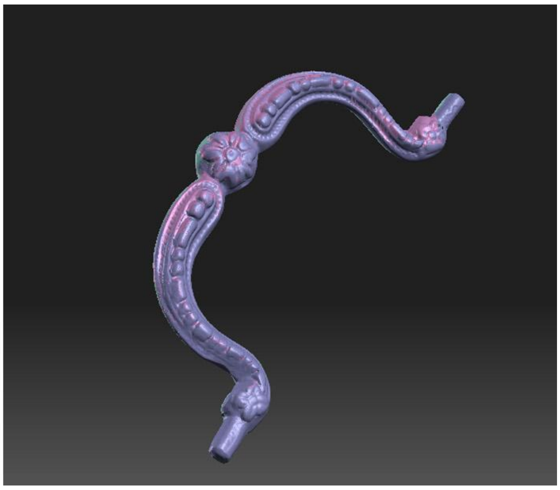
Four scanning cycles are required for the handle: one for the upper part, one for the lower part, one for the edges exposed at the front and one for the remaining edges. At each scan cycle it is useful to clean the images obtained from any separate parts, or parts of irrelevant scans, such as for example the support to the rotary table.



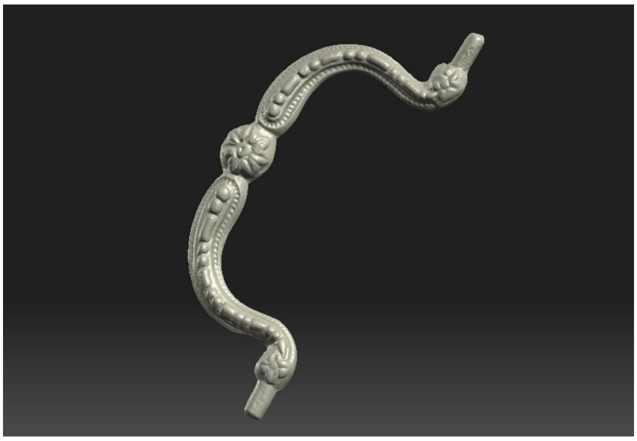


The overviews obtained are then aligned, that is, the common parts have to coincide so as to reconstruct the entire surface of the object. It is possible to act manually, or through scanner software by means of various methodologies such as the correspondence of surface characteristics, textures, points, etc.





After aligning the depth images and checking that the object has been scanned in all its parts without areas not covered by points, we proceed to the creation of a mesh. With the generation of a Mesh we pass from a data formed by a set of points (Depth image) to a data formed by a set of triangles (Mesh). It is important, for export purposes, to close all the holes present, that is, the parts that are not visible and that have not been affected by the scans.



Once the model has been obtained, without imperfections and totally closed, it is exported defining the resolution and the file format among those available both in the scanning software and in the software that is used for finishing the Mesh. There are several usable export formats. The most used are .stl, .obj, .ply, .lwo ... in our case we use the .obj format, supported by both 3d-Coat and Sculptris. The file obtained will be given the name "handle.obj".

Finishing the Mesh

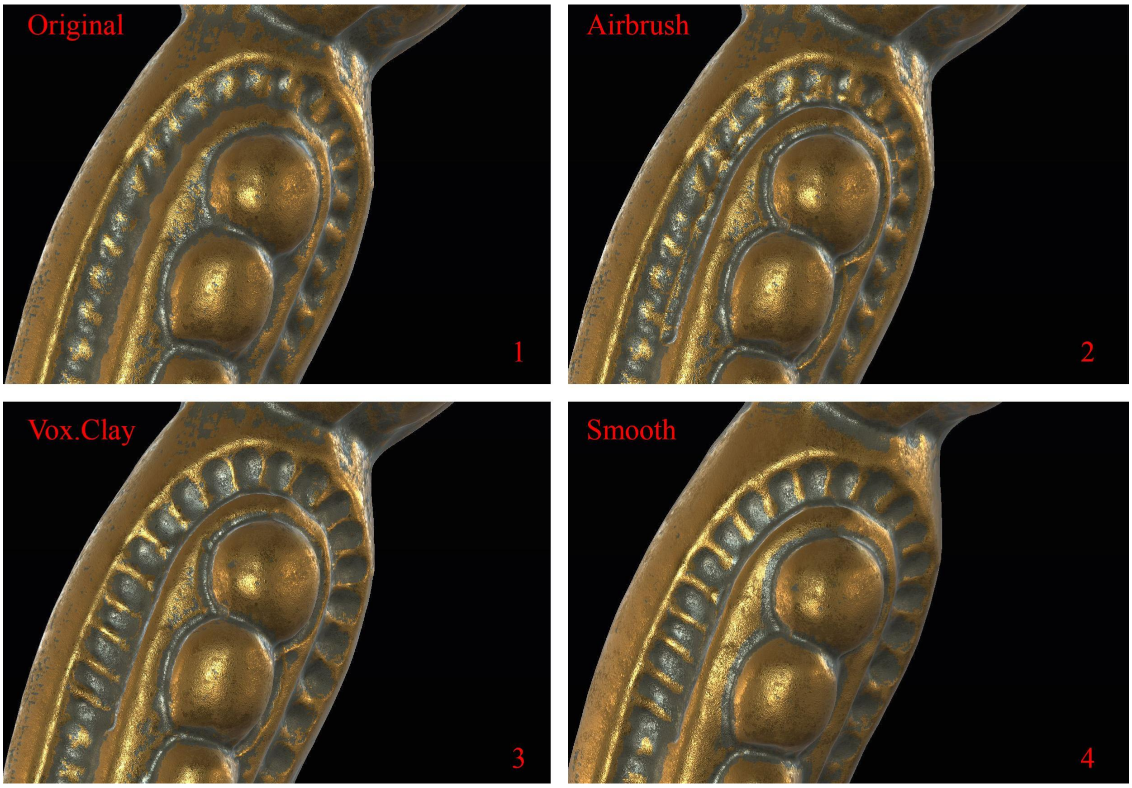
Scanning as well can present problems such as parts that have not been scanned correctly, undercuts or leveling due to the matting spray. It is important to minimize these problems during the scanning phase to have maximum fidelity to the original model. However, this is not always possible for reasons that may depend on the type of object, the type of opacifying spray, the features of the 3d scanner, or the acquisition software used. In the case in question, the surface of the mesh will be smoothed and decoration details will be marked.

The procedure is the same whether we are using 3d-Coat or Sculptris. Once the program is launched, the model that is displayed on the 3D view is imported.

The object imported in 3d-Coat and in Sculptris

As we can see, going to compare the virtual model with the real model, the scan shows details not as marked as in the real model, this may be due to the limitations of the 3D scanner, the presence of the spray being scanned or the not perfect alignment of scans.

For the physical realization of the model it will be necessary to go through a print and through a fusion with an inevitable further leveling of the details, it is appropriate to make them more evident.
With the use of a 3d sculpture program this is very simple:
use the "Vox.Clay" tool in 3d-Coat ("Draw" in Sculptris) to better define the cavities and the "Airbrush" tool ("Crease" in Sculptris) to make the corners more evident.
Finally, with the "Smooth" tool ("Smooth" also in Sculptris) the surfaces are finished.



The procedures must be applied to any object where it is deemed necessary.

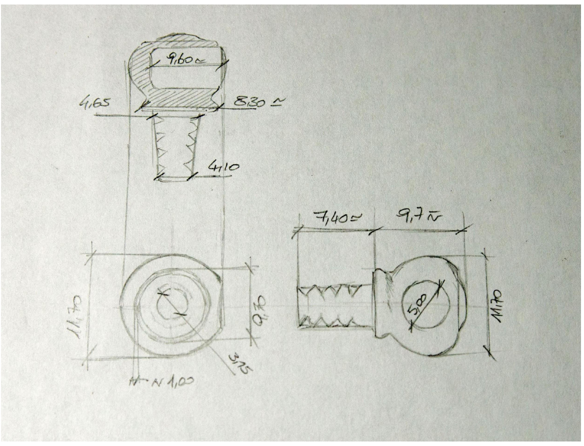
Once this phase is completed, the model is finished, and it is compared with the original piece, checking that all the dimensions have been maintained.


Hinge 3D modeling

Taking into consideration the hinges, it is known that these are two mirror pieces, and one has the shorter pin than the other probably due to a breakage.

The project focuses on the 3D modeling of a single hinge, the second will be a mirror copy of the modeled one. It must be said that only a 3D scan could be used, as for the handle, however, being an essentially geometric object, it is preferable to reconstruct it using CAD software such as Rhinoceros or FreeCAD. Following this direction, however, attention must be paid to the profile of the knob that is not easily detectable with precision. For this reason we prefer to resort to a 3D scan to be used as a guide for geometric modeling.

First of all, the object is measured and the measurements taken are shown in a dimensioned drawing.



The second step is to carry out the 3D scan following the same procedure of scanning the handle. Note that the hole that houses the handle pin is an undercut that the 3D scanner cannot analyze. This cavity can be used to insert a support to hold up the object during the scan and create the hole directly during the finishing phase.

The object is covered with the matting spray, three scanning cycles are performed, the overviews obtained are aligned, the solid object is created and the Mesh is exported in .obj format.



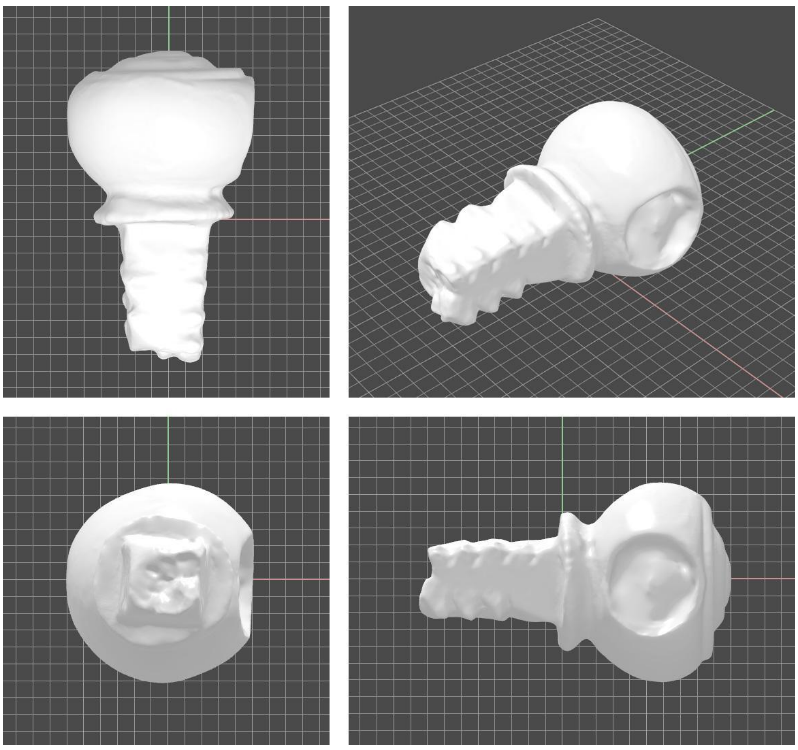
If you want to work in Sculptris it is better to remove the support mesh, as the program does not support Boolean changes.

Once the object has been imported, the support is removed (in 3d-Coat with the "Cut off" tool), the surface is smoothed and irregularities are eliminated using the "Vox.Clay", "Fill", "Smooth" tools.

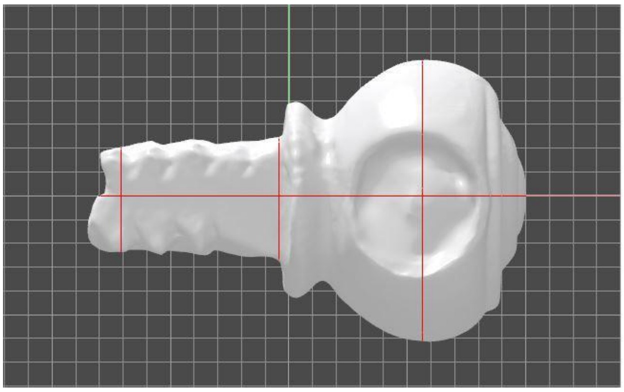
Before proceeding with the modeling in the CAD field, we analyze the object to be modeled and we can see how this is composed of two parts:

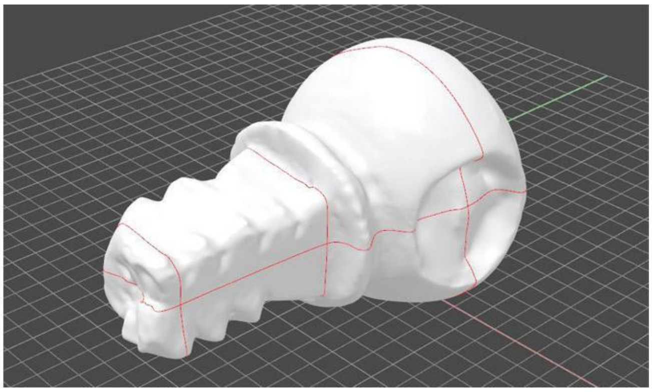
- The knob, a solid obtained by revolve, with a hole, in which the handle pin is inserted, which can be obtained by means of Boolean subtraction
- The square-section pin that can be considered an extrusion solid, the notches of which are obtained from the Boolean difference

Once the object has been analyzed, the software opens and the hinge mesh is imported. The object is moved and rotated until it is aligned with the reference system of the construction plane.

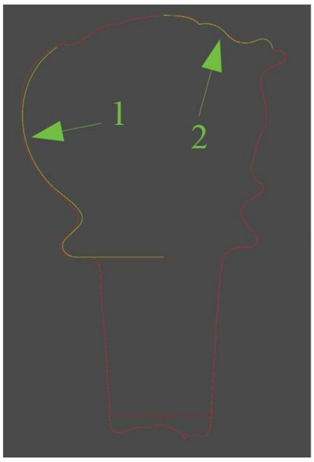


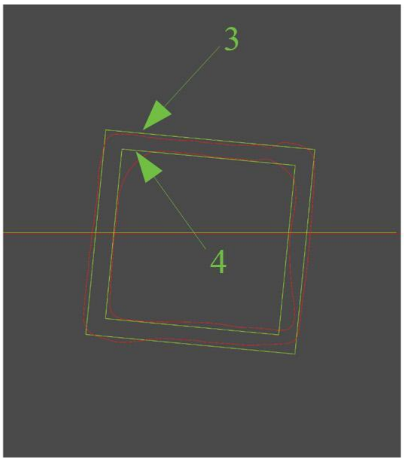
With the "section" command we create the revolution profile and two significant sections of the square section pin.

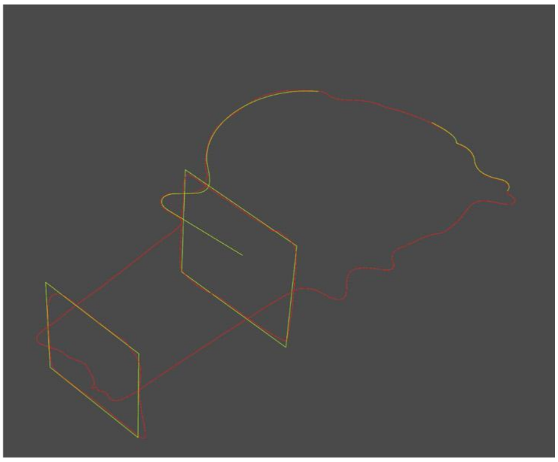




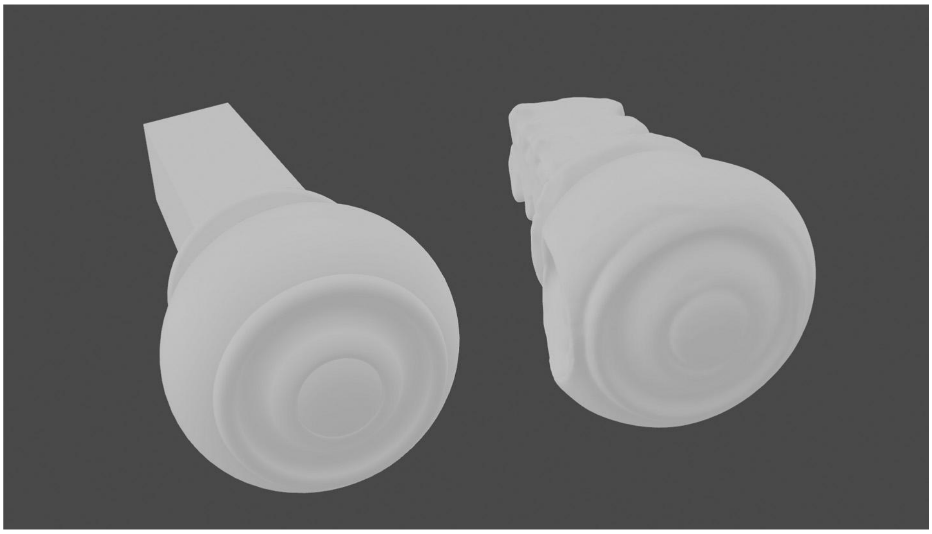
The mesh is hidden and the curves of the sections are redrawn on a regular basis with arcs, blend curves and lines.



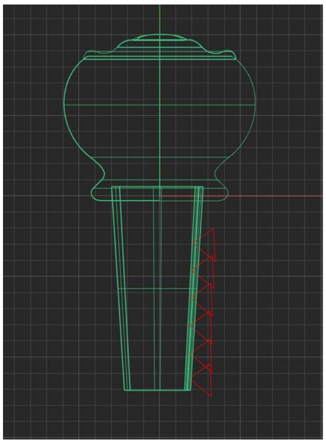


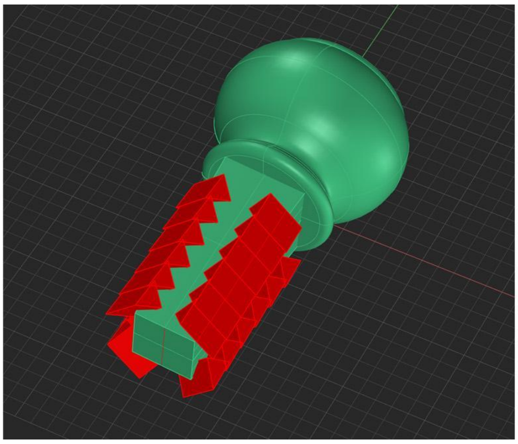


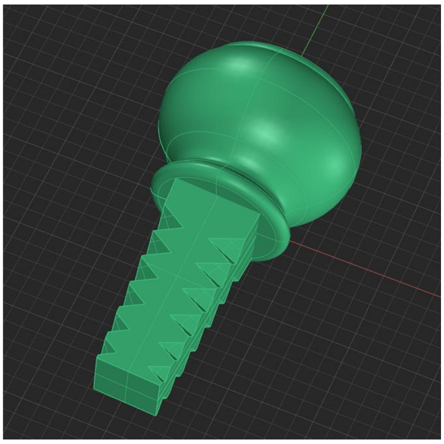
With the curves 1 and 2, with a revolution, the solid of the knob is created. A line is run over the two square sections (sweep) to create a box-shaped section which is then closed in a solid. The two solids are then united into a single polysurface closed through a Boolean Union. The solid obtained is compared with the reference mesh to verify that the proportions have been maintained.



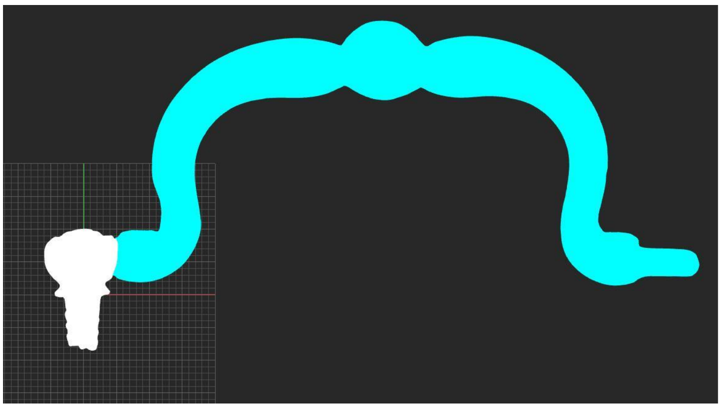
To achieve the grooves, triangles are created, which, once extruded, must be positioned in correspondence with the cuts. Finally, a boolean difference is made.

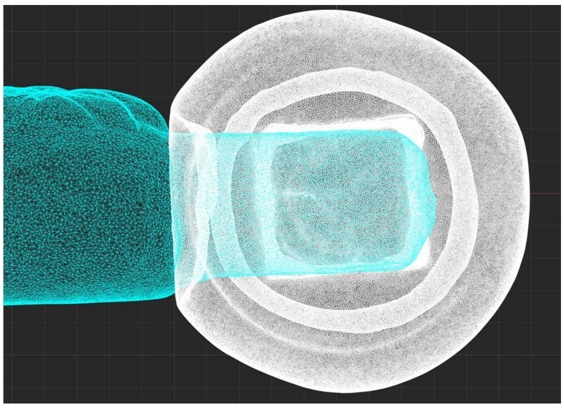




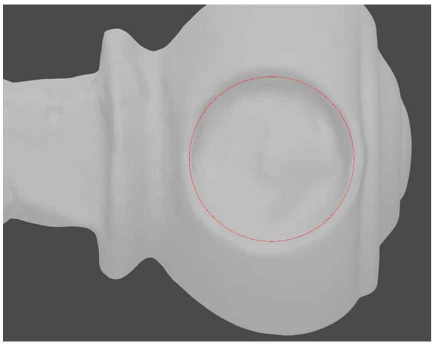
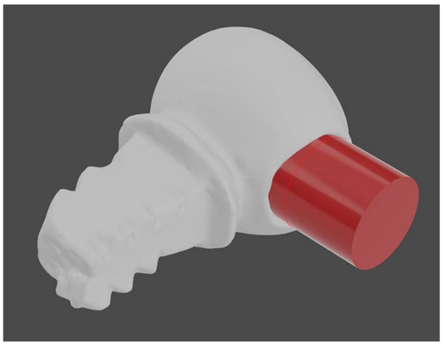
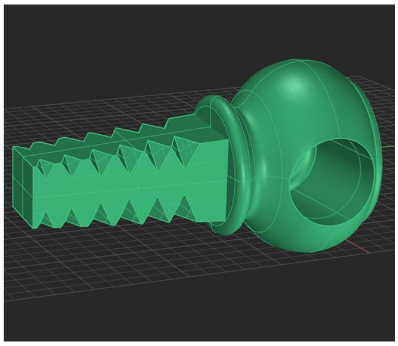


For the hole on the knob it is useful to also import the handle file and place the pin in its housing to understand the geometric characteristics of the hole that needs to be made.

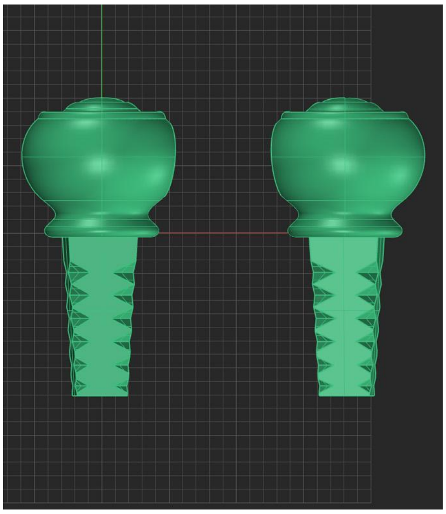




Draw a circle the size of the hole present on the Mesh of the 3d scan and create a cylinder by an extrusion. After that the hole on the modeled object is obtained through a boolean difference.

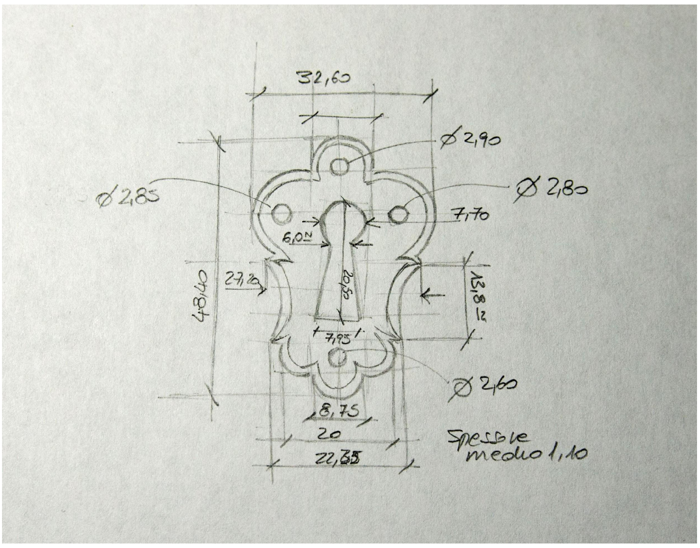
The last step is to check the measurements previously reported in the technical table and create a mirror copy of the hinge. Once obtained, the modeled pieces are assembled to check the correct operation of the handle.




Nozzle 3d modeling

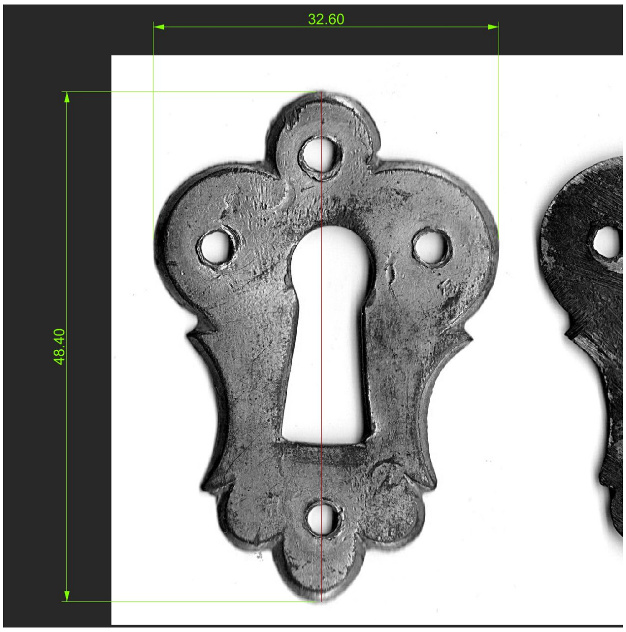
As for the nozzle, a scan could be carried out, however, considering that it is a flat plate, it is also convenient to proceed with a geometric modeling.

First, as always, a dimensioned drawing is prepared with the dimensions of the nozzle.

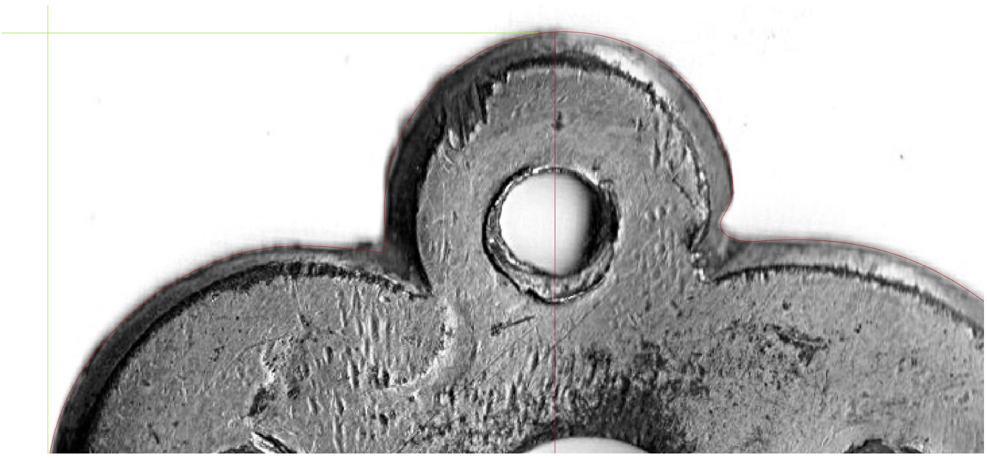


Proceed to scan (with a normal 2D scanner) the two faces of the plate.

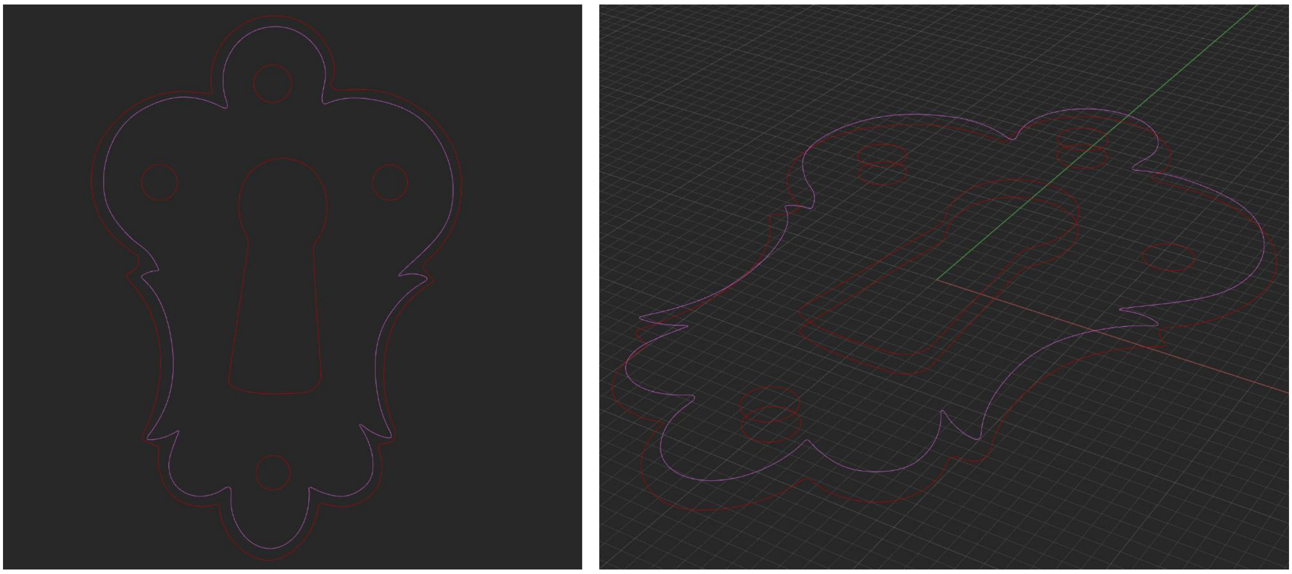
Once the program has started, insert the image of the nozzle as a background image and scale it so that its maximum height is the size measured on the original. Check that the maximum width is correct.



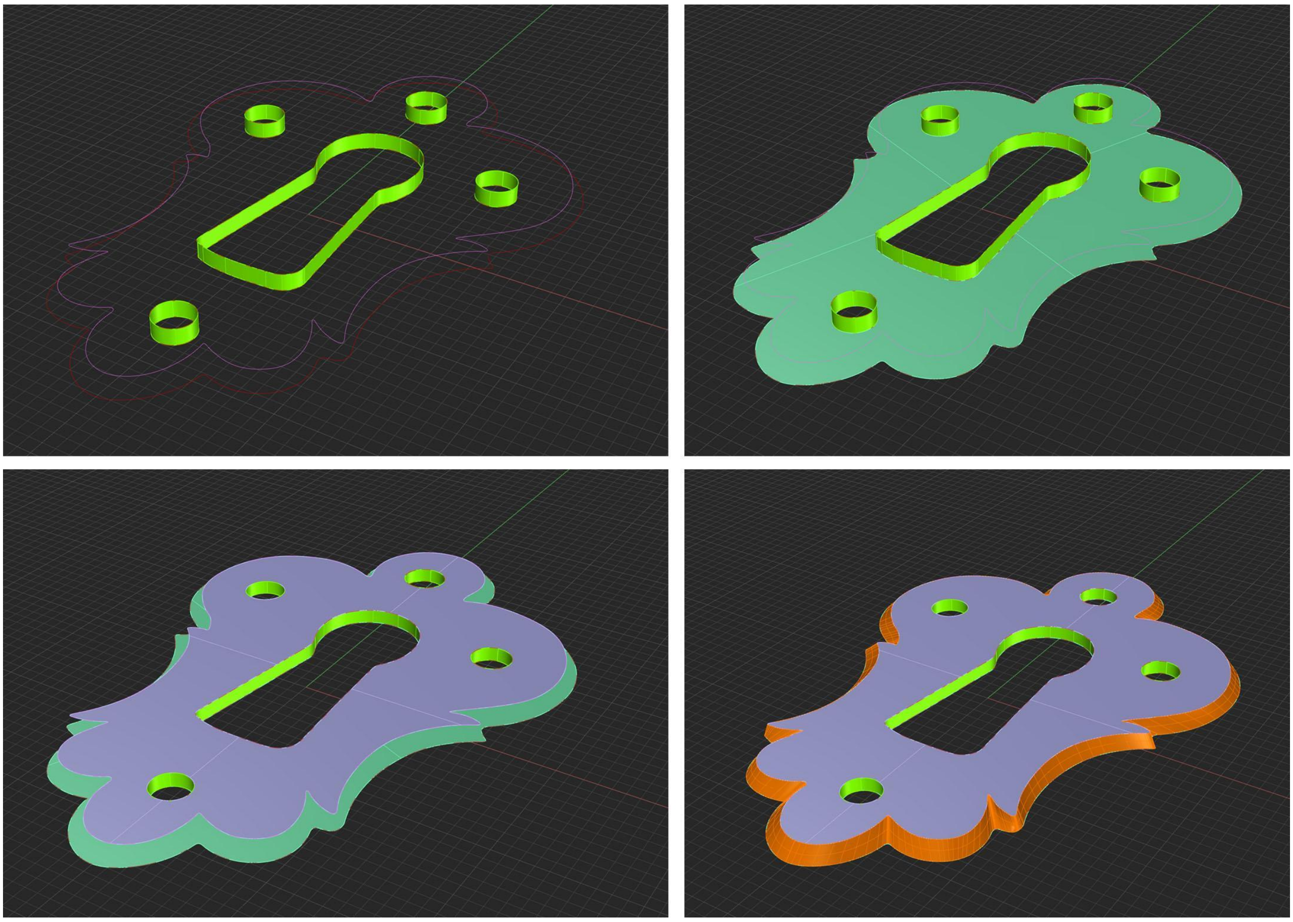
At this point, with lines, arcs, circles and curves for interpolation of points, we trace the external edge of the nozzle. The curves need to be adjusted by moving the control points.



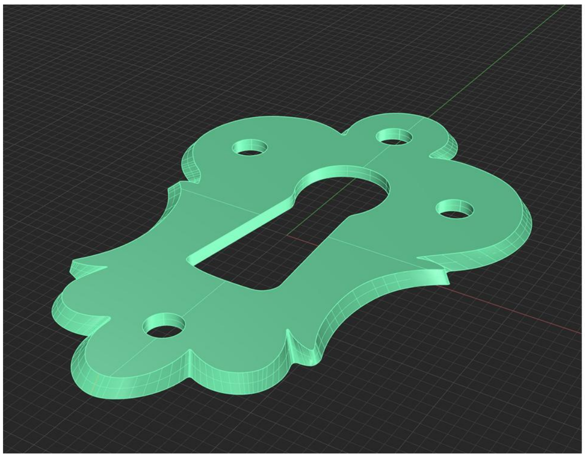
This completes all the tracing of the edges and holes and positions themselves in the correct position along the z direction.



The lateral surfaces of the holes are constructed by extrusion, the surfaces of the front and rear faces are made by planar surfaces and finally the lateral edge of the nozzle is constructed with a sweep.



By joining the single surfaces the solid of the nozzle is obtained. The dimensions are compared with those shown in the technical table and the model is completed.



Preparing for 3D printing

The four modeled objects will be cast in bronze, it is up to the restorer to decide whether to print them while also making silicone molds or whether to proceed directly with the direct casting of the prints.

In the case of direct printing, the pieces can be directly exported in .stl format without the need to increase the size, because, for pieces of this size, the lost wax investment casting foresees a zero or negligible shrinkage. If silicone molds are required, the size of the pieces must be increased by 2%.

3. Verification and conclusions

As for the goldsmith's workshop, the traditional working method and the one with 3D modeling aid will be compared, evaluating the benefits and the critical issues, obtaining a clear summary on the effective efficacy and feasibility of the use of 3d technology in the field considered.

III. Restoration of a plaster bust: seminar phases

As for the restoration, we will proceed with the reconstruction of the missing parts of the bust of the "Portrait of a laughing child", preserved in the Gipsoteca of the Istituto d’Arte (Artistic Lyceum) of Florence, which was subject to restoration by the CER as it had damages both on the face and on the bust. This plaster model is the replica of the original marble "Portrait of a Laughing Child", a work by Desiderio da Settignano dated between 1460 and 1464 and kept in the Kunsthistorisches Museum in Vienna.

Our object

Original in Vienna

Desiderio di Bartolomeo di Francesco, called Meo di Ferro was Italian sculptor born in Settignano, near Florence, into a family of sculptors and stonemasons. His sensitive treatment of the material contributed substantially to the birth of a formal language characterized by the sweetness of the figures and the strength of the expressions, which even influenced Leonardo in defining the technique of shading.

The representation of the child is one of the most fascinating subjects of Desiderio da Settignano's work. The plaster copy of the "laughing child" examined in the seminar is kept in the Gipsoteca of the Liceo Artistico Statale di Porta Romana in Florence.

The topics covered during this seminar are:

- Documentation
- Assessment of the condition of the work of art
- Learning the basics of 3D scanning
- Evaluation of 3D modeling software
- 3D modeling
- Assessment of possible scenarios for the realization of the pieces to be integrated

1. The moldmaking technique

The bust examined is a copy of the original model. The operation that allows the creation of a replica is called "moldmaking". With the term "moldmaking", we generally mean all those technical operations that allow to reproduce with precision and fidelity the formal originality of a sculptural work, and at the same time to allow its reproduction in materials with very different characteristics compared to the model given. It consists in detecting the "cast", a negative imprint from an original model, thus obtaining a shape to be used to reproduce one or more copies identical to the 1:1 scale model.

Copying a work in general is necessary when the conservation of the work is precarious, or when moving is difficult. It is also useful for study, documentation and dissemination for greater use and knowledge. The technical characteristics of the mold are determined by the shape, size and complexity of the model, the characteristics of the reproduction materials, the number of replicas required and the final destination of the work. The technical methods of reproduction depend on the types of mold material: clay, plaster and silicone rubbers.

The three most popular methodologies are:

- The “forma persa” (lost shape): made of plaster, on an original model in clay or plasticine. It is so defined because, once used to obtain the plaster model, this can be deformed only with the use of chisels that destroy the shape. It is the traditional molding used in sculptural art.

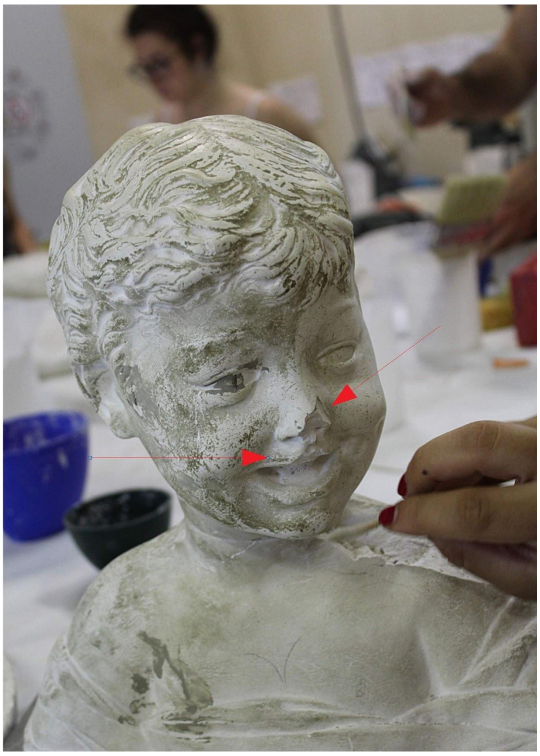
- The “forma a tasselli”, in plaster, usually on hard material originals: marble, bronze, plaster etc. The execution of dowels, with relative motherform, is designed to obtain the draft of the model. From this type of form it is possible to obtain a certain number of copies. With this technique, until a few decades ago, classical masterpieces were replicated in plaster. It is still used to build plaster molds to produce crockery and ceramics.

- The rubber form, in which silicone rubber is used, contained in a rigid motherform. The elasticity and resistance of the rubber allow the draft of the most complex models. When the molding is completed, a mold will be obtained capable of producing numerous copies identical to the original model. For these characteristics, the rubber form has replaced the one with blocks in the chalcography of works of art and in the relief of casts for restoration. To facilitate operations, a non-invasive and easily removable release agent is spread over the object to be reproduced.

The work was most likely made using the “forma persa” technique, which can be deduced from the clay residues on the artefact.

The work is placed on a painted wooden support, it is therefore deducible that there are pins (metallic or wooden) that act as support to the structure, in addition to the internal elements of the reinforcement.[2]

The artefact is largely covered by a coherent deposit layer of clay residues and an incoherent deposit of dust which constitutes a specific problem for plaster products, a porous and sensitive material, a not negligible problem. Moisture degrades gypsum by the direct action of solubilization of calcium sulphate and consequent disintegration of the material and by indirect action on the internal support elements, mainly in iron and wood, but also in canvas, whose volume increases, respectively due to the formation of corrosion products and for the swelling of the fibers, it is the cause of mechanical tensions, fractures and finally detachments of the plaster parts, as we can see in the left shoulder (photo on the left), in the back of the neck, in the nose and in the mouth (photo on the right).[3]



2. Restoration intervention: traditional method[4]

The restoration work developed in three phases: cleaning, stucco work and pictorial retouching.

