FabLab from A to Z

Sustainable Prototyping of Measurement Instruments and Components for Experiments in Advanced Physics and Related Fields

The FabLab Implementation Roadmap in the EL-BONGO physics Project

June - 2026

Content

List of acronyms and abbreviations

Table 1

Acronyms and abbreviations

Acronym	Definition	Acronym	Definition
Institutional acronyms			
|ESPOCH	Escuela Superior Politécnica de Chimborazo	**UNAH**	Universidad Nacional Autónoma de Honduras
UAN	Universidad Antonio Nariño	**UNMSM**	Universidad Nacional Mayor de San Marcos
UCV	Universidad Central de Venezuela	**USAC**	Universidad de San Carlos de Guatemala
UES	Universidad de El Salvador	**USFQ**	Universidad San Francisco de Quito
UFG	Universidad Francisco Gavidia	**USB**	Universidad Simón Bolívar
UIS	Universidad Industrial de Santander		
Technical, operational and safety acronyms			
ABS	Acrylonitrile butadiene styrene	**PCB**	Printed circuit board
ACH	Air changes per hour	**PETG**	Polyethylene terephthalate glycol-modified
BNC	Bayonet Neill-Concelman connector	**PLA**	Polylactic acid
CAD	Computer-aided design	**PoE**	Power over Ethernet
CNC	Computer numerical control	**PPE**	Personal protective equipment
CO_2	Carbon dioxide	**PTFE**	Polytetrafluoroethylene
DAQ	Data acquisition	**PVC**	Polyvinyl chloride
DC	Direct current	**RCD**	Residual current device
ESD	Electrostatic discharge	**SDS**	Safety data sheet
FDM	Fused deposition modelling	**SiPM**	Silicon photomultiplier
FFF	Fused filament fabrication	**SMD**	Surface-mount device
FPGA	Field-programmable gate array	**SPD**	Surge protective device
GFCI	Ground-fault circuit interrupter	**TPU**	Thermoplastic polyurethane
HEPA	High-efficiency particulate air	**UPS**	Uninterruptible power supply
HVAC	Heating, ventilation and air conditioning	**USB (interface)**	Universal Serial Bus

Acronym	Definition	Acronym	Definition
Technical, operational and safety acronyms			
MDF	Medium-density fibreboard	**UV**	Ultraviolet
MEMS	Microelectromechanical systems	**VLAN**	Virtual local area network
MuNRA	Muon Neutron RadiAtion detector	**VOC**	Volatile organic compound
NAS	Network-attached storage	**VPN**	Virtual private network
NI ELVIS III	National Instruments Educational Laboratory Virtual Instrumentation Suite III	**WEEE**	Waste electrical and electronic equipment

1. Introduction

1.1 Motivation

The development of research activities, teaching, technological innovation, and scientific experimentation requires increasingly flexible spaces that enable ideas, designs, and concepts to be transformed into functional physical prototypes. In fields such as physics, engineering, scientific instrumentation, and related disciplines, there is often a need to fabricate supports, mechanical parts, housings, adapters, experimental devices, measurement systems, electronic boards, laboratory assemblies, and auxiliary components that are not commercially available or that, when procured externally, involve high costs, long lead times, or design limitations that compromise the long-term sustainability of experimental developments. This need is shared across the EL-BONGO Physics partner institutions, including the Universidad Nacional Mayor de San Marcos (UNMSM), Universidad Industrial de Santander (UIS), Universidad San Francisco de Quito (USFQ), Universidad de San Carlos de Guatemala (USAC), Universidad Antonio Nariño (UAN), Escuela Superior Politécnica de Chimborazo (ESPOCH), Universidad de El Salvador (UES), Universidad Francisco Gavidia (UFG), Universidad Nacional Autónoma de Honduras (UNAH), Universidad Central de Venezuela (UCV), and Universidad Simón Bolívar (USB).

In this context, implementing specialised FabLabs within these universities represents a strategic step toward strengthening local scientific and technological capabilities. These facilities provide technical environments, according to each institution's level of development, equipped with digital fabrication tools, electronics workstations, computer-aided design resources, light-machining equipment, 3D printers, cutting systems, assembly areas, and basic testing instrumentation. The FabLabs facilitate rapid prototype development, the adaptation and repair of existing components, and the fabrication of customised solutions for scientific experiments, applied research projects, teaching activities, and student training.

1.2 Rationale

A FabLab oriented to the prototyping of measurement instruments and components for physics experiments enables a reduction in dependence on external fabrication services, optimises institutional resources, and shortens the time between the conception of an idea and its experimental validation. It also promotes a culture of interdisciplinary work by integrating knowledge of physics, mechanical engineering, electronics, programming, design, metrology, automation and data analysis.

From an academic standpoint, this space strengthens teaching through hands-on learning, enabling students, faculty, and researchers to actively participate in the design, construction, testing, and improvement of experimental devices. In this way, the educational process is no longer limited to closed commercial equipment and is oriented toward a comprehensive understanding of the physical, technical, and operational principles that underlie measurement instruments and experimental systems.

In the research setting, the FabLab specialises in providing direct support to projects that require non-conventional components, specific geometries, customised assemblies or rapid modifications during the experimental stage. This is especially important in laboratories where requirements change during the research process and where the capacity for iterative designs can significantly improve the quality, efficiency, and scope of the results.

In addition, the FabLab can serve as a platform for institutional technological development by facilitating the creation of prototypes with potential for technology transfer, the generation of intellectual property, specialised services, collaboration with other institutions, and the strengthening of internal capabilities. Its implementation helps consolidate an innovation ecosystem in which ideas can be designed, fabricated, tested, documented, and improved within the institution itself.

Therefore, having a specialised FabLab should not be understood only as the installation of digital fabrication equipment, but rather as the creation of an enabling infrastructure for research, practical teaching, technological development, and the solution of experimental problems. Its proper implementation will enable improvements in technical autonomy, increased project efficiency, strengthened human resource development, and a culture institutionally oriented toward innovation, experimentation, and continuous improvement.

1.3 Scope of the document

This document is intended to establish a technical and operational guide for the planning, implementation, commissioning, and basic operation of a FabLab oriented to the prototyping of measurement instruments, fabrication of components for physics experiments and development of technological solutions applied to related fields.

The guide includes definitions of the minimum and recommended requirements for laboratory installation, including physical infrastructure conditions, space layout, ventilation, electrical supply, technical furniture, data connectivity, material storage, chemicals and reagents, as well as general criteria for security, occupational health, and risk management.

The document also considers identifying the functional zones of the FabLab, such as design and computing areas, additive manufacturing, cutting and light machining, electronics, assembly, experimental testing, storage of supplies, and waste management. It also includes guidelines for the selection, installation, operation, and maintenance of equipment, especially those intended for 3D printing, cutting, machining, electronic soldering, instrumentation, data acquisition and fabrication of auxiliary components for scientific experiments.

The document includes criteria for organising the operation of the FabLab, such as user profiles, staff responsibilities, access procedures, safe use of equipment, training, activity records, preventive maintenance, inventory control, technical documentation of prototypes and continuous service improvement.

The scope also includes the incorporation of technical data sheets and specific requirements for the installation and operation of the equipment available or planned for the FabLab, so that the guide can be progressively adapted to the institutional context, budget availability, and research needs, teaching, innovation, or technological development.

This guide is addressed to institutional authorities, infrastructure managers, technical staff, researchers, faculty, students, safety officers and laboratory users who participate in the implementation, management or use of the FabLab.

This document does not replace manufacturers' technical manuals, current legal standards, internal safety regulations, or specialized studies that may be required for electrical installations, ventilation, fire protection, hazardous waste management, or chemical handling. In such cases, this guide should be supplemented by assessments from qualified professionals and applicable regulations.

1.4 Target audience

This document is intended for all individuals and areas involved in the planning, implementation, management, operation, maintenance, and use of the FabLab oriented to the prototyping of measurement instruments and the fabrication of components for physics experiments and field-related work.

First, it is intended for institutional authorities and decision-makers who require a clear reference on the objectives, benefits, and needs of the FabLab's infrastructure, equipment, budget, personnel, security, and sustainability. For this group, the guide helps clarify the laboratory's strategic importance and facilitates resource allocation for its implementation and operation.

It also addresses infrastructure, maintenance, logistics, information technology, and safety, including preparing physical spaces, ensuring the electrical supply, implementing ventilation systems, ensuring connectivity, procuring furniture and equipment, managing maintenance services, and verifying compliance with safe operating conditions.

The document is intended for the technical staff and operational managers of the FabLab, who will be responsible for the daily administration of the laboratory, supervision of equipment use, materials management, inventory control, maintenance programming, user training, and the application of safety procedures.

The guide is also intended for researchers, faculty, students, and technical users, who will use the FabLab for design, fabrication, adaptation, repair, or validation of prototypes, experimental components, measurement systems, electronic devices, mechanical supports, auxiliary parts or technological solutions applied to activities of research, teaching, innovation and experimental development.

Finally, the document can be used by safety, quality, risk management, and continuous improvement committees as a reference for evaluating minimum operating requirements, identifying opportunities for improvement, reviewing procedures, establishing performance indicators, and strengthening the culture of safe, responsible, and documented use of the FabLab.

Existing capabilities within the EL-BONGO Physics FabLab network

The partner institutions are implementing FabLabs at different levels of maturity. The selected photographs below document existing workspaces and operational capabilities in electronics, additive manufacturing, and integrated scientific prototyping. Detailed institutional profiles are presented in Chapter 13.

Figure 1
UAN: digital fabrication and electronics equipment

Figure 2

UIS: additive manufacturing area with Creality and Bambu Lab printers

Figure 3

ESPOCH: adapted 36 m² FabLab and collaborative work area

2. Objective of FabLab for instrumentation prototyping

Implement an entry-level academic and scientific FabLab, focused on the design, fabrication, integration, modification, and preliminary validation of measuring instruments, mechanical and electronic components, and auxiliary systems for experiments in advanced physics and related fields, through the coordinated use of digital prototyping tools, lightweight fabrication, electronics, instrumentation, computer-aided design, and collaborative work methodologies; with a modular, secure, and scalable infrastructure that strengthens institutional research, teaching, practical student training, and technological development capabilities, without commercial purposes, and with the possibility of progressive growth towards more complex equipment, processes, and capabilities.

2.1 General objective

Implementing a FabLab of this kind addresses a strategic need within a scientific and academic environment: a dedicated space for transforming ideas, conceptual designs, and experimental requirements into functional prototypes, support components, adapters, measurement systems, test benches, auxiliary mechanisms, and technical solutions of low to medium complexity.

In advanced physics and related fields, many experiments require specific components that are not always commercially available or, if available, may be expensive, have long lead times, or require specific adaptations. An academic FabLab allows for a faster response to these needs, reducing dependence on external suppliers for prototyping, modification, and experimental adjustments.

By designing it as an entry-level FabLab, the initial investment can be kept reasonable, prioritising basic but versatile equipment: design and computing workstations, 3D printers, light hand and power tools, electronics workbenches, basic instrumentation, technical furniture, safety systems, and assembly areas. However, from the initial design stage, its scalability must be considered so that in the future it can incorporate more complex equipment, such as higher-precision CNC, laser cutting, advanced data acquisition systems, specialised soldering stations, dimensional metrology, environmental chambers, vacuum systems, printed circuit board prototyping, or other resources according to the evolution of the research lines.

The investment in this FabLab is justified because it not only provides physical infrastructure but also creates a permanent institutional capacity to solve technical problems, accelerate projects, improve students' practical training, strengthen the culture of innovation, and support the generation of applied knowledge.

2.2 Specific objectives

Develop internal capabilities of prototyping for supporting scientific and technological research projects

Develop a core institutional capacity to design, manufacture, assemble, and modify prototypes of measuring instruments, experimental components, mechanical supports, housings, adapters, auxiliary systems, and support devices required for advanced physics projects and related fields.

Many research projects require specific technical solutions that are not available as standard products. The ability to manufacture parts, supports, assemblies, or auxiliary devices in-house reduces lead times, lowers costs associated with external services, and increases researchers' flexibility to adapt their experiments. This capacity is especially important in academic laboratories, where requirements frequently change during the testing, adjustment, and experimental validation phases.

Strengthen practical student training, thesis students, and early-career researchers

To contribute to the practical training of students, thesis writers, interns, and young researchers through their participation in the design, fabrication, integration, testing, and improvement of prototypes applied to real-world problems in measurement, instrumentation, and scientific experimentation.

Training in physics, engineering, and related disciplines should not be limited to theoretical knowledge. An academic FabLab allows students to understand the complete experimental development cycle: identifying a need, designing a solution, selecting materials, fabricating, assembling, testing, troubleshooting, and improving the prototype. This strengthens transversal skills such as critical thinking, problem-solving, experimental design, collaborative work, technical documentation, and safe tool handling.

Furthermore, the FabLab can become an active learning space where students participate in real research projects, thereby increasing their employability, capacity for innovation, and understanding of the practical challenges of experimental science.

Reduce dependence on external suppliers for solutions, techniques of low and medium complexity

Reducing institutional dependence on external suppliers for the design, manufacture, or modification of simple and medium-complexity components by prioritising internal attention to recurring needs such as prototyping, experimental maintenance, equipment adaptation, and the construction of auxiliary devices.

In many academic settings, a significant portion of research time is lost waiting for quotes, acquisitions, imports, or external services to address relatively simple technical needs. Having a FabLab enables in-house fulfilment of requirements such as supports, enclosures, connectors, adapters, bases, 3D-printed parts, small mechanisms, wiring, breadboards, and experimental assemblies.

This does not eliminate the need for specialised external services, but it does allow them to be reserved for more complex, precise, or critical work. In this way, economic resources are optimised, and the responsiveness of research groups is improved.

Implement a modular and scalable infrastructure for the progressive growth of the FabLab

Design and implement the FabLab with modularity, safety, flexibility, and scalability in mind, so it can start with basic equipment and later incorporate new tools, equipment, processes, and more complex technical capabilities to meet research and teaching needs.

An academic FabLab does not necessarily need to start with a highly complex infrastructure. It is more convenient to begin with a basic, well-organised, and sustainable configuration that allows for early results and demonstrates institutional value. However, from the outset, spaces, electrical installations, furniture, ventilation, storage, security, circulation, and operational management must be planned to allow for its orderly growth.

Scalability avoids improvised or duplicated investments. It also allows the FabLab to evolve based on actual user demand, project maturity, and budget availability. This approach reduces risks, improves sustainability, and makes it easier to justify future investments.

Improve the quality, traceability, and documentation of the prototypes developed.

Establish basic procedures for documenting the designs, materials, manufacturing parameters, versions, tests, modifications, and results of prototypes developed in the FabLab to promote technical traceability and the reproducibility of implemented solutions.

In a scientific environment, simply building a functional prototype is not enough. It is necessary to document how it was designed, what materials were used, what parameters were applied, what problems were encountered, and what improvements were made. Traceability allows other researchers or students to reproduce, correct, or improve their developments.

This is especially important in academic projects, theses, publications, technical reports, and institutional developments. Good documentation also helps prevent knowledge loss when students or project leaders change.

Promote integration between research, teaching and technological development

To integrate FabLab activities with research projects, courses, theses, pre-professional internships, laboratory work, and academic innovation activities, promoting the integration of knowledge generation, capacity building, and addressing experimental needs.

The FabLab should be more than just a workshop with equipment. Its main value lies in serving as a cross-cutting platform for research and teaching. It can support courses in instrumentation, electronics, experimental physics, mechanical design, data acquisition, sensors, automation, metrology, radiation, materials, or applied physics.

This integration allows the resources invested to have a greater institutional impact. The same equipment or space can support classes, theses, internal projects, experimental maintenance, and prototype development, maximising its use and better justifying the investment.

Increase safety, order, and efficiency in the activities of fabrication and prototyping

Organise the activities of manufacturing, electronics, assembly, storage, and prototype testing according to the criteria of safety, ergonomics, order, signage, proper tool use, risk control, and good laboratory practices.

Prototype manufacturing involves electrical, mechanical, thermal, chemical, ergonomic, and particle, fume, or noise exposure risks, depending on the tools used. Implementing the FabLab with differentiated zones, appropriate furniture, signage, work procedures, personal protective equipment, and access control helps reduce incidents and improve operational efficiency.

An orderly and safe environment also facilitates learning, supervision, and equipment maintenance. This is especially important when the space will be used by students and staff with varying levels of experience.

Generate an institutional platform for scientific innovation with low cost and high training impact

To establish a relatively low-cost scientific and technological innovation platform capable of generating practical solutions for experimental needs, strengthening human capabilities, and supporting the progressive development of proprietary technologies within academia.

While an entry-level FabLab does not replace specialised laboratories or high-precision industrial workshops, it can have a significant impact by facilitating rapid experimentation, idea validation, and the fabrication of functional solutions. Its greatest value lies not only in the products manufactured but also in the capacity they build within the institution.

The investment in time, financial resources, and personnel is justified because the FabLab generates cumulative benefits: it improves training, accelerates projects, reduces response times, fosters technical creativity, promotes interdisciplinary collaboration, and builds a foundation for more advanced technological developments.

3. Functional profile of FabLab for instrument prototyping

3.1 Type of FabLab

A Fab Lab focused on prototyping, measuring instruments, and components for physics experiments and related fields is a specialised academic space dedicated to the design, fabrication, assembly, testing, and improvement of devices, accessories, and auxiliary systems used in research, teaching, and experimental development. Unlike a Fab Lab with commercial or service-oriented purposes, this laboratory's primary objective is to strengthen the scientific, technological, and educational capabilities of a university or research centre.

Figure 4

UNAH: practical training around scientific instrumentation

Figure 5

ESPOCH: reception, verification, and installation of equipment

This space allows faculty, researchers, students, and technicians to transform ideas, conceptual designs, or experimental needs into functional physical prototypes. These prototypes could include mechanical support, housing, adapters, positioning systems, electronic components, sensors, data acquisition interfaces, parts for experimental setup, educational devices, and low- to medium-cost measuring systems.

The Fab Lab is conceived as a cross-disciplinary support environment for applied physics, experimental physics, scientific instrumentation, electronics, precision mechanics, optics, radiation, materials science, automation, metrology, and laboratory instruction. Its primary value lies not in mass production, but in facilitating experimentation, hands-on learning, technical problem-solving, and the development of internal capabilities for scientific instrumentation.

From an educational perspective, this Fab Lab enables students to gain a practical understanding of the relationships among design, measurement, manufacturing, calibration, quality control, and experimental analysis. From a research perspective, it would reduce dependence on imported components, shorten development times, adapt solutions to specific needs, and generate prototypes that could evolve into equipment, methods, or scientific publications.

3.2 Main lines of work

Design and fabrication of mechanical components for experiments

This research line focuses on developing circuits, electronic modules, reading interfaces, signal conditioners, simple power supplies, data acquisition systems, and devices based on microcontrollers or embedded systems.

Its practical application involves measuring physical variables such as temperature, pressure, humidity, radiation, light intensity, position, deformation, voltage, current, time, frequency, vibration, and other relevant magnitudes in applied physics experiments.

The impact on research is reflected in the ability to build measurement systems adapted to specific problems, integrate commercial sensors with custom software, and develop low-cost solutions for exploration experiments. For education, this line allows students to understand the complete measurement process: sensor, signal, conditioning, acquisition, processing, visualisation, and data interpretation.

Prototyping of electronic instrumentation and measurement systems

This research area focuses on the development of circuits, electronic modules, reading interfaces, signal conditioners, simple power supplies, data acquisition systems, and devices based on microcontrollers or embedded systems.

Its practical application involves measuring physical variables such as temperature, pressure, humidity, radiation, light intensity, position, deformation, voltage, current, time, frequency, vibration, and other relevant magnitudes in applied physics experiments.

The impact on research is reflected in the ability to build measurement systems adapted to specific problems, integrate commercial sensors with custom software, and develop low-cost solutions for exploration experiments. For education, this area allows students to understand the complete measurement process: sensor, signal, conditioning, acquisition, processing, visualisation, and data interpretation.

Development of experimental acquisition, control, and automation systems

This research area focuses on implementing systems that enable variable control, automation of experimental processes, and systematic data recording. It can include motor control, temperature control, timing, remote device activation, automatic sensor reading, and computer communication.

Its practical application is significant because many experiments require stability, repeatability, and continuous data acquisition. Automation reduces human error, improves the quality of the information obtained, and allows for measurements to be taken over extended periods.

The impact on research lies in improving the reliability of results, facilitating repetitive experiments, and enabling more complex configurations. For student training, this area supports learning in programming, experimental control, data analysis, virtual instrumentation, and integrated systems design.