Before cleaning, the small exfoliations and cracks were consolidated with infiltrations of "Acril" acrylic resin by syringing and by brush, then removing the excess surface resin by pad.

Cleaning

The removal of the coherent deposit was carried out through a mechanical action with the use of the scalpel and through the swab cleaning with cotton soaked in deionized water.

Stucco work

To rebuild the detached parts, it was necessary to use a dry mortar composed of selected alabaster gypsum, very fine fine ground calcium carbonate and specific additives "Wall putty k2". The stucco was then mixed in water and "Acril" acrylic resin diluted 10% (in water) so as to create a compound that is easily applicable and moldable thanks to the use of special spatulas.
In this way it was possible to restore readability to the work.


Cleaning


Stucco work

Pictorial retouching

Finally, the use of watercolors was used to uniform the appearance of the grouting with that of the original and ensure its reversibility.

3. Restoration intervention: method integrated by detection and 3D modeling technology

In the field of restoration, the use of 3D technology is increasing: there are countless fields of use in which these new technologies can be of support for the scholar and restorer. In fact, 3D surveys are the most effective technology to generate a three-dimensional model exceptionally faithful to the characteristics of the original work of art through non-invasive techniques. From this consideration the consequences of use that can result are severals:

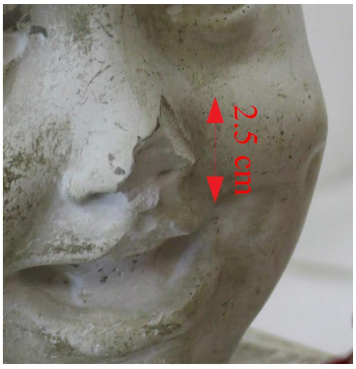
- Become a powerful means of presenting and analyzing a work of art
- Can integrate cataloging, traditionally based on textual data and photographs, to describe the shape and appearance
- 3D scans can be a cataloging tool itself: it is possible to use the 3D model to integrate all the information in a single context by indexing the various data of the analyzes and restoration interventions that often refer to different locations on the surface of the work
- Allow to extend the number of scholars who can analyze the work[5]
- Can be a useful tool, to be used alongside the analysis of materials and the study of historical documents, to propose or confirm the attribution of a work or identify false works
- Make simulations of deterioration of shape and material possible over time
- Allow to preview the effects expected from the restoration to be shown to multiple subjects, the public and institutions, to prevent any post-restoration discussions
- It is possible to contribute to the restoration thanks to 3D printing technologies by creating and remodeling the missing parts of a work. In the case of collapsed or fragmented works it is possible to scan the various fragments, hypothesize one or more recombinations of the same and, possibly, build support structures necessary for their reassembly
- Copies of permanent or temporary replacement of original works can be created at low cost or in support of blind people
- It is possible to make shells in compact materials for the transport of the works

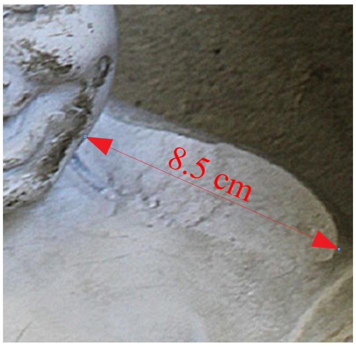
From this it is deduced that 3d technology in the field of restoration provides an important function of study, dissemination, and support for the restoration of works of art. In the case examined, the seminar assumes an intervention to reconstruct the missing parts. Since the work examined had already been restored, a reverse process is carried out, in which, once the work has been scanned, the missing parts on the nose, lips and shoulders of the bust will be restored. To proceed to a hypothetical restoration intervention.

At the end of the seminar the two different interventions will be compared trying to understand the possible benefits deriving from the use of 3D scanning and modeling.

Analysis of the object to be modeled

It is a bust with dimensions 36.4cm wide, 33.2cm high and 18.2cm deep.





The parts subject to intervention have an order size of 8.5cm for the shoulder, 2.5cm for the nose and about 1cm for the upper lip. The measurement of damages is important for the choice of calibration of the scanner according to the precision to be obtained. This is because depending on the distance between the object and the scanner, the measurement error may increase. With this in mind, it is possible to decide to proceed in 2 ways:

- Position the object at a sufficient distance so that it is always fully framed by the scanner cameras
- Position the object closer and in this way reduce the error of the scan.

In the first scenario through a low number of overviews it will be possible to reconstruct the entire object, however having a measurement error due to the distance of the object, in the second scenario it will be necessary to make a large number of scans due to the limited portion of the surface of the object scanned in each step. In the seminar, the first solution will be chosen since the reported error can be considered negligible.

Once the 3D model has been obtained from the 3D scan and the damages present before the restoration are artificially created, the organic 3D modeling of the parts considered detached will be carried out.

Softwares to support 3d digital sculpture such as ZBrush, 3d-coat, Blender or Sculptris are recommended for finishing 3D scanning and modeling. It should be taken into consideration that in this context, since it is necessary to work with Boolean operations, Sculptris is not recommended software.

3D scan

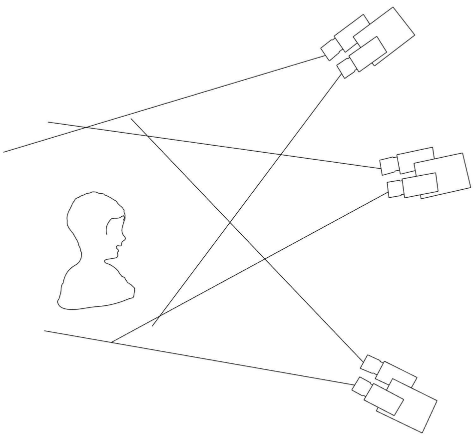
At this point it is possible to scan the model. The material of the bust is plaster, an opaque and non-reflective material that lends itself well to scanning. The 3D scanner used is the same structured light scanner that was considered in the previous seminar on the reproduction of the bronze pieces of the eighteenth-century desk.

Remember that 3D scanners can be laser or structured light:

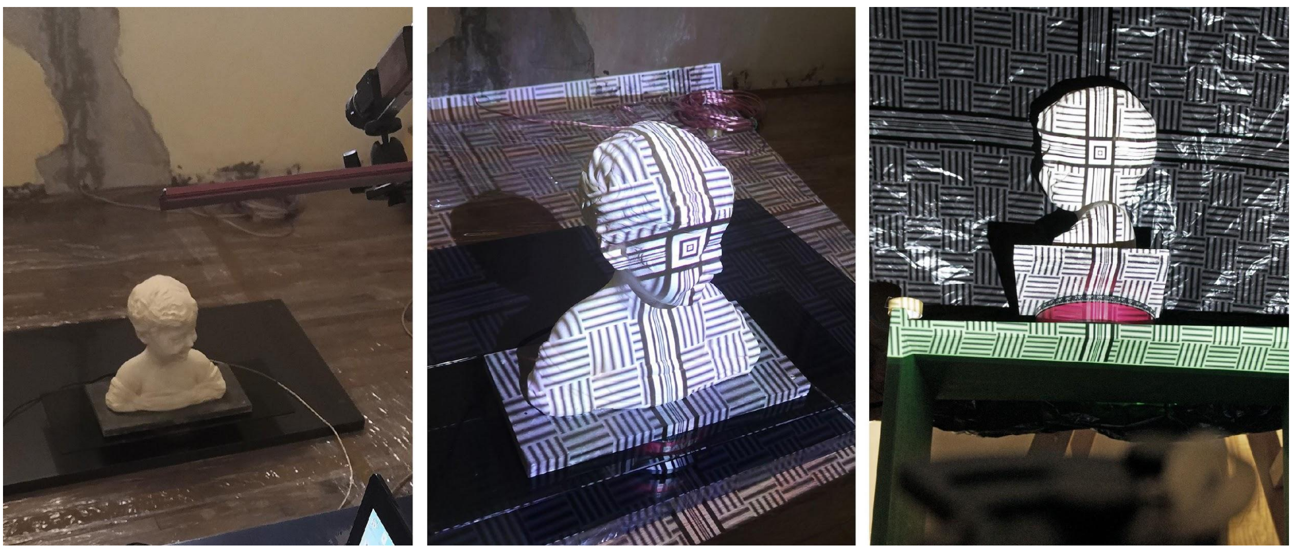
- 3D laser scanners are optical instruments that allow the digital 3D reconstruction of the geometries of the components to be detected, thanks to the reflection of a laser light beam and therefore without the need to use contact probes.
- Structured light 3D scanners are optical instruments that allow the digital 3D reconstruction of the geometries of the components to be detected, thanks to the reflection of light patterns on objects.

3D laser scanners are less affected by the surface optical characteristics of objects, so they perform better when scanning dark or shiny objects. Structured light scanners can still achieve very high accuracy and resolution performances even if they are less used in metrology. They can sometimes be faster than 3D laser scanners because they can acquire more points in a single frame and can generate 3D models directly in color.

We start with a series of overviews regarding the bust as a whole by placing it on a rotating table that allows 360° rotation around the z axis at a distance of approximately 1.3 meters from the 3d scanner cameras.

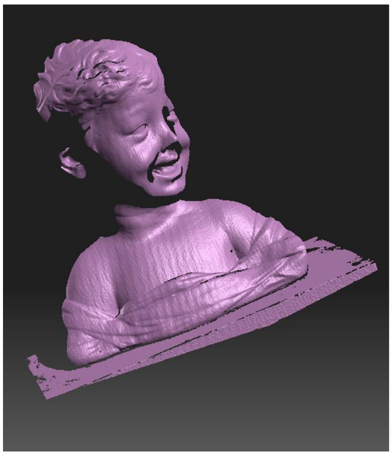


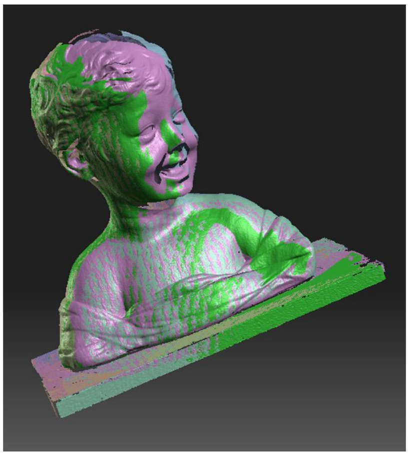
3 scanning cycles are sufficient to obtain the entire surface of the object.
One upper, one front and one from the bottom: in this way it is possible to cover all the undercut parts.
At every change of shot it is advisable to recalibrate the 3D scanner.

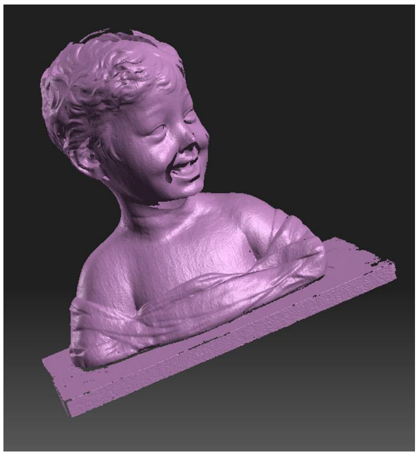


Bust scan stages

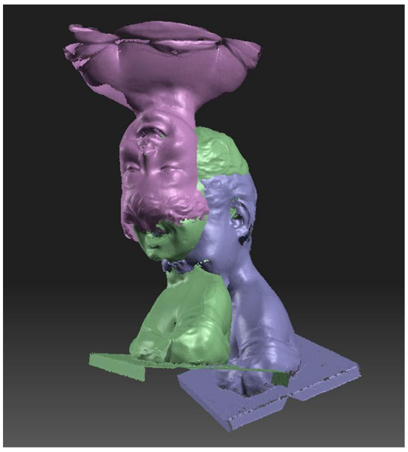
Each scan cycle makes 8 360° shots around the z axis of the rotary table. The individual scans are aligned and combined in an overview. Before creating the overview, the scans must be cleaned of any defects.

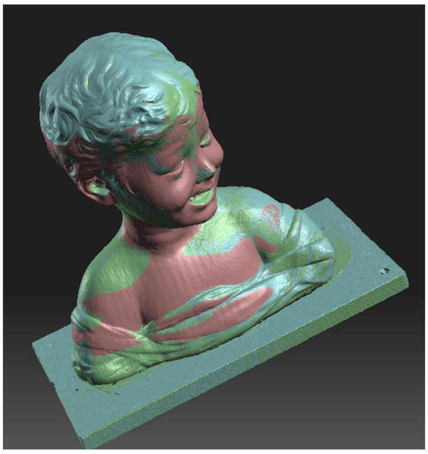

Single scan

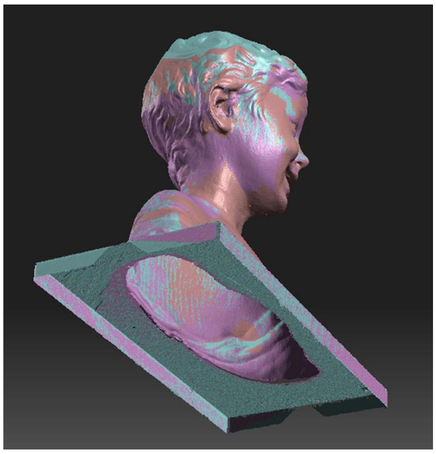

Scan cycle


Overview creation

Once the three cycles have been carried out, three overviews are obtained which are aligned by matching the surface characteristics and specific points.


The three overviews obtained


Overviews alignment


No scanned area

Note that under the base it was preferred not to scan in order not to put the object at risk. We opted for this choice because the geometry of the base is simple and it is possible to fix it in the 3D modeling phase.

At this point the Mesh is created, that is transforming the set of points obtained (the images of aligned depth) to a solid formed by triangles and it is exported in the .obj format.

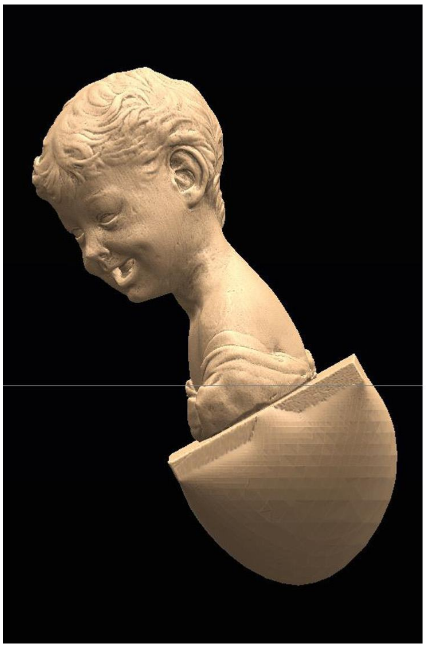
Mesh created by the transformation of the depth panoramas. Note how the 3d scanner software closed the bottom of the bust base.

3D modeling

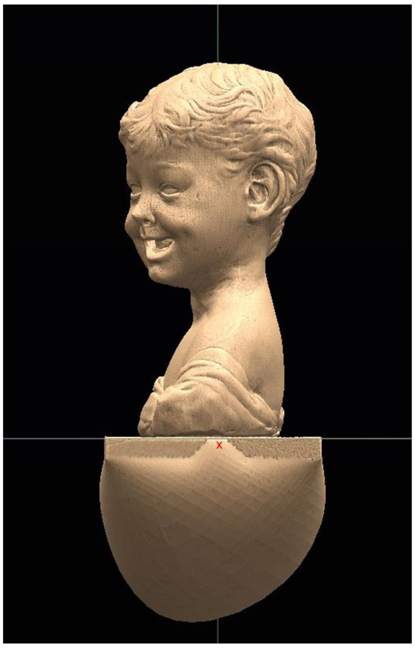
3d-Coat digital sculpture and 3D modeling software are used for modeling. For a brief introduction to the software, see respective paragraph on the reproduction of bronze elements of a Florentine desk.

Once the program is opened, the .obj model exported from the 3d scanner software is imported.

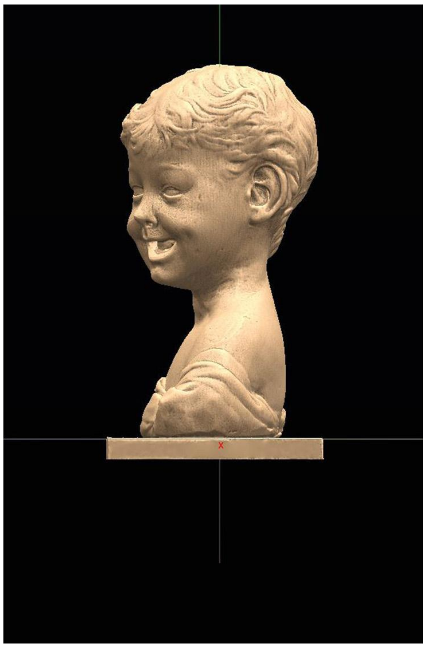
The 3d model is aligned to the axes of the reference system and, with the "cut off" tool, the excess material of the base created for closing the mesh under the base is removed.



Initial position of the mesh



Alignment to the axes of the reference system



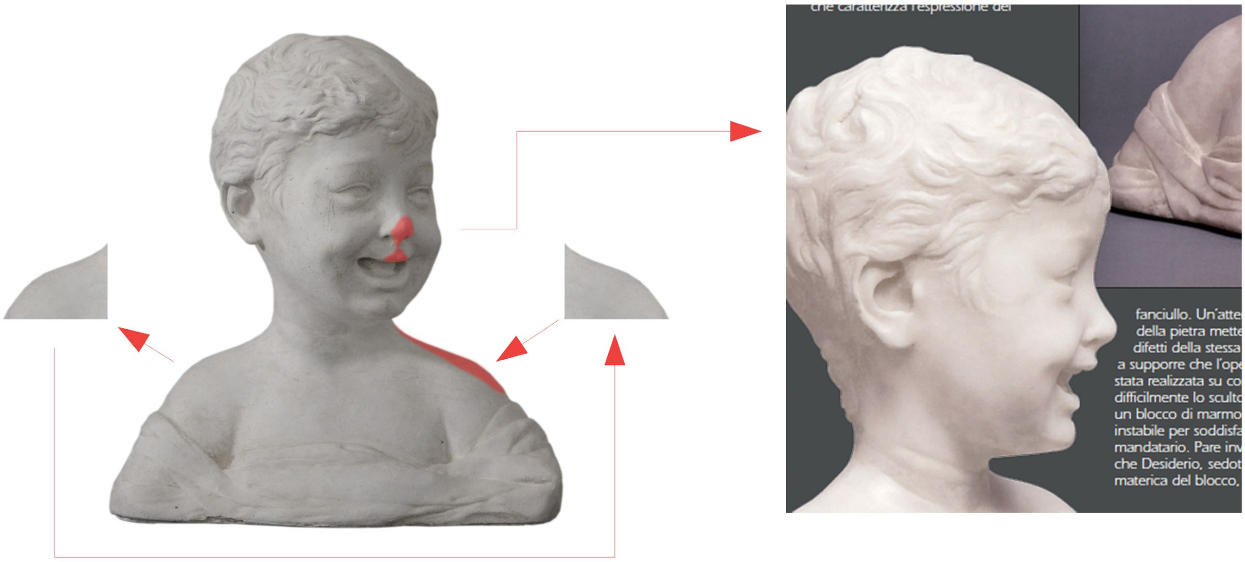
Removal of excess material from the bust base

Since the scan was done on an already restored model, the original fractures on the nose, upper lip and left shoulder are artificially created for the seminar.

Original model and the virtual model with artificially created detachments highlighted in red

Before proceeding, some considerations should be made. Since these are damages, it must be remembered that the interpretative and creative aspects should not influence the work. For this it would be necessary to search for 3D scans or already existing copies to lean on. Imagining that these do not exist and that it is not possible to operate on the model preserved in the Vienna museum, it is necessary to try to minimize the possibility of errors of interpretation by using photographic documents and/or drawings.

It is possible to take advantage of the fact that the shoulders are symmetrical, so it can be considered to use the right shoulder to model the left shoulder.

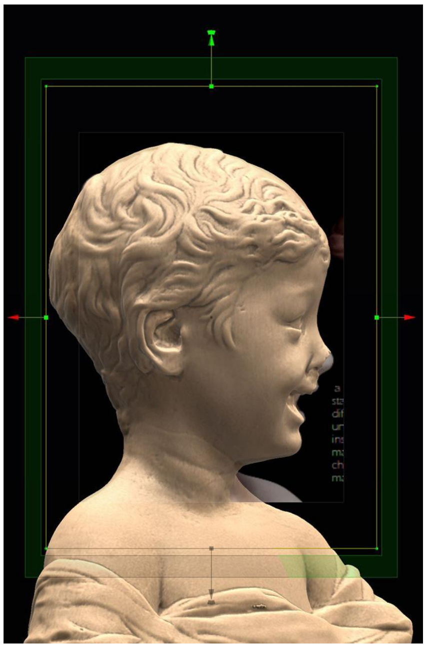


[Schematic representation](#) of the use of the right shoulder for the reconstruction of the left one.

After cleaning up the model from any imperfections (with the “smooth” tool) obtained from the 3D scan, a reference image is inserted in the background of the 3D window.
It is possible to scale the image and rotate the model around the z axis until you have a satisfactory overlap.

Insertion of the background image

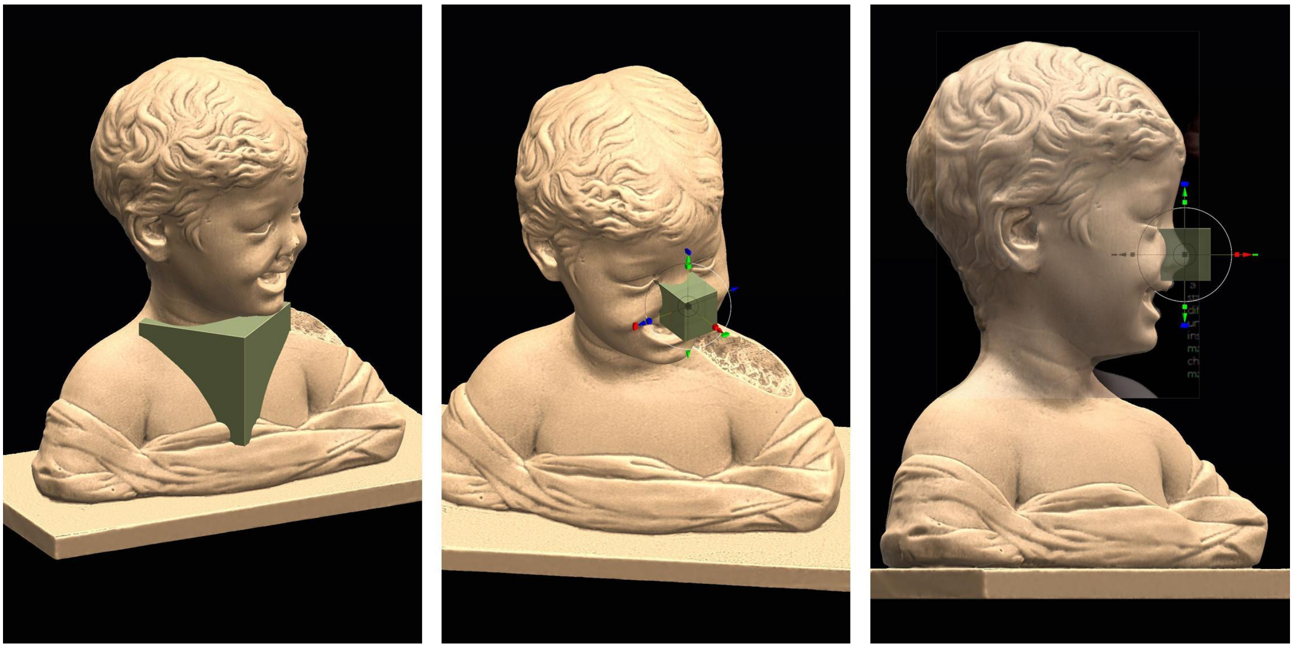
Resizing the image



Rotation of 3d model

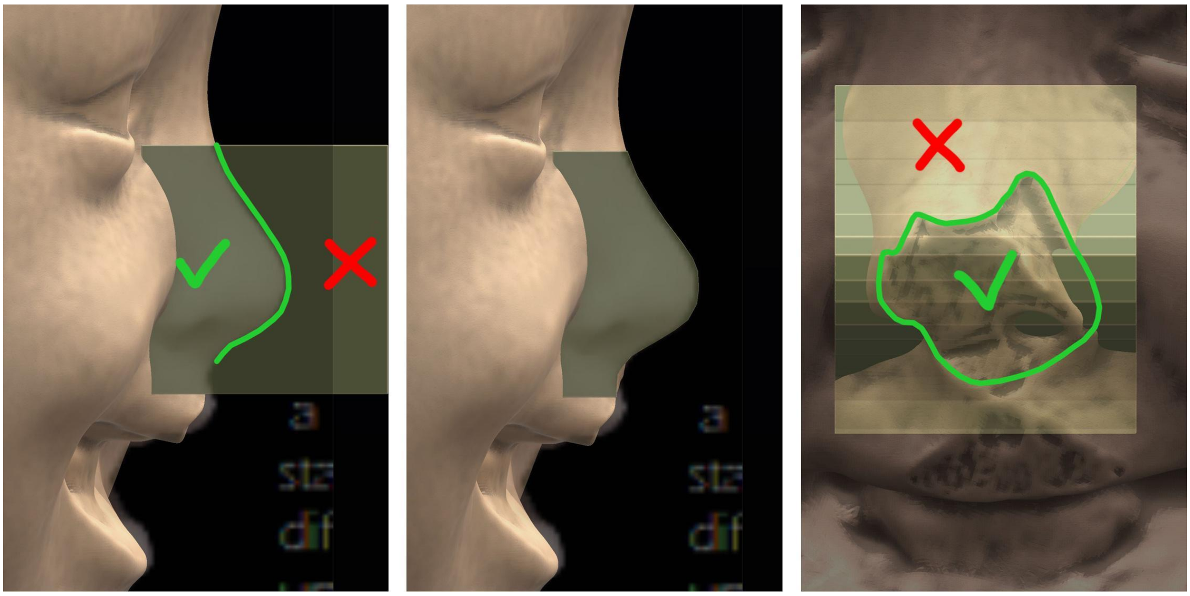
At this point there are various ways to follow, in our case we will follow that of creating the missing parts through separate Mesh, to ensure that the original scan is not modified and can serve as a reference for modeling.

A second cube-shaped mesh is inserted which will be modeled to recreate the part of the nose. It resizes and positions itself in correspondence with the missing part.

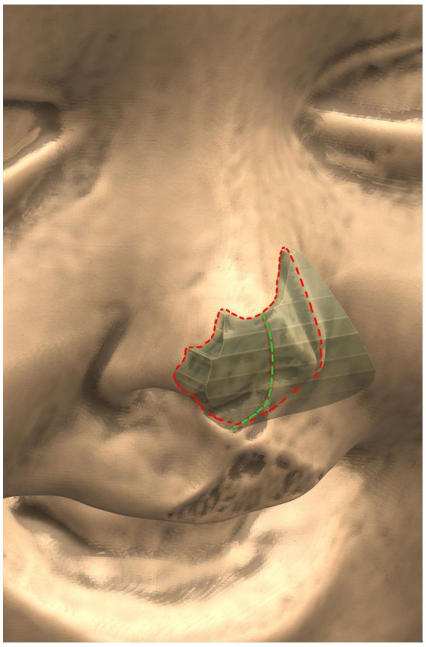


Creation of the second mesh and positioning at the nose to be modeled

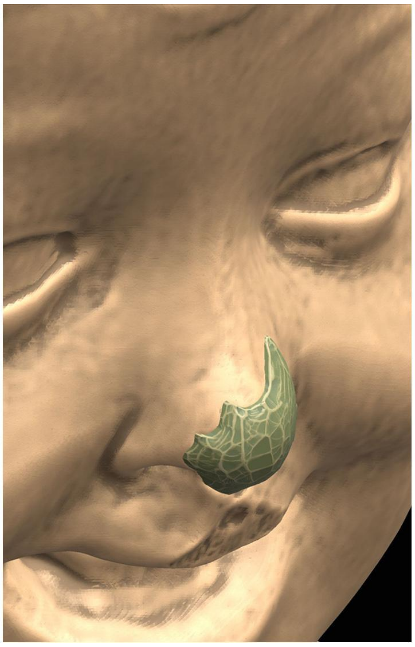
The Mesh is cut with the "Cut Off" tool both in the front view and laterally in order to obtain a solid with the same profile both of the detachment and of the nose present in the background image.



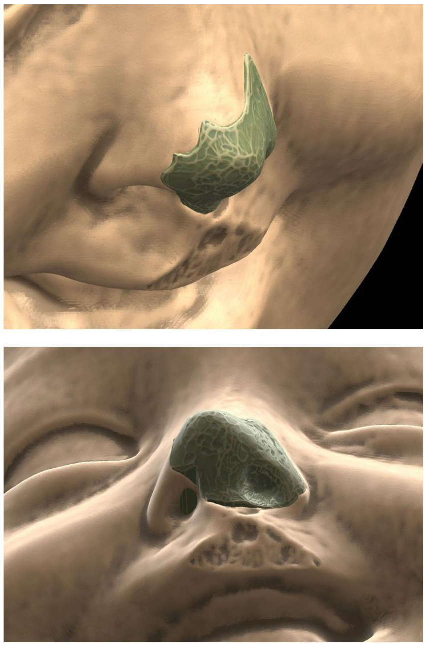
At this point it is possible to model the nose by referring to different photographs taken from different points of view, always remembering to respect the limits created by the previous cuts. Work on the surface with the tools "scrape" to flatten, "Vox.Clay" to increase or decrease the volume, "Smooth" to smooth, "Airbrush" to increase the volume constantly, "Fill" to fill.



The mesh to be modeled was cut such a way to provide references during the modeling



You start by removing excess material with the “Scrape” tool which can be used as an abrasive paper



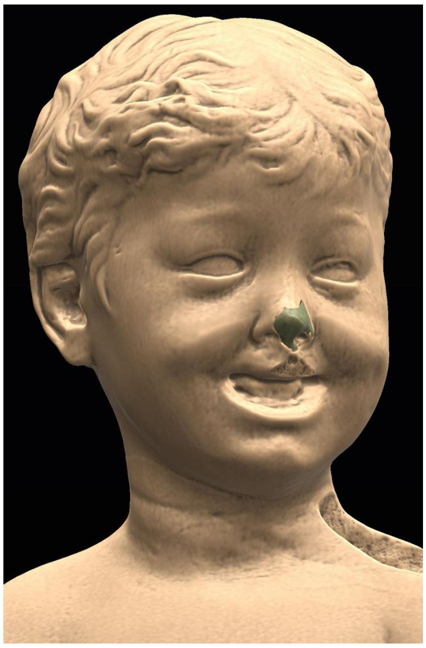
To refine the model, use the “Vox.Clay” tool to create the cavities

Modeling is continued with the "Airbush" and "Fill" tools. Using the "Smooth" tool, the surface is smoothed and the entire tip of the nose is finished a little at a time

The last step is to shape the impression of the tip on the fracture of the model. To do this, through a Boolean subtraction, the entire Mesh of the model of the bust with the missing Mesh of the newly modeled nose is removed. It should be borne in mind that, if you intend to use a glue, you must also consider inserting the air necessary to host it. In this case, before carrying out the operation, it will be necessary to increase the volume of the Mesh to be subtracted.

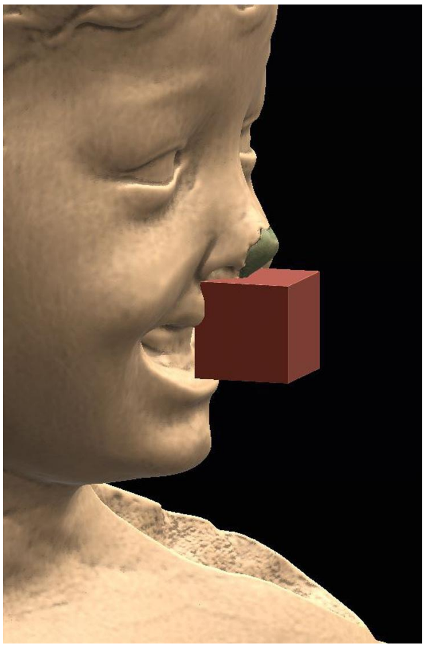
The Mesh B of the newly modeled nose enters the volume of the Mesh A of the bust

The part of Mesh B that enters Mesh A through a Boolean difference is eliminated

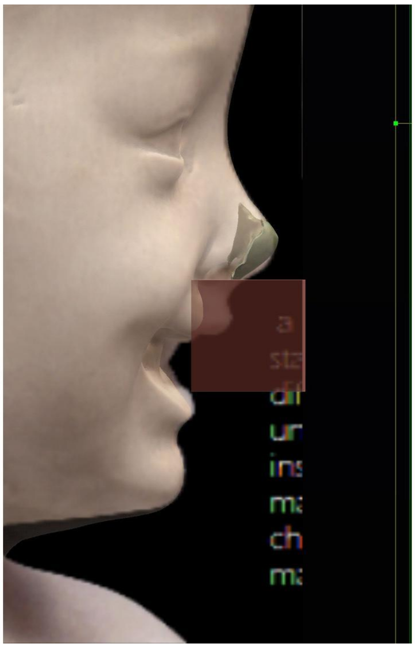


The missing nose tip modeling Is complete

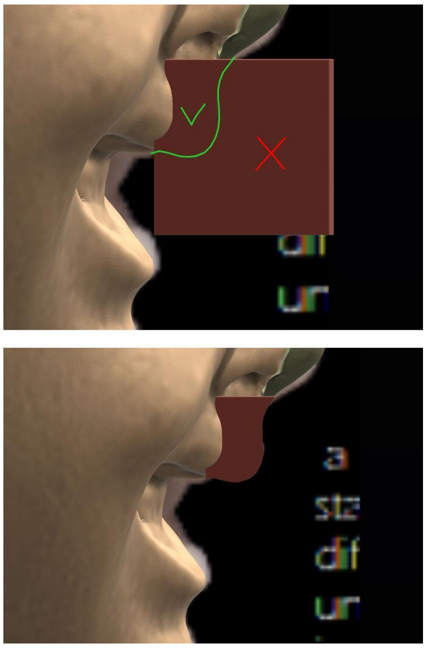
To model the upper lip, proceed by performing the same steps listed above, being able to use the same background image.



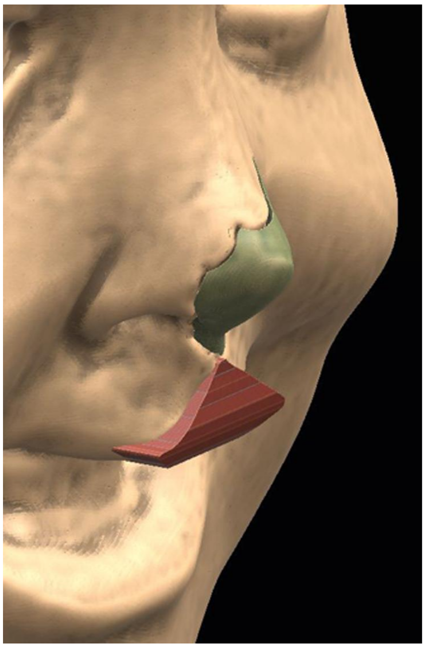
Inserting the cube



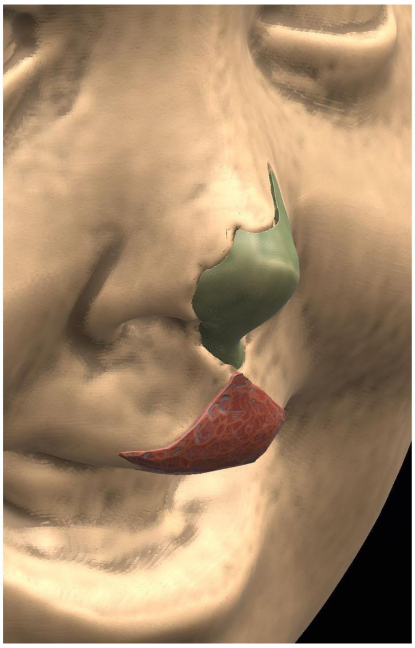
View of the background image



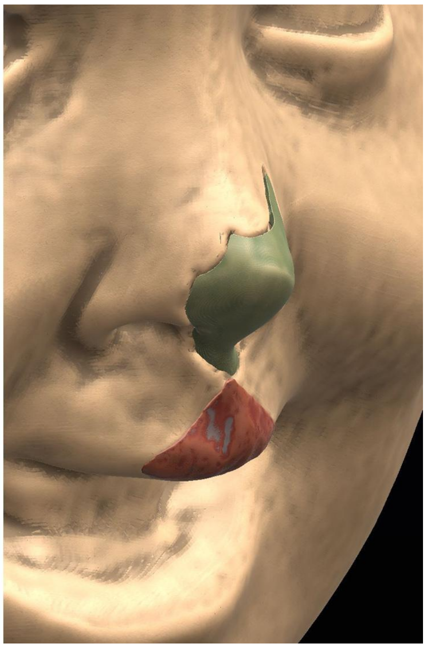
Use of the "Cut Off" tool to create the front profile



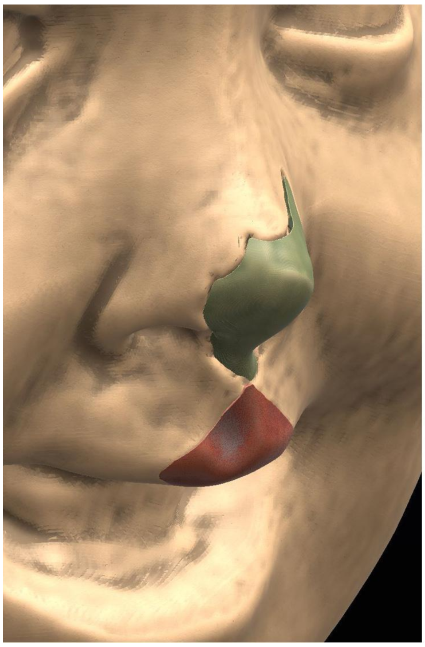
The Mesh after the action of the "Cut Off" tool



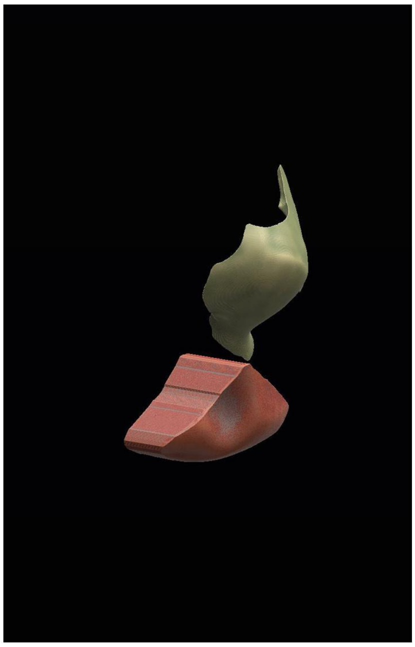
Using the "Scrape" tool to smooth the mesh and remove excess material



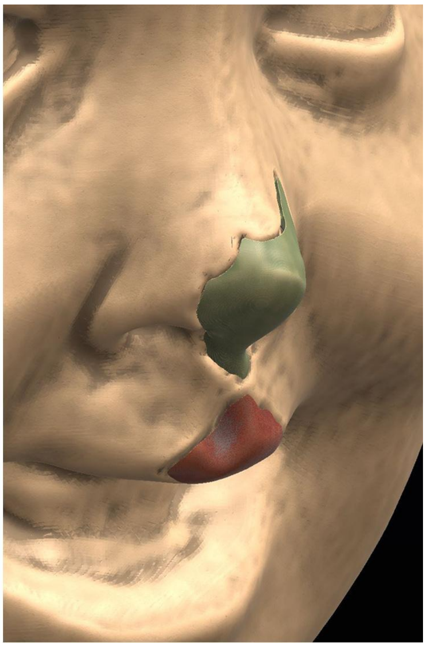
Use the tool "Vox.Clay" to create the cavities



Final finishing with “Smooth” and other tools



Mesh resulting from the sculptural modeling process



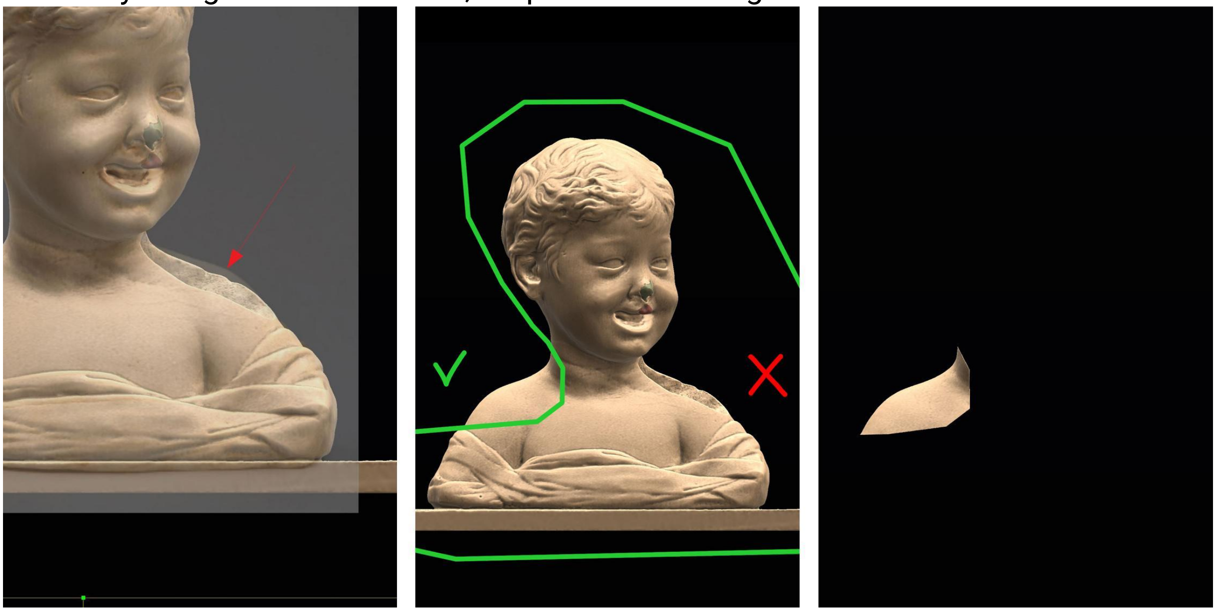
Final result following the Boolean difference to obtain the Impression of the lip of the bust

The face with the mesh of the nose and lip

As for the 3D modeling of the left shoulder, we intervene as previously programmed, or using the right shoulder. In this way an element already largely modeled can be used, with a considerable saving in terms of time.