Figure 6

UNMSM: Programmable high-voltage source module for Geiger-Muller detectors developed in the laboratories of the Faculty of Physical Sciences

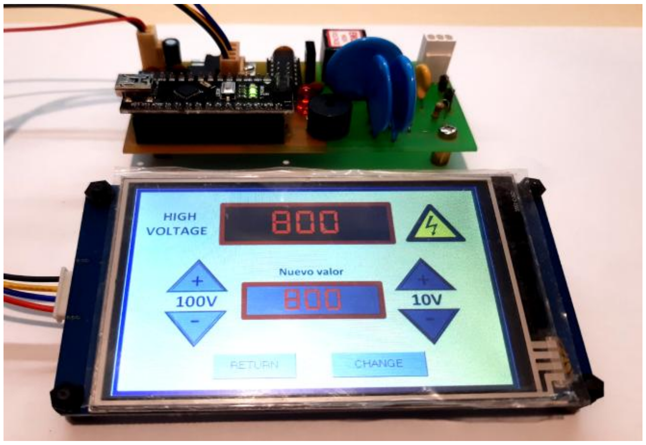
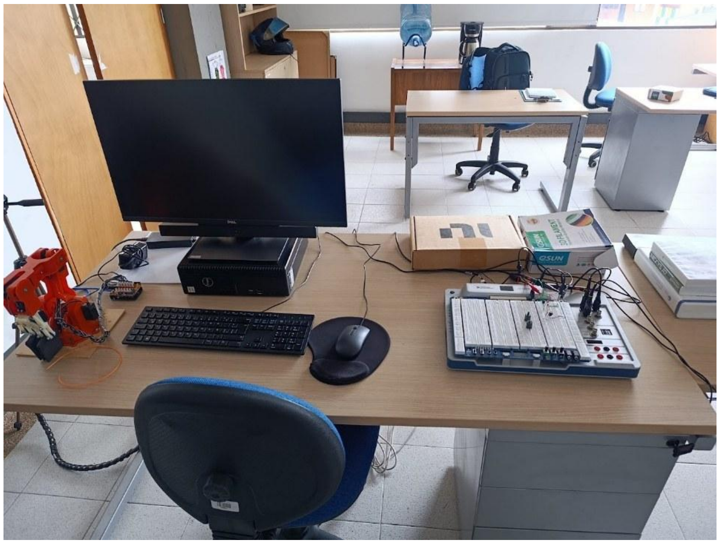


Figure 7

ESPOCH: Raspberry RS4D strong-motion seismograph

Figure 8:
UAN: NI ELVIS III workstation for circuit design, acquisition, and validation



Manufacturing teaching materials and experimental modules for teaching

This product line aims to design and build equipment, kits, and modules for laboratories teaching basic physics, modern physics, electricity, magnetism, optics, mechanics, thermodynamics, radiation, electronics, and instrumentation.

Its practical utility is high in educational settings, as it enables the use of equipment tailored to learning objectives, student levels, and available resources. Furthermore, it enables the renovation or expansion of existing laboratories without relying exclusively on commercially available equipment.

The educational impact is direct, as it promotes active learning, experimentation, physical reasoning, and the understanding of phenomena through observation and measurement. It also allows students to participate in the design and improvement of their own teaching equipment, strengthening their creativity and critical thinking skills.

Adaptation, repair, and improvement of laboratory equipment

This line of business is dedicated to repairing, modifying, performing minor maintenance on, or improving the functionality of laboratory equipment and accessories. This may include the manufacture of spare parts, connectors, brackets, housing, replacement parts, electronic interfaces, or auxiliary systems.

Its practical application lies in extending the lifespan of existing equipment, especially when the manufacturer no longer provides support, spare parts are expensive, or the equipment requires adaptation for new experimental uses.

The institutional impact can be considerable, as it reduces costs, prevents premature equipment obsolescence, and improves the availability of resources for teaching and research. For students, this line of business provides opportunities to learn about troubleshooting, reverse engineering, safety, technical documentation, and continuous improvement.

Development of prototypes for applied and interdisciplinary research

This line of research addresses the needs of research projects in applied physics and related fields, such as engineering, chemistry, materials science, environmental science, biomedicine, energy, radiation, metrology, and scientific instrumentation.

Its practical application is to provide technical support that translates scientific requirements into concrete experimental solutions. This can include test chambers, positioning systems, irradiation devices, sample holders, environmental sensors, small non-nuclear experimental reactors, optical systems, and test benches.

The impact on research lies in accelerating the generation of results, facilitating hypothesis validation, and promoting interdisciplinary projects. It also fosters the institution's technological autonomy by enabling the development of proprietary solutions tailored to its research areas.

Technical documentation, standardisation, and safety culture

This operational line establishes procedures for documenting designs, drawings, bills of materials, manufacturing parameters, usage protocols, risk assessments, and waste management. It also defines basic safety requirements for tools, electrical equipment, machinery, materials, reagents, and experimental devices.

Its practical application is fundamental to ensuring that prototypes are reproducible, safe, and maintainable. Documentation prevents knowledge from remaining solely within an individual's experience and allows other students or researchers to continue the work.

Its contribution is cross-cutting rather than a separate research topic: it supports reproducibility, safe operation, traceability, maintenance, and continuity between successive student and research teams. These practices are necessary for reliable scientific prototyping and for institutional preservation of technical knowledge.

3.3 Expected products

Measurement instrument prototypes

One of the main expected products would be in-house developed measuring instruments for educational or research purposes. These could include meters for temperature, humidity, radiation, light, pressure, magnetic field, current, voltage, vibration, or displacement.

Their need is justified because many experiments require specific, low-cost measuring systems or systems adapted to specific conditions. Their importance for research lies in the fact that they allow researchers to obtain their own experimental data, validate methodologies, and improve existing setups. For student training, these prototypes help them understand how a real measuring system is built, from the sensor to data analysis.

Figure 9

UNMSM: Electronic preamplifier board for an alpha spectrometer

Figure 10

UIS: 3D-printed angular support for a MuNRA hodoscope

Figure 11

UIS: MEMS accelerometer prototype for vibration recording.

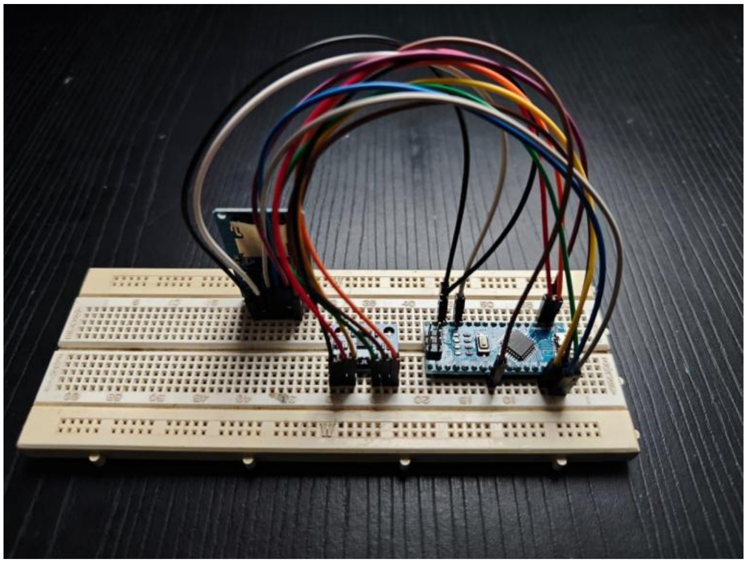
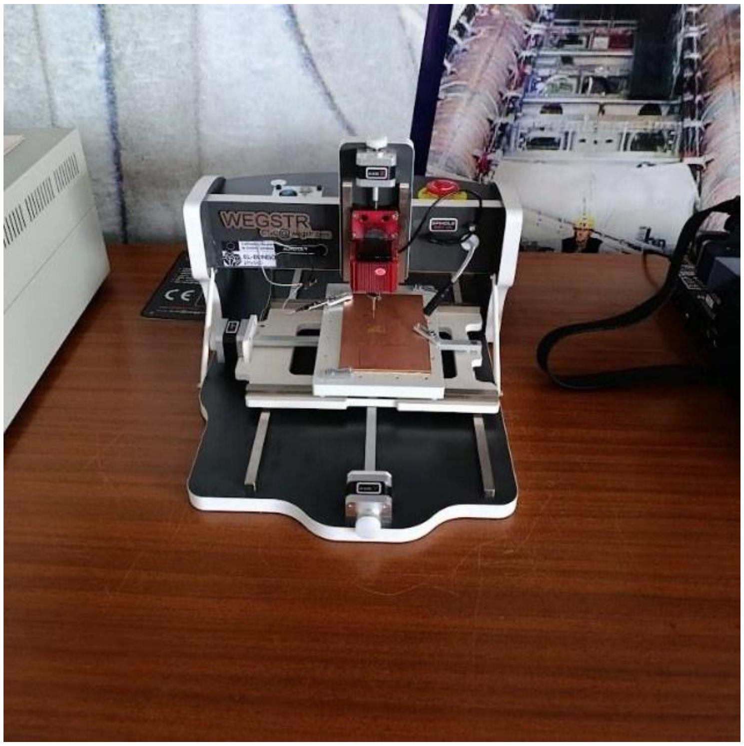


Figure 12

UAN: WEGSTR CNC router used for PCB preparation



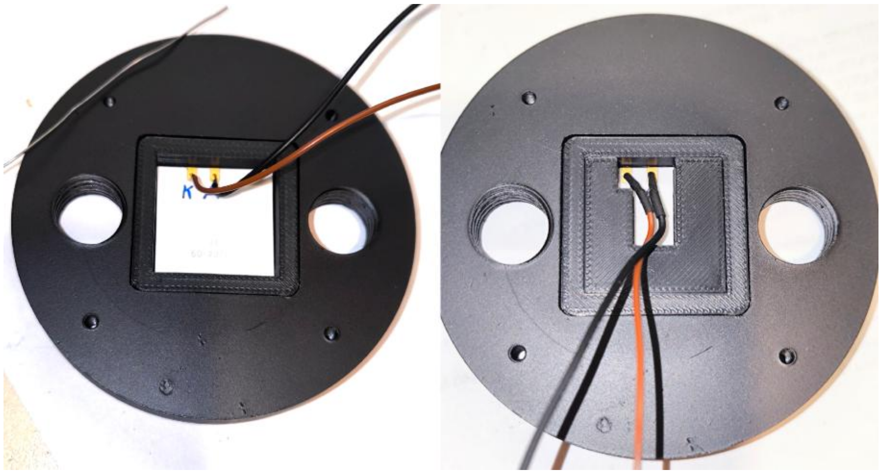
Custom mechanical supports, adapters, and components

The Fab Lab could produce mechanical parts designed for specific laboratory needs, such as sensor mounts, detector adapters, sample holders, alignment bases, mounting structures, couplings, guides, and housing.

These products are necessary because physics labs often require specific mechanical solutions for each experimental setup. Their importance lies in improving the stability, alignment, safety, and reproducibility of experiments. Furthermore, they teach students about the relationship between physical design, mechanical precision, and measurement quality.

Figure 13

UNMSM'S equipment specification



Rectangular support, made of ABS material, for the Hamamatsu S3209 PIN diode used in a radon measuring device. Universidad Nacional Mayor de San Marcos - Perú

Teaching modules for instructional laboratories

Another anticipated product would be experimental modules designed for courses in basic physics, modern physics, electronics, instrumentation, or metrology. These modules could be designed to demonstrate physical phenomena or to train students in measurement techniques.

Their need stems from the importance of having accessible, adaptable educational equipment aligned with curricular objectives. Their educational impact is significant because they allow students to learn by doing, measuring, comparing results, and analysing experimental errors. They also foster creativity and active participation in the laboratory.

Data acquisition and experimental control systems

The Fab Lab could develop systems based on microcontrollers, data acquisition boards, sensors, and software to record and control experimental variables. These systems could be applied in experiments involving temperature, radiation, optics, mechanics, electronics, or environmental monitoring.

These products are necessary because reliable data acquisition is essential to experimental physics. Their importance for research lies in their ability to systematically record information, automate measurements, and reduce human error. For student training, they enable the integration of knowledge across physics, electronics, programming, and data analysis.

Auxiliary devices for specialised experiments

The Fab Lab could also produce auxiliary devices for specific projects, such as test chambers, simple non-structural shielding, specialised sample holders, positioning systems, small optical benches, dark boxes, detector mounts, encapsulations, or sensor protection systems.

These products are necessary because experimental research frequently requires accessories that are not part of the main equipment but are essential for accurate measurements. Their importance lies in their ability to increase the laboratory's adaptability and enable the development of more comprehensive and reliable experiments.

Spare parts and improvements for existing equipment

The Fab Lab could manufacture replacement parts, casings, connectors, covers, brackets, buttons, bases, simple electrical adapters, or functional upgrades for laboratory equipment. Its necessity is justified by the difficulty of obtaining specific spare parts, especially for older or imported equipment. Its institutional impact is reflected in cost reduction, the recovery of out-of-service equipment, and increased availability of resources for teaching and research. For students, this activity has educational value because it allows them to understand the structure and operation of real equipment.

Manuals, drawings, protocols, and design repositories

In addition to physical products, the FabLab should generate technical documentation, operating manuals, blueprints, design files, manufacturing protocols, bills of materials, and safety guides.

These products are necessary to ensure the continuity, traceability, and reproducibility of the developments carried out. Their importance for research lies in their ability to validate, replicate, and improve prototypes. In the field of education, they serve as reference and learning materials for new generations of students.

3.4 General importance for research and student training

Implementing a Fab Lab with an educational and research focus strengthens the experimental culture within an academic institution. It not only provides tools for fabricating parts or devices but also creates an environment where students can learn to transform a scientific need into a concrete technical solution.

For research, the Fab Lab offers flexibility, rapid response, cost reduction, and innovation. It allows for adapting equipment, developing prototypes, improving experimental setups, and generating original solutions to specific scientific problems.

For education, its impact is equally significant. Students of applied physics and related fields can acquire practical skills in design, fabrication, instrumentation, electronics, programming, data analysis, safety, and technical documentation. These skills complement theoretical training and better prepare future professionals to tackle real-world problems in laboratories, research centres, technology industries, or scientific institutions.

In short, this Fab Lab should be understood as an academic platform for learning, research, creation, and solving experimental problems, rather than a commercial production workshop. Its main purpose is to contribute to the development of scientific and technological capabilities through prototyping, experimentation and practical training of students and researchers.

3.5 Summary of work lines and products

The FabLabs participating in EL-BONGO Physics are not all at the same stage of implementation. Some institutions have already developed and tested scientific prototypes, while others are installing equipment, preparing their workspaces, or completing operator training[1]. For this reason, the following summary includes only capabilities, activities, and outputs reported by the partner institutions. Planned equipment is not presented as an operational result.

Table 2

Reported capabilities and verified technical outputs of EL-BONGO physics FabLabs

Capability	Evidence currently documented in the network	Representative output or use
Additive manufacturing and mechanical prototyping	FDM printers have been reported at UIS, UAN, ESPOCH, UNAH and UFG. The available equipment includes Bambu Lab and Creality systems at different stages of installation and use.	UIS fabricated a 3D-printed angular support for two MuNRA (Muon Neutron RadiAtion) detectors. Other reported applications include housings, bases, adapters, sensor supports and experimental components.

[1] See https://gitmilab.redclara.net/el-bongo/wp2fablabs for some contribution along the work lines

Capability	Evidence currently documented in the network	Representative output or use
PCB preparation and electronic assembly	WEGSTR CNC routers, hot plates, reflow ovens, soldering and microsoldering stations, and digital microscopes are available or under implementation at several partner institutions. USFQ has installed a Roland MODELA MDX-50 PCB milling system, which is undergoing commissioning.	Preparation of prototype PCBs, assembly of SMD and through-hole components, inspection of tracks and solder joints, electronic repair, and fabrication of detector front-end and data-acquisition boards.
Instrumentation and signal validation	The network has reported oscilloscopes, function generators, DC power supplies, logic probes, multimeters and NI ELVIS III workstations for electronic testing and scientific instrumentation.	Characterisation of sensor signals, verification of electronic modules, trigger and timing measurements, circuit testing, and preliminary validation of acquisition systems.
Embedded systems, control and data acquisition	Arduino-based platforms, FPGA development boards, NI ELVIS III systems and other embedded devices are being used or incorporated into the partner FabLabs.	UIS developed a MEMS accelerometer system for vibration recording. FPGA and microcontroller platforms support acquisition, timing, trigger, communication and experimental-control applications.

Funded by the European Union

Capability	Evidence currently documented in the network	Representative output or use
Scientific-instrument development and experimental integration	Documented developments include electronic instrumentation, detector supports, acquisition systems and mechanically integrated experimental devices.	UNMSM has developed a programmable 2 kV high-voltage supply, an electronic preamplifier for an alpha spectrometer, and components requiring complementary mechanical machining. UIS has developed the MuNRA hodoscope support and the MEMS accelerometer prototype. USFQ reports detector-electronics and cosmic-ray instrumentation activities.
Training, operation and technical documentation	Practical activities, equipment demonstrations, technical guide preparation, and student participation have been reported at several nodes.	Training activities include scientific instrumentation practices, electronics assembly, detector testing, CAD modelling, and data acquisition. The expected supporting records include design files, firmware, raw data, test results, operating procedures and maintenance logs.

The cases documented so far show that the EL-BONGO Physics FabLabs are not developing through a single, identical equipment configuration. Each institution is organising its facilities around its available space, existing laboratories, research groups and teaching needs.

The common element is the prototyping workflow: identifying an experimental requirement, preparing the design, fabricating the required mechanical or electronic components, assembling the system, performing measurements, and documenting the results. A FabLab becomes an effective scientific capability when this complete workflow can be carried out safely and repeatedly, not merely when equipment has been purchased or installed.

The implementation status, institutional examples, documented outputs and pending confirmations for each partner are presented in Chapter 13

4. Physical infrastructure requirements

4.1 Scope and design criteria

A FabLab for prototyping measuring instruments is conceived as a space to support teaching, research, and experimental development. Unlike a commercial FabLab, its priority is not mass production or serving external clients, but rather training students, validating ideas, building prototypes, maintaining experimental equipment, and developing internal capabilities for laboratories in applied physics, scientific instrumentation, electronics, fine mechanics, optics, radiation, vacuum, cryogenics, or related fields.

Physical design must adhere to five principles: safety, flexibility, traceability, compatibility with academic activities, and scalability. Therefore, even an entry-level FabLab should be conceived with a modular approach: first, basic design, additive manufacturing, electronics, and assembly functions are enabled; then, areas for machining, finishing, measurement, environmental control, support chemistry, or specialised prototyping are incorporated, depending on the maturity of the academic program and the research demands.

Table 3
Scope and physical design criteria for prototyping FabLabs

Criterion	Implications for physical design
Academic use	It must allow for supervision, demonstrations, training, small group work, and competency-based access control.
Use in research	It must support changing prototypes, sensitive equipment, technical documentation, repeatable tests, and areas with less contamination.
Non- commercial	Mass-production flow is not required; flexibility, safety, maintenance, and project support are prioritised.
Scalability	Electrical, data, ventilation, storage, and furniture distribution installations must accommodate growth without major reconstruction.

4.2 Tiered implementation strategy

It's always advisable to start with an entry-level FabLab, with a controlled scope and low risk, to validate real user demand, establish procedures, train instructors, and foster a safety culture. Subsequent growth should be based on functional modules rather than solely on equipment purchases. Each new piece of equipment must be accompanied by adequate space, ventilation, power, furniture, training, maintenance, waste management, and access protocols.

Table 4

Tiered infrastructure and functional scope specification

Level	Area referential	Functions main	Infrastructure distinctive
Entry level	30 to 60 m^2	CAD design, FFF 3D printing, basic electronics, assembly, small tools, and simple dimensional metrology.	Modular tables, separate electrical networks, general ventilation, localised extraction for printers or welding, basic storage and training area.
Basic level extended	60 to 100 m^2	Larger user base, small laser cutting or lightweight router, resin-controlled printing, electronic instrumentation, and light finishing.	Separate zones for additive manufacturing, electronics, finishing, raw material storage and more robust localised extraction.
Intermediate level	100 to 180 m^2	Fine mechanics, desktop or bench CNC, instrumentation laboratory, more demanding measurement, basic optical or vacuum prototyping.	Risk zoning, machine room, dust and noise control, clean assembly area, compressed air, increased electrical capacity and data.
Advanced level	180 to 300 m^2 or more	Manufacturing complex scientific components, lightweight microfabrication, systems integration, environmental or metrological testing.	Specialised areas, environmental control by zone, separation of incompatible activities, segregated warehouses, logistics routes, and possible clean rooms or low-contamination rooms.

Criteria adapted from best practices in university laboratories, makerspace guidelines, and safety recommendations for non-production laboratories. The areas are for reference only and must be adjusted according to the risk matrix and the actual equipment list.

4.2.1 Experience from the EL-BONGO Physics implementations

The first implementations show that the starting point is not identical at every institution. The network has used both compact rooms and larger adapted laboratories, but the recurring sequence has been the same: prepare the room and services, register and verify the equipment, install by functional zone, commission the systems, and then formalise access, maintenance, and training.

Table 5

Institutional implementation cases, initial conditions, and key roadmap lessons

Institutional example	Implementation condition	Practical lesson for the roadmap
UNAH	A compact 4.2 m × 3.7 m room (about 15.5 m^2), with air conditioning, stabilised power, and grounding.	An entry-level FabLab can begin in a small area, but equipment zoning, storage, and user circulation must be tightly controlled.
ESPOCH	A 36 m^2 room refurbished with dedicated furniture, electrical adaptations, storage, UPS support, computer, screen, and projector.	Preparing the room and support services before full operation reduces installation delays and supports training from the beginning.
UAN and UIS	Existing academic laboratory spaces reorganised around work, digital fabrication, electronics, and instrumentation functions.	Integration with active research groups can accelerate use, provided responsibilities and equipment-use rules are explicit.
UFG	Equipment distributed by functional areas in specialised laboratories, with an institutional inventory of received systems.	A function-based inventory helps identify gaps, avoid duplication, and plan the next stage of installation.

Across these cases, the main constraint has not been the absence of equipment alone. Commissioning, ventilation for emission-generating processes, consumables, trained operators, maintenance records, and authorised-use procedures determine whether the equipment becomes a sustainable laboratory capability.

4.3 General location criteria

The location should facilitate interaction with teaching and research laboratories, but prevent noisy, dusty, or emission-generating activities from affecting sensitive spaces such as measurement laboratories, computer rooms, classrooms, optics laboratories, radiological laboratories, or fine analysis areas.