The torso is aligned again to the front view to better read the profile of the shoulders. Also in this case, try to limit the interpretative aspects as much as possible, a background image is used, which will serve to guide the modeling.[27]

After positioning in the correct way the background image, a duplicate of the bust is created. By using the "Cut Off" tool, it's pulled out the right shoulder.



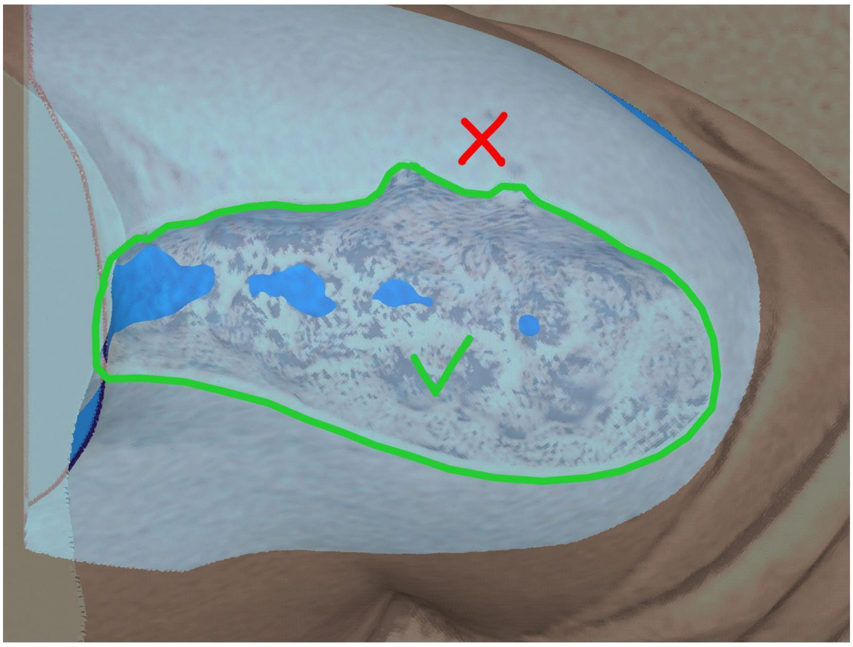
At this point, using the symmetry mode along the z axis, a mirror duplicate ("Clone w Symmetry" command) of the shoulder is created and using the cursor of the "Transform" tool, it is positioned in correspondence with the lack on the left shoulder.

Creation of the left shoulder starting from the right shoulder using the symmetry mode

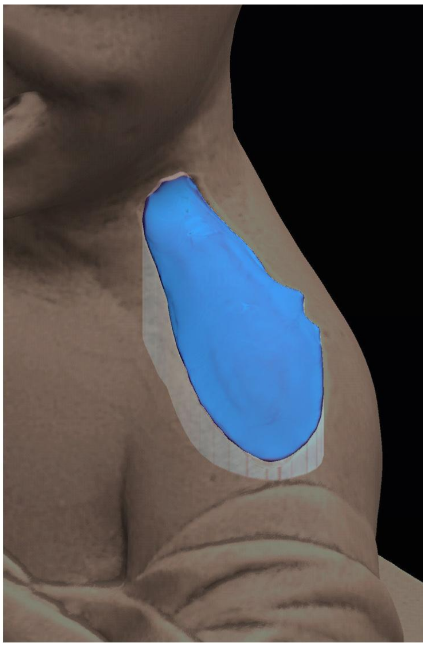
Positioning of the new mesh near the cavity on the left shoulder

As it is possible to see, although the mesh does not perfectly conform to the geometry of the bust, a good part of the modeling work is avoided.

All the material that leaves the perimeter of the cavity is eliminated using the "Cut Off" tool and with the various digital sculpture tools the Mesh is finished until a complete filling of the cavity with a surface treatment that follows the surface trend surrounding.

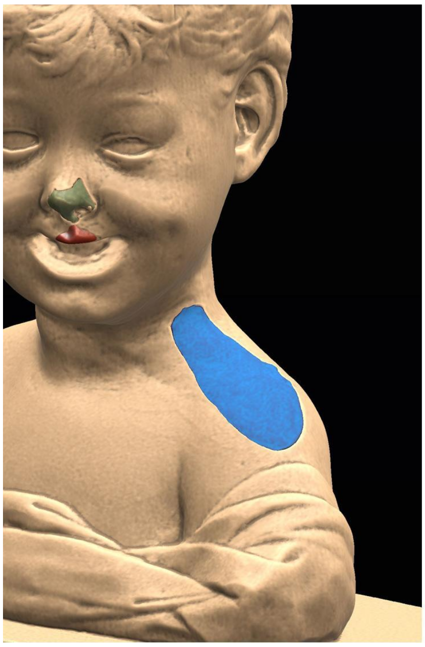


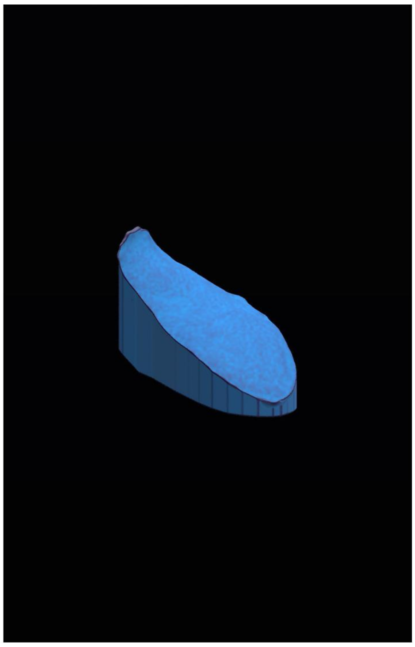
Elimination of the portion of mesh exceeding the perimeter of the cavity



Modeling and finishing with digital sculpture tools

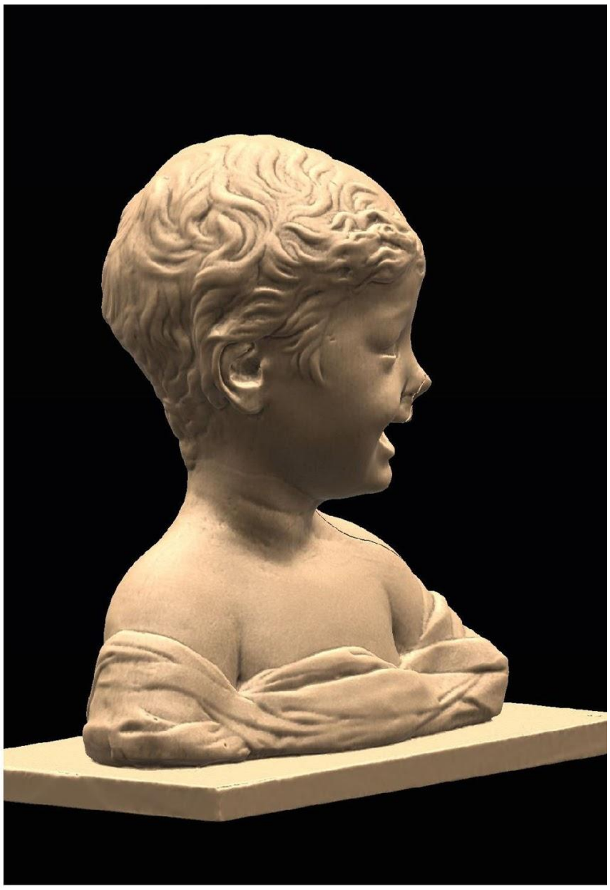
Once the surface has been smoothed and treated so that the Mesh integrates perfectly with the bust, it is necessary to obtain the cavity impression. As in the cases described above, a Boolean difference is used with a copy of the bust.

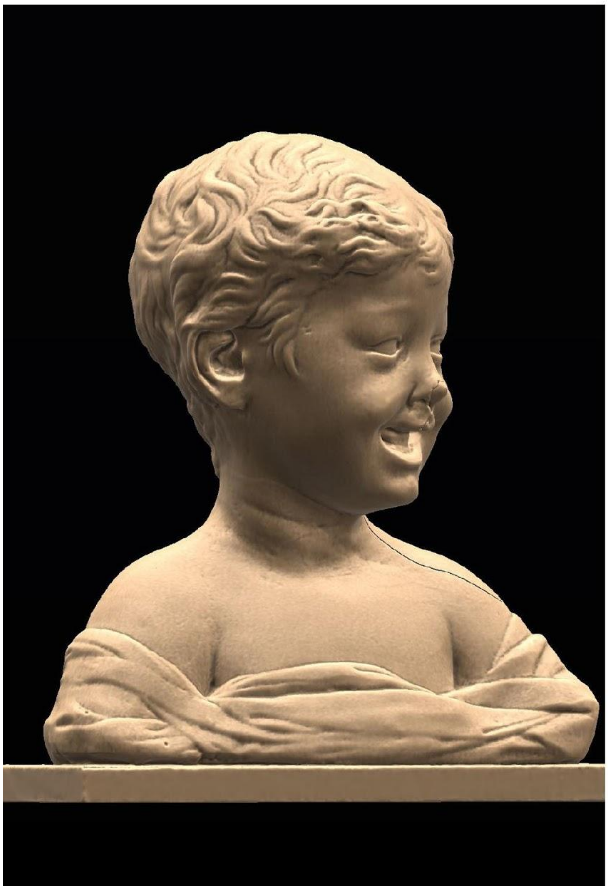

The Mesh once the modeling and finishing phase if finished


The Mesh before the Boolean subtraction


Mesh after Boolean subtraction. It is possible to see the mold of the cavity in the lower part

The physical realization of the models, or their casts, will depend on the decisions of the restorer or the restoration manager. During the seminar we will discuss the choices that are considered most appropriate.





4. Conclusions

As for the previous seminars, the examined working methods will compare: the traditional one and the one with the use of digital technology.

The opportunity, feasibility, costs, benefits and critical issues will be assessed in a comparison between restorers, 3D modeling technicians and students to understand how and when this technology can be applied in the integrative restoration of sculptural elements.

Chapter Two: From manual to digital prototyping

Workshop scenarios presented in this chapter were developed by two Polish organisations at the time of essential changes being introduced to vocational education system in Poland. The new law (http://prawo.sejm.gov.pl/isap.nsf/download.xsp/WDU20180002245/U/D20182245Lj.pdf) adopted in November 2018 complemented the recent structural reform of the education system, focusing now on improving quality and effectiveness of vocational education. Special emphasis was placed on practical vocational training in consultation with employers and its adaptation to labour market needs. From our perspective of seeking new ways to enrich formal VET curricula with non-formal learning activities for vocational students the following points of the reform are particularly important:

- The law introduces new options for VET learners to obtain additional vocational skills or qualifications beyond the core curriculum.
- It encourages VET schools to organise short-term vocational courses for students upgrading or extending their professional skills.
- It makes it mandatory for schools to design practical learning experiences in close touch with the market needs and taking advantage of state-of-the-art technologies.

The new law does not specifically mention cooperation of vocational schools with non-formal learning providers, highlighting the need to involve employers in the development of VET in all its stages as well as providing relevant apprenticeships for learners. Nevertheless, it communicates a clear message to school management and teachers in formal VET: design and implement learning programs that bring forth concrete skills and competences needed in the rapidly changing economy, mobilising all available human and material resources, both internal and external. The first effects of the new policy have become visible in gradual melting of stiff curriculum frameworks, which now have to incorporate more flexible learning pathways connecting school with practice-based learning environments, be it a production line at a local factory or a makerspace equipped with new digital tech.

This is exactly where our project fits in. Its two partners from Wadowice represent the formal and non-formal sectors of vocational training. **CKZ** is a centre offering first and second level vocational education in a number of areas including building construction, carpentry and electronics. **EST** runs a digital makerspace where young people learn how to construct objects like robots, drones or game assets. Some of these objects are created with digital tools - prototyped on a computer, their parts 3D-printed, fitted with electronics and manually assembled. The activities are of a hobbyist nature but foster skills, which are relevant for professional careers in various sectors of modern industry. As such, they can enrich the program of formal training in the areas of building construction, carpentry and electronics where 3D prototyping technology is gaining significance. The two institutions thus decided to develop and pilot together a workshop program for vocational learners in these subjects adding value to the activities that can be conducted in school alone.

The advantage of such a program linking school and out-of-school environments can be seen in the following aspects.

- Although a 3D printer is available in the school it is only used in restricted areas of the curriculum, the IT classes in particular.
- The process of preparing files for printing and the printing itself is time-consuming hence; it can hardly be managed during lessons.
- Teachers have limited capacities in terms of available time beyond the core curriculum.
- 3D printing attracts interests of students from across a wide range of vocational subjects, not all considered in their programs to be introduced to the arcanes of the technology.
- Hence a genuine interest of school management to find ways for curriculum enrichment activities in this field.

This background provided an excellent venue for us to explore. We outlined a program of workshop activities for learners from CKZ studying building construction, carpentry and electronics. The program was designed in close consultation with vocational teachers of these subjects and an expert in 3D printing. The objective was to align it with school curricular standards, the specifics of the technology to be introduced and actual interests of the students.

The new VET curriculum recently introduced to Polish schools divides the learning outcomes into knowledge, skills and competences common to a group of professions and those specific to certain areas of training. We were able to choose curricular standards relevant for all the three subjects (building construction, carpentry and electronics) that can be addressed in a workshop program on 3D design and printing. They all require an ability to work in a team and to choose appropriate tools to deliver technical tasks, including digital tools as needed. We further focused on the learning outcomes as required for each of the professions, which can be gained through engaging in 3D prototyping projects. E.g. in the case of building construction one of the skills to be mastered is the ability to make plans of building structures, design wooden constructions in the case of carpentry and build electronic appliances in the case of electronics.

A draft of the workshop program is presented in the main body of this chapter. We first outline a module shared by all the workshops and introduce students to 3D prototyping technology. We then present three specific learning pathways based on this foundation knowledge but relating to the particular subjects that the students are studying at school. These workshop scenarios have been originally designed for concrete vocational training context but are presented here in a form that makes them applicable in other settings where there is a need to enrich formal school program with introduction to 3D tech. We provide them as examples, not necessarily to be followed literally but rather as an encouragement to adapt them to particular requirements of a new context.

Recruitment of students for the workshops was a relatively easy task in view of the fact that CKZ is a large vocational school, attracting hundreds of learners to its courses. The topics of the workshops raised interest and curiosity when presented in the classes of building construction, carpentry and electronics. We presented the training as a competitive offer and a selection procedure was implemented to enroll students with adequate motivation, ability and career prospects. The help of their teachers was essential in the recruitment process in terms of sharing information, setting enrolment criteria and selecting the best candidates. As a result, we formed small groups of 5 - 6 students ready to join an extracurricular workshop program addressing their vocational interests and adjusted to their level of technical knowledge.

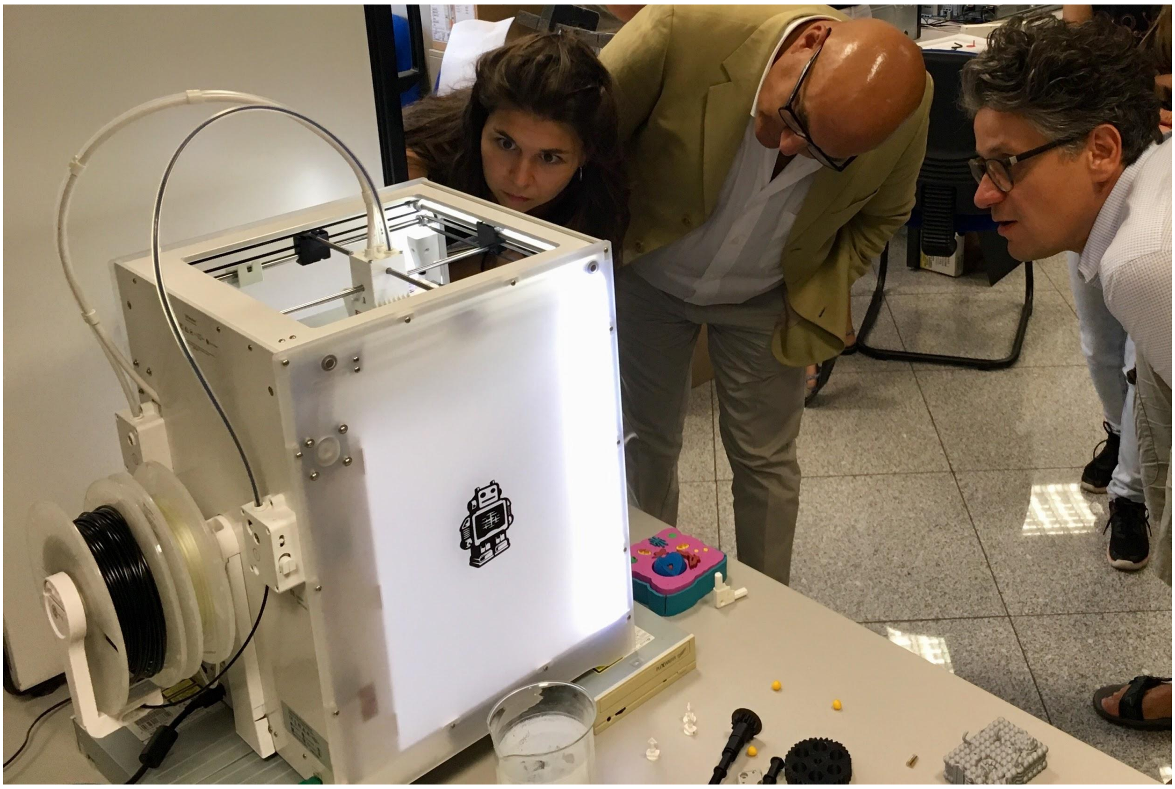
I. Introduction to 3D prototyping

Prototyping objects before the production stage can be done manually with wood, clay or other soft materials easy to be modeled. Although such techniques are still in use in traditional workshops, digital technology has radically changed the process. The change is reflected in vocational curricula, which cover skills in computer design of various constructions and utensils (e.g. houses, pieces of machinery, furniture). However, it is only in rare cases that students can follow and master the whole process of prototyping from the stage of digital design to producing a 3-dimensional physical model. The purpose of this introductory module is to provide foundation skills in this area, which are applicable in many professions taught in vocational schools.

Learning outcomes

Because of the learning experience, the students will be able to:

- Explain the basics of 3D technology
- Identify key parts of 3D printer
- Choose 3D modeling software appropriate for their level and needs
- Check the printer basic set-up parameters
- Get access to a database with objects to redesign and print



1. 3D modelling and 3D printing in a nutshell

3D printers are based on rapid prototyping technologies introduced to the industrial market in the 1980s. Due to patent expiry, 3D printing technology is today becoming increasingly available to consumers. 3D printing, also known as additive manufacturing, is a process of making three dimensional solid objects from a digital file. A printer melts a material and pours it on a base in a predefined manner thus creating successive layers to make it three dimensional. In this introductory workshop, students are practically acquainted with the following aspects of the technology.

- **Purposes and the main fields of using 3D technologies.** There are countless applications of 3D printing in manufacturing, education and services. The students will best grasp the scope and potential of the technology if presented with concrete examples from different fields (e.g. bioprinting in medicine, concrete 3D printing in construction or 3D printed jewellery). The choice of examples should be adjusted to the particular profile of the group.

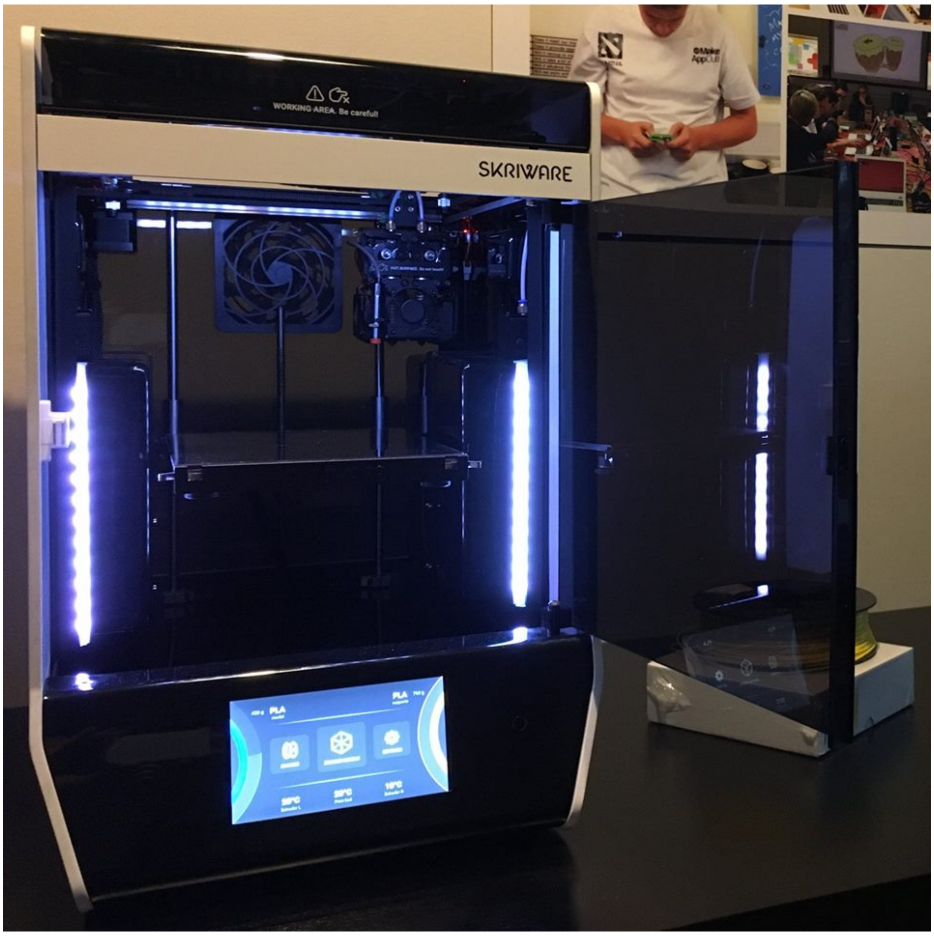
- **Differences between 2D and 3D design.** Many industries that formerly relied on two dimensional drawings and designs have moved into 3D visualisations. To intuitively grasp the progression the students should see how an object drafted in a 2D software can be easily transformed into a 3D model (e.g. with an online 2D-to-3D creator like Shapeways www.shapeways.com).

- **Phases of the 3D modelling process.** This part is intended as an overview of the whole process, not a detailed explanation of the steps, which will be done in the following workshops. On a concise video tutorial, the students should observe the following steps from 3D CAD modelling, through slicing, layer printing to the emergence of a complete physical object (e.g. www.youtube.com/watch?v=QdvSzXByi_g).

2. Construction of 3D printers and the most popular models

3D printers and materials are constantly developing, so this overview needs to take into account the latest news from the market. There are a number of dedicated portals where to draw relevant information from, e.g.: https://www.3dhubs.com. More time should be devoted to the particular printer used in the workshop, most likely an FDM printer due to its popularity and accessibility. At least the following key components are introduced, outlined here based on an example of the Skriware printer (https://skriware.com) used in piloting this workshop scenario:

- Software and its interface
- Extruder (if dual, you can show how different colors and materials can be combined to achieve various effects)
- Heated and removable printing bed
- Proximity sensors
- Printing parameters with impact on the quality of the process (printing area, time, temperature, etc.)



3. Modelling and 3D printing software useful for beginners

There are a number of programmes, which make first steps into 3D modelling quite easy. An overview of such programmes is presented at this stage with a more detailed description of the one, which will be used in the workshop. The choice depends on the available software and the teacher's preferences. A recommended list includes:

- TinkerCAD www.tinkercad.com. This is a particularly useful free online collection of software tools for 3D designing. It is a good programme to begin with because of its intuitive interface, a large resource of tutorials and community support. Students are introduced to TinkerCAD with a presentation of its basic functions. They will learn it practically when taking on concrete tasks in the following workshops.

- FreeCAD www.freecadweb.org. Another free open-source 3D modeller for designing real-life objects. Parametric modelling allows users to easily modify their designs by going back into the model history and changing its parameters. The programme is presented only briefly for interested students to explore its possibilities on their own.

- SketchUp www.sketchup.com. It is a web-based 3D modelling software with a wide range of applications for interior design, architecture, engineering and video game design. Its basic version is free and thus easily accessible for the students who want to enlarge their digital toolbox.

- Blender www.blender.org. The programme may be too difficult for the students not versed in simpler tools like TinkerCAD. Still it is worth presenting at this stage as an excellent free programme opening a pathway to more advanced 3D modelling projects.

4. Printer set-up and preparation for printing

This is an important part of work as improper set-up of the printer may result in bad quality prints, so sufficient time should be devoted for preparation in order not to waste it later for repeated printing. The following steps are introduced.

- **Printer software and its use.** Dedicated software should be preinstalled. The students are introduced to using its basic functions accessible through the panel on the printer.

- **Stabilising and leveling of the printer.** It has to stay firmly and stable on the hard ground with possibility of shaking eliminated. Otherwise, the moving head of the printer may cause vibrations of the whole device and even destroy the model.

- **Leveling the printing bed.** It should be leveled to the printing head. If this is not done properly, the model may not stick to the surface or the printer may not be able to print the first layers. Usually, the printers have special protocol and resources for leveling the bed.

- **Loading filament(s).** Depending on the printer model, you can load one or two different filaments. Students should be sensitised to use the right parameters and the filament type for the particular printer.

5. First steps in 3D printing

A good way to start learning 3D printing is to use ready models available in one of many different online databases. Through this approach, the students will learn the following:

- An efficient method to test the printer. If we know that the model was printed successfully before and has good reviews, we can be sure that the printer or our actions cause all the problems with the prints. Such a case is a great opportunity to explain some of the issues possible to occur during printing.
- All phases of the 3D printing process. How the printing is conducted and what factors affect the process - levelling the printer and the bed, positioning the model for printing, type of filament, etc.
- Useful content of the databases that help to master different uses of 3D printing. Through the variety of models and categories, the students can realise the potential of 3D printers to deliver complicated projects.

There are many different online databases with ready STL files, which can be printed on any FDM printer. Many of them are free. The most popular one recommended here is https://www.thingiverse.com. The repository contains models in many different categories and welcomes uploads of objects designed by users. Usually the designers upload not only the files which can be used by others, but also photos, presentations, links to related resources, recommendations for the 3D printer types and filaments, and many more. The users can share and discuss opinions on all of the records in the repository.

There are also other useful databases, which can be introduced:

- https://all3dp.com/1/free-stl-files-3d-printer-models-3d-print-files-stl-download
- https://skrimarket.com
- www.yeggi.com

With the above basic introduction, the students can proceed to their own projects. At this stage, the scenarios split into specific learning pathways addressing the groups' vocational profiles and interests. In what follows we present three different workshop plans on drone construction, designing spiral stairs and modelling truss bridges.

II. Drone building

Drones raise authentic curiosity among young people and a workshop on building a drone will fill up quickly with participants. Here we outline a programme of activities for a group of students with basic knowledge of electronics and 2D design skills.

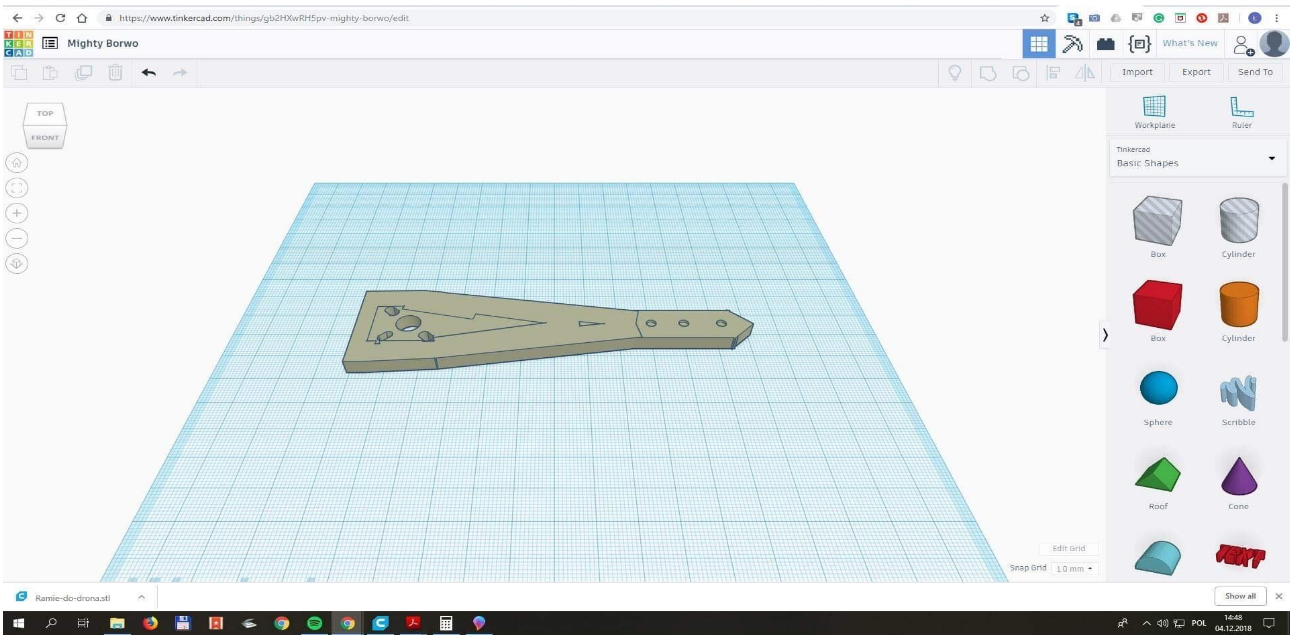
Learning outcomes

Because of the learning experience, the students will be able to:

- Identify key components of a drone
- Find and download parts which can be 3D-printed
- Design their own modified/improved parts
- Assemble the whole device
- Test the drone in a flight

1. Introduction to TinkerCAD

TinkerCAD www.tinkercad.com is a simple, online 3D design and 3D printing app, which the students with basic digital skills can master easily. The programme has an intuitive interface and it is an excellent tool to foster three-dimensional thinking skills necessary to model physical objects. It is used by budding designers to prototype various objects, including robots and drones. An important feature of TinkerCAD is that you can import STL files and then modify them. You can further export the files that are ready into a slicer program for 3D printing. TinkerCAD also has an excellent resource of tutorials so choose those most appropriate to the level of your group and the tasks that the students will undertake.



In this session, the students go through the following learning pathway.

- **Learning the basic functionalities of the programme.** This can be done with the support of one of the tutorials on the TinkerCAD portal. Students more versed in digital technology can directly proceed to design simple 3D objects. At least the following basic functions should be mastered before moving to the following stage: placing a shape to add or remove material, moving, rotating and adjusting shapes freely in space, and grouping together shapes to create detailed models.

- **Selecting and downloading a drone part.** Thingiverse database includes many drone designs. An example part to begin with can be a drone arm www.thingiverse.com/thing:3129911 that comes with a number of other parts to construct an operational vehicle. The students review the whole project and possibly identify weak parts of the construction through published comments. Then they download a first part for further elaboration in TinkerCAD.

- **Redesigning the drone part.** The arm shown in the above picture is rather weak to sustain a possible drone crash. It can easily be made thicker and stronger. The students apply recommended improvements in the existing design.

- **Comparison of projects.** The modifications proposed by the students will certainly differ. The group discuss their projects with the teacher and choose 2 - 3 best designs for printing.

- **Slicing the file for printing.** Once a 3D design is made, the file needs to be sent to a slicing software where it gets ready for the printer. The quality of the print will depend on the settings that are made here. Students learn the basic functions of the Cura slicing software https://ultimaker.com/software/ultimaker-cura while preparing their files for printing.

- **Printing the final objects.** Depending on the size of the objects, the time needed may go beyond the workshop. It is likely that the students will see their projects only at the next session. Then they should discuss the quality of the prints and usefulness of their designs for the whole construction. One model should be chosen to be followed by more printed parts.

2. Designing and printing drone parts

Students begin this session with an example drone part printed in the previous workshop. Now the task is to continue with the remaining parts needed to assemble a complete flying device. Depending on the level of the group and available time, the focus can be on less or more items. In each case, it is important to ensure that all the key elements are printed, some re/designed by the students and some downloaded from ready files available on Thingiverse www.thingiverse.com or similar portal. The students can divide the tasks among themselves or work in smaller groups. Each item of the drone can provide a pathway to practice certain skills in digital prototyping.

- **Frame.** Printing the remaining elements of the frame will consolidate students' skills in managing the process (loading filaments, adjusting parameters on the printer menu, etc.). The frame is the part, which breaks most often when the drone crashes so the students should be able to replace such parts.

- **Landing gear.** This is a device, which can facilitate safe landing, protecting the drone from sitting on the zip-ties ends and motor wires. The shape of the device can be more or less complex so the students will practice their designing skills on a project adjusted to their level. They will have to ensure the compatibility of the construction with the drone frame.

- **Camera and/or antenna mounts.** Both are relatively easy to design so the students can propose their original projects. These designs are a good opportunity to practice the following skills: dividing the whole object into smaller units to be put together at the end which makes designing complex objects easier, creating solid circular and rectangular shapes of which the mounts will be composed, adjusting their dimensions, creating hollow areas in the middle of these objects, aligning the elements together and finally grouping/merging them all together.

- **Propellers.** This is the most difficult part to design, as the propellers need to generate appropriate force to lift the drone. It is thus likely that the students will begin with a ready propeller project and optimise it for their own drone, taking into account parameters like the drone's size and weight, and corresponding shape of the propeller with its twists/angles accurately adjusted. It is a good idea to design different versions of the propellers (e.g. higher and lower angles of attack) and then test them when the whole device is assembled.

- **Other optional parts.** If time allows, the following drone parts can provide further opportunities for consolidating the skills gained while working on the above projects: remote casing, drone protective equipment, battery pack casing, etc.

3. Assembling with mechanical and electronic parts

At this stage, all the printable components should be ready. Now the students identify the other elements, which need to be acquired to construct an operational flying vehicle. There are a number of sites, which can facilitate this search, e.g. http://grinddrone.com. A comparison of different devices will be an occasion to go deeper into the drone construction before choosing particular elements for purchase. The teacher should ensure that the chosen elements could be acquired for the workshop at affordable prices. When this is done the group can start assembling the drone, using the elements printed in previous sessions and newly acquired components. At least the following items will be assembled and their functions learned in the process.

- **Brushless motor.** The design of the motor is an important part of the drone construction. The choice of an efficient motor means savings on battery life and maintenance costs. In the workshop, the students will compare the parameters of brushed and brushless motors and install the one suitable for their drone.

- **Electronic speed controller.** It is an electric circuit whose main responsibilities are to monitor/vary the drone's speed and direction during flight. A drone depends entirely on the ESC for all its flight needs and performance. Before installing it in the mainframe, the students will need to understand all these functions.

- **Flight controller.** It is the motherboard of the drone, responsible for the commands sent to the drone by the pilot. The students should learn the basics of the process of how the input from the receiver, the GPS module, the battery monitor and the onboard sensors are interpreted by the flight controller. Any alterations to these functions are possible only at a very advanced level - at this stage the students just need to install the controller in the body of the mainframe.

- **The receiver.** This is the unit responsible for the reception of the audio signals sent to the drone through the controller. The students will be acquainted with a 5-channel receiver in the process of assembling the unit.

- **The transmitter.** Transmits radio signals from the controller to the drone to issue commands of flight and directions. The students will need to ensure compatibility of the receiver and the transmitter that use a single radio signal in order to communicate to the drone during flight.

- **GPS module.** Responsible for the provision of the drone longitude, latitude and elevation points. Before starting learning drone navigation, the students will need to grasp the module's functions in tracking the distance, capturing details of specific locations on land and returning the drone safely to the pilot.

- **Battery.** Battery requirements are important to ensure sufficient power for flights and their duration. The students should install a battery, which will allow 10 - 15 minutes test flights and could be recharged or exchanged easily for consecutive tests.

- **Camera.** The students will build in a detachable camera with a stabiliser that facilitates taking photos and making films. If this is done properly, the workshop opens follow-up sessions on aerial photography that is a new exciting venue to explore with young people.

4. Test flights

Once the drone is assembled, the next session/s can focus on testing the device in actual flights. The students will need to go through a number of preparatory stages in the workshop before they go out and fly the drone. The idea is to gain baseline knowledge on drone navigation and safety rules that have to be respected.

- **Navigation in a flight simulator.** Before the group take their newly constructed drone out for its first flight, it is a good idea to use a simulator to get a feel for its handling and learn at least the basics of how to launch the device, navigate it and land. This will help to avoid potential issues, including a crash that may destroy the drone right in the beginning. The students can use the same controller that will be used in the actual flight, but now connected to a computer with a proper software installed. Ideally, they can practice both first-person view racing and handling of drone camera to achieve good photos and videos. This will obviously depend on the time available - if there is only one flight simulator, the practice will have to be organised in a number of sessions with individual students or small groups coming to the workshop. The objective is to have all the participants gain at least a basic grasp of the drone navigation skills.

- **Drone flight safety.** Practising with a drone simulator is never going to be the same as the real thing. For real flights, the students will have to learn at least the essentials of drone safety and maintenance to avoid any accidents. At this session they will be acquainted with the following:
    - Regular checks for drone damage and general maintenance
    - Maximum allowable altitude
    - Maintaining visual line of sight
    - Areas permissible for flying
    - Local regulations regarding flying drones

- **Outdoor flying.** The venue has to be chosen carefully respecting the above rules. In particular, flying over people is not permitted so it is a good idea to stay away from public places. Each student should be given an opportunity to navigate a brief flight and have an experience that is usually perceived by young people as attractive and enjoyable. If time allows, the students can also take aerial photos or make brief films (choose a good location for the flights with this prospect in view). Such pics can provide encouraging resources for continuation of the workshops or just excellent material for the closure of this learning pathway to be shared by the students via their social networks.

III. 3D printing in carpentry

3D printing has recently made its way into traditional artisanship, ranging from jewellery to furniture making. There are many reasons for this development. 3D tech makes it possible to design with much greater freedom than before, which helps artisans to prototype quickly and manufacture to a high standard. More complicated geometry and sculptural forms are now possible and products can be tailored to customers' tastes more easily. There is also the factor of cost-effectiveness as the cutting-edge technologies substantially reduce the time of prototyping. It thus makes sense to introduce students of traditional professions like carpentry into a new way of manufacturing that transforms the way new artisans work.

Learning outcomes

Because of the learning experience, the students will be able to:

- Explain how 3D technology is modernising the craftsmanship field
- Find and download furniture joints which can be 3D-printed
- Design a prototype of wooden spiral stairs
- Print the pieces and assemble the model
- Make the final wooden product

1. New artisans

In this session, the students gain an overview of how technology has been transforming handicrafts. A brief historical introduction is followed by presentations of various applications of 3D printing in modern crafts.

- **Advancements into modernity.** The purpose of this part is to help students realise the continuity of the craft modernisation process with the focus on recent developments. A good overview is presented in an online course on the ARTISAN youth project website https://www.youthart.eu/artisan/course/artisan-course. The advantage of the resource is that it can provide material for blended learning: an introduction made in class can be independently followed by the students online.

- **Jewellery prototyping.** In a traditional goldsmith's workshop, the whole process of producing a ring, from the preparation of the metal to the cleaning of the finished product, is done entirely by hand. With the use of 3D modelling and printing, the time needed to deliver the final object can be halved. Students compare the two processes on the basis of examples available at https://youthart.eu/3dlab/lp-courses/3d-lab-online-course/lessons/7-goldsmiths-art-iter-produce-of-a-florentine-style-ring-traditional-vs-3d-supported/

- **3D-printed models for ceramic molding.** In a modern ceramic workshop, molds are created with a 3D designed and printed model which speeds up the whole prototyping process. The model is properly coated to allow for producing multiple copies of the mold without the model wearing away or distorting as plaster or clay models tend to. The participants get acquainted with this new ceramic art making through a blog run by a young artisan from the UK http://jadecromptonceramics.blogspot.com

- **3D printing in furniture design.** This is a particularly interesting case for carpentry students as it exemplifies how tradition meets modernity in this craft sector. The students explore a chosen design of tables and chairs with 3D-printed joints, a solution that offers flexibility and cost-effectiveness to modernise furniture manufacturing https://vimeo.com/166923632

2. Introduction to TinkerCAD

TinkerCAD www.tinkercad.com is a simple, online 3D design and 3D printing app, which the students with basic digital skills can master easily. The programme has an intuitive interface and it is an excellent tool to foster three-dimensional thinking skills necessary to model physical objects. It is used by budding designers to prototype various objects, including DIY furniture. An important feature of TinkerCAD is that you can import STL files and then modify them. You can further export the files that are ready into a slicer program for 3D printing. TinkerCAD also has an excellent resource of tutorials at different levels and applicable in different areas of learning.

In this session, the students go through the following learning pathway.

- **Learning the basic functionalities of the programme.** This can be done with the support of one of the tutorials on the TinkerCAD portal. Students more versed in digital technology can directly proceed to designing simple 3D objects. At least the following basic functions should be mastered before moving to the following stage: placing a shape to add or remove material, moving, rotating and adjusting shapes freely in space, and grouping together shapes to create detailed models.
- **Selecting and downloading a furniture joint.** Yeggi database includes many furniture joint designs. An example part to begin with can be a joint for assembling a plywood box www.myminifactory.com/object/3d-print-plywood-box-joint-3mm-thick-31995. The students review the whole project and possibly identify weak parts of the construction. Then they download a set of joints for further elaboration in TinkerCAD.
- **Redesigning the joints.** E.g., an angle joint is rather weak to sustain a heavier load of items in the box. It can easily be made thicker and stronger. The students apply relevant improvements in the existing design.
- Comparison of projects. The modifications proposed by the students will certainly differ. The groups discuss their projects with the teacher and choose 2 - 3 best designs for printing.
- **Slicing the file for printing.** Once a 3D design is made, the file needs to be sent to a slicing software where it gets ready for the printer. The quality of the print will depend on the settings that are made here. Students learn the basic functions of the Cura slicing software https://ultimaker.com/software/ultimaker-cura while preparing their files for printing.
- **Printing the final objects.** Depending on the size of the objects, the time needed may go beyond the workshop. It is likely that the students will see their projects only at the next session. Then they should discuss the quality of the prints and usefulness of their designs for the whole construction. One model should be chosen for assembling a functional plywood box.

3. Prototyping wooden stairs

Students begin this session with basic knowledge and skills on how to design a simple shape in TinkerCAD. Now their task is to apply these competences in a project that relates to their vocational programme of training in carpentry - making wooden spiral stairs. Building a spiral staircase is more complicated than building a regular one, as it requires a precise layout of its dimensions as well as the size, shape and position of each step. 3D prototyping comes as an excellent method to visualise possible variations and to consider their advantages and disadvantages.

- **Planning the layout of the staircase.** Spiral staircases work best in tight spaces where there is not much foot traffic, such as room corners. Before the students get started on their project, they should consult local building codes, which may specify criteria about spiral staircases. Then they should decide where to fit the wooden stairs, what spatial dimension is available and what the exact parameters should be maintained (measure from floor to floor, optimal diameter, etc.).

- **Calculating the exact number and spacing of steps.** The amount of vertical distance between each step is a crucial factor in the whole construction, which has to be calculated together with the steps' thickness. These parameters have to be decided before proceeding to the next stage.

- **Designing steps and centre column.** Each step will have the same size so the students have to prototype just one item. In their TinkerCAD designs they need to set the steps' length, depth and thickness (how deep a step should be may be regulated by a national building code). Then they can model the steps with a hole at the narrow end for the centre connecting column. The shape of a typical stair is very simple so it provides an ideal project for beginners in 3D design. Similarly the column - a regular cylinder.

- **Slicing the file for printing.** Once the best design is chosen by the group the file needs to be sent to a slicing software where it gets ready for the printer. Students consolidate knowledge gained in the previous session while preparing their files for printing. In that way they get a deeper understanding of the whole process from the TinkerCAD design to producing a physical prototype.

- **Printing components of the model.** For the visualisation of the whole project the steps can be small, still the time needed to print all of them may go beyond the workshop. It is a good idea to let the students print at least one item so that they can follow the whole process to the end. The rest can be printed after the workshop at occasions where there is someone in the lab to monitor progress of printing.

- **Assembling a model of spiral steps.** The construction is easy to put together if all its elements are designed properly. Some adjustments may be needed: for example, the centre column may be too loose to hold the steps tightly. In such cases, the students can easily adjust the respective parameters in TinkerCAD and print the files again. The final result is a physical model visualising all the details of the construction.

4. Making wooden steps for a spiral staircase

This scenario is written for a situation when the students already have an opening ready for the stairs to be installed, either in a real setting (e.g. a house or an apartment) or in a simulation environment (e.g. school carpentry workshop). All the measuring of the staircase space, which is an essential phase of the construction process, has already been done. Now the students proceed from the 3D printed model to the actual realisation of their project.

- **Choosing material.** The students choose appropriate type of hard wood for the steps as well as metal cylinders for the centre column and step bases. The metal parts can be later covered with wood veneers if this was planned in the project.
- **Cutting steps.** The challenge is to proportionally recreate the dimensions of the model in the wooden material. This provides a good exercise in measuring skills essential to make all the parts fit and hold together.
- **Finishing the elements.** Polishing and painting
- **Assembling the construction and fitting into the staircase.** Due to a carefully designed model, the actual stairs should perfectly fit the opening and provide a comfortable walk up to the next floor.

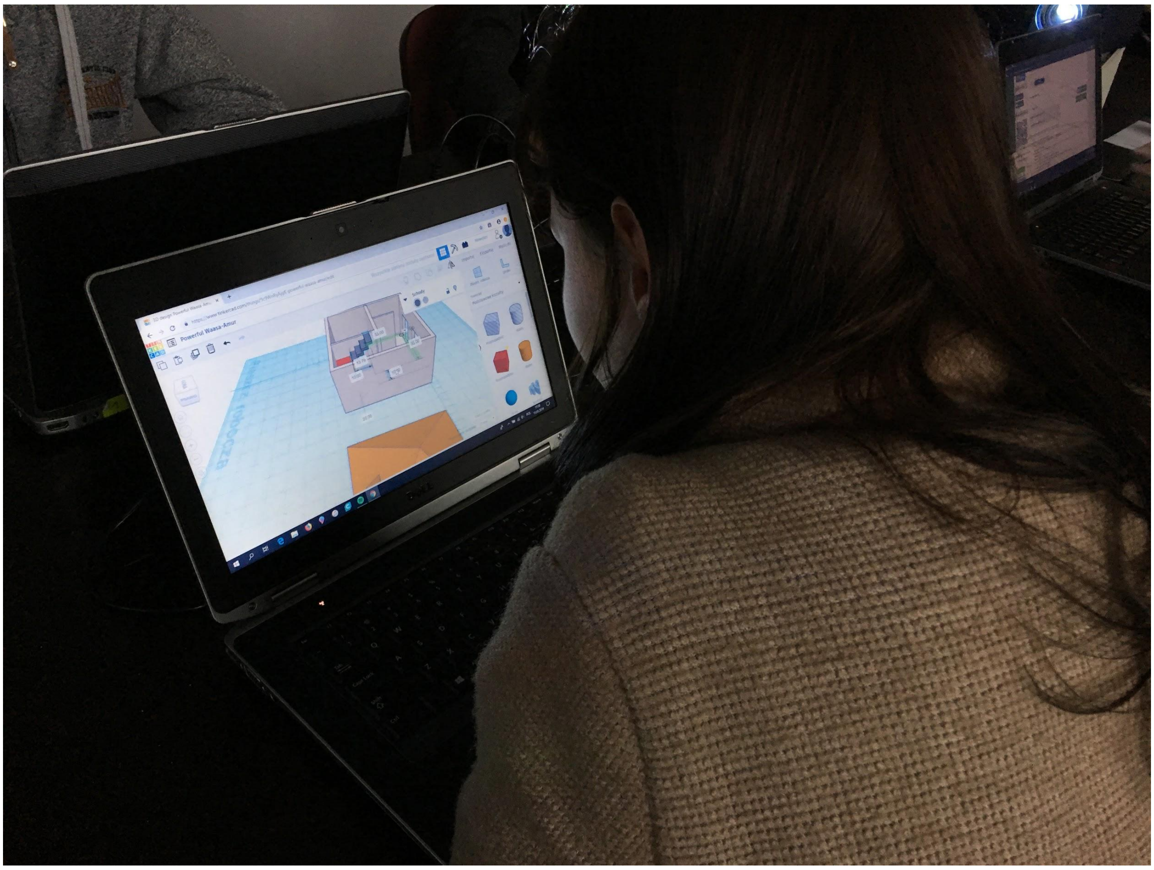
IV. 3D printing in building construction

Architects and other professionals in building construction are increasingly using 3D printers to produce physical, highly detailed architectural models. With 3D prototyping technology, they can create simple and complex structural models significantly reducing the time needed to visualise connections between structural features in multiple configurations and how the core structural elements work together. In this learning scenario students of building construction at initial VET level explore the usefulness of the technology in designing and testing trusses widely used in various constructions.

Learning outcomes

Because of the learning experience, the students will be able to:

- Explain how 3D technology is modernising the field of building construction
- Find and print example truss models for various purposes
- Design a prototype of a simple truss bridge
- Print the bridge pieces and assemble the model
- Test the bridge parameters in a simulation setting



1. The new look of architecture

In this session, the students gain an overview of how 3D technology has been transforming architectural design and building construction. This is done through exemplifying various cases of applications of the technology ranging from pitching design work to printing whole buildings.

- **Showcasing design ideas.** With 3D-printed tangible models that present precise building or construction site information architects can visualise their ideas and present them to clients. In the highly competitive industry, a vivid presentation of an architectural project helps to win more business. Students explore and compare particular cases of such an approach through the resources available at https://hobs3d.com/services/architectural-model-making

- **3D printing of construction elements.** Complex formwork elements can be produced using 3D printers. A number of companies around the world have started testing a wide range of possible applications of printing with concrete and other materials for various architectural projects. In particular, there is an interest in developing constructions with internal components that are light, stiff and strong. The students are acquainted with these new developments through resources published on relevant sites, e.g. https://www.voxeljet.com/industries/construction-and-architectural-design, https://pro3dcomposites.com/new-look-architecture-3d-printed-lattices.

- **3D-printed buildings.** To construct homes or commercial buildings using 3D printing is starting to become a real possibility. Structures can be built with super-sized printers using special cement mixtures that are thicker than concrete so there is no need for support beams. Students explore various examples of 3D-printed houses showcased at www.dezeen.com/tag/3d-printed-houses and discuss pros (lower construction costs, reduced construction waste, increased design shapes, etc.) and cons (lack of building codes, limited materials that can be used, etc.).

2. Understanding trusses

A truss is a triangulated system of straight interconnected structural elements. Trusses are commonly used in buildings mainly where there is a requirement to support very long spans, such as in large roofs (e.g. in airport terminals, industrial buildings, etc.) serving two main functions: to carry the roof load and to provide horizontal stability. The students at the initial VET level of building construction already have basic knowledge of geometry (properties of triangles and polygons) and have started learning truss construction at school. In this workshop, they consolidate and further develop their understanding of how trusses work through experimenting with 3D-printed models.

- **Finding and downloading a truss model.** Yeggi database includes a wide selection of truss models (www.yeggi.com/q/truss). All the files come with descriptions and notes on their use. This material is an excellent opportunity to consolidate knowledge on truss construction and parameters. The students should work in smaller groups, each choosing a truss that can be easily printed in the lab for testing.

- **Redesigning the chosen trusses**. Using TinkerCAD or similar software the students have a task to apply changes in the downloaded projects that will simplify the constructions but not negatively affect their performance (stiffness, stability, resistance to load, etc.). Each group previews possible effects of these changes before the tests. Then both the original and modified models are printed from each group (this will certainly take time beyond the workshop that should be planned in advance).

- **Truss design challenge experiment**. With all the models printed, the students engage in a mini-lab structural engineering test on how strong the individual constructions are. They apply different loads to their constructions and monitor the effects. It is likely that most of the modified trusses prove weaker to the original designs. A modification not affecting the strength of its original model will practically document a good understanding of the truss geometry and properties.

3. Designing a truss bridge

Truss bridges are constructions characterised by joining numerous small structural members into a series of interconnected triangles. Its elements/units are connected through compression, tension or both. Due to their unique structure, which allows for an efficient use of materials they are very economical. As such, truss bridges are an excellent case for learning core principles of building construction. In this workshop students face a task to design and print a bridge prototype connecting two sides of a river flowing through their town.

- **Introduction to truss bridges.** There are many designs used for constructing truss bridges. Through exploring and comparing different types (Howe, Pratt, Pennsylvania, Baltimore, etc.) the students choose the constructions that fit the specific needs of the local topography. It is a good idea to elicit at least 2 - 3 different constructions for elaboration in smaller groups. There are many useful portals providing an overview of truss bridge types and designs, e.g. https://sciencestruck.com/truss-bridge-design

- **Digital modelling of a truss bridge.** The students are introduced to an engineering software for truss designing (such as https://trusstool.com or https://skyciv.com depending on their level). In each subgroup, they model a simple bridge, mapping its dimensions, creating nodes, adding members, applying loads and analysing its performance. As a result, they should arrive at 3D models of their bridges that can be prototyped on a printer.

- **Creating elements of the bridge model.** The prototype will be constructed of metal struts and plastic connectors. Each group will be provided with a supply of aluminium rods, which can be easily cut to form the struts of correct length. The connectors will have to be designed by the students using TinkerCAD. They start with examples available at www.yeggi.com/q/truss+connectors and modify them for their own bridge projects.

- **Assembling the whole construction.** When all the elements are ready, they should be assembled into a bridge model. Some adjustments of the components will probably be needed as connectors may be too loose or tight for the struts or their angles not designed properly. Depending on the results, the workshop can be extended into another session/s.

4. Testing performance of the model bridges

This workshop offers a learning path combining maths, engineering, design and architecture. Depending on particular interests and available time, the assembled bridge models can provide a resource for going deeper into one of these fields or even further exploring the whole spectrum of themes.

- **Maths.** With the models printed out the students will be able to verify their calculations done in https://trusstool.com or https://skyciv.com and investigate properties of various triangular configurations.

- **Engineering.** Truss bridge models are a particularly interesting case of structural engineering. Physical models will provide an opportunity for testing the different truss bridge constructions. This can be done as a competition between the subgroups. Each group should set up their bridge across a gap. Then they gradually apply weights until the bridge collapses. The winning model is the one able to withstand the largest amount of weight. A number of questions arise: Why a given bridge fail where it did? What restricted it from holding more weight? How could its design be improved?

- **Design.** Skills in this area can be further practiced in a number of ways: redesigning the original project based on the test results or designing a new construction with a different type of truss, improving the connectors to make the model stronger, etc.

- **Architecture.** In this scenario, the students were given a task to prototype a bridge over a river in a specific spot in their town. They can further make a 3D-printed model of the whole area to show how their project fits the existing environment. This is obviously a very demanding project but as such, it can engage students that are more ambitious in follow-up extracurricular activities.

Chapter Three: Towards connectivity of things

The workshop scenarios presented in this chapter were brought together by the Computer Technology Institute "Diophantus", which is an institute supervised by the Greek Ministry of Education as the technological pillar supporting ICT in education and as the publishing body of Greek school books and electronic educational materials.

According to the "Cedefop Survey on Vocational Education and Training in Europe" (2018) the educational system in Greece is significantly constructed on an educational programme that heads to tertiary education, while VET often represents a less appealing and relatively weak component. In the past, vocational learning mainly took place during the job and was achieved in non-formal and informal settings. Recent VET reforms aim at addressing some of the education and training challenges such as improving VET's ability to smooth the transition from education to the labour market, modernizing VET, providing better practical skills to improve the relevance of VET and creating a positive culture for VET. The main reasons for the lack of social acceptance and attractiveness of VET are the following:

- perceptions related to weaker school performance for those attending vocational schools
- lower parental educational level;
- limited possibilities for social mobility as rates of successful entrance to higher education are restricted, and
- gender orientation of pupils in vocational training which favors boys. These features are reproduced over time, being responsible for relevant perception and attitude related to VET.

The aim of the scenarios outlined in this chapter is precisely to follow up on one of the already implemented actions of the Greek National Strategic Framework for VET, namely to focus on linking formal and informal education through new specializations and curriculum. These scenarios have not been designed to become presential workshops, but have been implemented in the form of online courses, which can be applied in other settings where there is a need to enrich the formal school programme with an introduction to IoT. The modular format of the online course, as well as the self-paced structure, makes it ideal for students who wish to enhance their learning through extracurricular programmes, especially if they come from remote areas in Greece.

As for the implementation of the online course, it was presented by the teachers collaborating with CTI in VET schools (EPAL) in Patra, Mesologgi and Argos and the students could follow up at their own pace outside of school. Teachers from the 1st Laboratory Center – Professional High School of Patras and Experimental High School of Laggouras, Patras also implemented certain activities in class with their students.

Chapter Three is based on and inspired by the educational materials created in the context of three successful projects. The first one is named GAIA (http://gaia-project.eu/index.php/en/about-gaia/), whose goal was to increase awareness about energy savings and sustainability, based on real-world sensor data produced in buildings, while also lead towards behavior change in terms of energy efficiency. In order to achieve this goal, GAIA produced material for makers who would like to experiment with IoT hardware and software in the context of energy and sustainability. The focus of the material is to familiarize students with concepts related to energy consumption, sustainability and building monitoring, using popular IoT technologies. The second project called "Introduction to Arduino" was carried out at the University of Patras, Department of Science of Materials, led by Mariangela Komninou. Within the framework of this project a guide for the use of Arduinos and IoT was created for use by Greek schools. The chapter on IoT in Agriculture and Precision Farming is based on the results of the project SKIFF: Skills for Future Farmers http://future-farmer.eu/ which is especially useful for the VET students in Agriculture programs. Even though the technology described is not so effective for small scale farms, it is important to raise awareness on the benefits of this technology.

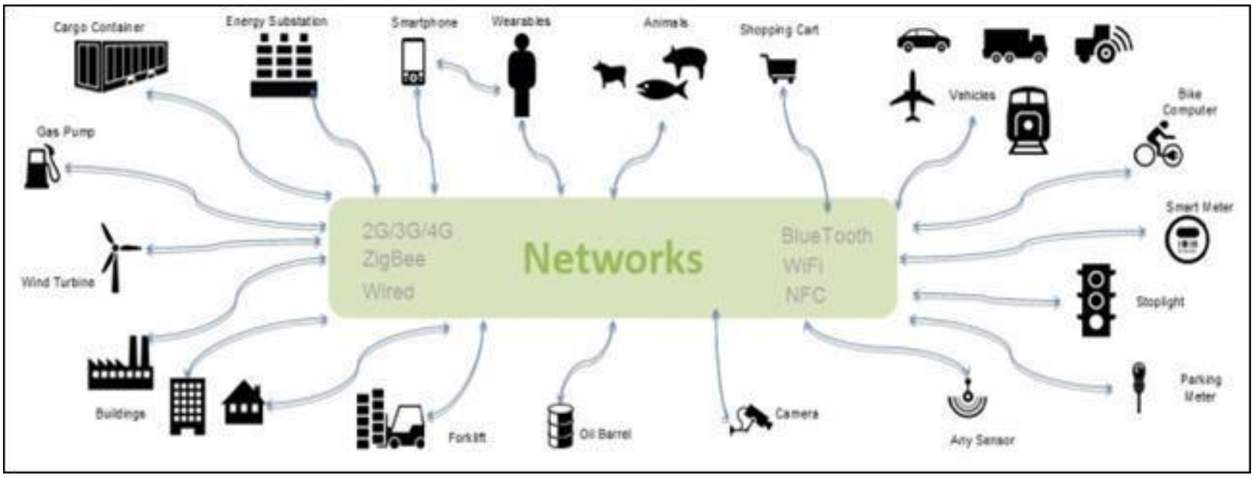
This flexibility is what made this material perfect for adaptation for VET schools. The adapted material presented in these chapters aims to acquaint VET students with the technology behind "intelligent spaces and precision farming. The learning programmes focus on Arduino technology for introducing basic skills in handling microcontrollers used in various smart interactive devices, on the one hand and drones in agriculture, on the other.

I. Introduction to the Internet of Things

Learning outcomes

After this section, the students will be able to:

- understand the basic concepts and applications related with the Internet of Things
- identify the main IoT networks types
- identify basic electronics components
- recognize additional electronics components used in IoT applications



1. What is the IoT?

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction (Wikipedia). One of its applications is the Smart Home, where IoT devices are a part of the larger concept of home automation, which can include lighting, heating and air conditioning, media and security systems. Long-term benefits could include energy savings by automatically ensuring lights and electronics are turned off. Other fields of applications are: Medical and healthcare, Transportation, Vehicle-to-everything communications, Building and home automation Industrial applications (including Manufacturing and Agriculture), as well as Infrastructure applications (Metropolitan scale deployments, Energy management and Environmental monitoring) and Military Applications (Internet of Battlefield Things and Ocean of Things).

As mentioned above, the Internet of Things is a network of physical objects or things. They use embedded electronics to inter exchange data with other devices or machines typically the type of communication between devices has some constraints about the transfer rate, mostly due to power consumption constraints. As a consequence, there are specialized protocols to transfer data between two machines in IoT applications. An IoT device can log, collect data, and communicate with other devices or machines or to remotely control physical variables. We use them to analyze and visualize data which is published, in some cases, in the cloud, in specialized servers that accept this type of data. It can be argued that IoT devices are just smart devices, in other words, embedded electronic devices that can connect to other devices through ethernet, Wi-Fi Bluetooth and many other technologies. One of the main differences between IoT devices and classic smart devices used in the industry is that IoT devices are power efficient and that they use wireless connections to transfer data to other machines which can be several kilometers apart.

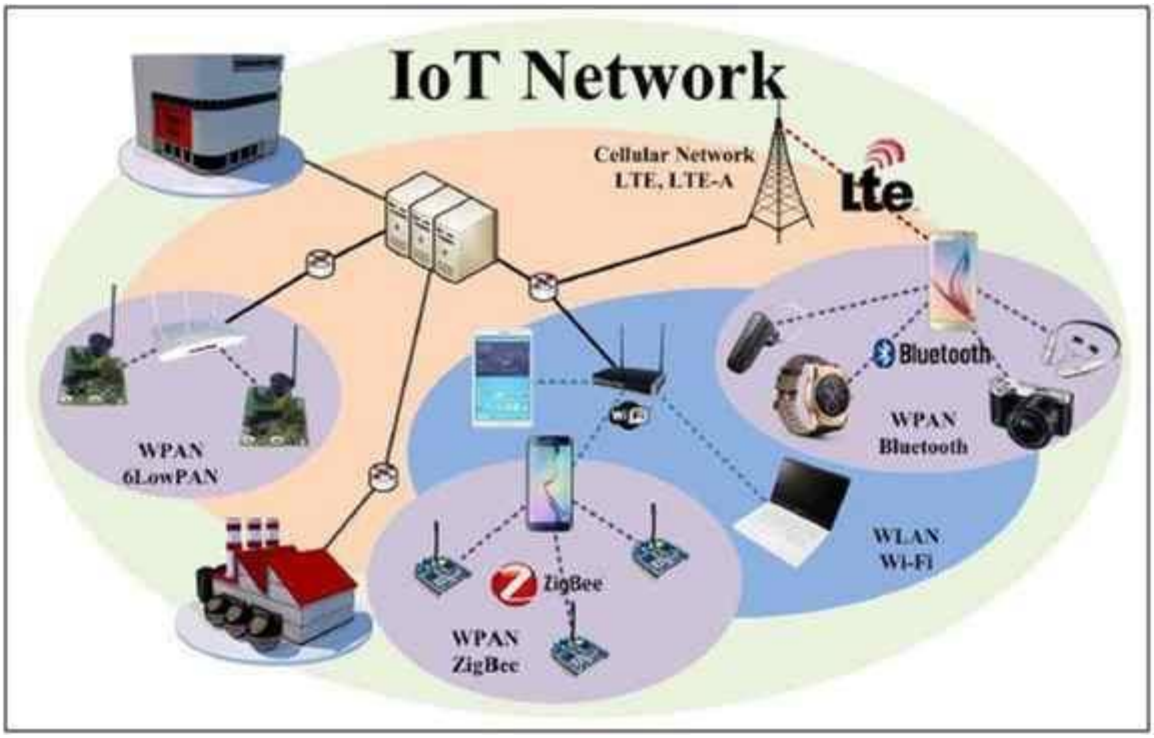
The Internet of Things is considered as the next big technology revolution after the invention of the Internet. It is supposed to make tremendous impacts on lives and may possibly lead to the improvement of millions of lives throughout the world. According to Cisco, over 50 million devices are expected to be connected to IoT by 2020.

IoT is influencing our lifestyle from the way we react to the way we behave. From air conditioners that you can control with your smartphone to Smart Cars providing the shortest route or your Smartwatch, which is tracking your daily activities. IoT is a giant network with connected devices. These devices gather and share data about how they are used and the environment in which they are operated. It's all done using sensors, sensors are embedded in every physical device. It can be your mobile phone, electrical appliances, Pecos barcode sensors, traffic lights and almost everything that you come across in day-to-day life. These sensors continuously emit data about the working state of the devices, but the important question is how do they share this huge amount of data, and how do we put this data to our benefit. IoT provides a common platform for all these devices to dump their data, and a Common language for all the devices to communicate with each other. Data is emitted from various sensors and sent to IoT platform. Finally, the result is shared with other devices for better user experience.

We have Smart appliances, Smart Cars, Smart Homes, smart Cities, where IoT is redefining our lifestyle and transforming the way we interact with Technologies. The future of the IoT industry is huge. Business Insider intelligence estimates that 24 billion IoT devices will be installed by 2020 and ITC predicts that IoT Revenue will reach around three hundred and fifty seven billion in 2019 resulting in a lot of job opportunities in the IT industry.

For some examples, can also watch this video: https://youtu.be/QSIPNhOiMoE

IoT devices typically use wireless networks to transmit data. Depending on the application the distance between the transmitter and receiver the networks can be significantly different and they can make use of wire infrastructure tools. In an IoT network we can find a WAN, a wide area network which transmits data at large ranges using Ethernet or a cellular network; or for medium ranges we use a WLAN, a local network. For short ranges, generally oriented for applications between two machines, we can use a WPAN, a personal network. We can use a Wi-Fi connection to access external services through our router for WAN connections or to act as a web server in a WLAN, so that it interacts with another device to visualize data, for instance. Or we can use WPAN networks such as bluetooth connection between our smartphone and our IoT device.



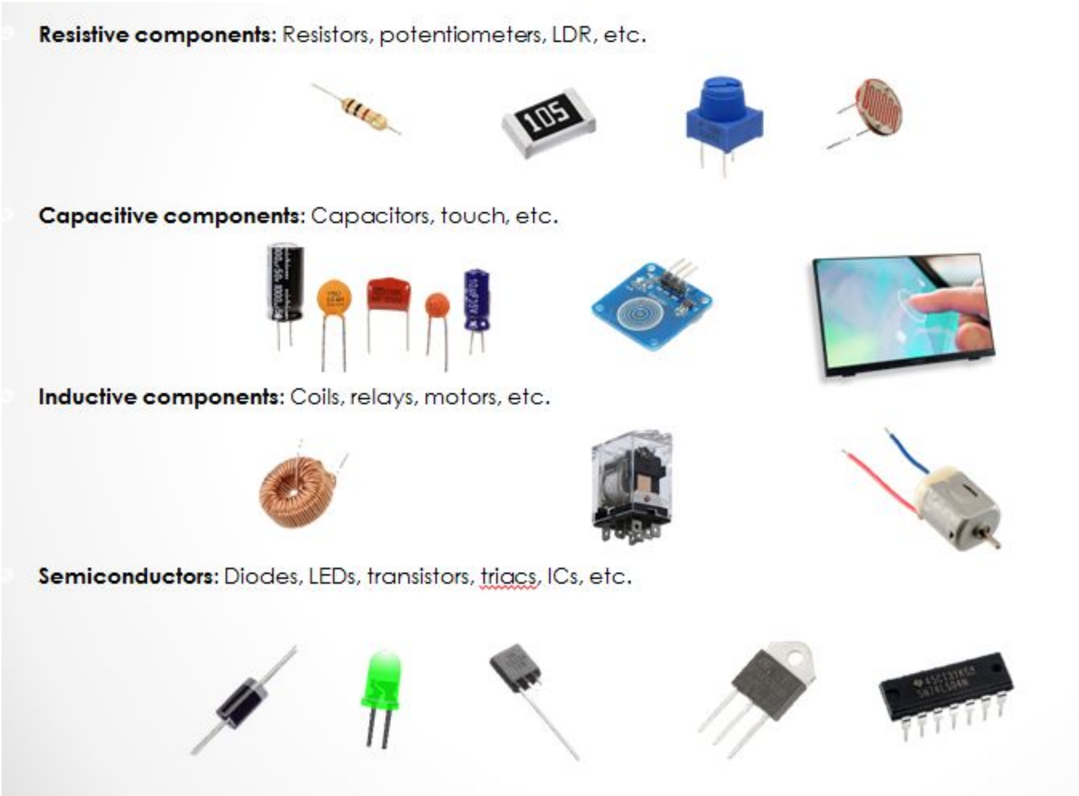
When IoT devices transmit data to an external server, these data can be visualized through services supporting all transmission protocols used in IoT applications such as MQTT or HTTP. One such platform is Thingsboard, which is an open-source server-side platform that allows you to monitor and control your IoT devices. It is free for both personal and commercial usage and you can deploy it anywhere. In any case, all platforms typically offer features for storing and visualizing data, creating a dashboard to manage your devices and many other services, such as management, security, whole integration, etc.

Sources used in this section:

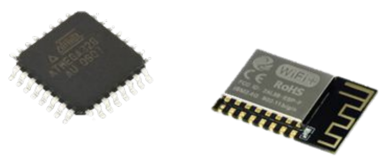
- https://www.c-sharpcorner.com/UploadFile/f88748/internet-of-things-iot-an-introduction/
- https://www.edx.org/course/introduction-to-the-internet-of-things
- https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT

2. Electronics basics

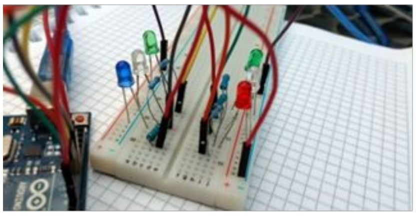
The electronics components used in IoT applications can be categorized in the following types:



The main component in a circuit is the **microcontroller**, the brain of our smart device. It's a programmable device, which means that we can upload code with a specific logic. The microcontroller should respond to the signals according to the code.

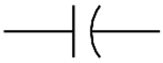


The **breadboard** is a board with all the necessary components to make an experimental model of a circuit. We can also have **shields** and modules which are special boards that are ready-to-use and contain all necessary components to test a specific electronic component, for example a microcontroller or any other sensor.



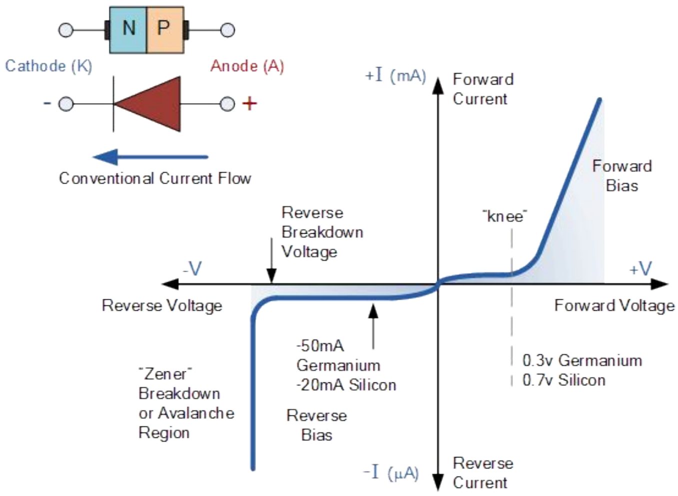
In order to provide appropriate power for these electronic circuits we have two main power supplies: **the alternating current AC** and the **direct current DC**. The Alternating current is the home power we normally use for most of our appliances. Its magnitude and the direction varies. The main advantage is that it's easy to transport without significant losses. On the other hand, the direct current DC offers constant magnitude and direction. The main advantage DC has is that it is easy to work with, and there are different kinds of power generating sources, like photovoltaic, chemical or electrical. These the main ones we use in our circuits, e.g. solar panels or batteries or just our home power. Of course, there are other power generating sources like fuel, geothermal, and nuclear, wind, etc.

A **resistor** is basically found in every circuit and it's used to limit the current on a specific branch of that circuit or to adapt the voltage. The main characteristic of a resistor is that it follows the Ohm's law which relates the resistance, the voltage and intensity and it's measured in Ohms. 

A **capacitor** is used to store energy and they are highly used in our circuits because they can be used as filters but they are mostly used also to provide current peaks in our devices. Because they store this energy, they can then release it easily. In direct current the capacitor simply behaves like an open circuit. 

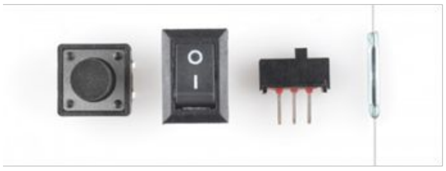
Coils are used to generate an electromotive force due to a change of the flow of current. Also used as filters coils are just they can generate an electromotive force on this is due to the change of flow of current so these forces are used to attract things like a magnet and it behaves like a wire if we work in dc current. 

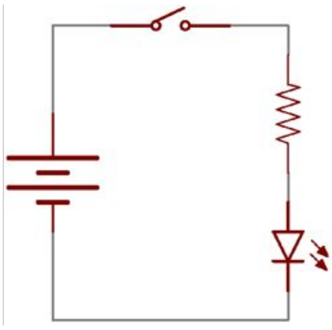
Diodes are the most basic semiconductor type and they are made from the union of n-type and p-type semiconductors. The main characteristic of a diode is that the current only flows in one direction so we have to properly polarize the diode in order to drive the current. There's a special kind of diode which is called Zener which is used for voltage stabilization. The most common use for diodes is to allow or block the current.



Transistors are also made from semiconductor materials that can be used for amplifying signals or for switching applications like allowing or not allowing the current to flow. Amplifier: A tiny current on one lead produces a larger current at the other leads. Switch: A small current through on one lead makes the current flow on the two other leads.

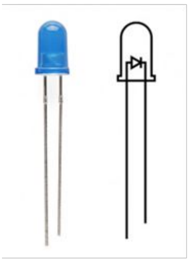
Push buttons and **switches are** used in many kinds of devices and machines so we are used to interacting with them. The user pushes or switches a plunger in order to open or close a circuit. There are different kinds of push buttons or switches depending on the number of poles.

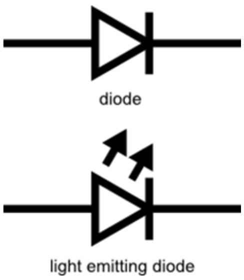


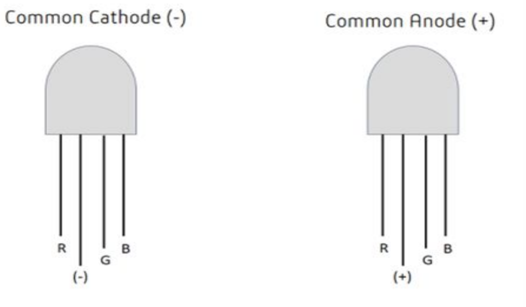


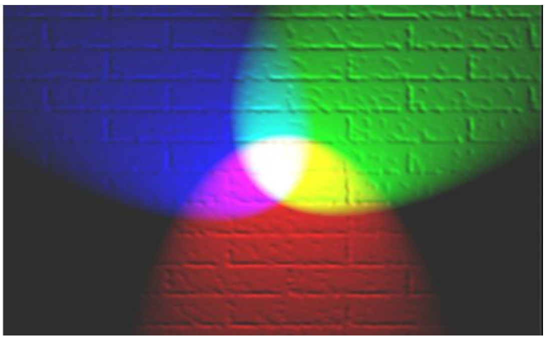
A **Potentiometer** is a resistor of three pins. The third pin is a variable resistor and it can be rotary or linear. We can vary the amount of resistor or between two of the terminals on they can be used for instance as a voltage divider so they can provide us a signal that varies between two different ranges.

A **LED** is a type of diode that emits light and can be of different kinds of colors, shapes and sizes. We normally use them in machines and processes to indicate their state: for example, if they are blinking there's an error or if it is green the state is correct, and red is wrong. The polarity in LEDs is important for driving the current properly. RGB LEDs are a composition of three LEDs (red, green and blue), and they can generate light by combining colors to generate other ones. They have four pins: one for each color and a common pin.

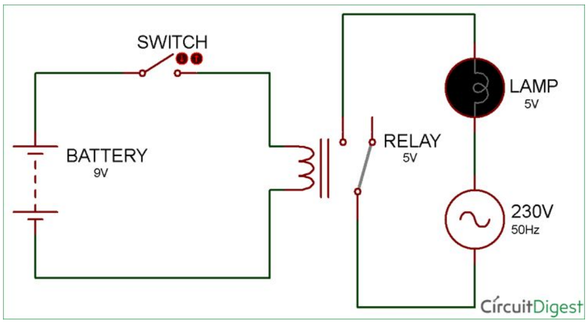








Finally, we have the **relays** which are switches that can be electrically activated or deactivated. A change in the current of a relay's input generates a magnetic field with a coil that attracts a mechanical switch. Mechanical relays are able to handle high current switches (from 2A to 15A), but they degrade over time.



https://learn.sparkfun.com/tutorials/light-emitting-diodes-leds/all

There are additional components often used in IoT applications, found in the following table:

Temperature/Humidity sensor 	**What it does** Measures the temperature and humidity of environment **How to recognize it** It is a white box with holes	**Number of pins** 3 **Note** There is one less accurate and it is blue
Screen 	**What it does** Shows two lines of characters and numbers so that we can see the measurements **How to recognize it** It is a rectangle screen on a board	**Number of pins** 16 **Note** Some come with a back lighting and others not. There are TFT screens (touch or not) of various sizes that can show graphics or more characters

WiFi 	**What it does** Connects with with an access point and with the internet **How to recognize it** It has a zig zag line, which is it’s antenna	**Number of pins** 24 **Note** There are different versions with different features. Special knowledge of programming and networks are required.
Carbon monoxide sensor MQ7 	**What it does** It detects carbon monoxide **How to recognize it** Through the sign “MQ-7”	**Number of pins** 6 **Note** The Pins need to be connected
Smoke sensor MQ2 	**What it does** It detects flammable gases (methane, butane, LPG, smoke) **How to recognize it** Through the sign MQ-2	**Number of pins** 4 **Note** Some have a variable resistor with potentiometer to adjust its sensitivity

II. Introduction to Arduino

1. What is Arduino?

Learning outcomes

After this section, learners will be able to:

- Define Arduino
- Understand its development
- Know about its possible applications

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike.

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide.

Arduino IDE, Integrated Development Environment, is the software used in order to program Arduino, but it can also be used to program third-party hardware like ESP32. It is a lightweight application and cross-platform, it allows installing or managing boards and has a full, integrated set of libraries with a large number of features. It's very easy to use because the user simply has a 'setup' function and a 'loop' function where the code is placed. The user can verify, upload and save the code, create new files and dispose of a monitor. In 'tools' [menu], we can select the board, the port, etc.

2. Why Arduino and how do I use it?

Learning outcomes

After this section, learners will be able to:

- Understand the usefulness of Arduino
- Identify its main advantages
- Find guides and resources for learning how to use the Arduino platform

Thanks to its simple and accessible user experience, Arduino has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles, or to get started with programming and robotics. Designers and architects build interactive prototypes, musicians and artists use it for installations and to experiment with new musical instruments. Makers, of course, use it to build many of the projects exhibited at the Maker Faire, for example. Arduino is a key tool to learn new things. Anyone - children, hobbyists, artists, programmers - can start tinkering just following the step by step instructions of a kit, or sharing ideas online with other members of the Arduino community.

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handyboard, and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

- Inexpensive - Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than $50

- Cross-platform - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.

- Simple, clear programming environment - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.

- Open source and extensible software - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to.

- Open source and extensible hardware - The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

To learn how to use Arduino see the getting started guide. If you are looking for inspiration you can find a great variety of Tutorials on Arduino Project Hub.