- Locate the FabLab in an easily accessible area for students, teachers and researchers, with access control and user registration.
- Prioritise a first-floor area with logistical access for the entry of equipment, materials, cylinders, furniture, or heavy components; if it is on upper floors, verify load capacity and safe transport.
- Avoid direct proximity to quiet classrooms, administrative offices, or laboratories sensitive to vibration, dust, electromagnetic fields, noise, or fumes.
- Ensure clear, marked, and unobstructed evacuation routes; no storage should encroach on aisles, exits, or emergency routes.
- Ensure sufficient electrical power, grounding, a stable data network, adequate lighting and the possibility of implementing local exhaust ventilation.
- Physically separate, or separate through functional barriers, design and clean electronics activities from cutting, sanding, drilling, resins, solvents or machining activities.
- Plan for future growth towards neighbouring areas or through adjacent modules; do not locate the FabLab in a residual space without the possibility of expansion.

4.4 Minimum recommended area and scalability

For an entry-level academic FabLab, a minimum size of 35 m^2 is recommended if it will simultaneously house design workstations, two or three 3D printers, an electronics workbench, an assembly area, hand tools, and storage. A smaller space can function as a didactic prototyping workshop, but not as a FabLab with safe circulation and the capacity for group training.

Table 6

Functional component distribution and recommended spatial expansion thresholds

Functional component	Entry level 35-60 m^2	Growth recommended
Design, computing and documentation	6-10 m^2; 2 to 4 workstations.	Migrate to a classroom-laboratory or co-design area of 12-20 m^2.
Manufacturing additive FFF	5-8 m^2; printers on ventilated shelving or in a cabinet.	Dedicated area with greater extraction, monitoring and separation of materials.
Electronics and Instrumentation	6-10 m^2; bench with soldering iron, power supply, oscilloscope, multimeter, ESD tools.	Separate laboratory for instrumentation, testing and basic calibration.
Light mechanical assembly and adjustment	6-10 m^2; sturdy table and hand tools.	Mechanical prototyping area with bench, pillar drill, mini lathe or lightweight CNC.
Finishing and powder work	3-6 m^2; limited and controlled area.	Separate rooms with extraction, dust control, noise and cleaning.
Storage technical	4-8 m^2; supplies, filaments, electronic components, PPE.	The warehouse is segregated by material type and compatibility.
Safety and waste zone	1-3 m^2; containers identified.	Technical-chemical waste point, WEEE, sharps and contaminated material according to risk.

To promote scalability, the infrastructure must be designed with reserves: conduits and electrical panels with additional capacity, ducts or points provided for ventilation, a distributed data network, reconfigurable furniture, access points that allow the entry of new equipment, and a storage area that does not depend on corridors or improvised corners.

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4.5 Proposed internal zoning

Zoning should separate activities based on risk, cleaning requirements, noise, particle emissions, or the need for concentration. An entry-level setup can be compact, but it should not uncontrollably mix 3D printing, welding, sanding, computing, and reagent storage.

Table 7

Proposed internal zoning matrix for risk and emission segregation

Area	Function	Infrastructure criteria
Zone A: Design, training, and documentation	CAD modelling, file preparation, plan review, logs, and brief training.	Clean, quiet space with good lighting, data network, screens or whiteboard, and furniture for seated work.
Zone B: manufacturing additive	FFF 3D printing and, if justified, resin printing with specific controls.	General ventilation, localised extraction or ventilated cabinets, washable surfaces, temperature control, and dry filament storage.
Zone C: Electronics and Instrumentation	Soldering, PCB assembly, sensor testing, data acquisition, and simple calibrations.	ESD tables where appropriate, welding fume extraction, focused lighting, regulated outlets, cable management and grounding.
Zone D: Mechanical assembly and adjustment	Assembly of supports, housing, optical mounts, small parts and experimental components.	Sturdy table, bench vices, hand tools, perimeter space for tool movement and storage.
Zone E: finishing and particle generation	Sanding, minor cutting, drilling, deburring, occasional painting or controlled glueing.	It must be isolated or at least separated; it requires localised extraction, resistant surfaces and easy cleaning.
Zone F: Measurement and Verification	Dimensional inspection, functional testing, and simple electrical or mechanical measurements.	Cleaner, more stable environment, without vibration or dust, with a level table and recording of results.
Zone G: storage and waste	Supplies, spare parts, PPE, tools, solid waste, WEEE and minor chemical waste if applicable.	Shelving that is closed or marked, segregation by compatibility, restricted access and identified containers.

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4.6 Ergonomics and workstation organisation

Ergonomics must be considered from the design stage, as users will alternate between tasks involving computing, welding, fine assembly, tool handling, instrument observation, and moving parts. Fatigue increases the likelihood of errors, damage to prototypes, and accidents.

Table 8

Ergonomic guidelines and workstation design standards

Element	Recommendation practice
Work tables sitting	Approximate height of 72 to 75 cm; adjustable chairs; lumbar support; legroom; monitors at a suitable viewing height.
Standing work tables	Approximate height of 85 to 95 cm, adjustable if possible; anti-fatigue mats for prolonged work periods.
Fine work in electronics or instrumentation	Localised lighting, magnifying glass or microscope where appropriate, armrests, fume extraction and component organisation.
Tools manuals	Conveniently located; tool panels; avoid awkward postures; provide clamps and supports to avoid holding parts by hand.
Handling of loads	Use small carts and shelving at a safe height; avoid storing heavy items above shoulder height or at floor level.
Cable management	Cable trays, fixed power strips, sufficient outlets and a ban on improvised permanent extensions.
Positions shared	Marking of areas, usage log, mandatory cleaning and replacement of tools at the end of each activity.

4.7 Environmental conditions and support services

Environmental conditions should not be defined solely by user comfort, but also by the dimensional stability of prototypes, the repeatability of tests, and the protection of electronic components, sensors, polymeric materials, and measuring equipment.

Table 9

Environmental control specifications and support service infrastructure guidelines

Condition	Entry level	Scalability
Temperature	20 to 26 °C as a general operating range, avoiding sudden changes.	Measurement or fine assembly zones with more stable control according to instrument requirements.
Humidity relative	40 to 60% as a desirable range for comfort, electronics and sensitive supplies.	Control or dehumidification for filaments, optical components, sensors or hygroscopic materials.
General ventilation	Sufficient air renewal for occupancy and the heat of the equipment.	Zoned design, air balance and monitoring when specific emissions exist.
Extraction located	Recommended for welding fumes, 3D printers, resins, cutting, sanding or vapors.	Dedicated systems with appropriate filters or safe discharge, validated by occupational safety.
Lightning	500 lux general; 750 to 1000 lux for fine electronics, inspection or instrument reading.	Glare control, focused lighting and possible specialized lighting for optics or metrology.
Noise	Separate noisy sources; use barriers or booths if there are drills, CNC machines, compressors or extraction systems.	Acoustic assessment and hearing protection where appropriate.
Vibration	Avoid installing precision equipment next to rotating machinery or compressors.	Anti-vibration tables or independent bases for measurement, optics or calibration.
Electrical energy	Separate circuits for computing, electronics and equipment; sufficient outlets; grounding.	Dedicated panel, UPS for instruments, and three-phase capacity if larger machines are incorporated.
Data and communications	Stable wired and Wi-Fi network; access points near workstations.	Network for equipment, data acquisition, servers, repositories, cameras or remote instrument control.

4.8 Floors, walls, ceilings, and finishes

The finishes must allow for frequent cleaning, withstand heavy use, generate low dust, be slip-resistant, and be compatible with laboratory activities. Setting up an academic Fab Lab in environments with deteriorated floors, porous walls, ceilings with loose particles, or exposed, unprotected installations is not recommended.

Table 10

Architectural material specifications and surface finish standards for FabLab facilities

Element	Recommendation
Floors	Non-slip, wear-resistant, easy to clean, preferably continuous or with minimal seams. In electronics areas, consider dissipative finishes or ESD mats. In areas with chemicals, use compatible surfaces and secondary containment if applicable.
Walls	Washable, light-colored, resistant to moderate impacts, and without shedding particles. Avoid porous or difficult-to-clean surfaces in areas with resins, solvents, dust, or paint.
Roofs	Sturdy, free of loose material, with protected light fixtures and easy access for maintenance. Avoid ceilings that accumulate dust over measurement or fine assembly areas.
Table finishes	Resistant, non-absorbent surfaces suitable for the risk: ESD for electronics, steel or technical laminate for assembly, sacrificial surfaces for minor cutting.
Baseboards and corners	Choose durable baseboards and, in areas that are cleaned frequently, joints that do not accumulate dust.
Doors and windows	Doors wide enough for equipment and evacuation; windows controlled to avoid interfering with extraction, temperature, or dust.
Signaling	Clear pictograms for PPE, evacuation routes, restricted areas, electrical, chemical, laser, heat, cutting or entrapment hazards.

5. Electrical requirements and power supply

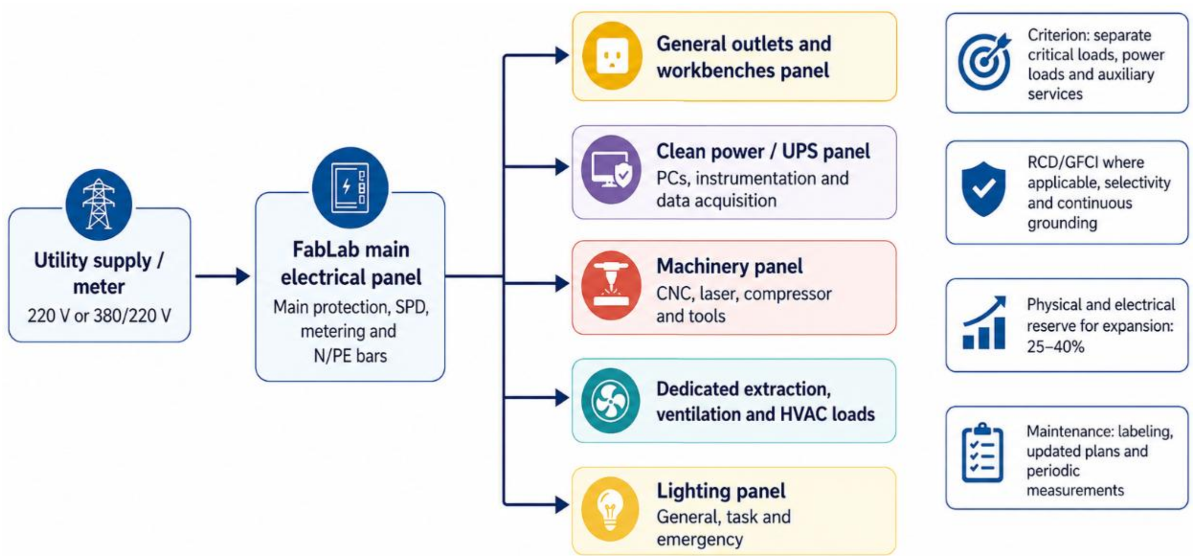
5.1 Scope

This chapter summarises the recommended electrical and power supply requirements for implementing an entry-level academic FabLab, considering its scalability. The approach is neither commercial nor for mass production; therefore, the infrastructure must prioritise safety, flexibility, reliable measurement, protection of sensitive equipment, traceability of changes, and the possibility of gradual growth.

The scope covers general criteria for load calculation, distribution by panels, outlets, stabilised power and UPS, grounding, surge protection, lighting, and scalability. It does not replace the calculation report or the final electrical technical specifications.

Figure 14

Recommended electrical architecture.



These recommendations should be reviewed and adapted by a licensed electrical engineer, taking into account the applicable National Electrical Code, institutional standards, actual building conditions, and the safety requirements of each piece of equipment.

- Applicable to university laboratories or research centres with activities of design, light manufacturing, assembly, electronic soldering, data acquisition, 3D printing, light machining, low/medium power laser cutting and test benches.
- It does not consider high-power industrial installations, strict cleanrooms, experimental high voltages, ionising radiation with dedicated systems, or equipment requiring special substations; these cases require specific engineering.

- It must be coordinated with ventilation, local exhaust, fire safety, ergonomics, furniture layout and management of chemicals or reagents.

5.2 Implementation levels approach

It is recommended to plan the FabLab as a modular installation, starting with a reasonable capacity and allowing for future expansion through conduits, panel space, and electrical reserves. The following table provides a practical reference; the values should be adjusted based on the actual equipment inventory.

Table 11

Modular power and area specifications across FabLab development tiers

Level	Activities typical	Area referential	Power installed the initial indicative	Infrastructure criteria electric
Entry level	CAD design, basic electronics, 3D printing, soldering, light instrumentation, and low-power test benches.	30-70 m^2	8-15 kW installed; estimated demand 5-10 kW	Single-phase or three-phase power supply, depending on availability; dedicated panel; separate circuits for computing/instrumentation, general outlets, lighting and extraction.
Intermediate level	Laser cutting, a desktop or medium-sized CNC machine, a small compressor, electronics workbenches, and a larger number of 3D printers.	70-120 m^2	15-35 kW installed; estimated demand 10-25 kW	Preferably, a three-phase 380/220 V supply; main panel with sub-panels; central or distributed UPS for critical loads; greater extraction and HVAC capacity.
Advanced level, scalable	Robust machining, experimental benches, small environmental chambers and high-sensitivity instrumentation.	120-250 m^2 or more	35-80 kW or more, depending on equipment	Sub-panels by zone, metering, selectivity, feeder, and conduct reserve; possible institutional support.

5.3 General principles of electrical design

- People's safety first: use thermomagnetic protection, differential/RCD or GFCI protection where appropriate, effective grounding, closed and labelled panels, signage, and lockout/tagout procedures for maintenance.
- Load separation: Do not mix noisy or high-starting-current loads, such as motors, compressors, lasers, or CNC machines, with sensitive instrumentation, data acquisition equipment, oscilloscopes, control PCs, or precision power supplies on the same circuit.
- Flexibility: Use technical channels, cable trays or accessible ducts that allow adding circuits without breaking floors or walls.
- Scalability: Allow 25-40% reserve capacity for switchboards, ducts and main feeders, and leave free space for future switches.
- Maintainability: Prepare and keep up to date the single-line diagram, load schedule, outlet plan, circuit identification, grounding tests and maintenance records.
- Electromagnetic compatibility: physically separate power, data, analogue signal, instrumentation and control cables; use separate conduits or separators when necessary.
- Reasonable operational continuity: only back up critical loads with UPS; do not power thermal loads, motors, power tools, compressors or high-start-up machines with UPS unless specifically designed.

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5.4 Electrical load calculation

Table 12

Equipment-based electrical planning for the EL-BONGO Physics FabLabs

Equipment family	Examples already reported by partner institutions	Electrical design check
Measurement and data acquisition	Oscilloscopes, function generators, DC supplies, NI ELVIS III, computers, network equipment, and acquisition systems.	Use clean, grounded circuits; identify the subset requiring UPS support; record nameplate power and critical shutdown requirements.
Additive manufacturing	Bambu Lab P1S and Creality FDM printers.	Provide dedicated or clearly assigned outlets for prolonged operation; verify ventilation and avoid permanent extension-cord loading.
PCB fabrication and thermal assembly	WEGSTR CNC routers, hot plates, reflow ovens, soldering and microsoldering stations.	Separate thermal and motor loads from sensitive instruments; verify current, startup behaviour, fume extraction, and emergency isolation.
Laser processing	Fastler Serie S PRO laser cutter installed at ESPOCH.	Use a dedicated circuit coordinated with extraction, interlocks, emergency stop, and the manufacturer’s electrical requirements.
Auxiliary inspection and control	Digital microscopes, logic probes, FPGA boards, and low-power embedded systems.	Group only compatible low-power loads and provide sufficient bench outlets, ESD measures, and cable management.

Practical load-identification table based on equipment already received by EL-BONGO Physics partners. Final calculations must use each unit’s nameplate data and the local electrical code.

The calculation should be based on the actual equipment inventory, not a generic value per square meter. In an academic FabLab, simultaneous use is usually lower than in a commercial workshop, but the diversity of equipment makes it essential to classify loads by type, criticality, and usage pattern.

Minimum information to be collected by the team

- Nominal power in W or kW, nominal current, voltage and number of phases.
- Starting current or peak consumption, especially in motors, compressors, pumps, extractors, CNC, lasers and high-power switched-mode power supplies.
- Load type: resistive, inductive, electronic, motor, switched-mode power supply, measuring equipment or critical load.
- Usage time: continuous, intermittent, occasional, per experimental campaign or only during practice.
- Sensitivity to voltage variations, interruptions, electrical noise or micro-cuts.
- Need for a dedicated circuit, ventilation, extraction, safety interlock or emergency stop.

Practical estimation formula

For the first approximation, it is recommended to calculate the design demand using the following logic:

a. Group loads by family: lighting, general outlets, electronics/instrumentation, computing, machinery, HVAC/extraction and special loads.
b. Add up the installed power of each group: P_installed = sum of nominal powers.
c. Apply a simultaneity or demand factor to each group based on expected use. As an initial reference: 0.6-0.8 for workbenches, 0.5-0.7 for 3D printers, 0.4-0.6 for hand tools, 0.8-1.0 for critical ventilation/extraction, and 1.0 for safety lighting or continuous loads.
d. Consider that continuous or prolonged use loads should not be designed to the limit of the switch; in continuous use circuits, it is common to work with a conservative criterion of approximately 80% of the nominal capacity of the circuit.
e. Add growth reserve. For entry-level installations: a minimum of 25%. For planned growth: 30-40% in panels, ducts, and feeders.
f. Convert to kVA if transformer, feeder, or UPS sizing is required: S(kVA) = P(kW) / power factor. For initial estimation, a power factor of 0.85-0.95 can be used, verifying actual manufacturer data.

Table 13
Electrical load group sizing, demand factors, and estimated power demand

Load group	Power installed example	Demand factor initial	Demand dear	Observation
General and task lighting	1.2 kW	1.0	1.2 kW	Essential load for safe operation; separate from force.
Computers and network	2.0 kW	0.8	1.6 kW	It can run on a clean energy circuit if the grid is unstable.
Instrumentation and data acquisition	1.5 kW	0.8	1.2 kW	It requires surge protection and, in part, a UPS.
Electronics and soldering benches	3.0 kW	0.6	1.8 kW	Multiple outlets, circuits per bank or per group of banks.
3D printers and lightweight prototyping	3.0 kW	0.7	2.1 kW	Prolonged charging; ensure proper ventilation and do not overload extension cords.
Small laser/CNC cutting/compressor	5.0 kW	0.6	3.0 kW	Prefer dedicated circuits and consider startup peaks.
Auxiliary extraction/ventilation	1.5 kW	1.0	1.5 kW	It must operate in conjunction with processes that generate fumes or vapours.
Booking a minimum 25%	-	-	3.1 kW	Booking about the demand is partial.
Total estimated, entry-level	17.2 kW installed	-	15.5 kW approx.	Reference example: validate with real equipment.

In this example, although the installed capacity exceeds 17 kW, the expected demand is approximately 15-16 kW, including reserve capacity. If the addition of laser cutting, CNC machining, or a compressor is confirmed, it is advisable to evaluate a three-phase power supply and dedicated circuits from the outset.

5.5 Electrical panels and internal distribution

The FabLab must have its own dedicated electrical panel or sub-panel, even if it is located within an existing university building. This facilitates maintenance, labelling, power consumption measurement, protection coordination, and fault isolation without affecting other laboratories.

Recommendations for entry-level

- A FabLab main panel with main switch, surge protection, separate neutral and ground bars, and room for expansion.
- Independent circuits for: lighting, general outlets, electronics banks, computing/instrumentation, prototyping equipment, extraction/ventilation and special loads.
- Thermomagnetic circuit protection, sized according to conductor, expected current and applicable standard.
- Differential/RCD or GFCI protection for general-purpose sockets, areas with washing facilities, humidity, portable equipment or risk of accidental contact.
- Clear labelling: circuit name, powered zone, voltage, originating panel, and UPS/non-UPS condition.

Recommendations for scalability

- Migrate to a main panel with sub-panels by zone: electronics and instrumentation; machinery/prototyping; computing/network; lighting; HVAC/extraction; special loads.
- Incorporate metering by sub-panel or main circuits to manage consumption, identify anomalies and justify future expansions.
- Maintain 25-40% free poles and physical space for additional protections, contactors, relays, meters or communication modules.
- Coordinate selectivity between protections so that a failure in one piece of equipment does not disconnect the entire FabLab.
- Plan for oversized conduits, spare trays, and accessible junction boxes.

Table 14

Electrical load group sizing, demand factors, and estimated power demand

Board or circuit	Recommended use	Design criteria
TG-FabLab	Main reception and distribution	Main switch, SPD, metering, N/PE busbars, phase identification and backup.
General shots	Small tools, chargers, and non-critical equipment	Multiple circuits to prevent overload; RCD/GFCI where applicable.
Electronics banks	DC power supplies, soldering irons, oscilloscopes, generators, multimeters	Dedicated circuits per bank or group; transient suppression; good grounding.
Clean Energy / UPS	Control PCs, data acquisition, network, and critical instrumentation	Do not connect motors or heaters; identify sockets with a different colour/label.
Machinery	CNC, laser, compressor, power tools	Dedicated circuits; consider start-up; emergency stop when applicable.
Ventilation/extraction	Extractors, filters, fans, HVAC	Dedicated power supply; interlock with equipment that generates fumes or vapours.
Lightning	General, task and emergency lighting	Separate power; includes emergency lighting and zoned circuits.