3. Programming environment Arduino IDE

Learning outcomes

After this section, learners will be able to:

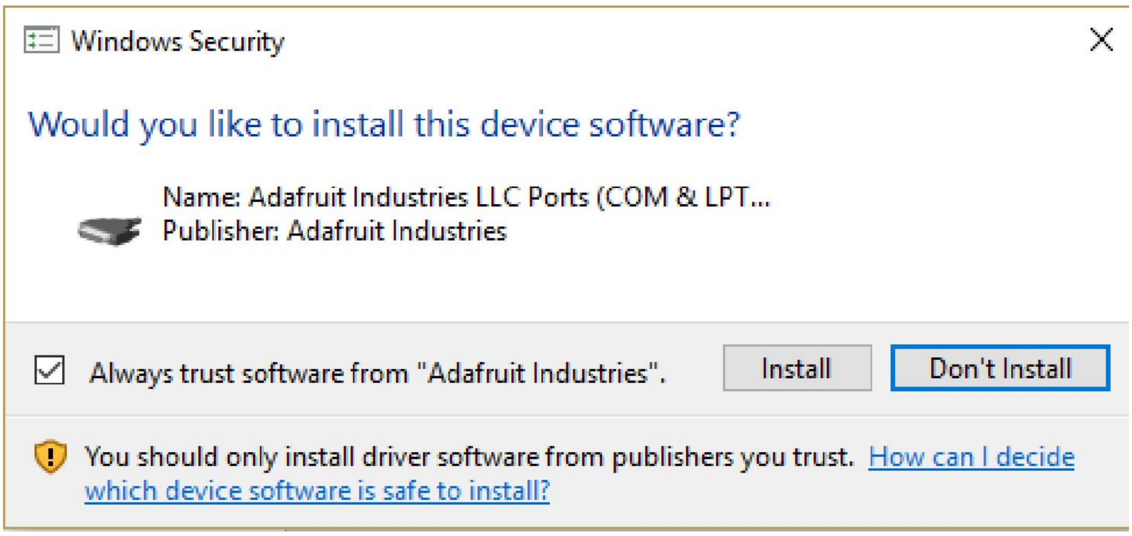
- Download and run the software Arduino IDE

The programming environment commonly used for Arduino is available for free from the website https://www.arduino.cc/en/Main/Software and is suitable for Windows, Mac OS X and Linux operating systems. The installation for Windows operating system environment is done with the following steps:

- Step 1. "Download" the software for our operating system from https://www.arduino.cc/en/Main/Software from the Windows Installer link

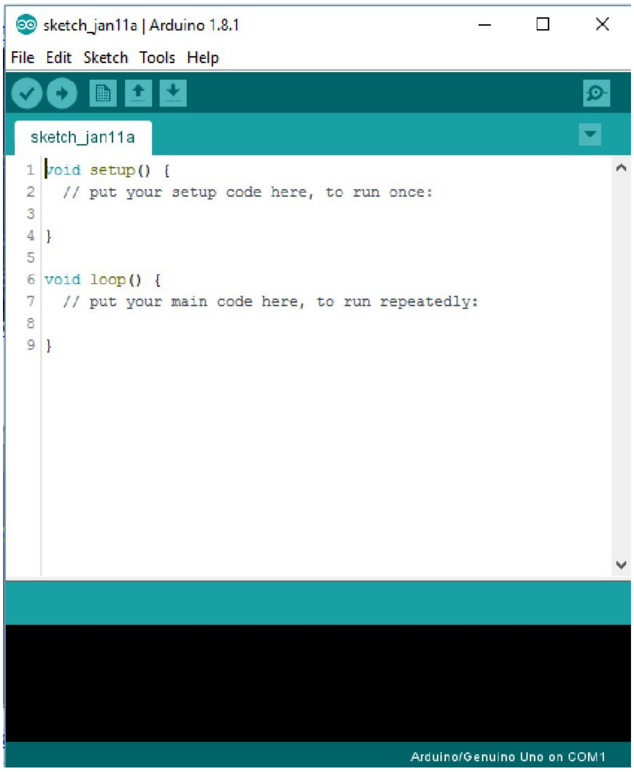
- Step 2 .We run the Arduino-rr-windows.exe file that we just downloaded (rr) is the current version e.g. 1.8.1)

- Step 3. We confirm that we will install the guides for the serial ports and the USB ports.

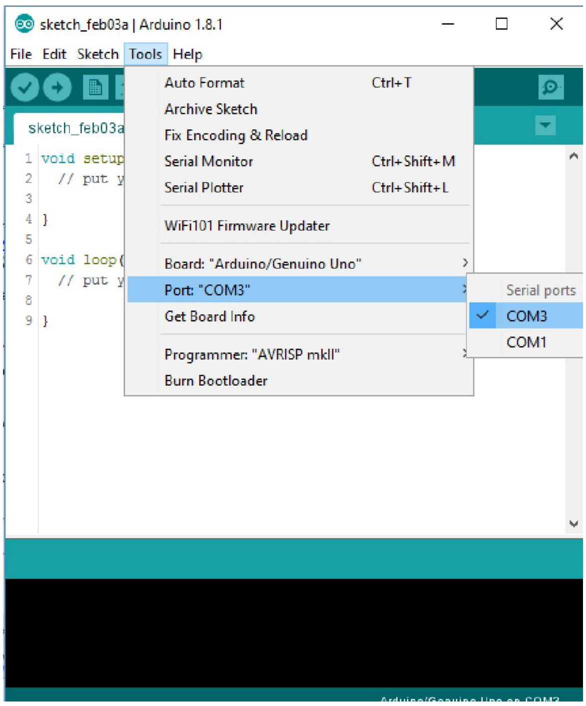


- Step 4. Execute the shortcut created on the desktop

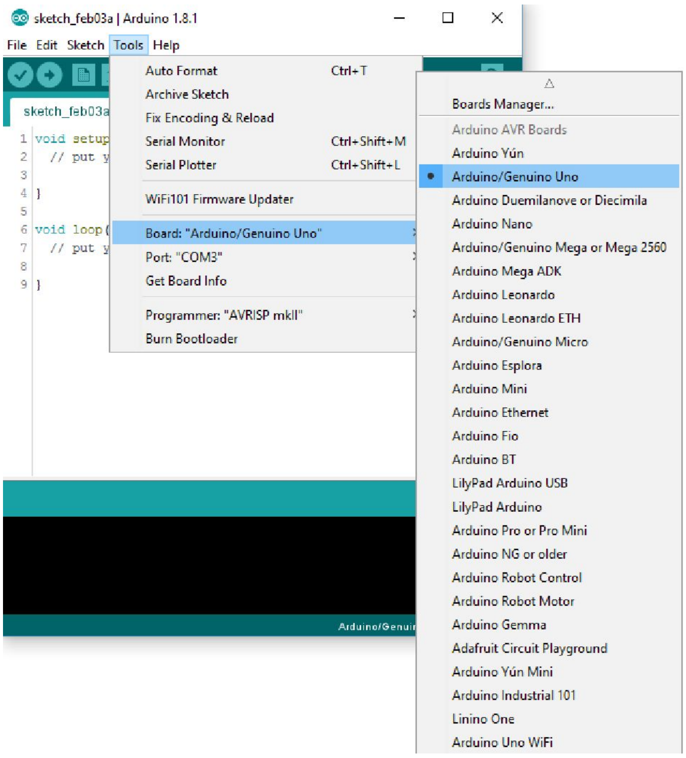
- Step 5. Connect the Arduino board via the USB cable to the computer and the new add-on window appears and look for the appropriate drivers in path C:\Program Files (x86)\Arduino\drivers



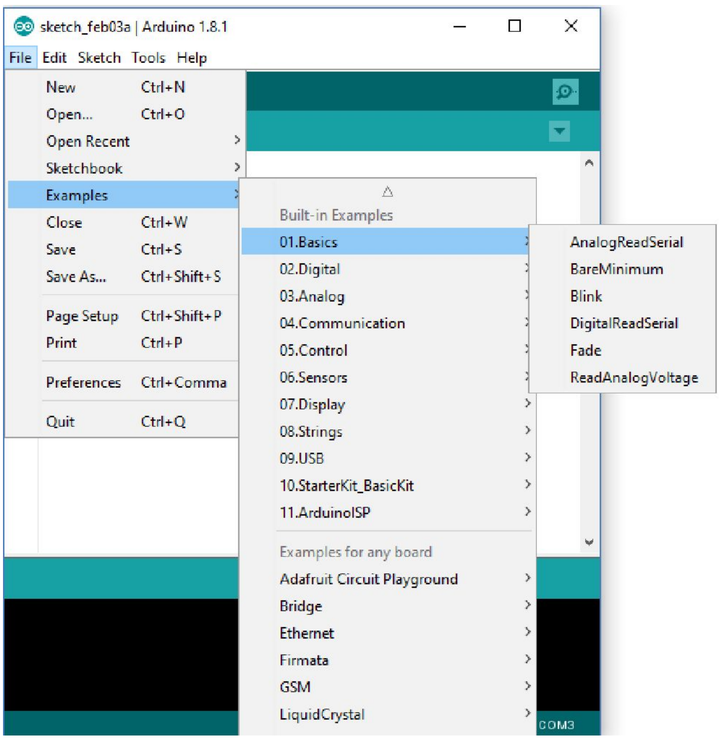
- Step 6. After connecting the Arduino board to the computer's USB and starting the Arduino IDE we select in the Tools-Port the new serial port that has appeared e.g. COM3



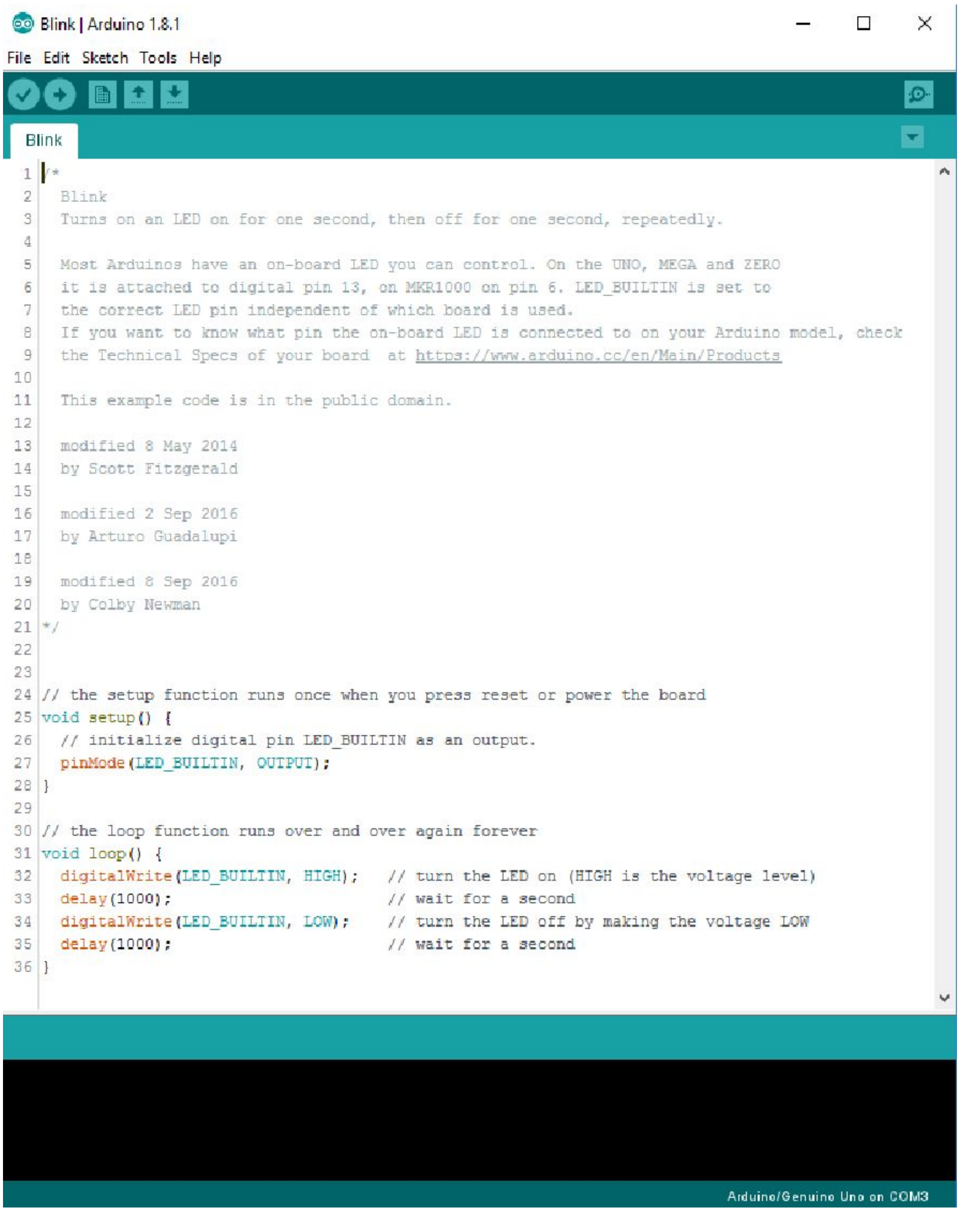
- Step 7. Select the type of Arduino board that we have at our disposal from the Tools-Board



In the programming environment there are several ready-made examples with comments in the code that we can choose from File-Examples. For example in Examples-01.Basics we can select the example Blink.



The example in the following Figure has been selected by the Basic Examples group. It contains ready-made code with comments. To run the program, first press the button to check for errors and compile it in a language understood by the Arduino processor and then the next button to load the program in Arduino memory and start running. When this is done, we see the LED flashing.



4. Other Environments

Learning outcomes

After this section, learners will be able to:

- find information about other programming environments

Programming Environments

- PlatformIO IDE http://platformio.org/platformio-ide

Based on Scratch

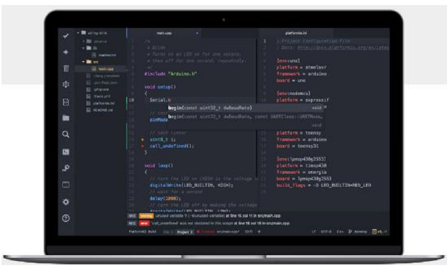
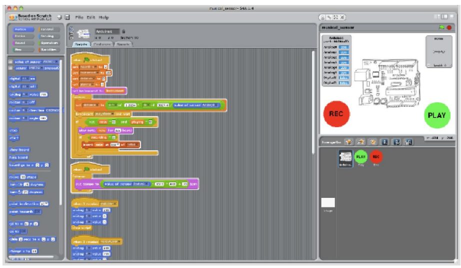
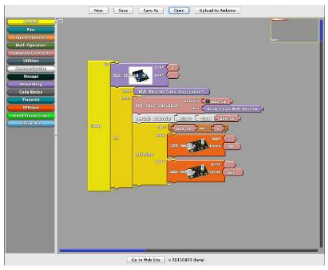
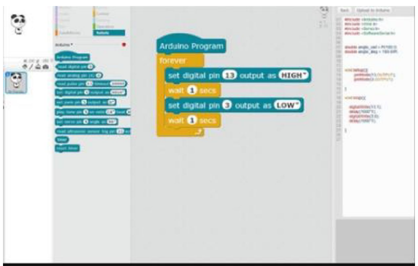
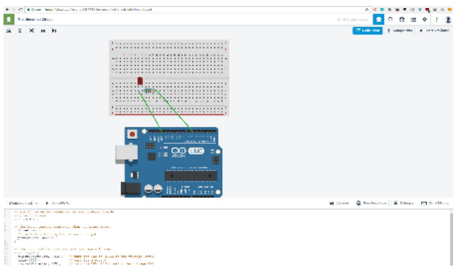
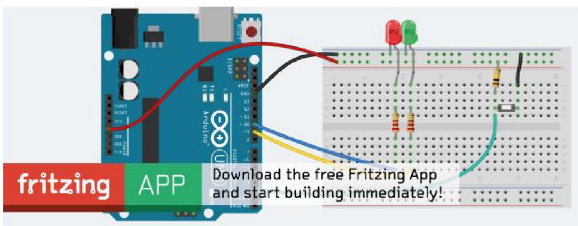
- S4A http://s4a.cat/
- Ardublock https://sourceforge.net/projects/ardublock/?source=navbar
- mBlock http://www.mblock.cc/
- Minibloq http://blog.minibloq.org/p/download.html

Simulator

- Autodesk Circuits https://circuits.io

Design

- Fritzing http://fritzing.org/home/ https://www.arduino.cc/en/Main/Software

5. Communication between the user and Arduino

Learning outcomes

After this section, learners will be able to:
- Identify the uses of screens
- Learn about the different types of screens

In the C programming language the communication between the program and the user is done mainly by printing variable values on the screen with the printf function and reading values from the keyboard (with display on the screen) with the scanf function. In Arduino, however, there is no screen or keyboard, so a basic and simple way to communicate with Arduino is through the use of LEDs, which light up when a condition applies, with any feedback required only with switches and potentiometers. However, this is not enough if more information is needed such as e.g. when it is necessary to capture the temperature and humidity measured by a sensor. In this case, more information is required to use the serial port for communication with the computer. Of course, there are cases where different types of screens are used, such as liquid crystals for displaying 2 lines and 16 characters (LCD 2x16), TFT screens of various sizes with the ability to display graphics and the ability to enter feedback with contact screens (TFT touch). Also in some cases an accessory is used that connects to the Internet in Arduino either wireless (WIFI ESP8266) or wired (Ethernet shield). Both the Arduino screen connection and the creation of an Internet connection via wireless or wired connection require a lot of programming knowledge, electronics (several connections are required) and TCP / IP protocol knowledge. We will then use the two-way user-program communication in Arduino the serial port that connects to the computer via the USB port.

III. Agricultural application of IoT

Learning Outcomes

After this section, learners will be able to:

- communicate via a mobile phone with Arduino in order to make a measurement of soil moisture
- activate the irrigation system

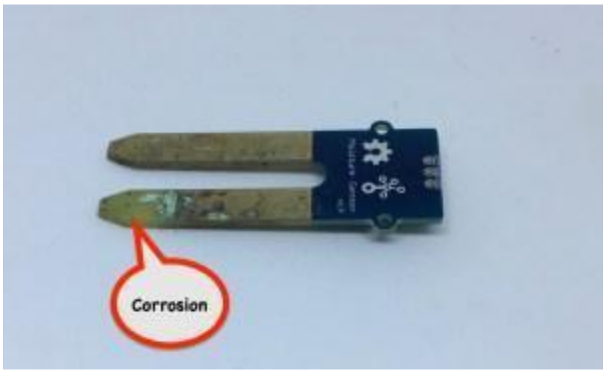
The purpose of this application is to communicate via a mobile phone with the system we have created and which only corresponds to the specific number.

By making a call, it undertakes to make a measurement of soil moisture. It then replies with a text message (sms) to this mobile phone stating the soil moisture at an absolute value and percentage.

Finally, if it receives a call again within a specified time frame, then it activates the irrigation system. If we make a call outside the time limit, an sms will just be sent again.

1. Parts of the system

There are several methods for measuring soil moisture: Resistive and Capacitive.
The 1st method has a significant disadvantage - Electroplating activity. Lifespan about 1 month.



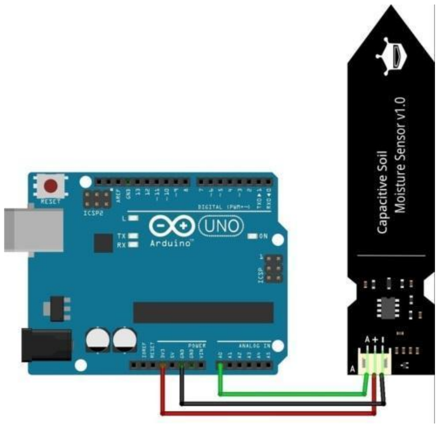
The 2nd method detects moisture in the soil by measuring the volume of water around the sensor. It basically measures the capacity of a capacitor whose dielectric (which affects it) depends on the volume of water in the ground.

When measuring, it does not need to come in direct contact with the ground. Therefore, there is no corrosion.

2. The soil moisture sensor

The soil moisture sensor is connected to Arduino with 3 cables:

- Red: Voltage: 3.3 ~ 5.5 VDC
- Black: Ground
- Green: Operating Output Voltage: 0 ~ 3.0VDC



Code

```
void setup()
{
        Serial.begin(9600); // open serial port, set the baud rate as 9600 bps
}
void loop()
{
        int val;
        val = analogRead(A0); //connect sensor to Analog 0
        Serial.println(val); //print the value to serial port
        delay(100);
}
```

3. Connecting with the user: The SIM800L GSM Module

The Sim800L is the part of the system that offers its connection via mobile network with the end user.

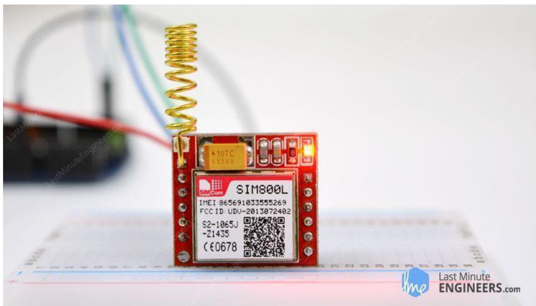
The SIM800L GSM / GPRS is a modem miniature.

It consists of a chip (SIM800L GSM cellular chip from SimCom)

It runs on 3.4V-4.4V, so a LiPo battery is ideal for powering it.

The communication speeds are 1200bps -115200bps

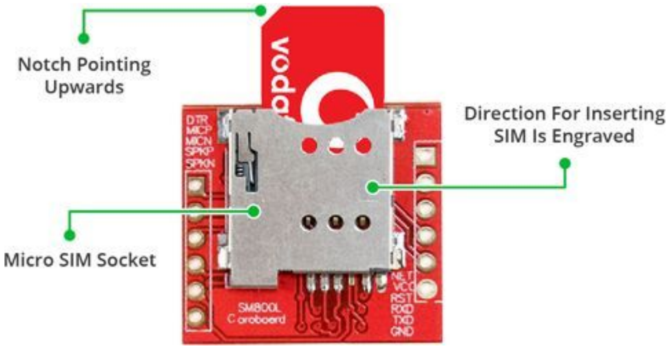
It usually comes with a helical antenna attached to the appropriate pin. However, there is also the u.fl connector in case we want to put an external antenna (stronger)

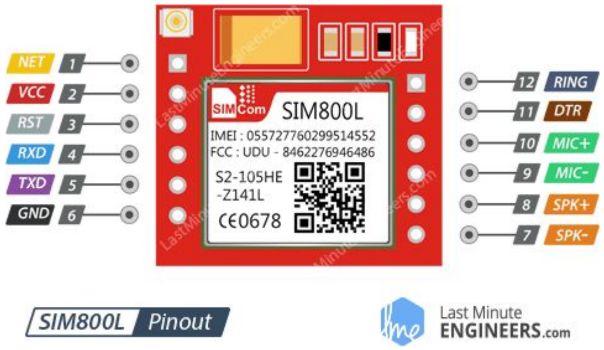


On the back there is a slot to put a sim card so that it can be connected to a mobile network and correspond to a specific number.

The features are the following:

- Supports Quad-band: GSM850, EGSM900, DCS1800 and PCS1900
- Connect onto any global GSM network with any 2G SIM
- Make and receive voice calls using an external 8Ω speaker & electret microphone
- Send and receive SMS messages
- Send and receive GPRS data (TCP/IP, HTTP, etc.)
- Scan and receive FM radio broadcasts
- Transmit Power:
    - Class 4 (2W) for GSM850
    - Class 1 (1W) for DCS1800
- Serial-based AT Command Set
- FL connectors for cell antennae
- Accepts Micro SIM Card

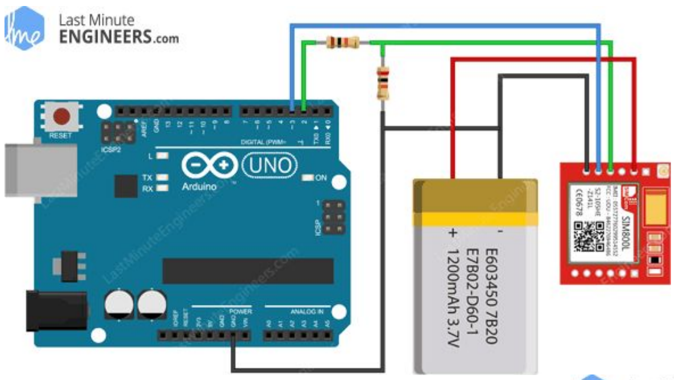


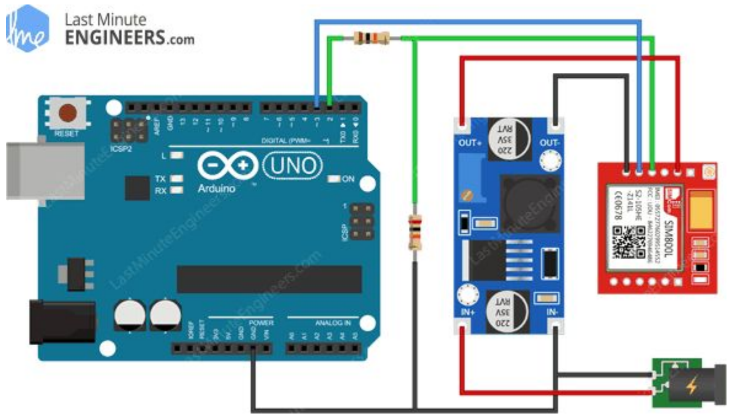


There is a led element in the upper right position which shows us the status of sim800L

The three states are the following:

- It works without a connection to the mobile network.
- GPRS data connection is active
- A connection has been made between the sim800L and the mobile network & it can send and receive calls and sms





To send AT commands and to communicate with sim800L we can use the serial communication port. Arduino provides a serial communication port between it and the PC or any device we want. For this purpose, the connection with a USB cable is used (when it comes to PC) or pins 0 and 1 when it is a more specialized connection (eg another device).

In essence, the serial port is a way to view / display the data sent to us by the Arduino on the computer screen. In this case, we just use it as an intermediate space. We send data to the serial (which we can read on the screen) and from there the commands we have sent directly to sim 800L are transferred through another communication channel to sim800L or vice versa and the results they produce are displayed in the serial port.

4. Example of sending AT commands to sim800L

Code

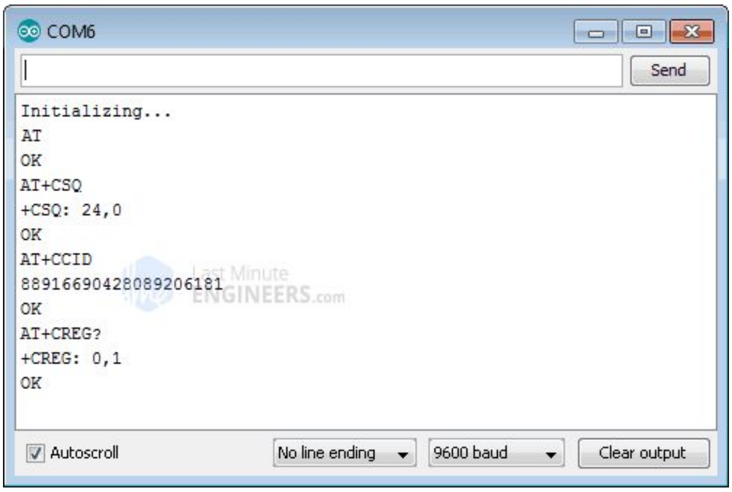
```
#include <SoftwareSerial.h>
//Create software serial object to communicate with SIM800L
SoftwareSerial mySerial(3, 2); //SIM800L Tx & Rx is connected to Arduino #3 & #2
void setup()
{
  //Begin serial communication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);
  //Begin serial communication with Arduino and SIM800L
  mySerial.begin(9600);
  Serial.println("Initializing...");
  delay(1000);
  mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
  updateSerial();
  mySerial.println("AT+CSQ"); //Signal quality test, value range is 0-31 , 31 is the best
  updateSerial();
  mySerial.println("AT+CCID"); //Read SIM information to confirm whether the SIM is
plugged
  updateSerial();
  mySerial.println("AT+CREG?"); //Check whether it has registered in the network
  updateSerial();
}

void loop()
{
  updateSerial();
}
void updateSerial()
{
  delay(500);
  while (Serial.available())
  {
    mySerial.write(Serial.read());//Forward what Serial received to Software Serial Port
  }
  while(mySerial.available())
  {
    Serial.write(mySerial.read());//Forward what Software Serial received to Serial Port
  }
}
```

AT – It is the most basic AT command. It also initializes Auto-baud'er. If it works you should see the AT characters echo and then OK, telling you it's OK and it's understanding you correctly! You can then send some commands to query the module and get information about it such as

AT+CSQ – Check the 'signal strength' – the first # is dB strength, it should be higher than around 5. Higher is better. Of course it depends on your antenna and location!

AT+CCID – get the SIM card number – this tests that the SIM card is found OK and you can verify the number is written on the card.

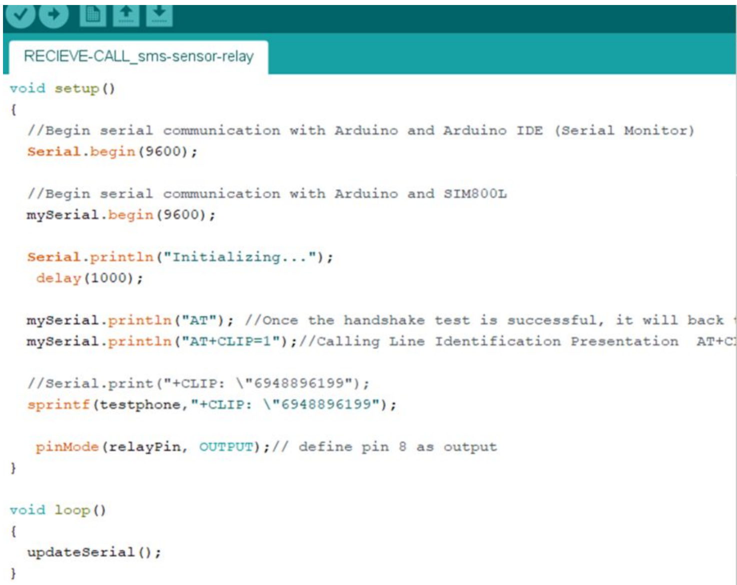
AT+CREG? Check that you're registered on the network. The second # should be 1 or 5. 1 indicates you are registered to home network and 5 indicates roaming network. Other than these two numbers indicate you are not registered to any network.



AT+CSQ Signal Quality Report	
Test Command **AT+CSQ=?**	Response **+CSQ:** (list of supported **<rssi>**s),(list of supported **<ber>**s)
Execution Command **AT+CSQ**	Response **+CSQ: <rssi>,<ber>** **OK** If error is related to ME functionality: **+CME ERROR: <err>** Execution Command returns received signal strength indication <rssi> and channel bit error rate <ber> from the ME. Test Command returns values supported by the TA.
	Parameters **<rssi>** 0 -115 dBm or less 1 -111 dBm 2...30 -110... -54 dBm 31 -52 dBm or greater 99 not known or not detectable **<ber>** (in percent): 0...7 As RXQUAL values in the table in GSM 05.08 [20] subclause 7.2.4 99 Not known or not detectable

AT+CCID Show ICCID	
Test Command **AT+CCID=?**	Response **OK**
Execution Command **AT+CCID**	Response **Ccid data** [ex. 898600810906F8048812] **OK**
Parameter Saving Mode	NO_SAVE
Max Response Time	2s
Reference	Note

Read Command **AT+CREG?**	Response TA returns the status of result code presentation and an integer <stat> which shows whether the network has currently indicated the registration of the ME. Location information elements <lac> and <ci> are returned only when <n>=2 and ME is registered in the network. **+CREG: <n>,<stat>[,<lac>,<ci>]**
	OK If error is related to ME functionality: **+CME ERROR: <err>**
Write Command **AT+CREG=[<n>]**	Response TA controls the presentation of an unsolicited result code +CREG: <stat> when <n>=1 and there is a change in the ME network registration status. **OK**
	Parameters **<n>** 0 Disable network registration unsolicited result code 1 Enable network registration unsolicited result code +CREG: <stat> 2 Enable network registration unsolicited result code with location information +CREG: <stat>[,<lac>,<ci>] **<stat>** 0 Not registered, MT is not currently searching a new operator to register to 1 Registered, home network 2 Not registered, but MT is currently searching a new operator to register to



```
RECIEVE-CALL_sms-sensor-relay
void setup()
{
  //Begin serial communication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);

  //Begin serial communication with Arduino and SIM800L
  mySerial.begin(9600);

  Serial.println("Initializing...");
   delay(1000);

  mySerial.println("AT"); //Once the handshake test is successful, it will back
  mySerial.println("AT+CLIP=1");//Calling Line Identification Presentation  AT+C

  //Serial.print("+CLIP: \"6948896199");
  sprintf(testphone,"+CLIP: \"6948896199");

   pinMode(relayPin, OUTPUT);// define pin 8 as output
}

void loop()
{
  updateSerial();
}
```

Write Command **AT+CLIP=<n>**	Response TA enables or disables the presentation of the CLI at the TE. It has no effect on the execution of the supplementary service CLIP in the network. **OK** If error is related to ME functionality: **+CME ERROR: <err>**
	Parameters **<n>** 0 Disable +CLIP notification. 1 Enable +CLIP notification. **<m>** 0 CLIP not provisioned 1 CLIP provisioned 2 Unknown (e.g. no network, etc.)
	Unsolicited Result Code When the presentation of the CLI at the TE is enabled (and calling subscriber allows), an unsolicited result code is returned after every RING (or +CRING: <type>) at a mobile terminating call. **+CLIP: <number>,<type>[,<subaddr>,<satype>,<alphaId>,<CLI validity>]** Parameters **<number>** String type (string should be included in quotation marks) phone number of calling address in format specified by <type>. **<type>** Type of address octet in integer format; 129 Unknown type 161 National number type 145 International number type 177 Network specific number **<subaddr>** String type (subaddress of format specified by <satype>) **<satype>** Integer type (type of subaddress) **<alphaId>** String type (string should be included in quotation marks) alphanumeric representation of <number> corresponding to the entry found in phone book. **<CLI validity>** 0 CLI valid 1 CLI has been withheld by the originator.

AT+CMGS Send SMS Message	
Test Command **AT+CMGS=?**	Response **OK**
Write Command 1) If text mode (+CMGF=1): **+CMGS=<da>[, <toda>]** **<CR>text is entered** **<ctrl-Z/ESC>** ESC quits without sending 2) If PDU mode (+CMGF=0): **+CMGS=<length>** **<CR>PDU is given** **<ctrl-Z/ESC>**	Parameters **<da>** GSM 03.40 TP-Destination-Address Address-Value field in string format(string should be included in quotation marks); BCD numbers (or GSM default alphabet characters) are converted to characters of the currently selected TE character set (specified by +CSCS in 3GPP TS 27.007); type of address given by <toda> **<toda>** GSM 04.11 TP-Destination-Address Type-of-Address octet in integer format (when first character of <da> is + (IRA 43) default is 145, otherwise default is 129) **<length>** Integer type value (not exceed 160 bytes) indicating in the text mode (+CMGF=1) the length of the message body <data> (or <cdata>) in characters; or in PDU mode (+CMGF=0), the length of the actual TP data unit in octets (i.e. the RP layer SMSC address octets are not counted in the length) Response TA sends message from a TE to the network (SMS-SUBMIT). Message reference value <mr> is returned to the TE on successful message delivery. Optionally (when +CSMS <service> value is 1 and network supports) <scts> is returned. Values can be used to identify message upon unsolicited delivery status report result code. 1) If text mode(+CMGF=1) and sending successful: **+CMGS: <mr>** **OK** 2) If PDU mode(+CMGF=0) and sending successful:

RECIEVE-CALL_sms-sensor-relay-2 | Arduino 1.8.12 (Windows Store 1.8.33.0)

Αρχείο Επεξεργασία Σχέδιο Εργαλεία Βοήθεια

RECIEVE-CALL_sms-sensor-relay-2

```
  Serial.println("EMPTY SERIAL STOP*******");
}

void power_relay(void)
{
  digitalWrite(relayPin, HIGH);         // turn the relay OFF (HIGH is OFF if relay is LOW trigger. change it to LOW if you have got HIGH trigger relay)
  delay(10000);
  digitalWrite(relayPin, LOW);
}

void get_soil_measurement(void)
{
  soilMoistureValue = analogRead(A0);  //Get returned Sensor value from A0 port
  Serial.println(soilMoistureValue);
  soilmoisturepercent = map(soilMoistureValue, AirValue, WaterValue, 0, 100);
}

void sms()
{
  mySerial.println("AT+CMGF=1");                    // Configuring TEXT mode
  updateSerial();
  mySerial.println("AT+CMGS=\"+30MOBILE_CONTROLER\"");  //change 30 with country code and MOBILE_CONTROLER with phone number to sms
  updateSerial();
  sprintf(Enimerwsi,"SOIL HUMIDITY=%d%% %d",soilmoisturepercent,soilMoistureValue);
  mySerial.print(Enimerwsi);                        //text content should be followed by Ctrl+Z
  updateSerial();
  mySerial.write(26);                               //'Ctrl+z' is actually a 26th non-printing character described as 'substitute' in ASCII table.
}
```

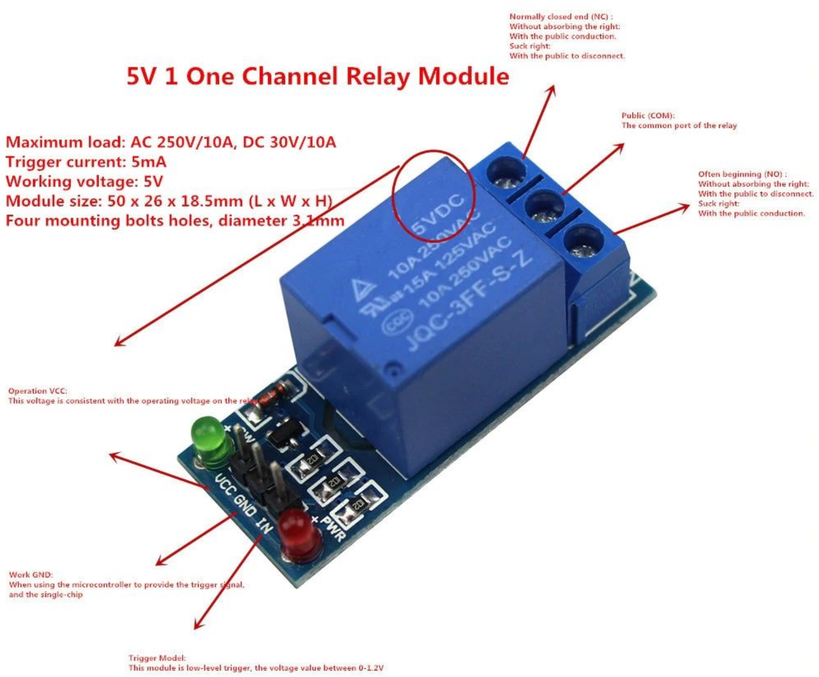
Ολοκλήρωση αποθήκευσης.

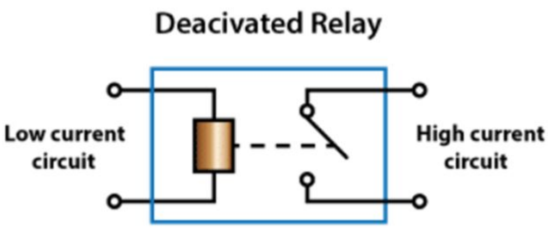
Το σχέδιο χρησιμοποιεί 6290 bytes (19%) του χώρου αποθήκευσης του προγράμματος. Το μέγιστο είναι 32256 bytes.
Οι καθολικές μεταβλητές χρησιμοποιούν 707 bytes (34%) δυναμικής μνήμης, αφήνοντας 1341 bytes για τοπικές μεταβλητές. Το μέγιστο είναι 2048 bytes.

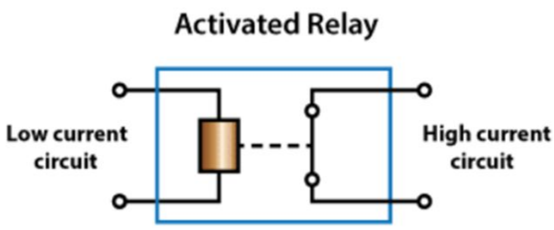
5. Relay

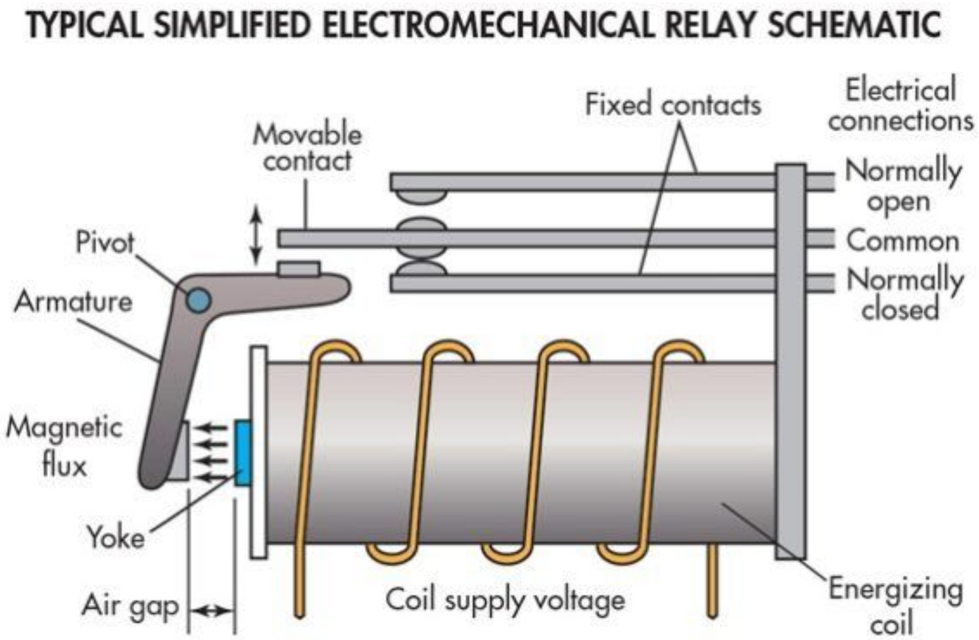
We can activate and deactivate high voltage electrical appliances using Relay. These devices cannot be powered by Arduino alone.

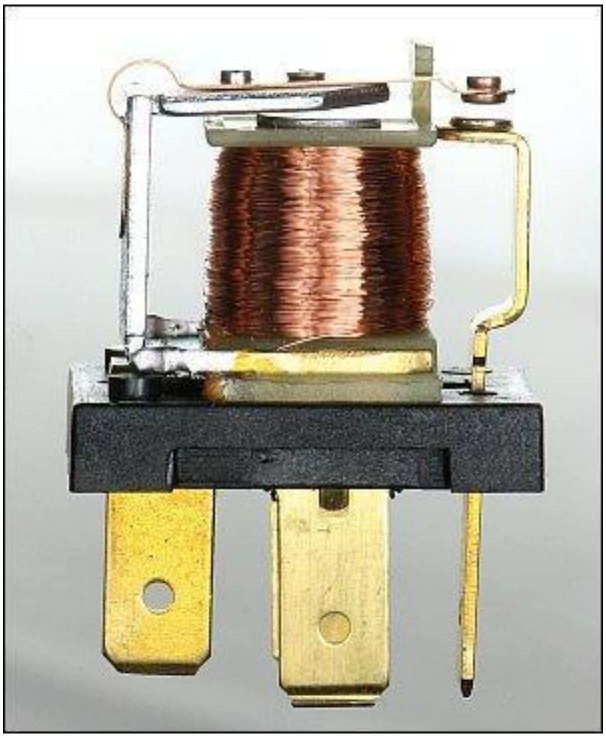
As we saw in the previous Unit, a Relay is basically a switch that works with the help of an electromagnet. The electromagnet is activated by a low voltage - for example 5V from the Arduino and moves a contact which acts as a switch to a high voltage circuit.





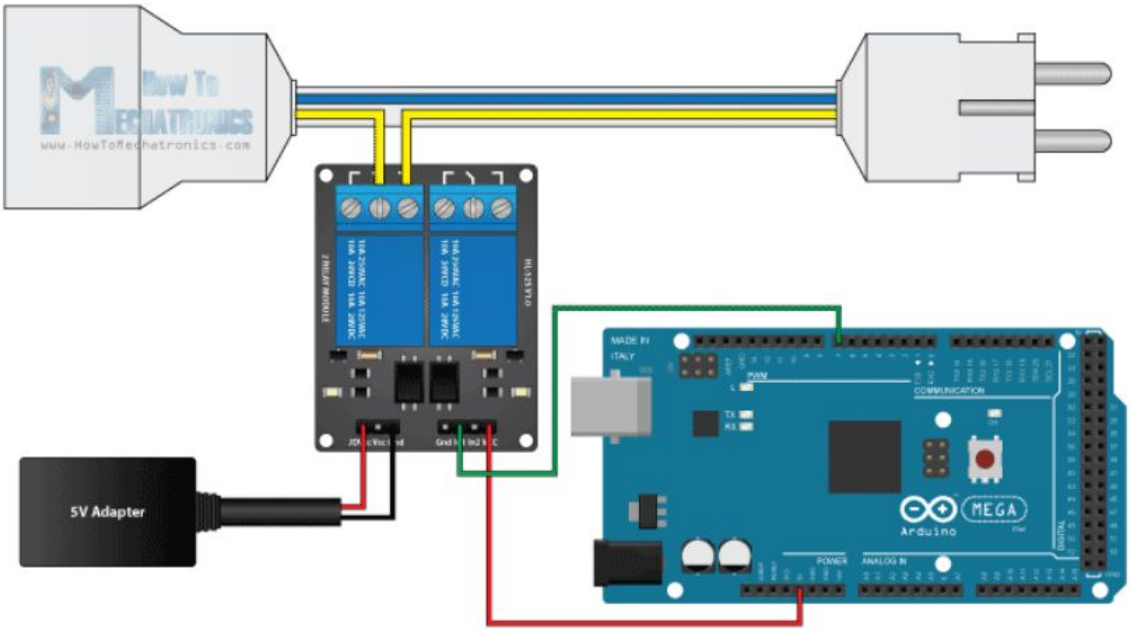



TYPICAL SIMPLIFIED ELECTROMECHANICAL RELAY SCHEMATIC
Fixed contacts
Electrical connections
Movable contact
Normally open
Common
Normally closed
Pivot
Armature
Magnetic flux
Yoke
Air gap
Coil supply voltage
Energizing coil



With the connection of the high voltage cable with the Relay, the following happens:

When the Arduino activates the Relay, then the electrical device connected to the upper left slot (female) is powered. That is, the relay closes the circuit and it is like connecting the yellow cable (phase).



Code:

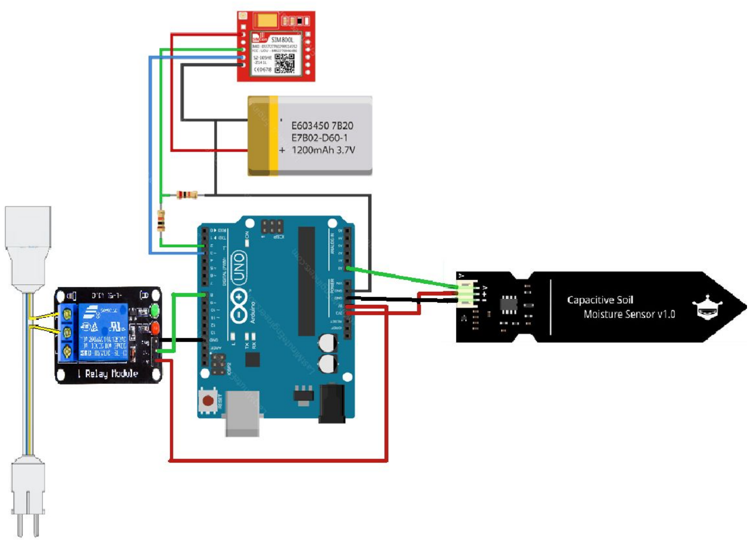
```
int in1 = 7;
void setup()
{
        pinMode(in1, OUTPUT);
        digitalWrite(in1, HIGH);
}
void loop()
{
        digitalWrite(in1, LOW);
        delay(3000);
        digitalWrite(in1, HIGH);
        delay(3000);
}
```

In this application we compose all the above components together in a system controlled by a program that we have uploaded to Arduino Uno.

A key part of the program is also dedicated to controlling which number is calling so that the system does not react to unknown numbers but also when it calls.

Depending on the time of the call, we may ask for information about the humidity of the soil, or we may ask for an activation or a device that starts watering (eg an solenoid valve, a motor / irrigation pump).

Also crucial is the point that the system does not interpret the following "ringtones" of a call as new calls to it.



IV. The NodeMCU Board

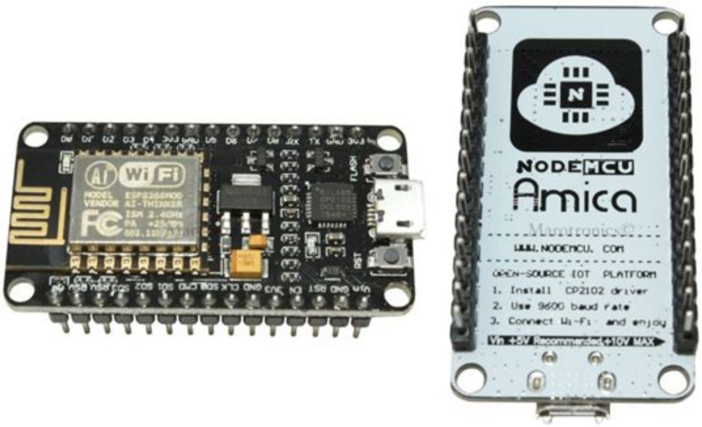
1. Introduction to NodeMCU

Learning outcomes

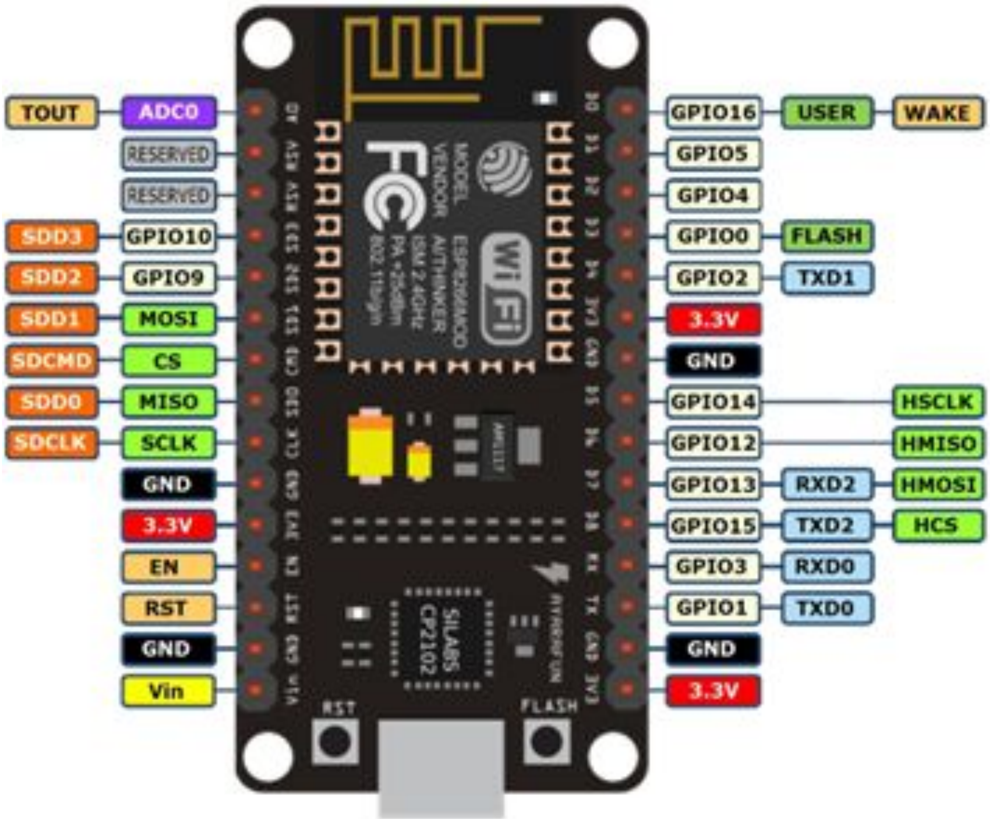
After this section, learners will be able to:

- state what is the NodeMCU board
- describe and analyze the applications of NodeMCU board and ESP8266 chip
- distinguish the basic elements of Arduino IDE
- setup the Arduino IDE to their computers based on NodeMCU settings

The NodeMCU (Node MicroController Unit) is an open source software and hardware development environment that is built around a very inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains all crucial elements of the modern computer: CPU, RAM, networking (wifi), and even a modern operating system and SDK. When purchased at bulk, the ESP8266 chip costs only $2 USD a piece. That makes it an excellent choice for IoT projects of all kinds.



Through its pins we can read inputs - light on a sensor, a finger on a button, or a Twitter message -and turn them into an output - activating a motor, turning on an LED, publishing something online. It also has WiFi capabilities, so we can control it wirelessly and make it work on a remote installation easily! We can tell our board what to do by sending a set of instructions to the microcontroller on the board. To do so we can use the Arduino Software (IDE).



2. Blinking with NodeMCU

Learning outcomes

After the completion of this section the students will be able to:

- describe what is a LED and its use
- state what is a resistor and its function
- combine electronic elements in order to create a circuit
- create the code to make a LED blink

In this section we 'll try the Blink program, programming the NodeMCU to flash a LED with a delay that we 'll have already defined.

We connect our NodeMCU and our LED as above on the breadboard, taking care of connecting the shorter of the two legs of the LED to GND of the NodeMCU (through a 220 Ohm resistor) and the longer leg to the pin D7.

The resistor is an electronic component which is used to limit the current flow through a circuit. In our case we use it in order to protect the LED from burning or stress.
Pin D7 (Digital pin 7) corresponds to Pin 13 on Arduino IDE. So we copy the following code into the Arduino IDE code editor:

CODE:

```
void setup() {
  pinMode(13, OUTPUT);
}
void loop() {
  digitalWrite(13, HIGH);
  delay(1000);
  digitalWrite(13, LOW);
  delay(1000);
}
```

and we hit the Upload button. Then we enjoy our first Blinking program.

Let's talk about the details of our program.

There are two sections: void setup() and void loop().
Anything that belongs to void setup() section (inside curly brackets {}) is running once, when the program begins.

pinMode(13, OUTPUT); prepares the pin 13 (D7-Digital 7) of the NodeMCU to accept output commands like "turn off" or "turn on", 0 or 1, in binary logic.

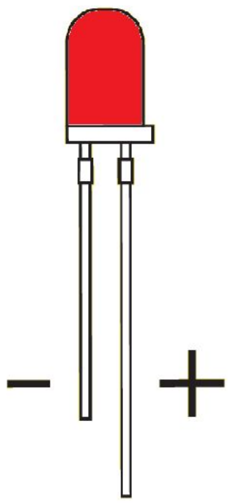
Anything that belongs to void loop () section (inside curly brackets {}) is running again and again, until we plug the NodeMCU off.

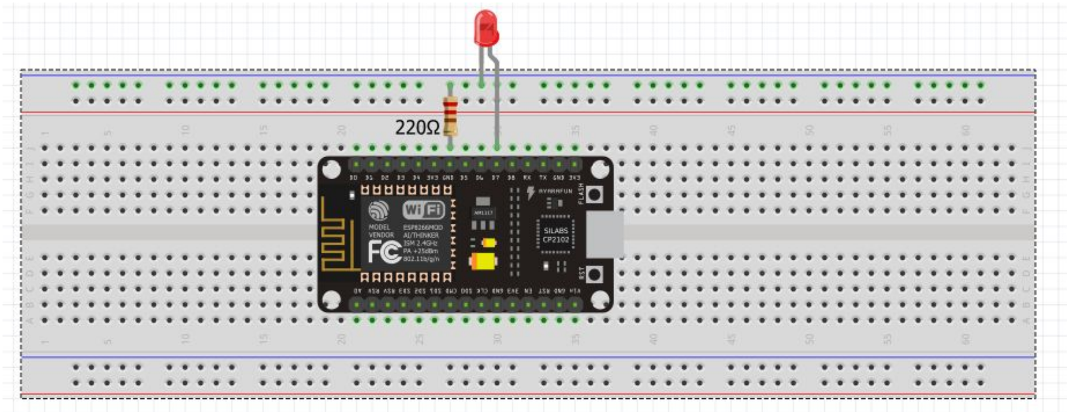
digitalWrite(13, HIGH); commands the pin 13 (D7-Digital 7) to turn on and digitalWrite(13, LOW); commands the pin 13 (D7-Digital 7) to turn off

Between the above two commands there are two delay (1000); each tells the program to wait for 1000 ms (1 sec) before executing the following command.

Now, try to change the program in order to send an SOS message via the NodeMCU and the LED.

Don't be afraid of the failure. Success is coming after our last failure if we keep trying!





3. Multiple LEDs example

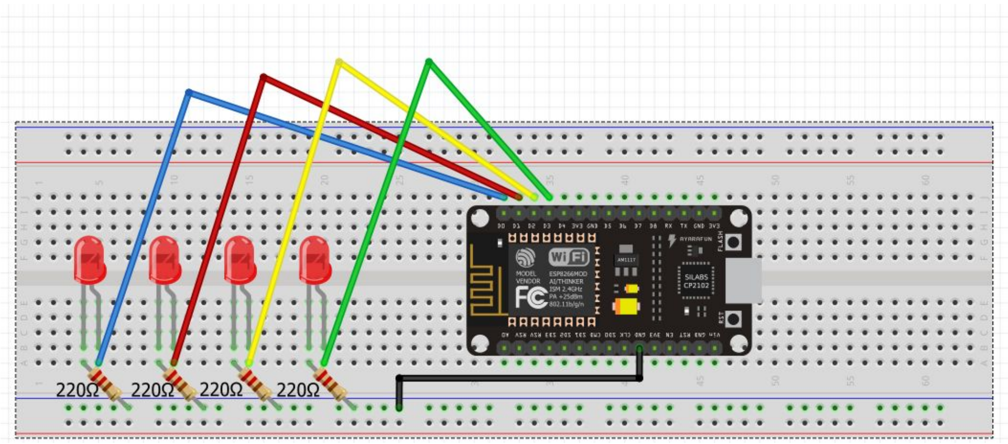
Learning outcomes

After the completion of this section the students will be able to:

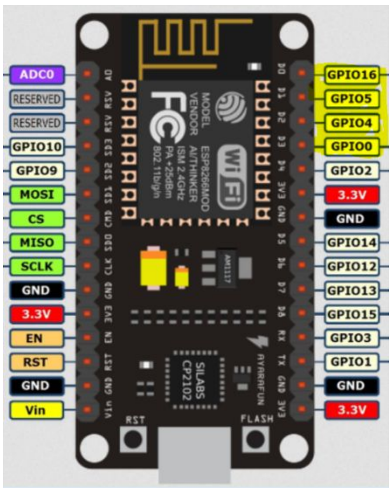
- create a circuit with multiple LEDs onboard
- program the NodeMCU to make the LEDs turn ON and OFF, one by another
- change the blinking speed to faster or lower
- add more LEDs to the circuit

Light the LEDs up, one by another...
Now, let's try to create a program with four LEDs that they will be turned on and after a while they will be turned off in a row.

First of all, we connect the LEDs, the cables and the NodeMCU on the breadboard, according to the following picture (you can use any cable color you like, not only the ones that are displayed below):



As we notice, we use **pins D0, D1, D2, and D3**, or **pins 16, 5, 4 and 0** if we talk in Arduino IDE language.



So we have to declare them as output pins and then **digitalWrite()** them high or low, using a delay after any of these commands.

Then, we copy the following code to the Arduino IDE and upload our program:

Code:

```
void setup() {
   pinMode(16, OUTPUT);
   pinMode(5, OUTPUT);
   pinMode(4, OUTPUT);
   pinMode(0, OUTPUT);
}
void loop() {
  digitalWrite(16, HIGH);
  delay(200);
  digitalWrite(5, HIGH);
  delay(200);
  digitalWrite(4, HIGH);
  delay(200);
  digitalWrite(0, HIGH);
  delay(200);
  digitalWrite(16, LOW);
  delay(300);
  digitalWrite(5, LOW);
  delay(300);
  digitalWrite(4, LOW);
  delay(300);
  digitalWrite(0, LOW);
  delay(300);
}
```

The next step is to find out how we can add more LEDs and what we should do if we want to make them light on and off faster. What is the maximum amount of LEDs that we can handle?

4. Playing with buttons

Learning outcomes

After the completion of this section the students will be able to:

- describe and use push buttons in circuits
- create a circuit to turn an LED on when we push a button
- create the code for the above circuit
- describe the use of comments inside an Arduino IDE program
- describe the binary system and match binary to decimal numbers and vice versa
- combine many LEDs and pushbuttons to create binary sequences

NodeMCU is not just an output device. It can accept triggers from its environment and act respectively, according to the program that it has on its memory.

In this example we 'll try to light on an LED every time we push a pushbutton. It is called so, because it connects its legs when someone pushes it for a moment and removes the connection when the button is not pressed anymore.

Our components will be arranged on the breadboard like below:

We notice here that we use D0 (pin 16) as an input pin to accept commands from the button and D1 (pin 5) as an output pin to send the signal to the LED for the ON-OFF operation.

In our case, when the pushbutton is open (unpressed) there is no connection between the two legs of the pushbutton, so the pin is connected to ground and we read a LOW. When the button is closed (pressed), it makes a connection between its two legs, connecting the pin to 3.3 volts, so that we read a HIGH.

As for the code for the above, it looks like that:

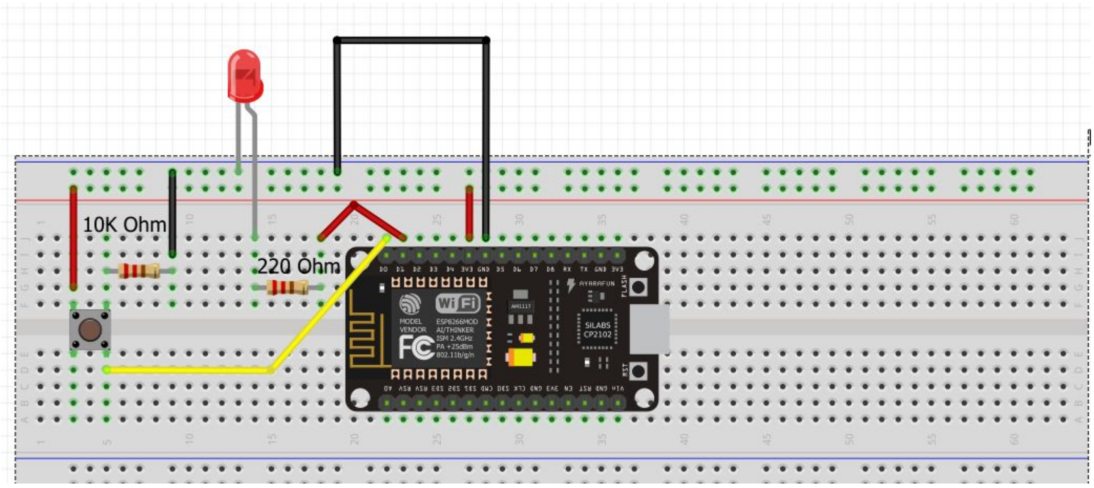
Code:

```
int ledPin = 5; // choose the pin for the LED
int inPin = 16;   // choose the input pin (for a pushbutton)
int val = 0;     // variable for reading the pin status
void setup() {
  pinMode(ledPin, OUTPUT);  // declare LED as output
  pinMode(inPin, INPUT);    // declare pushbutton as input
}
void loop(){
  val = digitalRead(inPin);  // read input value
  if (val == LOW) {         // check if the input is LOW (button released)
    digitalWrite(ledPin, LOW);  // turn LED OFF
  } else {
    digitalWrite(ledPin, HIGH);  // turn LED ON
  }
}
```

If you are wondering what are // characters, they are used as comments starting characters, so everything that follows in the same line is not interpreted. We can give notices to the other programmers about our ideas and explain our thoughts in a few words.

Another new structure that we notice in our code is the IF structure. With this, we can decide what actions we choose based on a condition.

So in our example, first we read the state of pin16 and if it is LOW (unpressed) then we turn the LED off (pin 5). If not, we turn the LED on.
So, copy the code in bold and paste it to Arduino IDE. Then upload your code to NodeMCU and.......play with the button!



V. Light sensing

1. Introduction

Learning outcomes

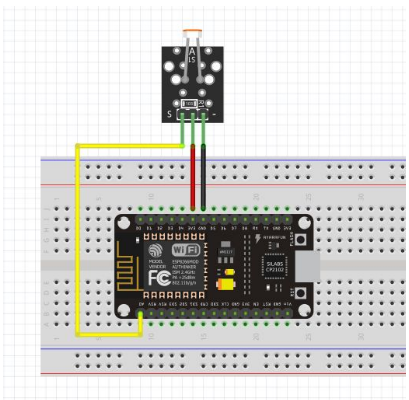
After the completion of this section the students will be able to:

- describe and use a photoresistor
- build a circuit to sense and measure the light
- use the Serial Monitor inside the Arduino IDE
- visualize the light amount to values into the Serial Monitor

In this section, we' ll learn how we can measure the amount of light with the help of an electronic device that is called 'photoresistor'.

It is a variable resistor that decreases its resistance when the light is passing through it. It is an analogue input device which means that we read not only two states (0 and 1) but many values between 0V and 3.3V or in case of Arduino IDE values between 0 and 1023 respectively.

So, how can we find the exact amount of light that passes through the device at any time using NodeMCU and Arduino IDE? The answer is "we cannot do it using only these", but we can build a circuit that will help us watch the changes that the light causes, passing through the photoresistor. For the purposes of this experiment we have to build the following circuit.



Our next challenge is to watch the changes of passing light on our screen. For this to be done we need the **Arduino IDE's Serial monitor**.

2. Handling a laser beam

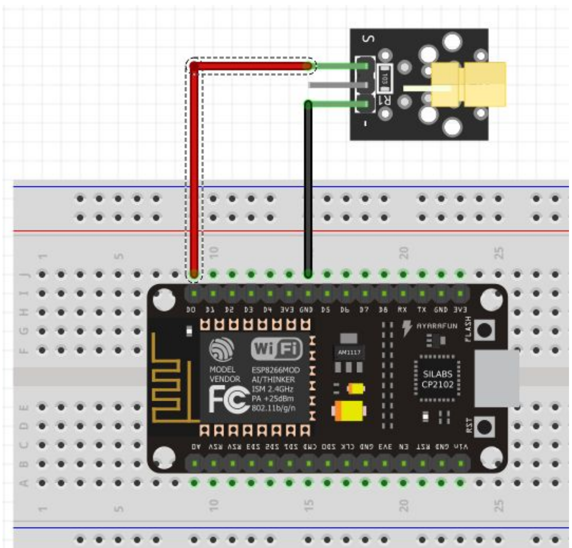
Learning outcomes

After the completion of this section the students will be able to:

- handle a laser beam
- create a circuit turn a laser beam ON and OFF
- code the NodeMCU to flash the laser beam

We must be very careful when we handle laser pointers and laser beams. Remember, never to point the beam to your eyes or the eyes of any person as it may harm you or them.

Now let's return to our playing environment. First, we have to build the circuit below:



In this picture we notice that the Signal (red cable) is connected to D0 pin. Considering that D0 matches to number 16 in Arduino IDE our program will be as below:

Code:

```
void setup() {
  pinMode(16, OUTPUT);
}

void loop() {
  digitalWrite(16, HIGH);
  delay(500);
  digitalWrite(16, LOW);
  delay(500);
}
```

Copy the above code to the Arduino IDE and then upload it to the NodeMCU. As you can see, the beam is blinking with a delay of half a second. Try to change the tempo and have more fun.

3. Making noise with a buzzer

Learning outcomes

After the completion of this section the students will be able to:

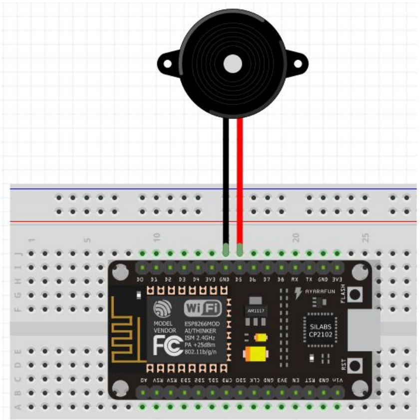
- describe what is a buzzer and its uses
- create a circuit with a buzzer and NodeMCU
- program the NodeMCU to produce single audio signals (beeps)
- produce melodies combining specific commands in Arduino IDE, with NodeMCU and a buzzer

A buzzer or beeper is an audio signalling device, which may be mechanical, electromechanical, or piezoelectric (piezo for short). Typical uses of buzzers and beepers include alarm devices, timers, and confirmation of user input such as a mouse click or keystroke.

The one that we'll use in this lesson is the piezo buzzer which looks like the one below:

So as you can see, there is a (+) leg which goes to the digital pin of the NodeMCU that we choose and the other pin goes to the GND pin.

Build the diagram below to experiment with the sound of buzzer:



Then we can code our circuit to just beep forever, with the code below:

Code:

```
void setup()
{

}

void loop()
{
   tone(14, 494, 500);
   delay(1000);
}
```

Copy the code to Arduino IDE, upload it to NodeMCU and listen to the beep.
We notice here that the setup() section is empty and the loop() section contains a **tone()** function and an one second delay. The three numbers inside the tone() function represent: the **pin** we send the sound (D5 or 14 in our case), the **frequency** of the sound wave we send and the **duration** of the tone.

You can change the last two parameters and play with the speed of the beeps and the sound of them.

But instead of listening just beeps, we can program our circuit to compose melodies, using notes.

An example of this, is below:

Code:

```
int speakerPin = 14;

int length = 15; // the number of notes
char notes[] = "ccggaagffeeddc "; // a space represents a rest
int beats[] = { 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 2, 4 };
int tempo = 300;

void playTone(int tone, int duration) {
  for (long i = 0; i < duration * 1000L; i += tone * 2) {
    digitalWrite(speakerPin, HIGH);
    delayMicroseconds(tone);
    digitalWrite(speakerPin, LOW);
    delayMicroseconds(tone);
  }
}

void playNote(char note, int duration) {
  char names[] = { 'c', 'd', 'e', 'f', 'g', 'a', 'b', 'C' };
  int tones[] = { 1915, 1700, 1519, 1432, 1275, 1136, 1014, 956 };

  // play the tone corresponding to the note name
  for (int i = 0; i < 8; i++) {
    if (names[i] == note) {
      playTone(tones[i], duration);
    }
  }
}

void setup() {
  pinMode(speakerPin, OUTPUT);
}

void loop() {
  for (int i = 0; i < length; i++) {
    if (notes[i] == ' ') {
      delay(beats[i] * tempo); // rest
    } else {
      playNote(notes[i], beats[i] * tempo);
    }

    // pause between notes
    delay(tempo / 2);
  }
}
```

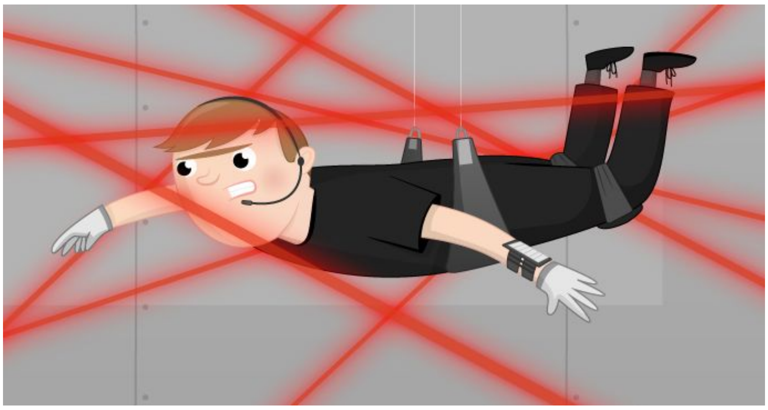
You can copy that, paste it in the Arduino IDE and then upload it to the NodeMCU. You may need to come close to the buzzer in order to hear the melody.

4. Building a laser trap

Learning outcomes

After the completion of this section the students will be able to:

- create a circuit based on a laser pointer, a photoresistor, a buzzer and a NodeMCU board
- create a program to make the above circuit function as a laser trap
- describe the concept of a variable
- use different types of variables as Boolean or integer
- reset the circuit after its activation to stop the buzzer beeping



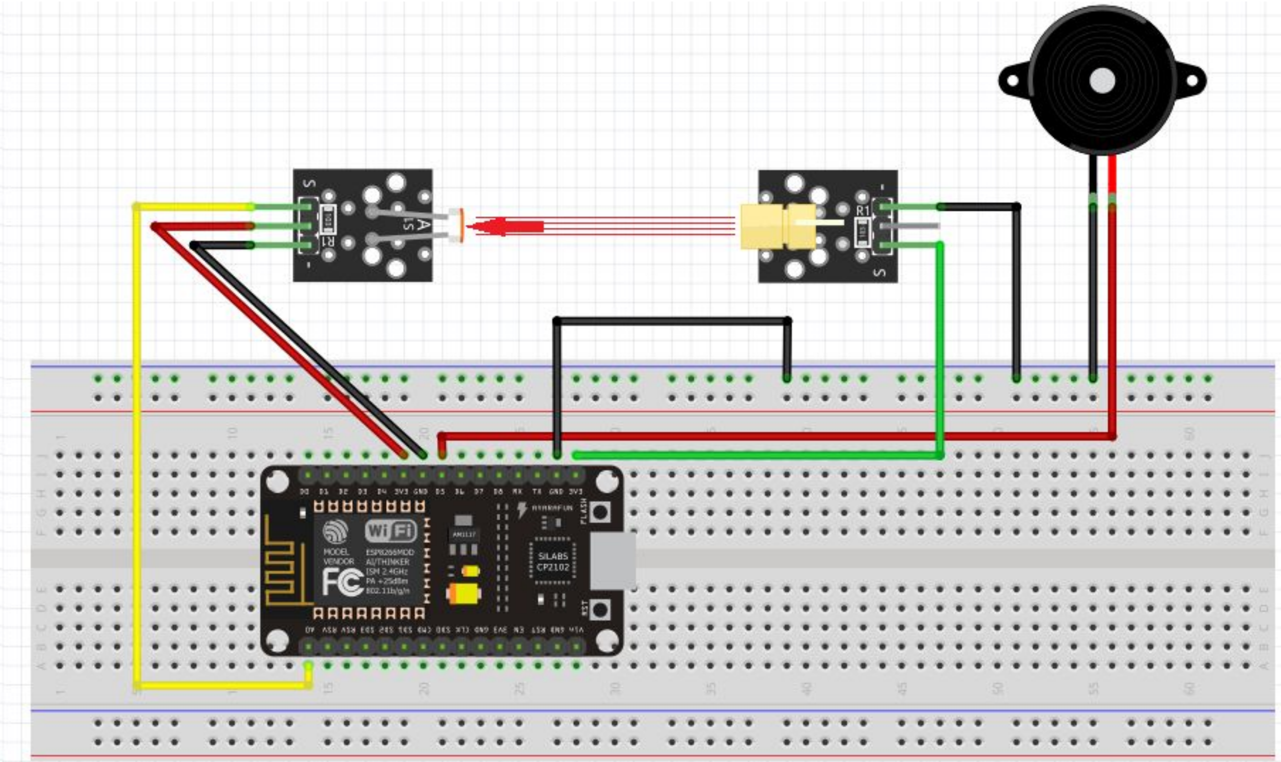
Have you ever watched an action movie when the star actor tries to avoid the laser beams into a room, in order not to activate the alarm and get caught?

https://youtu.be/mr834Cs9ncs

That's what we 'll try to build in this lesson. An alarm system made of a laser pointer, a photoresistor and a buzzer which will be activated at certain circumstances.

In a few words, the laser beam will be active all the time and it will be pointed to the photoresistor from a distant point. As long as nothing interrupts the invisible beam, the light that passes through the photoresistor gives high values measured in Arduino IDE as discussed earlier.

But when something blocks the beam (for example someone who stands in the middle), then the light that passes through the photoresistor becomes from **HIGH** to **LOW** and that activates the buzzer which is making an annoying sound like a siren.



VI. Blynk and its uses

1. How Blynk works

After the completion of this section the students will be able to:

- describe the Blynk application, its uses and its basic elements
- state the main features of Blynk
- describe the necessary hardware to make Blynk work

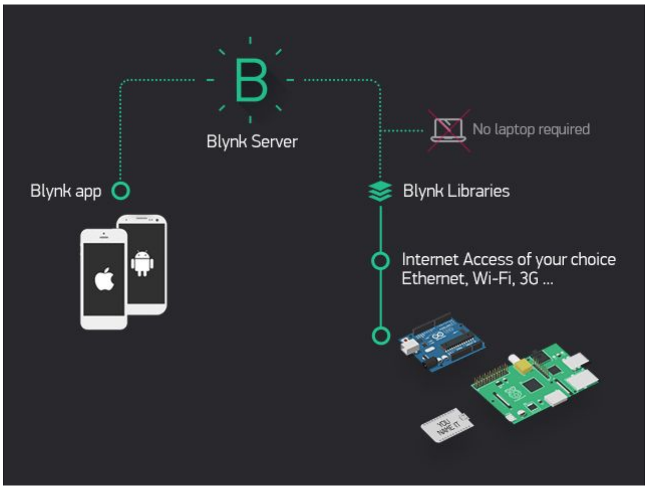
Blynk was designed for the Internet of Things. It can control hardware remotely, it can display sensor data, it can store data, visualize it and do many other cool things.
There are **three** major components in the platform:

- **Blynk App** - allows you to create amazing interfaces for your projects using various widgets we provide.

- **Blynk Server** - responsible for all the communications between the smartphone and hardware. You can use the Blynk Cloud or run your private Blynk server locally. It's open-source, could easily handle thousands of devices and can even be launched on a Raspberry Pi.

- **Blynk Libraries** - for all the popular hardware platforms - enable communication with the server and process all the incoming and outcoming commands.

Now imagine: every time you press a Button in the Blynk app, the message travels to the Blynk Cloud, where it magically finds its way to your hardware. It works the same in the opposite direction and everything happens in a blynk of an eye.



2. Arduino IDE + libraries installation

After the completion of this section the students will be able to:

- prepare the Arduino IDE to support Blynk applications
- install all the libraries needed to support Blynk
- customize the Arduino IDE to code Blynk sketches for our devices

In order to prepare the Arduino IDE to support Blynk Applications, you need to follow the following steps:

A. Download the appropriate version of Arduino IDE from the link below
https://www.arduino.cc/en/Main/Software

B. Install the software

C. Download the Blynk library (.zip) from the github repository
https://github.com/blynkkk/blynk-library/releases
or direct link to the latest zip file:
link to latest library file

D. Extract the contents of the file

E. Execute the arduino IDE software and navigate to File -> Preferences

F. Locate the sketchbook location

G. Copy (and paste) the contents of the extracted folder to the sketchbook folder

3. Smartphone Installation - Blynk account

Learning outcomes

After the completion of this section the students will be able to:

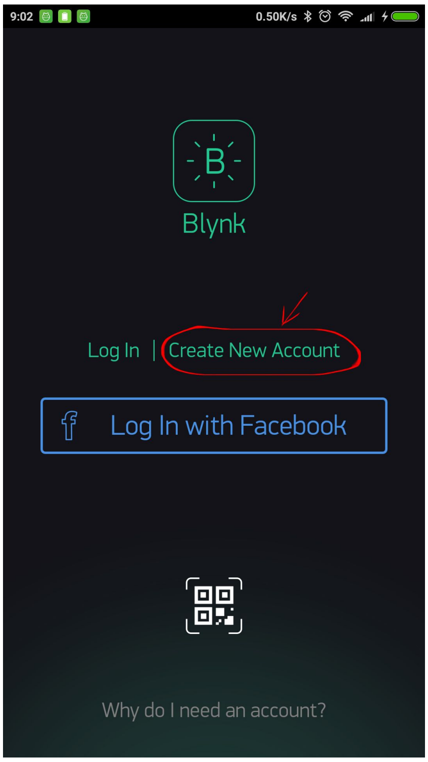
- install The Blynk app to their smartphone
- create a Blynk account in the Blynk server
- login to the Blynk server with their account

Blynk Apps for iOS or Android

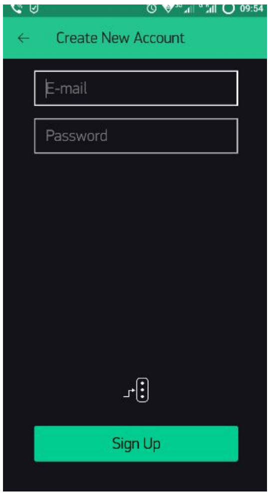
First of all the smartphone application has to be installed
[Blynk - Android app]
[Blynk - iphone app]

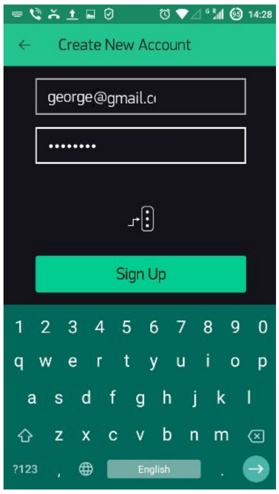
Create a Blynk Account

After you download the Blynk App, you'll need to create a New Blynk account. We recommend using a real email address because it will simplify things later.



Open the application and select " Create New Account "





Write your email and a password to create an account on the Blynk server

4. Controlling a device

Learning outcomes

After the completion of this section the students will be able to:

- create a new project in Blynk
- place widgets inside Blynk's desktop
- adjust Blynk's widgets
- prepare the code to make our device communicate with the smartphone
- create a circuit to experiment with blinking a LED via their smartphone

Creating a new project in Blynk

In this section we will learn how to control a remote device using the smartphone

At the beginning we usually plan and design our application, but we can modify or even change anything later.