5.6 Outlets, conduits and power points

The layout of electrical outlets should facilitate configuration changes without requiring permanent extension cords. In an academic FabLab, equipment is frequently relocated, so it's advisable to use cable trays on walls, columns, tables, or overhead trays with controlled drops.

- Install sufficient power outlets on workbenches: as a practical reference, 4 to 8 points per bench, depending on the number of users and measuring equipment.
- On perimeter walls, provide points at 1.5 to 2.0 m intervals in flexible work areas; adjust spacing to the architecture and furniture.
- Use dedicated circuits for equipment with high power consumption, significant start-up, or manufacturer instructions: laser cutting, CNC, compressors, small ovens, vacuum pumps, environmental chambers, extractors, or servers.
- Visually differentiate between standard outlets, UPS/clean power outlets, and special outlets. Recommended to be labelled with circuit and original board.
- Avoid using multiple extension cords as a permanent solution. Power strips should only be used temporarily and within their rated capacity.
- In areas near washing facilities, where humidity, liquid handling, metal casings, or portable tools are present, use differential- or RCD protection or GFCI protection in accordance with applicable regulations.
- Install separate conduits for power, data, and sensitive signals. Maintain physical separation between power cables and instrumentation or communication cables.
- Consider outlets at different heights: on the table for electronics benches, at machine level for dedicated equipment, and on ceilings/columns when drops are required for mobile tables.

Table 15

Power receptacle density, conduct containment, and area-specific wiring specifications

Area	Recommended shots	Observations
Electronics and Instrumentation Bench	4-8 outlets per bank, plus UPS outlets if applicable	Include grounding point, technical trunking, task lighting and data.
3D printing area	1 dedicated outlet per printer or small group	Avoid overloading during prolonged operation; assess extraction if emissions occur.
Small laser /CNC cutting	Dedicated circuit by equipment	Check power, start-up, extraction, grounding and manufacturer's manual.
Computing and design	2-4 doses by season	Preferably clean energy/UPS for critical stations and grid.
Flexible area or mobile tables	Downpipes from roofs or columns with mechanical protection	Avoid cables on the floor; use cable reels or certified systems.
Laundry room or wet area	Only necessary and protected points	Use differential/GFCI protection and a location that minimizes splashing.

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5.7 Stabilised power, surge protection and UPS

Stabilised power and UPS backup should be used selectively. Not everything in the FabLab requires UPS. The goal is to protect data continuity, measurements, control computers, the network, sensitive instrumentation, and equipment whose interruption could cause data loss, sample damage, or operational risk.

Loads that should be considered critical

- Computers that control experiments, data acquisition, or long-running manufacturing processes.
- Oscilloscopes, analysers, precision power supplies, DAQ systems, stepper motor controllers for experimental benches and calibration or metrology equipment.
- Switches, routers, network storage, local servers, and access control if they depend on the lab.
- Environmental or security monitoring systems that must continue operating in the event of micro-outages

Loads that should not normally be shipped via UPS

- Laser cutting, CNC, compressors, large pumps, main extractors, heating elements, ovens, multi-unit 3D printers, power tools and high starting peak loads.
- Equipment whose manufacturer prohibits or limits use with UPS, or that requires a specially sized industrial UPS.
- Surge protectors connected in cascade to UPS systems are not permitted unless authorised by the manufacturer; it is preferable to use certified and properly sized distribution systems.

Table 16

Power conditioning specifications, surge suppression, and critical load ups Allocation

Element	Entry level	Scalability
UPS distributed	High-quality online or interactive UPS for controlling PCs, the network, and critical instrumentation. Autonomy: 10-20 min.	Online double-conversion UPS, central or zone, with bypass, monitoring, and replaceable batteries. Runtime: 15-30 minutes, or depending on continuity required.
Sizing	Measured or estimated critical load x 1.25 to 1.5. Verify active power W and apparent power VA.	Study of critical loads, power factor, autonomy, growth and maintenance of batteries.
Stabilisation/AVR	Useful if the network experiences frequent voltage variations.	Regulators, isolation transformers, or conditioners for high-sensitivity instrumentation, according to the manufacturer's requirements.
Surge protection	SPD on the main panel and fine protection for sensitive equipment.	Coordinated scheme type 1/2/3 according to the installation exposure and applicable standard; periodic maintenance.
ID	Labelled and differentiated UPS outlets.	Separate clean energy circuits, with metering and prohibition of non-critical loads.

5.8 Grounding, equipotentiality and protection of persons

The grounding system must be designed as a single, continuous, low-impedance system coordinated with the protective devices. A separate ground for instruments without equipotential bonding should not be improvised, as this can create dangerous potential differences or introduce noise through ground loops.

- All grounded electrical outlets must be connected to the protective conductor of the appropriate circuit.
- Metal equipment enclosures, switchboards, metal trays, conduits and conductive structures must be connected to the grounding system where appropriate.

- The ground bar of the panel must be clearly separated from the neutral bar in sub-panels, in accordance with the installation architecture and applicable regulations.
- It is recommended to perform initial and periodic measurements of grounding resistance, continuity of the protective conductor, polarity of electrical outlets and tripping of differentials/RCDs.
- For sensitive instrumentation, prioritise equipotential bonding, short protective conductor runs, separation of power and signal cables, and appropriate filters over isolated grounds without criteria.
- Avoid connecting the protective earth to pipes, structures, or elements not designed for that purpose, unless local regulations and electrical design explicitly permit it.

Table 17

Grounding system architecture, equipotential bonding, and personnel protection standards

Risk or need	Extent recommended
Electric shock due to insulation failure	Continuous protective conductor, RCD/GFCI where applicable, and maintenance of plugs and cables.
Atmospheric or switching overvoltages	Coordinated SPDs, effective grounding and post-severe event review.
Noise in measurements	Separate power and signal, avoid ground loops, use shielded cables and equipotential references.
Potential differences between teams	Equipotential bonding of metallic masses and taps with the common ground of the system.
Failures in extension cords or portable equipment	Visual inspection, removal of damaged cables, periodic testing and use of differential protection.

5.9 General, task and emergency lighting

The lighting must allow for safe, precise work, instrument reading, parts inspection, electronic soldering, and movement without excessive shadows or glare. It is recommended to combine uniform general lighting with task lighting.

Table 18

Luminous performance standards, task lighting criteria, and emergency systems

Area or task	Indicative illuminance level	Recommendations
Circulation and storage	150-300 lux	Avoid dark areas, mark routes and signs.
General work at FabLab	300-500 lux	Uniform LED luminaires, low glare and regular distribution.
Electronics, assembly and instrumentation benches	500-750 lux	Add adjustable task lighting; avoid reflections on screens and instruments.
Fine inspection, SMD soldering, reading small scales	750-1000 lux or support located	Articulated lamps, illuminated magnifying glass, and high colour rendering index.
Machinery and cutting	Approximately 500 lux on the work plane	Avoid shadows in the cutting area; protect the lighting from dust or particles, if applicable.
Emergency and evacuation	According to local regulations	Autonomous or backup-connected lighting fixtures; clearly visible routes and exits.

- Use a neutral colour temperature, typically 4000-5000 K, avoiding environments that are too warm for prolonged technical work.
- Prefer luminaires with low flicker, good glare control and a CRI greater than 80; for critical visual inspection, consider a CRI greater than 90.
- Separate lighting circuits from power circuits so that a machinery failure does not leave the laboratory without light.
- Install emergency lighting in evacuation routes, electrical panels, exits, and areas where a sudden stop could create a risk.
- In workbenches, supplement with adjustable task lamps to avoid forced postures and eye strain.

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5.10 Quality of energy and electromagnetic compatibility

- Evaluate the quality of the building's network: voltage variations, micro-cuts, transients, harmonics, and voltage drops during the start-up of motors or air-conditioning equipment.
- Place machinery with motors or switching loads on circuits separate from measuring instruments.
- For low-signal measurements, use physical separation between power conductors and signal cables; use shielding and grounding of screens according to the instrumentation design.
- Include overvoltage protection on the panel and point-of-use protection for sensitive equipment.
- Use certified, high-quality power supplies in experimental benches; avoid generic chargers or adapters without adequate protection.
- Consider energy monitoring in research FabLabs to record events that may explain failures or measurement anomalies.

5.11 Emergency stop, lockout and safe operation

- Equipment such as CNC machines, lasers, compressors, motion systems, or benches with actuators must have an accessible and verified emergency stop.
- Emergency shutdowns should not indiscriminately shut down equipment that needs to maintain extraction or safe control, unless determined by risk analysis.
- The panel must allow zones to be sectioned off for maintenance without de-energising the entire building.
- There must be a lockout/tagout procedure for electrical work or machinery maintenance.
- Users must receive basic induction: do not overload outlets, do not use damaged cables, identify UPS outlets, report protection tripping, and do not modify connections.

5.12 Recommendation for progressive implementation

Table 19

Progressive electrical implementation roadmap: stages, key actions, and tangible deliverables

Stage	Recommended actions	Deliverables
Stage 1: diagnosis	Survey existing and future equipment, review the building service entrance, perform preliminary voltage measurements, and evaluate available switchboards.	Inventory of loads, base plan, and building restrictions.
Stage 2: Design essential	Define zones, circuits, outlets, lighting, grounding, UPS and growth reserve.	Preliminary load table, single-line diagram, outlet and lighting plan.
Stage 3: Installation initial	Implement dedicated panels, minimum circuits, outlets per bank, lighting, SPD, grounding and distributed UPS for critical loads.	Operational entry-level installation and initial electrical testing.
Stage 4: Validation	Continuity, polarity, ground, differential, circuit load tests, thermography, if available and documentation of results.	Test report, as-built drawings and final labelling.
Stage 5: Scalability	Add sub-panels, new dedicated circuits, central or zone UPS systems, energy metering, and power quality improvements.	Expansion plan, budget and timeline.

5.13 Technical References

The following references can be used as a framework for consultation. The applicable standard will be the local legislation and institutional regulations in effect at the location where the FabLab is installed.

- National Electrical Code - Utilisation, Peru. Basic document for electrical installations for utilisation and local safety criteria.
- OSHA 29 CFR 1910.304, Wiring Design and Protection: requirements on receptacles, grounding, circuits and protection of people.
- OSHA, Electrical Incidents - Ground- Fault Circuit Interrupters: description of the function of GFCIs and their role in protection against earth faults.

- OSHA, Laboratory Safety Guidance: General guidelines for non-production academic and research laboratories.
- NFPA 70 / National Electrical Code, as an international reference for the design of installations, protections, earthing and branch circuits when accepted by the competent authority.
- IEEE Std 1100, Recommended Practice for Powering and Grounding Electronic Equipment, is a reference for powering and grounding sensitive electronic equipment.
- IEC 60364, Low- voltage electrical installations, is an international reference framework for low-voltage installations.
- Ergonomics and lighting guidelines in laboratories: use of task lighting, reduction of visual fatigue and suitability of the work surface.