As a first application we will control an led that we will connect to our arduino IDE microcontroller unit (MCU)

A. Open the Blynk application of our smartphone
B. Click on New Project
C. Write the Project Name : NodeMCU LED
D. Choose Device : ESP8266
E. Choose Connection Type : WiFi
F. Click : Create

At the moment an email was sent to your account with the authentication token of the project but you can find it and copy it or resend it inside the menu project settings
Inside the project

A. Click on the plus sign
B. Select Button
C. Click on the button
D. Click on PIN
E. Select Digital and GP13
F. Turn slider to switch
G. Click on the back button

5. Reading Temperature and Humidity

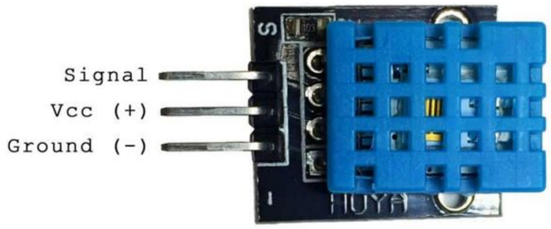
Learning Outcomes

After the completion of this section the students will be able to:

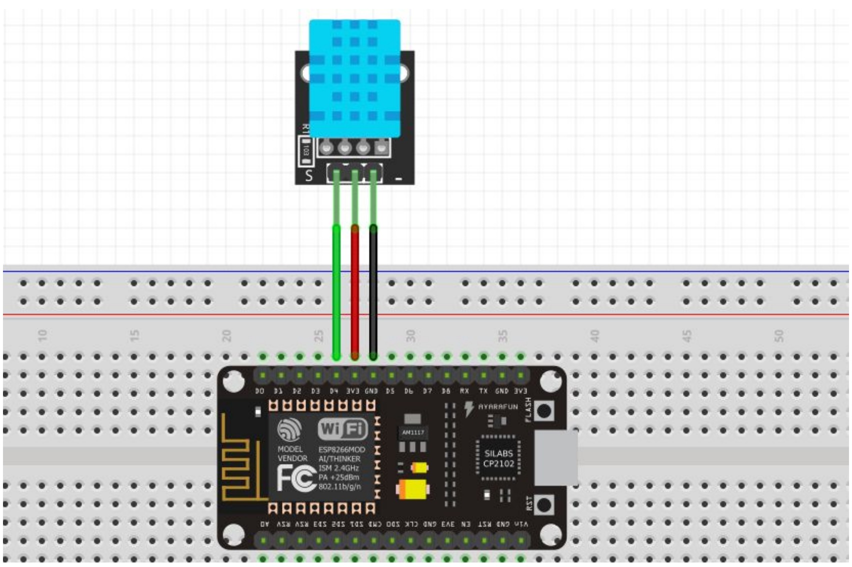
- describe the DHT11 sensor and its uses
- build a circuit with a NodeMCU and a DHT11 sensor to read the Temperature and the Humidity of the environment
- create a program to read the results to their smartphone
- create a Blynk project with widgets and adjustments to visualize the current results and history of them

Setting up the DHT11 sensor

The DHT11 sensor is a Digital Temperature and Humidity sensor which can be connected and send environmental data to the NodeMCU.

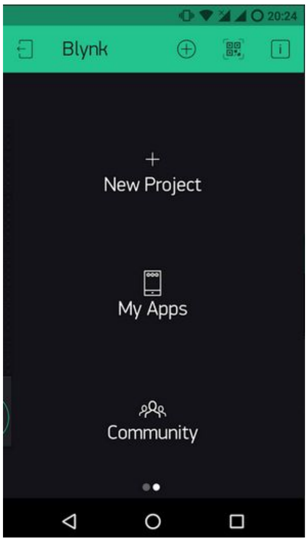


Here, we'll create a circuit that will send the data to the Blynk server and through this to our mobile phone. So, create first the circuit following the diagram below:

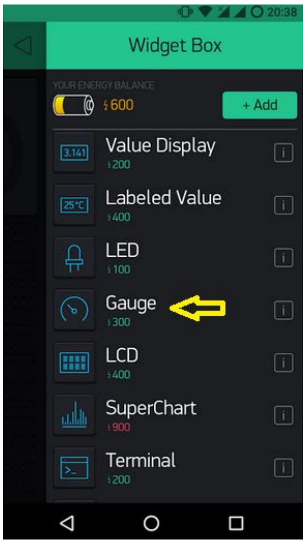


In this diagram, we notice that we connect the S(ignal) pin of the DHT11 to the D4 pin of the NodeMCU. So the data will be directed to GPIO2.

Now, it is time to create a new project on the Blynk app. So, open the Blynk app, login to the server if not already logged in and make a new project called "DHT11".



Our next job is to add some widgets for the visualization of the data that the Blynk app will receive. Pressing we choose one gauge for the Temperature and another one for the Humidity.



Following all the above, now we have to label the gauges and adjust the pins that they will "listen to". The first gauge will be named Temperature, will listen to Virtual Pin 6 and its limits will be 0 to 50 Celsius degrees. and the Humidity gauge settings:

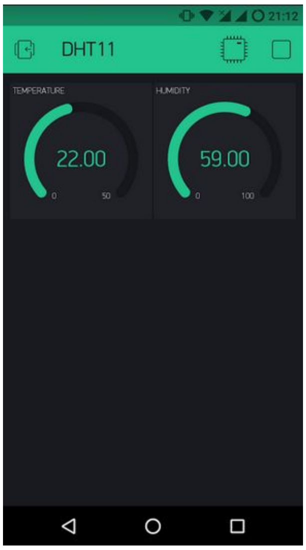
Then we have to create the code for all this to work together:

Code:

```
#define BLYNK_PRINT Serial

#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <DHT.h>

// You should get Auth Token in the Blynk App.
// Go to the Project Settings (nut icon).
char auth[] = "????????????????????????????";

// Your WiFi credentials.
char ssid[] = "XXXXXXXXXXXXXXXXXXXXXXX";
char pass[] = "YYYYYYYYYYYYYYYYYYYYYYYYY";

#define DHTPIN 2          // What digital pin we're connected to

// Uncomment whatever type you're using!
#define DHTTYPE DHT11     // DHT 11
//#define DHTTYPE DHT22   // DHT 22, AM2302, AM2321
//#define DHTTYPE DHT21   // DHT 21, AM2301

DHT dht(DHTPIN, DHTTYPE);
BlynkTimer timer;
```

```
// This function sends Arduino's up time every second to Virtual Pin (5).
// In the app, Widget's reading frequency should be set to PUSH. This means
// that you define how often to send data to Blynk App.
void sendSensor()
{
  float h = dht.readHumidity();
  float t = dht.readTemperature(); // or dht.readTemperature(true) for Fahrenheit

  if (isnan(h) || isnan(t)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }
  // You can send any value at any time.
  // Please don't send more that 10 values per second.
  Blynk.virtualWrite(V5, h);
  Blynk.virtualWrite(V6, t);
}

void setup()
{
  // Debug console
  Serial.begin(9600);

  Blynk.begin(auth, ssid, pass);

  dht.begin();

  // Setup a function to be called every second
  timer.setInterval(1000L, sendSensor);
}

void loop()
{
 Blynk.run();
  timer.run();
}
```

Copy the above code, paste it into Arduino IDE, insert the Authentication code that came to your email address before, the WiFi name and the WiFi password, and then press the button . Now, watch the changes of Temperature and Humidity of the environment around DHT11, directly into your mobile phone like the next picture:



You can also add a history graph like below, choosing the Superchart and adjusting the settings according to the current setup!

Feel free to experiment with the widgets and have fun with BLYNK!

VII. Combining our knowledge

1. Controlling the colors

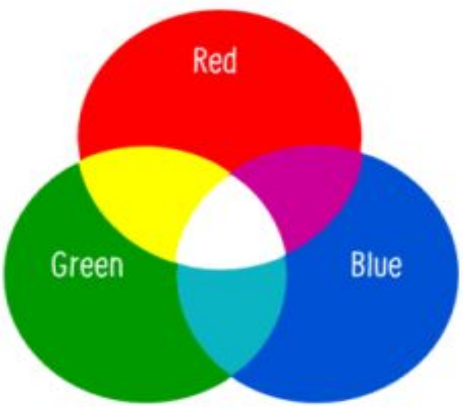
Learning Outcomes

After the completion of this section the students will be able to:

- describe the RGB color model
- state the difference between an RGB LED and a single color LED
- distinguish and use the legs of an RGB LED
- create a circuit with an RGB LED
- program the NodeMCU to change the color of an RGB LED with their smartphone
- create a ZeRGBa project to their smartphone

Changing colors on an RGB LED using Blynk

For any light source that emits light directly to our eyes, the color that is perceived by our brain has three basic components, some amount of red, green and blue. Variations in their amount help us to create various colors.



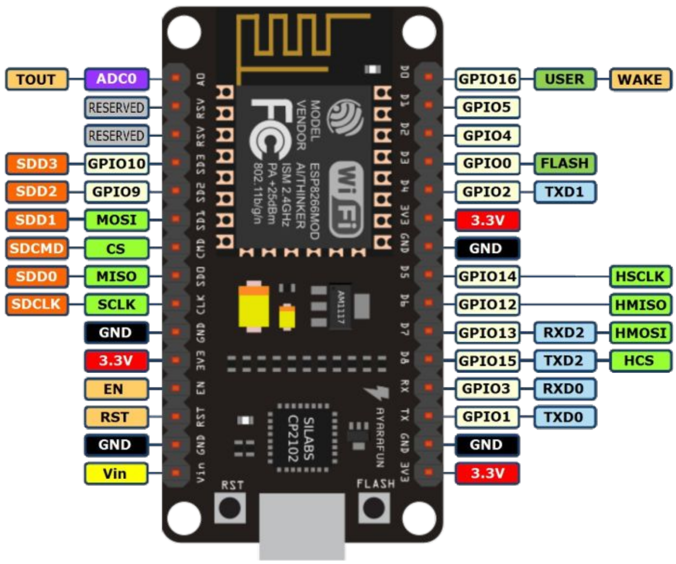
An RGB led is a single LED which provides us all three kinds of colors. They come in two forms: common cathode (one which we'll be talking about in this project) and common anode. Common cathode has a common GND pin for all three colors. Here's a picture of this and its pins-colors matching:

Actually, there are three LEDs, one red, one green and yes, one blue in one package. By controlling the amount of each of the individual LEDs you can mix pretty much any color you want.

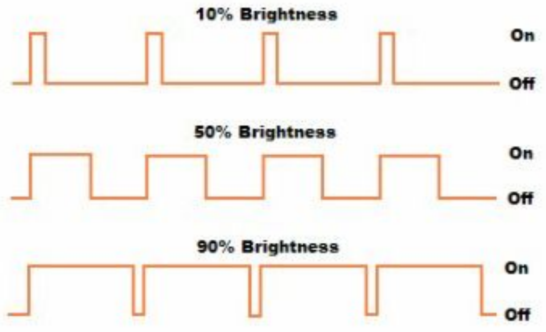
You can play with the amounts of basic colors that you need in order to create a new color here:

[RGB color calculator]

As we have discussed in previous sections the digital ports can have only one of the two values: 0 or 1, TRUE or FALSE, ON or OFF. So, it is clear that we could not control the amount of light that any of the individual leds emits by connecting its legs to digital ports.

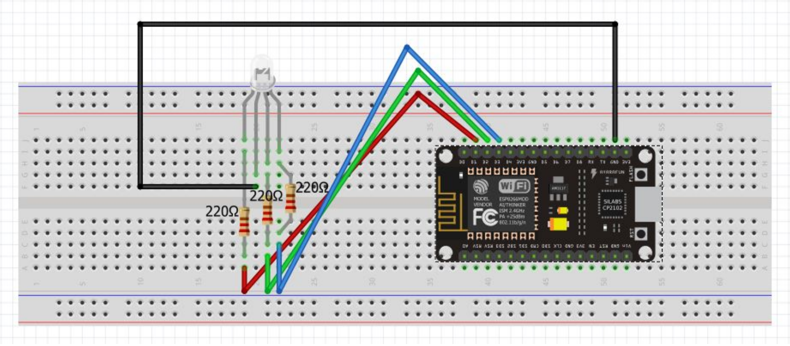


Here is a problem that is fortunately solved and the solution is called PWM. Pulse Width Modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off.



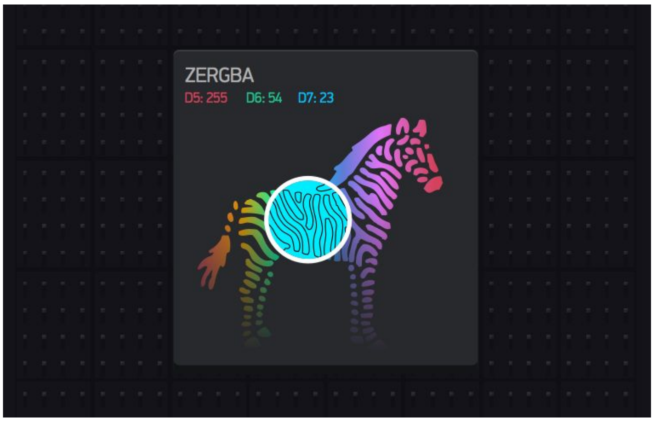
This on-off pattern can simulate voltages in between full on (3.3 Volts) and off (0 Volts) by changing the portion of the time the signal spends on versus the time that the signal spends off. The duration of "on time" is called the pulse width. To get varying analog values, you change, or modulate, that pulse width. If you repeat this on-off pattern fast enough with an LED for example, the result is as if the signal is a steady voltage between 0 and 3.3v controlling the brightness of the LED.

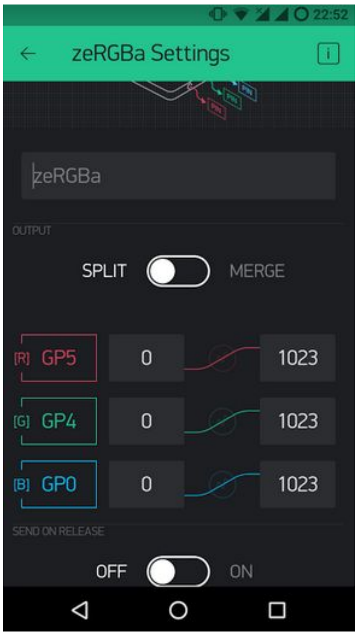
So in our case we choose three of the digital pins (D1, D2, D3) to connect the legs of Red, Green and Blue respectively. The cathode leg goes to GND pin. The diagram is as below:



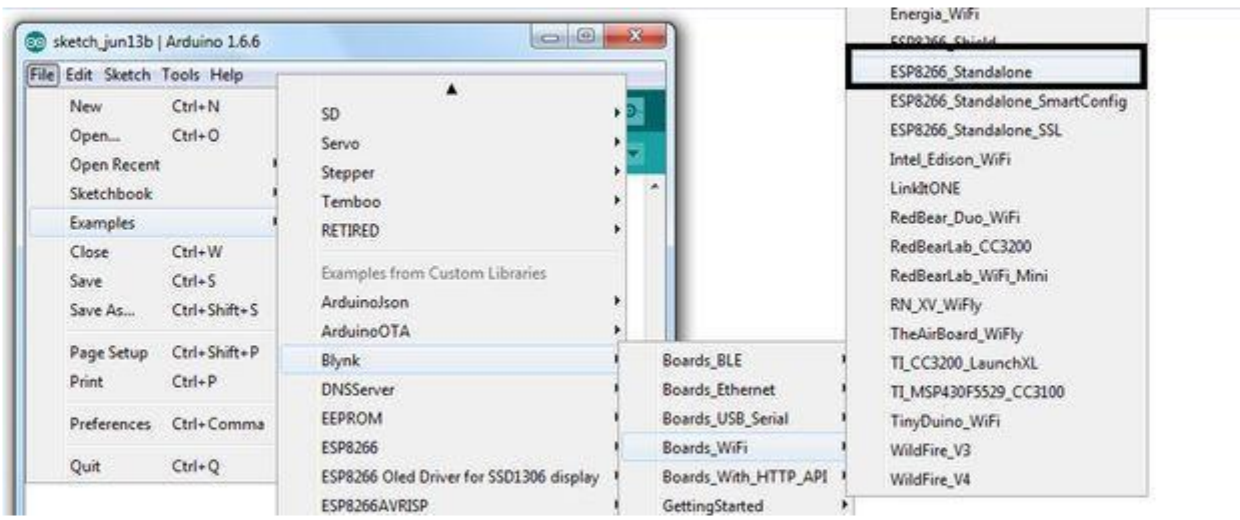
Then, create a new Project in Blynk app named "RGB LED". The auth key will be sent to your email address. You will need it later.

Place the ZeRGBa widget on the desktop of the project and adjust it based on the following screenshots:





The final step is to create the code that will transfer our (color) commands from Blynk to the RGB LED. We just need the default Blynk program that we used on a previous section. So, go to **File->Examples->Blynk-Boards_Wifi->Esp8266Standalone**



Change the credentials to yours. If you don't know them, ask the admins. The auth[] is the key that you received previously on your email. The ssid[] is the name of your WiFi network and the pass[] is the password.

char auth[] = "????????????";
char ssid[] = "XXXXXXXXXX";
char pass[] = "YYYYYYYYYYY";

Finally Save the file and Press Upload.

If all went according to the instructions, then you can choose the color you like on your mobile's screen and send it to the RGB LED.

2. Activating devices

Learning Outcomes

After the completion of this section the students will be able to:

- describe the Relay device and its uses
- create a circuit with a Relay and a NodeMCU to control a high or low voltage device with their smartphones
- build the code to make their smartphone communicate with the circuit
- create a Relay project in Blynk app

Using a relay to activate other devices

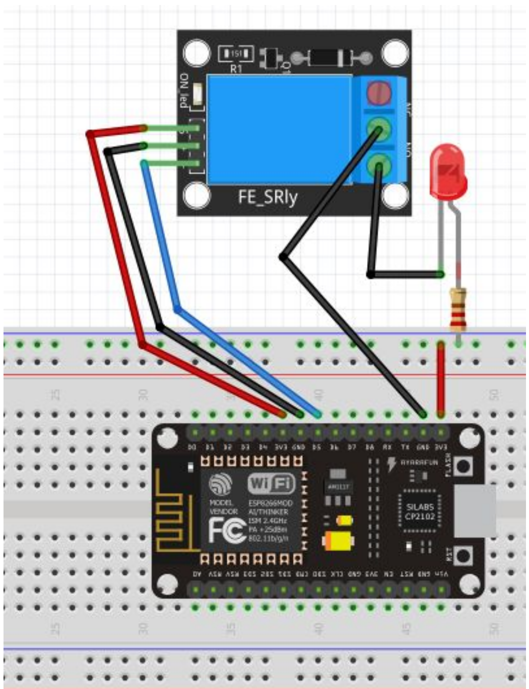
One of the most useful things you can do with the IoT is to control higher voltage (120-240V) devices like fans, lights, heaters, and other household appliances. Since the NodeMCU operates at 3.3V it can't control these higher voltage devices directly, but you can use a relay to switch the 120-240V current and use the NodeMCU to control the relay.

A Relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate the switch and provide electrical isolation between two circuits. In this project we will use a NodeMCU to control the relay. We will develop a simple circuit to demonstrate and distinguish between the NO (Normally open) and NC (Normally closed) terminals of the relay.

The NodeMCU can be programmed to turn on the relay when a certain event occurs, for example when the [temperature]() of a thermistor gets higher than 30° C. Or when the resistance of a photoresistor drops below 400 Ohms. Almost any sensor can be used to trigger the relay to turn on or off. The trigger doesn't even need to be from a sensor. It can occur at set time intervals, it can be triggered from the press of a button, or even when you get an email.

In our case we 'll build a circuit that will activate the relay whenever we press a button on our mobile into the Blynk application.

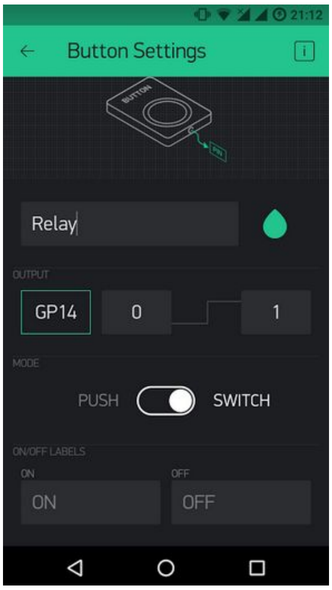
First of all we have to create the circuit below:

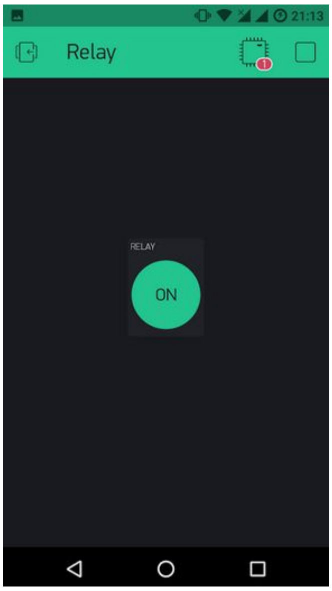


It is a simple circuit with a relay that is taking commands from D5 pin (GPIO **14**) and controls the device that is connected on the other side, which is a single LED. In place of a LED we can have any other device of high or low voltage that will take commands from the relay.

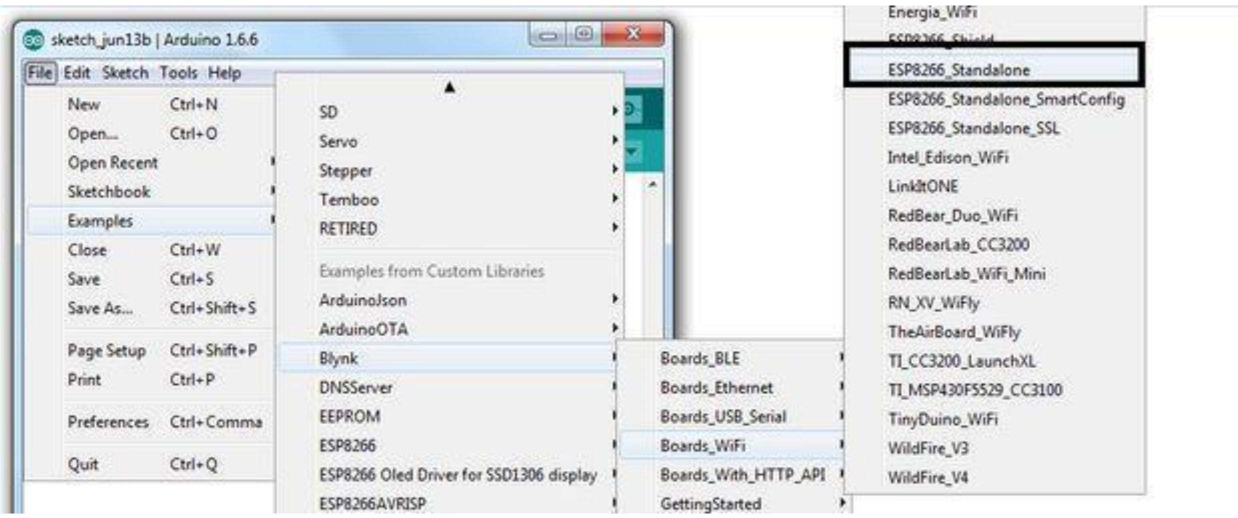
Then, create a new Project in Blynk app named "Relay". The **auth key** will be sent to your email address. You will need it later.

Place a button widget on the desktop of the project and adjust it based on the following screenshots:





Finally, we have to create the code into Arduino IDE. It is similar to the previous section. We just need the default Blynk program that we used on a previous section. So, go to **File->Examples->Blynk-Boards_Wifi->Esp8266Standalone**



Change the credentials to yours. If you don't know them, ask the admins. The auth[] is the key that you received previously on your email. The ssid[] is the name of your WiFi network and the pass[] is the password.

char auth[] = "????????????";
char ssid[] = "XXXXXXXXXX";
char pass[] = "YYYYYYYYYYY";

Finally Save the file and Press Upload.

If all went according to the instructions, then you can switch ON and OFF the LED.

3. Building an autonomous air-conditioner

Learning Outcomes

After the completion of this section the students will be able to:

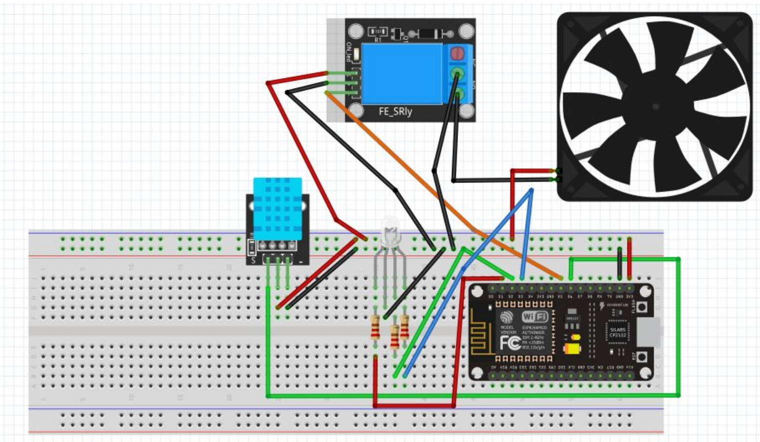
- create a circuit which uses many of electronic devices to simulate the operation of an autonomous Air-Conditioner
- build a program to automate the process and communicate with their smartphone
- create a Blynk project to supervise the history and the current environmental conditions of the place that the AC is installed

Learn how to activate the fan when the heat is on.

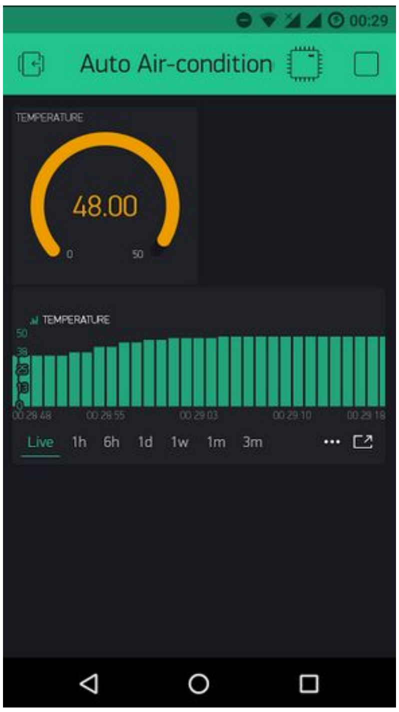
Now that we know all these about NodeMCU, sensors, Blynk, etc. let's try to build an autonomous air-conditioner. It will monitor the temperature and if it is under 20°C then the RGB LED will light BLUE. If it is above 20°C and under 25°C, the RGB LED will light GREEN. If it is between 25°C and 30°C the RGB LED will light ORANGE. And finally, if the temperature is over 30°C then the RGB LED will light RED and the relay will be turned ON, activating a fan or another LED to emulate this function.

All this time, we will be monitoring the temperature on our Blynk app watching also the history of the results.

The circuit diagram will be as below:



The Blynk project will be as simple as this screenshot:



The code is as below:

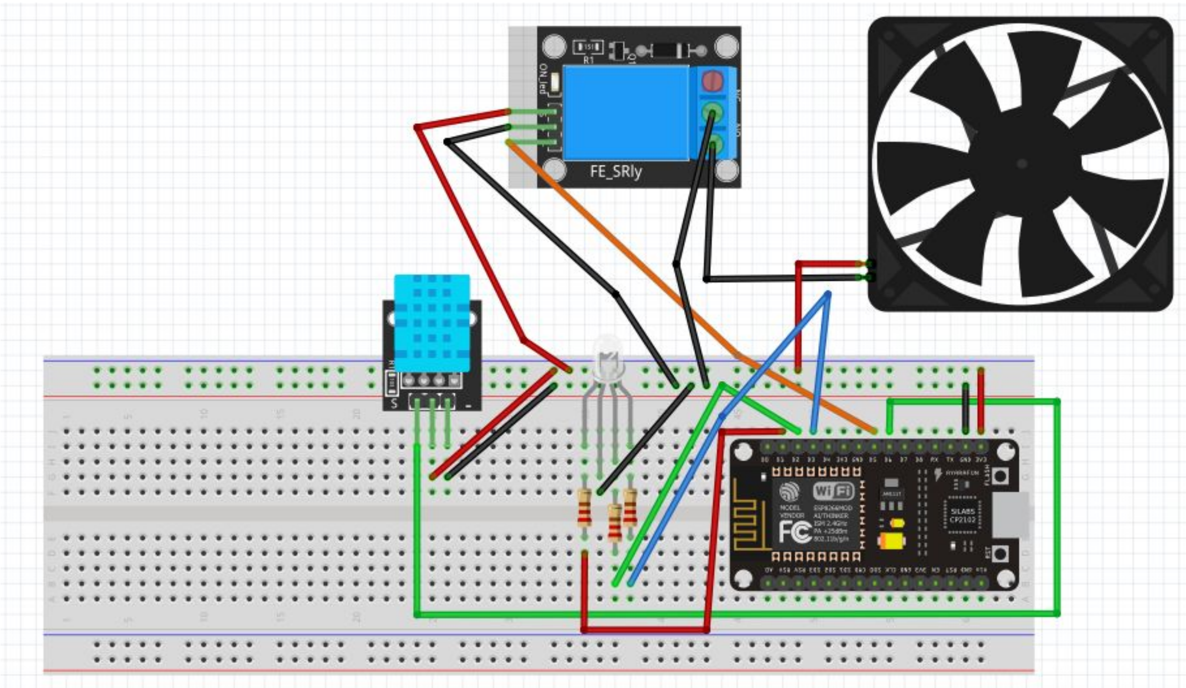
```
/*************************************************************
  Download latest Blynk library here:
    https://github.com/blynkkk/blynk-library/releases/latest

  Blynk is a platform with iOS and Android apps to control
  Arduino, Raspberry Pi and the likes over the Internet.
  You can easily build graphic interfaces for all your
  projects by simply dragging and dropping widgets.

    Downloads, docs, tutorials: http://www.blynk.cc
    Sketch generator:           http://examples.blynk.cc
    Blynk community:            http://community.blynk.cc
    Follow us:                  http://www.fb.com/blynkapp
                                http://twitter.com/blynk_app

  Blynk library is licensed under MIT license
  This example code is in public domain.

 *************************************************************

  This example shows how value can be pushed from Arduino to
  the Blynk App.

  WARNING :
  For this example you'll need Adafruit DHT sensor libraries:
    https://github.com/adafruit/Adafruit_Sensor
    https://github.com/adafruit/DHT-sensor-library

  App project setup:
    Value Display widget attached to V5
    Value Display widget attached to V6
 *************************************************************/

/* Comment this out to disable prints and save space */
#define BLYNK_PRINT Serial


#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <DHT.h>

// You should get Auth Token in the Blynk App.
// Go to the Project Settings (nut icon).
char auth[] = "??????????????????????";
```

```
// Your WiFi credentials.
// Set password to "" for open networks.
char ssid[] = "XXXXXXXXXXXXXXX";
char pass[] = "YYYYYYYYYYYYYYYY";

#define DHTPIN 12         // What digital pin we're connected to

// Uncomment whatever type you're using!
#define DHTTYPE DHT11     // DHT 11
//#define DHTTYPE DHT22   // DHT 22, AM2302, AM2321
//#define DHTTYPE DHT21   // DHT 21, AM2301

int redPin = 5;
int greenPin = 4;
int bluePin = 0;

DHT dht(DHTPIN, DHTTYPE);
BlynkTimer timer;

// This function sends Arduino's up time every second to Virtual Pin (5).
// In the app, Widget's reading frequency should be set to PUSH. This means
// that you define how often to send data to Blynk App.
void sendSensor()
{
  float h = dht.readHumidity();
  float t = dht.readTemperature(); // or dht.readTemperature(true) for Fahrenheit

  if (isnan(h) || isnan(t)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }
  else {
    Serial.println(t,0);
    if (t <20){
      digitalWrite(14, LOW);

      analogWrite(redPin, 0);
      analogWrite(greenPin, 0);
      analogWrite(bluePin, 255);
      }
    else if (t <= 25 && t >=20) {
      digitalWrite(14, LOW);
```

```
 analogWrite(redPin, 0);
   analogWrite(greenPin, 255);
   analogWrite(bluePin, 0);
   }
  else if (t > 25 && t <= 30) {
   digitalWrite(14, LOW);

   analogWrite(redPin, 255);
   analogWrite(greenPin,93);
   analogWrite(bluePin, 0);
  }
  else {
     digitalWrite(14, HIGH);

     analogWrite(redPin, 255);
     analogWrite(greenPin, 0);
     analogWrite(bluePin, 0);
  }
 }
 // You can send any value at any time.
 // Please don't send more that 10 values per second.
 Blynk.virtualWrite(V5, h);
 Blynk.virtualWrite(V6, t);
}

void setup()
{
 // Debug console
 Serial.begin(9600);

 Blynk.begin(auth, ssid, pass);
 // You can also specify server:
 //Blynk.begin(auth, ssid, pass, "blynk-cloud.com", 8442);
 //Blynk.begin(auth, ssid, pass, IPAddress(192,168,1,100), 8442);

 dht.begin();

 // Setup a function to be called every second
 timer.setInterval(1000L, sendSensor);

 pinMode(redPin, OUTPUT);
 pinMode(greenPin, OUTPUT);
 pinMode(bluePin, OUTPUT);
```

```
 pinMode(14, OUTPUT);
}

void loop()
{
  Blynk.run();
  timer.run();
}
```

You can play with the limits that the RGB LED changes color and try the setup with a hot air blower.



Chapter Four: IoT in Agriculture

I. Precision Farming

Learning Outcomes

After the completion of this section the students will be able to:

- Identify Precision Agriculture (PA)
- Understand different implementations of PA
- Identify Unmanned Air Vehicles / Drones
- Understand how data are collected for PA applications
- Identify the four stages of a Precision Agriculture Cycle

1. Introduction

Precision agriculture (PA) is an integrated information and agricultural management system that is based on several technical tools such as global positioning system, geographical information system and remote sensing. It is designed to increase whole farm production efficiency with low cost effect while avoiding the unwanted effects of chemical loading to the environment. The goal of precision farming is to gather and analyze information about the variability of soil and crop conditions in order to maximize the efficiency of crop inputs within small areas of the farm field. To meet this efficiency goal the variability within the field must be controllable.

PA is also a whole-farm management approach using information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimising returns on inputs whilst potentially reducing environmental impacts. The simple description of the PA is a way to "apply the right treatment in the right place at the right time" (Gebbers and Adamchuk, 2010) and the purpose is to improve performance, production, and economic and environmental quality.

Finally, PA is an innovation in agriculture allowing the right treatment of crops and livestock at the right time with the smallest scale possible (up to treatment of individual plants or animals). It will become the 'license to produce' for farmers in the EU. Technology for practicing PA has become available to farmers during the last decades, such as Farm Management Information Systems (FMIS) and Global Navigation Satellite Systems (GNSS) and various sensors. They pave the way for implementation of PA as a farming concept.

GNSS allows linking data to specific geographical coordinates (georeferencing) and this can be combined with auto-guidance of machines. Controlled Traffic Farming (CTF) and auto-guiding systems are the most successful applications on arable land showing clear benefits in nearly all cases. For Variable Rate Application (VRA) methods, such as optimizing fertilizer or pesticide use to areas of need, the success varies greatly according to the specific factors of the application.

Many sensors are currently available and used for data gathering or information provision as part of the PA implementation. Devices exist to assess the status of soils, to record weather information or micro-climate data, to quantify the physiological status of crops and they are based on remote sensing principles. Special interest is devoted lately to the use of low-cost light-weight unmanned aerial vehicles (UAV) often called drones, but now more correctly termed remotely piloted aerial systems (RPAS), initially developed for military purposes which are now being applied in civil applications. RPAS are already available and operational, enabling the generation of very-high resolution (2 to 10 cm) farm-level imagery.

2. Why precision agriculture?

The world population continues to increase and is projected to reach 10.0 billion in the year 2050 (Lutz et al., 1997). The production of agricultural products is important to everyone and producing food in a cost effective manner is the goal of every farmer, large scale farm manager and regional agricultural agency. A farmer needs to be informed to be efficient, and that includes having the knowledge and information products to forge a viable strategy for farming operations. These tools will help him understand the health of his crop, extent of infestation or stress damage, or potential yield and soil conditions. Commodity brokers are also very interested in how well farms are producing, as yield (both quantity and quality) estimates for all products control price and worldwide trading. Precision agriculture deals with the study of the application of technology to produce agricultural products to fulfill worldwide food requirements as compared to conventional agricultural methods and lower adverse impact on the environment.

3. Data collection

Data collected by different sensors should be geo-referenced into maps to provide information on crop physiological status and soil condition status, through Geographic Information Systems (GIS). In particular, models are needed in order to understand the causalities and interrelations between plant, soil and climate before inputs can be spatially adjusted. A FMIS is a system for collecting, processing, storing and disseminating data in the form of information needed to manage the farm. It is made available to farmers through consulting, advisory and training services. Public service advice is generally very limited.

Applications of PA include auto-guiding systems and variable-rate technology that allow for precise tillage, seeding, fertilization, irrigation, herbicide and pesticide application, harvesting and animal husbandry. Crop management and aspects of animal rearing are optimized thanks to the use of information collected from sensors mounted on-board agricultural machinery (soil properties, leaf area, animal internal temperature) or derived from high resolution remotely sensed data (plant physiological status). The benefits to be obtained include increased yields and profitability (mainly for arable farmers), increased animal welfare, and improvement of various aspects of environmental management.

PA can play a substantial role in meeting the increasing demand for food while ensuring the sustainable use of natural resources and the environment. Nevertheless, the size and diversity of farm structures make its adoption in Europe challenging. According to the EP’s report awareness-raising and information campaigns among farmers should take place, appropriate guidelines are needed, and an EU 'precision farming calculator' tool which would bring decision-support value to farmers and advisers should be developed. This should be accompanied by research and development studies.

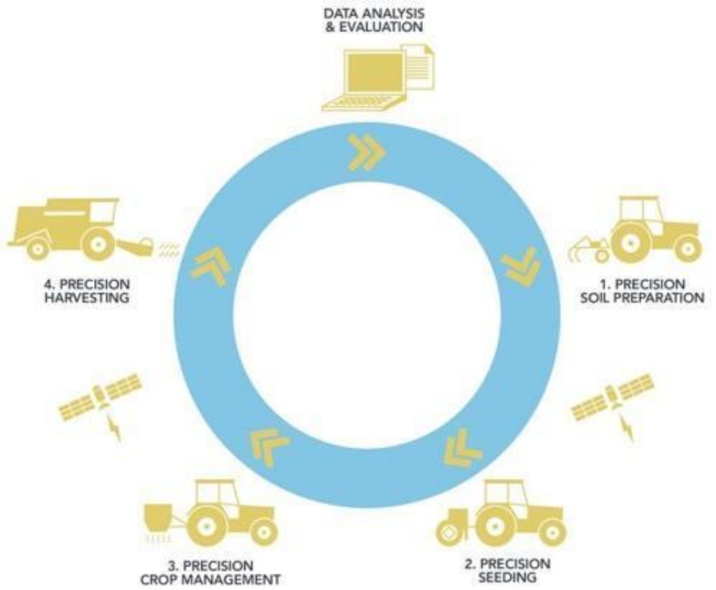
4. Integrated system of Precision Agriculture

The whole process of an integrated system of PA separates in 4 stages (Precision farming cycle). The first one has to do with all data collection that are useful for elaboration such as production maps, results of soil analysis and other chemical analyzes. During the cultivated period more data are gathered such as weather data, crop protection and seed treatment (Elms & Green, 1997). Many of this stage processes can be automated through the use of appropriate systems and sensors.

The second stage concerns the analysis and elaboration of the collected data. The way in which data of each system are combined depends on the cultivation and the algorithm that has been used (McCauley, 1999, McKinion et al., 2001). At this stage the use of an appropriate database for the exportation of results is needed (library). The ultimate purpose is to define management zones within a parcel, which are characterized by common soil or agronomic and oenological characteristics (Blackmore et al., 2003). The third stage involves the implementation of field work and oenological interventions, according to the results of the previous stage. At this point it is necessary to adapt the equipment that is used to support the application of variable crop needs (variable rate application - VRA) in each of the field management zones (Bowers et al., 2001).

The fourth stage concerns the evaluation of the techniques applied which helps in the next year planning. The mapping of production and other parameters can be the starting point for the creation of management zones but also can be a point evaluation of the previous year.

5. Precision farming cycle



II. Unmanned Air Systems (Drones)

Learning Outcomes

After the completion of this section the students will be able to:

- Identify the types of drones
- Identify the main parts of a drone
- Identify the advantages of drones vs manned vehicles vs satellite

1. Types of Drones

Drones or UAVs are flying robots. There are three types of drones:

- Fixed-Wing systems: typical airplane shapes
- Rotary-Wing systems: single or multirotor systems
- VTOL wings: Wing-copters

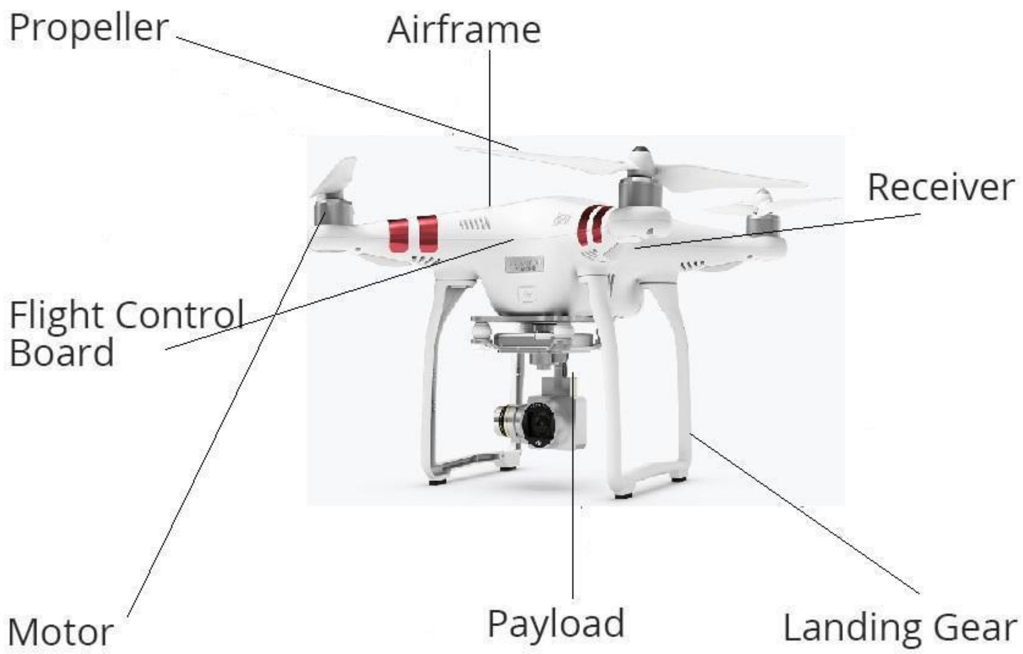
Respectively these categories look like this:

Images source: Geosence, Thessaloniki, Greece

2. Drone parts

The main parts of a UAV or drone include the:

- propeller
- airframe
- motor
- receiver
- payload
- flight control board
- landing gear



Phantom III mondel by DJ

3. Fixed wing vs Rotary wing

Fixed - Wing

+ Aerodynamic shapes
+ Less complicated designs and electronics
+ Simple/Easy maintenance
+ Fly more time
+ Fly in higher speed
+ More wind resistant
+ In case of stall they glide
- Need space to take off
- Need space to land
- Cannot loiter
- More expensive

Cover big areas in one battery
Mapping/surveying
Precision agriculture
Border patrol
Study of phenomena
SaR
Wing span
Battery powered or fuel motor

Rotary - Wing

+ More complex designs (3 - 4 - 6 – 8 rotors)
+ Relative cheap
+ Vertical take off
+ Vertical Landing
+ Loiter
- Complicated electronics
- A lot of moving parts
- Complex maintenance
- High demand of power
- Less wind resistant
- Fly less time
- Reduced cruising speed
- If they stall, they crash

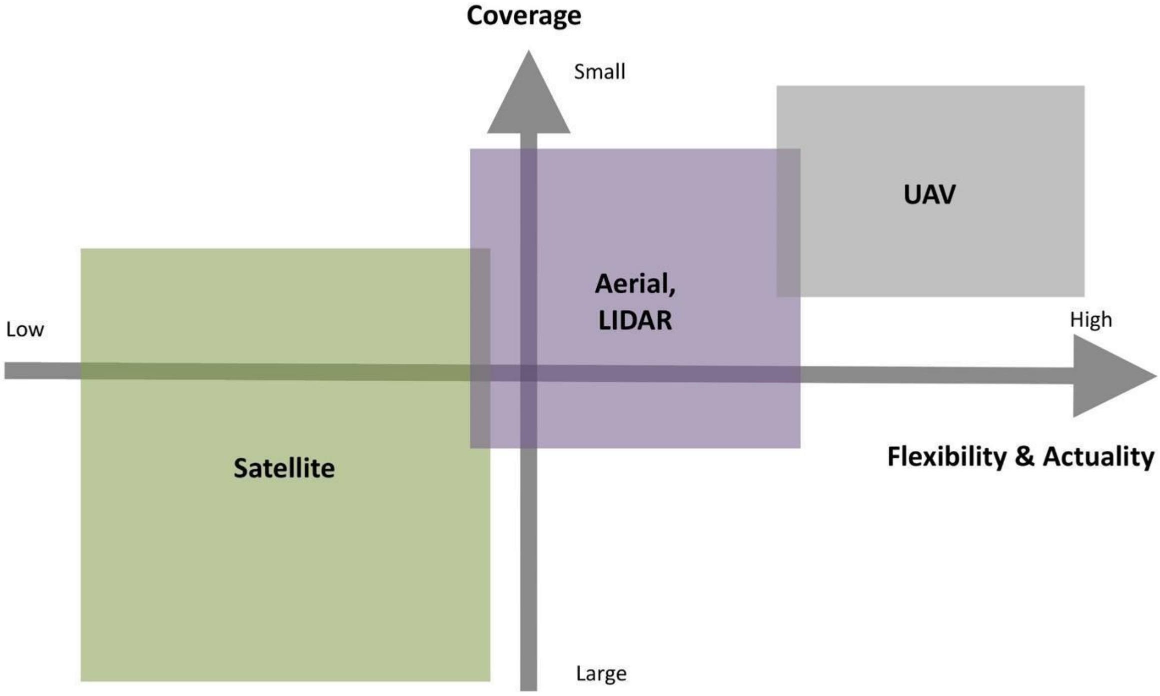
- Inspection and close mapping
- Industrial inspection
- Construction inspection
- Oblique images
- Small scale mapping
- Filming
- SaR
- Diagonal length between rotors
- Battery powered motors
- Recovery if a rotor fail (applies to 8 + rotor systems)

References

Introduction to Modern UAV Photogrammetry, PowerPoint Presentation, Geosense, Thessaloniki, Greece Vital UAV Operation, I1 Cert, Online Training Course, FlyingIQ, USA

4. Drones vs Manned vs Satellite

A comparison among unmanned (drones), manned and satellite related to the coverage of a surface.



The UAVs are more flexible tools and they can provide data at the exact time we need it, compared to satellites or even manned air vehicles. Satellites can cover an area only at certain times (when they pass above it), where manned need a pilot, are expensive and if the area is not accessible or weather conditions are not suitable the data cannot be obtained on time.

UAVs or drones can fly theoretically whenever we need them, they can provide big data in a short time and there is no risk for human life (no pilot).

How it looks like an image from a drone, a manned air vehicle and a satellite respectively? Imagine a strawberry, it will be like this:

Chart and images source: Geosense, Thessaloniki, Greece

III. Drones in Agriculture

Learning Outcomes

After the completion of this section the students will be able to:

- Describe the three main PA management strategies
- Enumerate the benefits of smart farms
- Examine the plant health in a crop field
- Measure fields and other crop parameters
- Measure water stress

1. Precision Agriculture management strategies

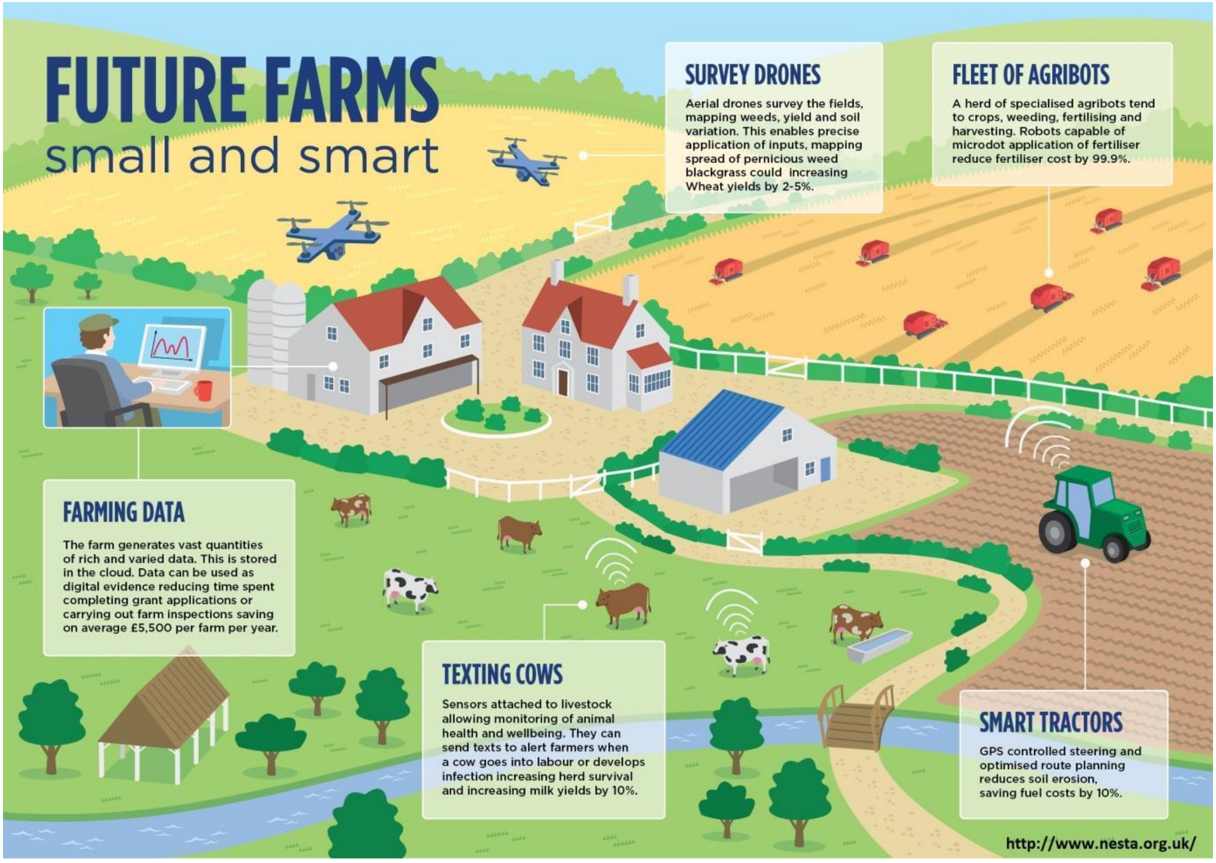
As perception, PA is not identified with any particular management tactics. It simply allows the administrator (producer, agronomist, consultant, company or expert system) to better understand and control handling of parcels. Since Precision Agriculture is developed in an integrated system, the various management strategies become possible to describe (even integrated into special software) provide constant and consistent practices, especially with regard to their effects on the environment.

Three are, in general, three main strategies that can be applied (Blackmore, S., 1994):
Strategy A: Protection of production - Large quantities of inputs - No interest in the environment. Unique will of the farmer is to improve and protect the production. The environmental criteria deliberately are not considered and high amounts of inputs are used. The spatial variables input quantities are financially the best and simultaneously capable to maintain low or no levels of weeds.

Strategy B: Reduced inputs - Ultimate collection - Moderate environmental concern. A higher level of risk for loss of production is accepted and inputs are limited to economically optimal levels, according to the degree of the risk undertaken. Environmental considerations are taken into account, but not clearly defined and the input quantities are such that keep pests and diseases at moderate levels. The lubrication applied in the most economically optimal values.

Strategy C: Reduced inputs - High interest in the environment. Environmental protection comes first, either because of the understanding of its importance (environmentally conscious), or due to financial incentives (financial support, subsidies, agro-tourism, etc.). The applied input quantities are such that keep the enemies and diseases in moderate levels. Inputs apply on prices economically lower than the optimal, but high enough to prevent significant yield losses.

A typical smart farm



http://www.nesta.org.uk

2. Benefits of the use of drones

The use of drones in agriculture will provide the farmer with specific benefits such as:

- Availability of many different sensors
- Easy of use
- Fast and accurate scouting
- Accurate spatial reference
- Cut down costs in fertilizers and prescriptions
- Assess any action taken
- Production forecast
- Decision support tools
- Traceability

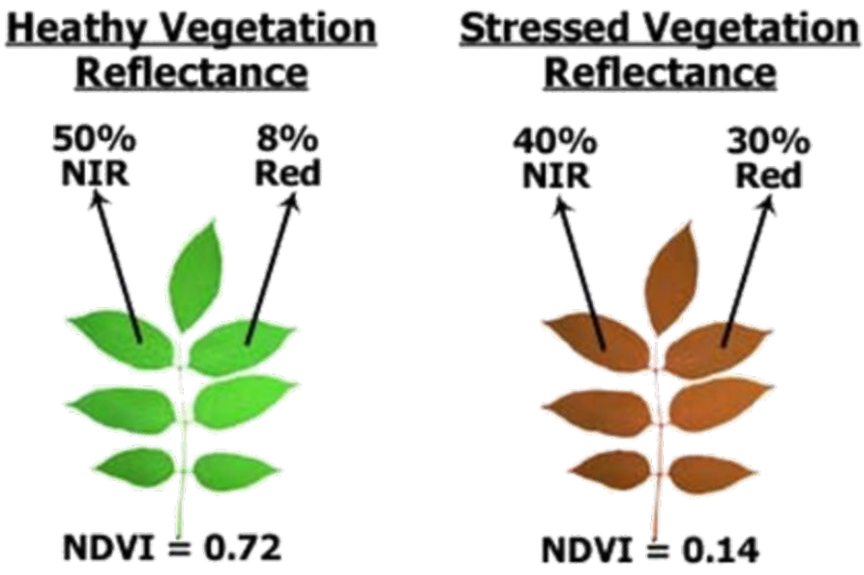
An example is in rice in Japan, where the use of drones has increased the production yield by 15% and decreased the production cost by 30%!!!

In Greece the use of drones in cereals, rice or other crops is limited or does not exist according to a survey that took place in 2015, in which the researchers/authors have studied if the farmers were familiar with the use of drones in agriculture and if they have ever heard about their benefits to crop production.

The results can be found in the following paper:
Trivellas A., Perdikaris A., Barmpagalou A. (2015). The use of unmanned aircrafts on precision agriculture, GREEN-AgriChains 1st International Conference of Agrifood Supply Chain Management (SCM) and Green Logistics, May 2015, Thessaloniki, Greece

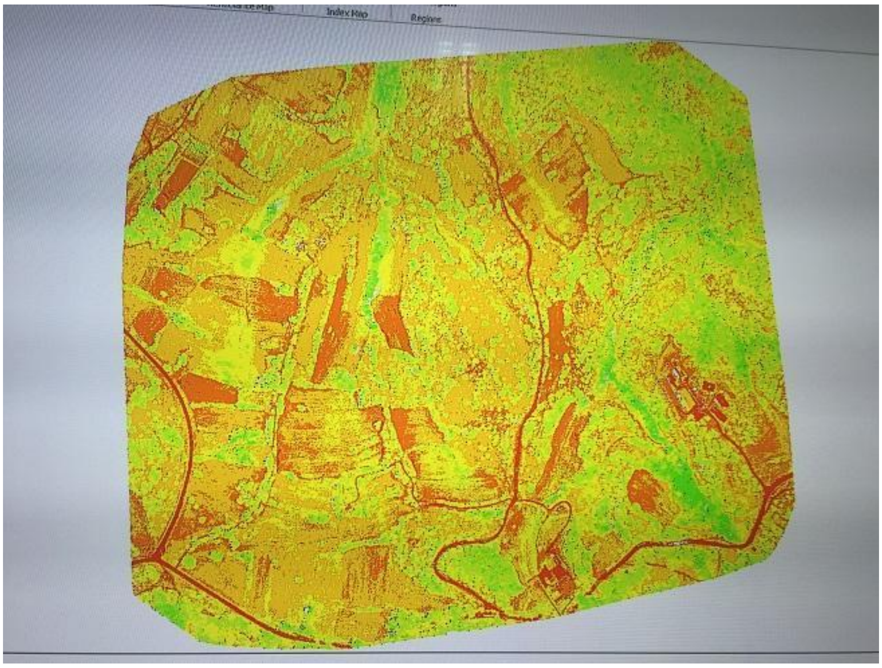
3. Measuring Plant Health

By measuring the NVDI index we can examine the plant health in a crop field. The NVDI index can be calculated according to the following scheme:



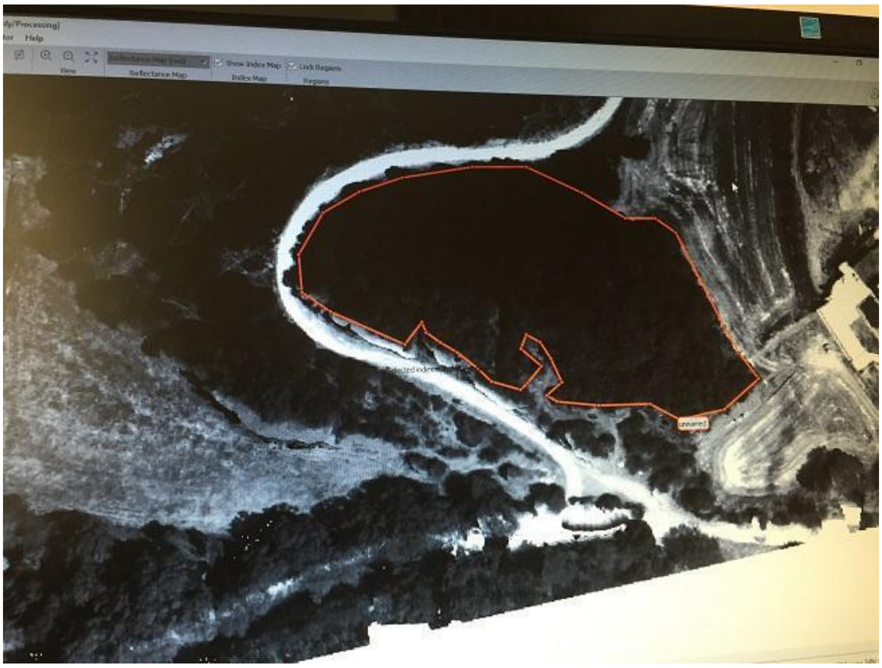
$$NDVI = \frac{NIR - Red}{NIR + Red}$$

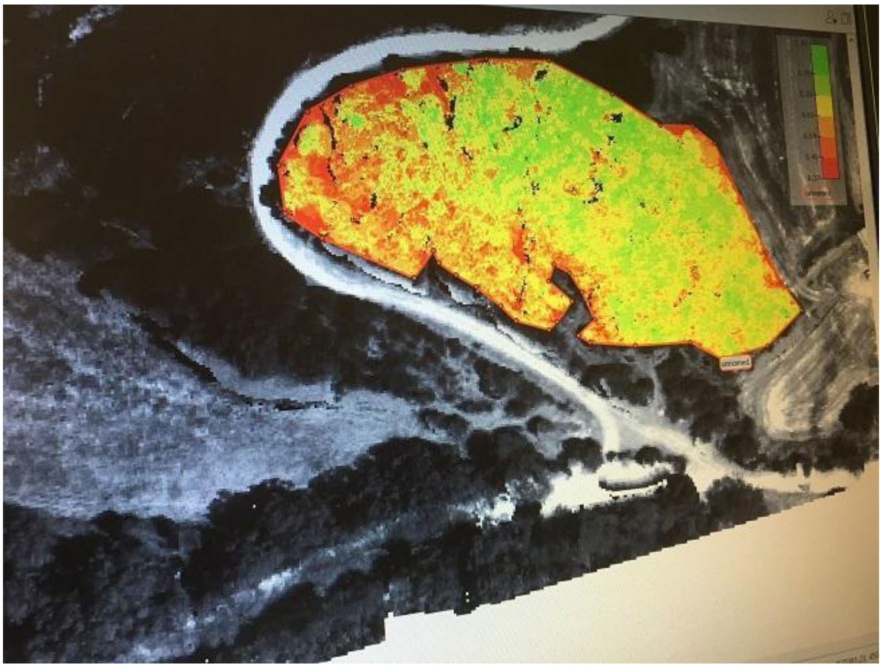
Let's describe a real case that took place in July 2016, in the North of the second capital of Greece, Thessaloniki, where cereals are cultivated. At that time cereals had just been harvested, thus there were no crops in the fields. Only limited areas covered from trees. The whole process takes 15 minutes for scouting an area of 7Ha, almost 280Ha in less than an hour!!! The image processing takes place in our office, producing a reflectance map and an index map (e.g. NDVI). The result of looks like this:



The first image corresponds to a RGB camera and the second presents nvdi index of the same area. See the variability even for small areas.

See also the following example, which is proof that Precision Farming can offer a lot even to small farms:



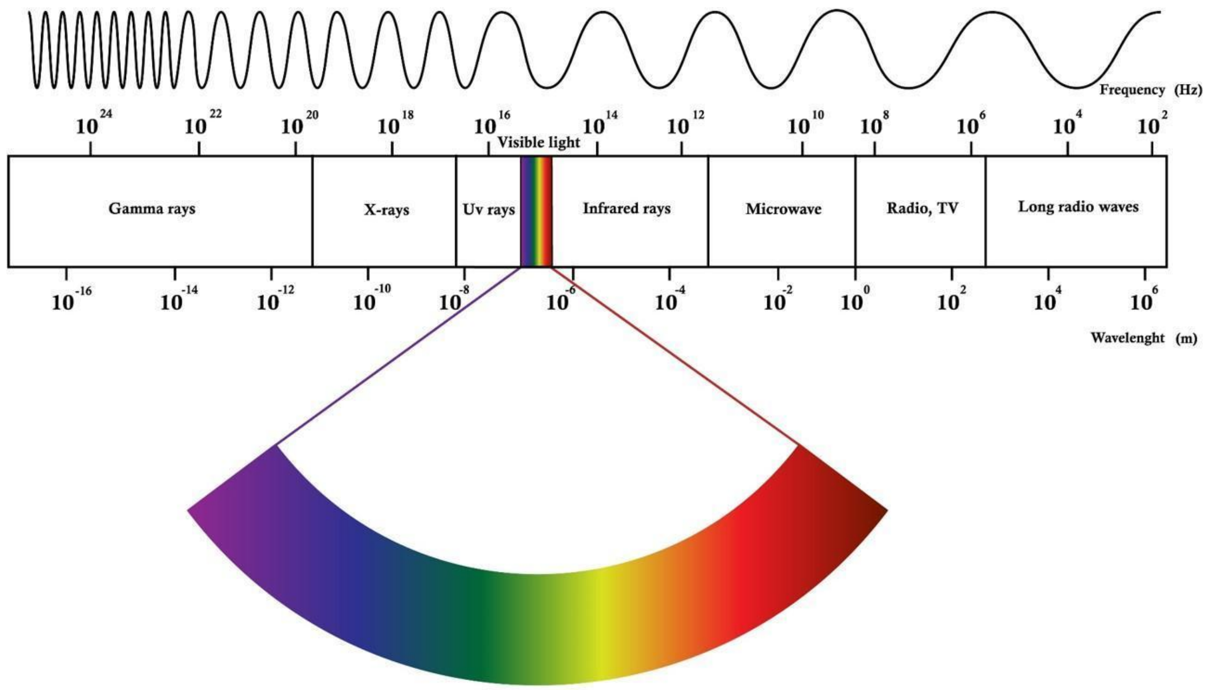


The area corresponds to 0.1Ha! See the plant health situation close to roads, marked with green (healthy) and red (not health or absence of plants) and diversity for such a small field!

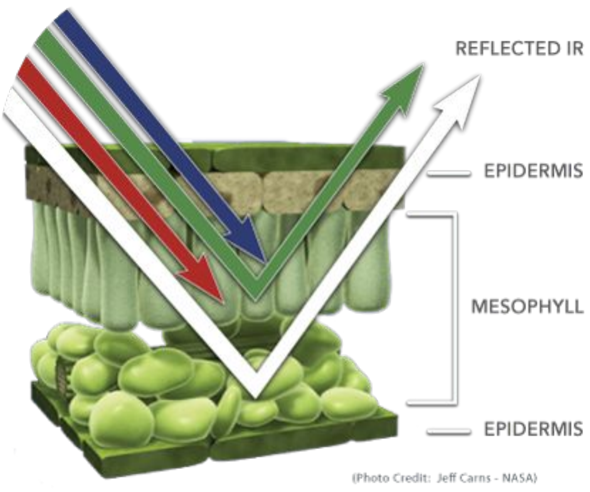
What do we really measure in this case? See next chapter and what NDVI index is.

4. How the NDVI index is measured

One of the most important processes on earth is photosynthesis. The following image shows what is really happening with light when it falls on a leaf. The light consists of different wavelengths, it is like if we see through a prism, many different wavelengths make up the spectrum of sunlight, as shown in the image follows:



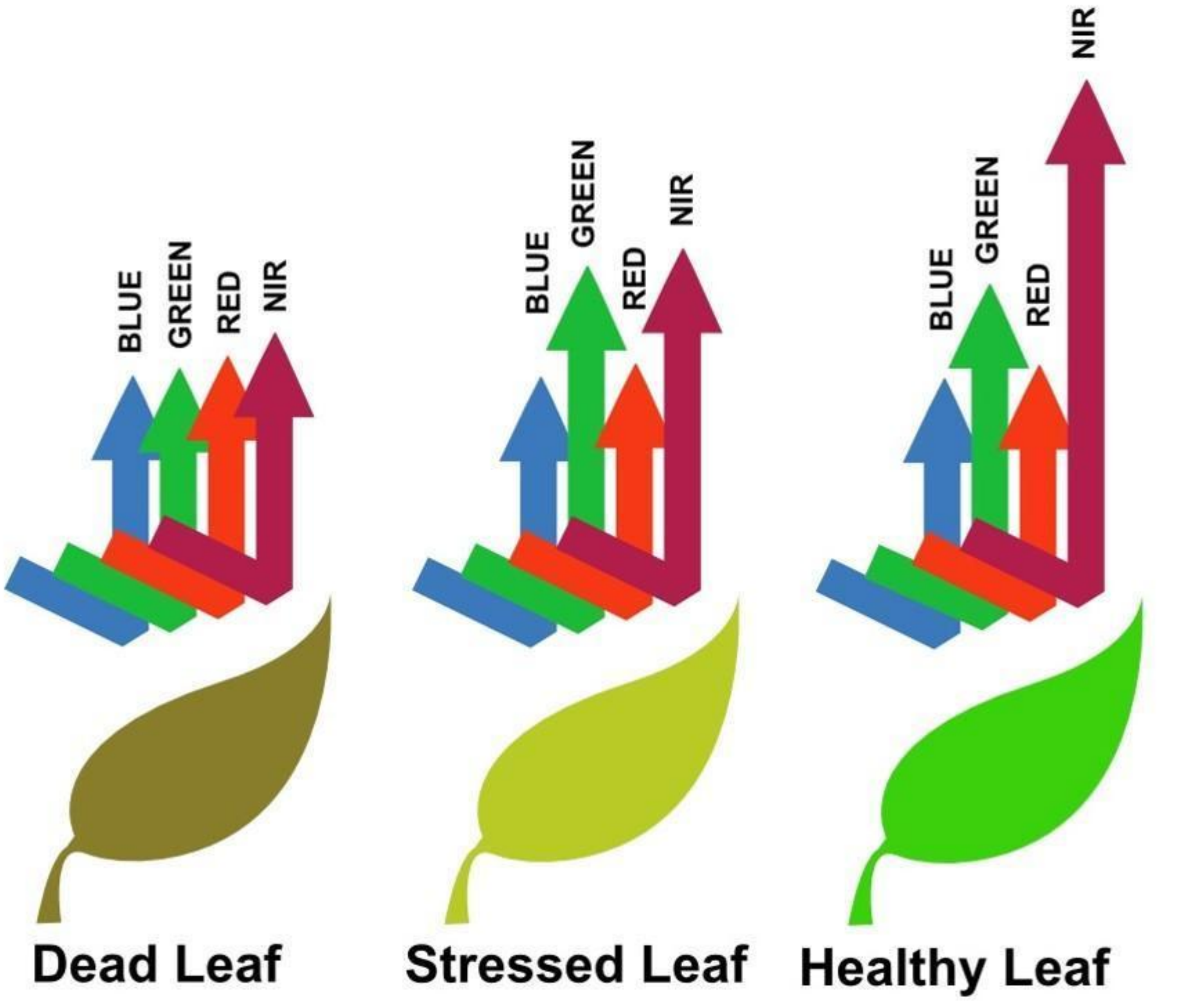
What we do is to study the absorption and reflection in various wavelengths.



When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm)

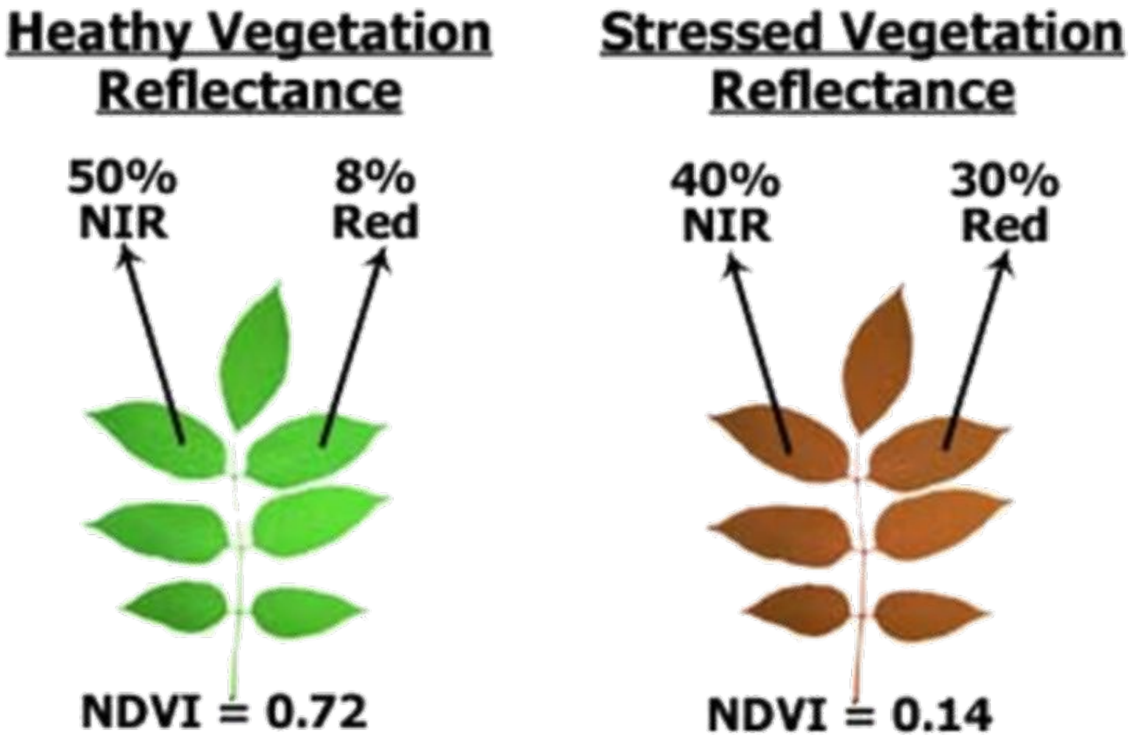
Depending on the reflection we get as seen in the following image we can conclude the condition of the leaf and generally the whole plant.

The wavelengths reflected are different from a quantitative point of view as can be seen:



And at this point comes the NDVI index. NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation (right) absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (left) reflects more visible light and less near-infrared light.

If we consider it with a more quantitative view, as seen from the following image NDVI corresponds to:

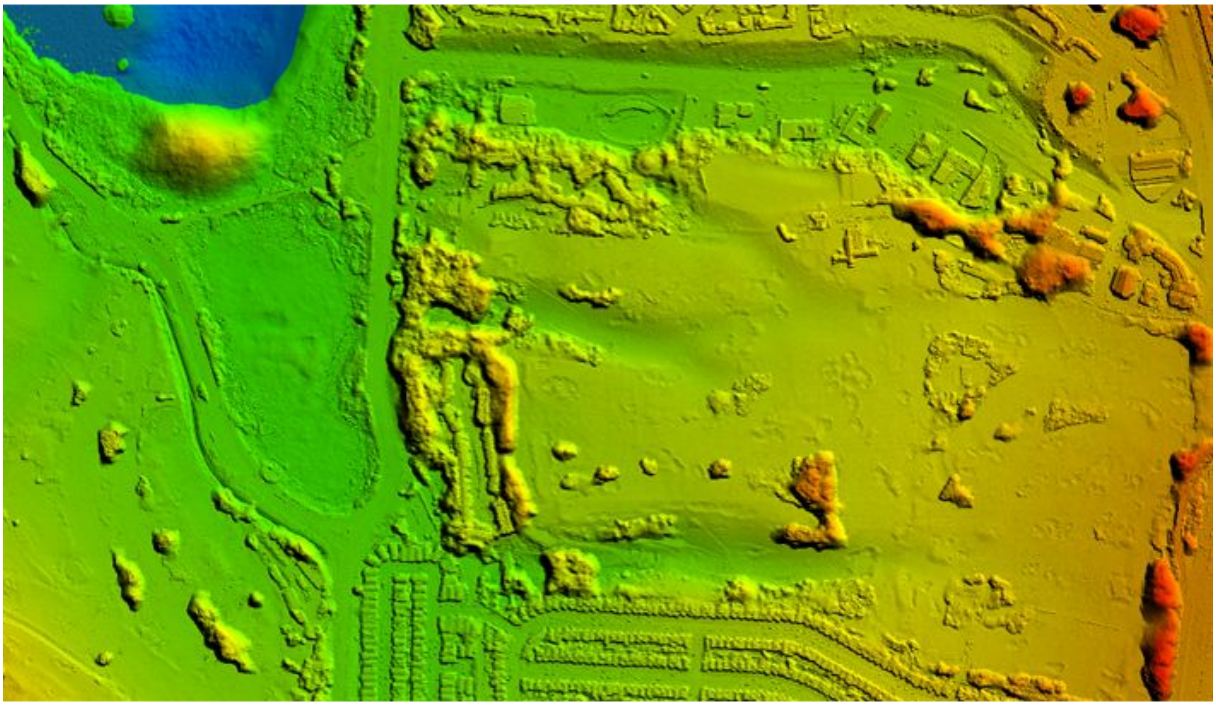


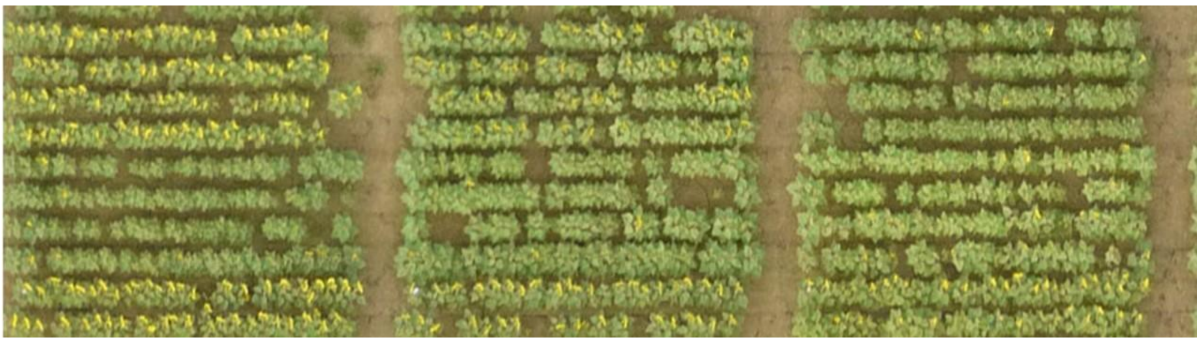
$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Values of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1), however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest density of green leaves.

5. Measuring fields and other crop parameters

It is possible to measure several field parameters such as inclination or heights (1st image), as well as some crop parameters such as volume and crop size or flourish (2nd and 3rd images, clockwise).





Images provided by Geosense, Thessaloniki, Greece

6. Measuring water stress

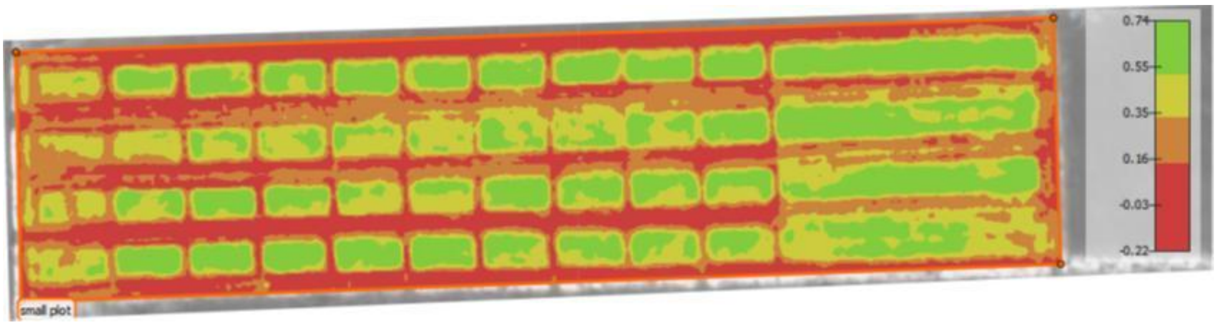
NDVI can be used as an indicator of Drought. What it is measured is the difference between the average NDVI for a particular month of a given year and the average NDVI for the same month over the last 20 years. This difference is called NDVI anomaly.
We accept the hypothesis that in most cases vegetation growth is limited by water, thus the relative density of vegetation is a good indicator of agricultural drought.

It is obvious that in order to estimate the drought it is essential to have data from past years.

7. Example: Precision agriculture in rice fields

Precision farming is focusing on the optimization of agricultural inputs such as fertilizers, pesticides, water etc. and on increasing the yields, reducing the cost of cultivation and minimizing the environmental impact through specific management related to time and place.

The following image is a NDVI view of a rice field. The colours correspond to cm per pixel and the value above 0.4 correspond to healthy plants. Even in small fields (this is an experimental field) the diversity is obvious.



Rice Experimental plots, NDVI Index
5m x 3m = 83 x 50 pixel = 4150 pixel per plot

Image source: Geosense, Thessaloniki, Greece
Sources used in this unit:

- http://future-farmer.eu/
- https://www.youtube.com/watch?v=tbkTi3zNN9s
- https://www.youtube.com/watch?v=du7wJX6hEP4
- https://youtu.be/1KxgsLzd1-8

Resources to follow-up

This publication presents concrete learning scenarios that we validated in the course of project activities in the three partners' countries: Greece, Italy and Poland. We made an effort to make them as practical as possible to facilitate adoption of our ideas across the boundaries of formal and non-formal VET and thus encourage follow-up programmes by other organisations.

The learning scenarios are modularised and cover various areas of VET curriculum in line with the expertise of our organisations. While designing them we were drawing on a wide range of publications and online resources which are worth consulting by other teachers who may plan to enrich their training programme. In what follows we thus summarise the most useful and accessible resources with brief information on their content and relevance. They are grouped here into the specific themes covered by the publication.

3D modeling

Tinker CAD: This software runs directly in the web browser and uses boolean modeling to create objects. In practice, one form is added to or subtracted from another to create increasingly complex objects. Easy to learn and free. Very useful for those approaching 3D modeling for the first time.

Free CAD: Open source and multi-platform software for 2D and 3D CAD modeling. Very simple to use and with numerous tutorials and a very large community Network.

Blender: One of the most comprehensive open source 3D modeling software, whose features compete with the most famous commercial software. For this reason it is one of the most used programs. The documentation that can be found on the web and as paper manuals is very wide, but perhaps, given its characteristics, even among the most difficult to learn.

Zbrush: One of the most widespread software in the world for digital sculpture. Not particularly easy to learn however at an affordable price.

Sculptris: Very simple and intuitive program to approach the world of digital sculpture. From the same Z-Brush software house.

Rhinoceros: It is used in various fields, in design it has become a standard tool. Characterized by an easy-to-learn interface and a fairly affordable price, it is possible to use the trial version for 90 days, enough time to learn it and to evaluate the eventual purchase.

3DCoat: A very affordable professional software that allows you to create organic forms and sculpture 3D models through digital tools and polygonal constructions. Equal to Z-Brush features.

SketchUp: It is a web-based 3D modeling software with a wide range of applications for interior design, architecture, engineering and video game design. Its basic version is free and thus easily accessible for the students who want to enlarge their digital toolbox.

3D printing

3DSourced: its overarching goal is to become the most informative 3D printing web source. The presented content is carefully vetted with attention dedicated to removing commercially-influenced bias. The platform provides comprehensive guides to 3D printers, 3D printing technologies, software, scanners, services, brands, and more.

Thingiverse: A large online database with ready STL files, which can be printed on any FDM printer. Contains models in many different categories and welcomes uploads of objects designed by users.

All3dp is one of the leading 3D printing magazines with more than 2 million users per month.
Aimed at both beginners and professionals, All3DP.com provides compelling content that is useful, educational, and entertaining.

Yeggi is a search engine for printable 3D models, collecting data from all 3D communities and marketplaces offering 3D models to print. It will give you the best results to find 3D models on the internet. Online since 2013 with an extensive index.

Cura: slicing software used for preparing STL files for printing, one of the most popular on the market. You can prepare prints with a few clicks, integrate with CAD software for an easier workflow, or dive into custom settings for in-depth control.

Internet of Things

Arduino: An open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

NodeMCU: An open source software and hardware development environment that is built around a very inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains all crucial elements of the modern computer: CPU, RAM, networking (wifi), and even a modern operating system and SDK. When purchased at bulk, the ESP8266 chip costs only $2 USD a piece. That makes it an excellent choice for IoT projects of all kinds.

Blynk was designed for the Internet of Things. It can control hardware remotely, it can display sensor data, it can store data, visualize it and do many other cool things. There are three major components in the platform: Blynk App - allows you to create amazing interfaces for your projects using various widgets we provide. Blynk Server - responsible for all the communications between the smartphone and hardware. You can use the Blynk Cloud or run your private Blynk server locally. It's open-source, could easily handle thousands of devices and can even be launched on a Raspberry Pi. Blynk Libraries - for all the popular hardware platforms - enable communication with the server and process all the incoming and outcoming commands.

References

1. NURBS is an acronym for *Non Uniform Rational B-Splines*). Quite simply, NURBS are a mathematical representation through which it is possible to accurately define 2D and 3D geometries such as lines, arcs and free-form surfaces.

2. Miriam Graziano “Bambino ridente di Desiderio da Settignano – Intervento di restauro” Corso “fresco”, CER – Scuola professionale Edile e CPT di Firenze

3. Miriam Graziano “Bambino ridente di Desiderio da Settignano – Intervento di restauro” Corso “fresco”, CER – Scuola professionale Edile e CPT di Firenze

4. Miriam Graziano “Bambino ridente di Desiderio da Settignano – Intervento di restauro” Corso “fresco”, CER – Scuola professionale Edile e CPT di Firenze

5. Traditionally, a work has been studied through direct manipulation and visual inspection, an operation granted to a limited number of experts, with time and space limitations. Other studies can be done through two-dimensional images that depend on the specific point of view and specific lighting. The disclosure of the 3D survey allows to expand the number of scholars who can analyze the work in its complete form, from any point of view, for an unlimited time, in any place, independent of the type of lighting and without the risk of damaging the 'original.