6. Ventilation, extraction and environmental control

The goal of the ventilation, extraction, and environmental control system in an academic Fab Lab is not to maximise production but to protect users, preserve prototype quality, ensure reasonable conditions for sensitive equipment, and allow for the orderly growth of the lab. In a university and research environment, the system must be designed to accommodate a variety of activities: design and computing, electronics, instrumentation, 3D printing, assembly, light fabrication, occasional use of adhesives, soldering, prototype testing, and technical storage.

The recommended approach is preventive and progressive: reducing pollutant generation, separating incompatible processes, capturing emissions at the source, preventing recirculation of contaminated air, maintaining stable environmental conditions, and monitoring system performance. This approach is consistent with good industrial and laboratory ventilation practices, in which local exhaust ventilation captures pollutants near their source before they disperse into the work environment.

6.1 Recommendations for an entry-level FabLab

To make a reasonable investment, it is recommended to implement a basic yet safe, modular, and measurable system. An entry-level FabLab can operate with adequate general ventilation, localised exhaust for emission processes, basic temperature and humidity control, and clear operating and maintenance procedures.

Table 20

Baseline Environmental Control Parameters and Minimum HVAC Specifications for Entry-Level FabLabs

Element	Recommendation for entry-level
Zoning minimum	Separate, even if through different areas, the clean design/electronics/metrology zones from the zones where particles, fumes, odours, or heat are generated.
General ventilation	Ensure adequate outdoor air renewal in accordance with local regulations and expected occupancy. In spaces with laboratory-type activities or the use of hazardous materials, use higher renewal rates and continuous ventilation where appropriate.
Extraction located	Use fume extractors for welding, articulated arms or small hoods for low-volume adhesives/resins, and ventilated cabinets or enclosures for 3D printing.
Thermal control	Maintain a temperature compatible with comfort and equipment stability. As an operating reference: 20-26 °C, adjustable according to climate, occupancy, and instrument sensitivity.
Humidity control	Maintain a moderate relative humidity of approximately 40-60% to reduce the risk of static electricity, corrosion, material deformation, and user discomfort.
Filtration	Use HVAC system filtration and, for local captures, HEPA and/or activated carbon filters depending on the expected contaminant. Filtration should not replace external extraction when significant contaminants are present.
Monitoring essential	Install at least one visible sensor or recorder for temperature, humidity, and CO_2. Supplement this with inspections for odours, dust, user complaints, and filter status.
Management operational	Define equipment usage procedures, ventilation times before/after processes, prohibitions of unauthorised hazardous materials, and maintenance records.

6.2 Environmental zoning criteria

Air distribution should complement the physical layout of the FabLab. Treating the entire space as a single, homogeneous room is not recommended if it contains clean activities, emission-generating activities, and activities requiring environmental stability. Zoning helps reduce risks, facilitates monitoring, and prepares for future scalability.

Table 21

Environmental controls linked to equipment already present in the network

Activity observed in partner FabLabs	Main emission or environmental concern	Minimum operational control
FDM 3D printing with Bambu Lab and Creality equipment	Heat, odours, ultrafine particles, and material-dependent VOC emissions.	Prefer enclosed equipment or ventilated cabinets; maintain an authorised-material list and avoid locating printers beside clean measurement benches.
Soldering, microsoldering, reflow, and hot-plate work	Flux fumes, local heat, hot surfaces, and accidental contact.	Use source-capture fume extraction, heat-resistant work surfaces, clear hot-zone marking, and controlled cooling areas.
WEGSTR PCB routing and light mechanical finishing	Fine particulate matter, debris, noise, and contamination of electronics benches.	Use local capture or suitable vacuum cleaning, separate the work from clean electronics, and prohibit dry sweeping.
Laser cutting at ESPOCH	Process fumes, particles, odours, fire risk, and material-dependent toxic gases.	Provide dedicated external extraction, approved-material control, interlocks, fire response provisions, and documented filter or duct maintenance.
Oscilloscopes, microscopes, sensors, and metrology work	Dust, direct air currents, unstable temperature or humidity, and vibration.	Place in the cleanest available zone, away from cutting and thermal processes; monitor temperature and humidity when measurements require it.

Table 22

Environmental-control priorities derived from the fabrication and instrumentation processes already installed in the EL-BONGO Physics network

Area or activity	Consideration environmental
Design, computing and documentation	Heat load from computers, occupancy and CO_2. Requires comfort, air renewal and low noise.
Electronics and Instrumentation	It requires clean air, controlled humidity, absence of direct currents on workbenches, and spot extraction for welding.
3D printing and lightweight digital manufacturing	It can generate ultrafine particles, VOCs, odours, and heat. It requires enclosure, local exhaust ventilation, and evaluation of the materials used.
Assembly and metrology	It requires reasonable thermal stability, low dust presence, adequate lighting, and control of vibrations or air currents if sensitive measurements are used.
Use of adhesives, resins, solvents or welding	It requires strict control, low storage quantities, use in ventilated areas, and source control. It should be prohibited. Unauthorised materials.
Storage technical	It must be organised, ventilated according to materials, with segregation of incompatible products and clear labelling.

6.3 General ventilation and local exhaust

General ventilation

General ventilation serves three main functions: providing outside air for occupants, diluting low-concentration residual pollutants, and aiding in thermal control. For an academic FabLab, the size must be determined by the number of simultaneous users, the thermal load of equipment, the room volume, the frequency of use, and the presence of emission processes.

- Do not use general ventilation as the sole control for processes that generate fumes, vapours, strong odours, particles, or emissions from 3D printing.
- Prevent airflow from carrying contaminants from manufacturing areas to electronics, metrology, or discussion areas.
- Keep air inlets and outlets free of obstructions; do not block diffusers with shelving, panels, or equipment.
- Consider HVAC system noise, especially in teaching, computing, measurement, and technical discussion areas.

Reference calculation of air renewal

As an initial guideline, the renewal flow rate can be estimated using the following relationship:

Flow rate (m^3/h) = Volume of the environment (m^3) × air changes per hour (ACH)

The ACH value should be defined by a specialist based on the risk. For general-use, design, and computing spaces, the ventilation criteria for buildings and classrooms may be sufficient if there are no significant emission sources. For laboratory-type areas or areas with hazardous materials, some institutional guidelines recommend more stringent minimum values, for example, around 6 ACH for laboratories with hazardous materials. This value should not be automatically copied; it must be validated against local regulations, the materials inventory, and the actual level of risk.

Table 23

Air renewal rates, localized exhaust criteria, and zoning specifications by operational area

Area	Criterion	Observation
Design / Computing	Comfort and occupancy ventilation	According to local HVAC and occupancy regulations
Electronics with soldering occasional	General ventilation + smoke extraction	ACH base + localised extractor
3D printing	Enclosure or cabinet ventilated	External extraction or validated technical filtration
Laser, resins, solvents	Dedicated system	Specific design, secure download, and compatibility assessment

Localized extraction

Local exhaust ventilation should capture the contaminant as close as possible to its point of generation. In an entry-level FabLab, it is recommended to prioritise electronic soldering, adhesives, resins, 3D printing, cutting/engraving, sanding, light machining, and any processes that produce a visible odour, dust, or smoke.

- Electronic welding: Use a fume extractor with an articulated arm and appropriate filters. Position the nozzle close to the welding area without interfering with the work.
- 3D printing: opt for enclosed printers or ventilated cabinets. For multiple printers, consider ventilated racks or balanced common extraction systems.
- Adhesives, resins, or solvents: work in small quantities, with local ventilation, a containment tray, and prior approval from the safety officer.

- Laser cutting requires dedicated extraction, material-compatible filtration, safe discharge, and prohibition of materials that generate hazardous or corrosive gases.
- Machining or sanding: control particles with local capture, aspiration with suitable filters and wet cleaning or methods that do not redisperse dust.

6.4 Environmental control: temperature, humidity, filtration and pressure

Table 24

Environmental variable control parameters and baseline ambient specifications

Variable	Recommendation
Temperature	Maintain comfortable and reasonably stable conditions. Reference operating range: 20-26 °C. For metrology or sensitive instruments, define specific tolerances per piece of equipment.
Humidity relative	Maintain a moderate range, approximately 40-60%. Very low humidity increases ESD risks; high humidity can affect materials, corrosion, filaments, and electronics.
General filtration	Use HVAC filters in accordance with the building design and outdoor air quality. In environments with dust or outdoor pollution, improve filtration and maintenance.
Filtration located	HEPA filters for fine particles, activated carbon, or other media for VOCs/odors where applicable. A filter replacement and disposal plan must be in place.
Pressure differential	Keep clean areas neutral or slightly positive relative to emission areas; keep welding, 3D printing, or manufacturing areas with a negative where possible.
Noise and comfort	Select fans, extractors and diffusers that do not generate noise levels incompatible with teaching, concentration or measurement.
Vibration and currents	Avoid direct current on scales, sensors, microscopes, optics, dimensional measurement equipment, or sensitive testing equipment.

6.5 Physical design recommendations for the system

- Locate emission zones near exterior walls or technical ducts to facilitate unloading, maintenance, and future expansions.
- Prevent the recirculation of air extracted from processes into the indoor environment if it contains fumes, VOCs, odours, particles, or unknown contaminants.
- Provide space for ducts, fans, filters, inspection chambers, silencers, and maintenance access.

- Separate, when necessary, chemically incompatible extraction streams to avoid corrosion, reactions, or cross-contamination.
- Provide visible switches or controls for local extractors, with mandatory use signage before starting the process.
- Include alarms or flow indicators for critical hoods, ventilated cabinets, or extractors when the risk justifies it.
- Maintain up-to-date duct plans, filter locations, design flow rates, discharge points, and maintenance routines.

6.6 Operational management and maintenance

A poorly used or unmaintained ventilation system can create a false sense of security. Therefore, the FabLab must operate under simple, verifiable rules compatible with academic use.

Table 25

Operational management protocols, ventilation maintenance, and quality control standards

Aspect	Recommendation operational
Usage procedures	Each piece of equipment that emits must have visible instructions: turn on extraction, wait for stabilisation, operate, ventilate after use, and turn off, in accordance with the procedure.
Materials control	Maintain a list of authorised and prohibited materials. The use of resins, solvents, adhesives, special filaments, or laser materials must be approved beforehand.
Training	Train students and users in ventilation, extraction, filters, odours, failure signs and incident reporting.
Maintenance	Check filters, hoses, ducts, nozzles, fans, and discharge points. Record date, person responsible, findings, and actions taken.
Verification	Measure or verify flow rates and performance of extractors when installed, after changes, and periodically.
Environmental Registry	Record temperature, humidity, CO_2, odour complaints, incidents, and laboratory configuration changes.

6.7 Recommended scalability

Scalability should be planned from the outset to avoid costly renovations. Even if the FabLab starts with basic equipment, it is recommended to reserve physical space, electrical capacity, ductwork, exhaust points, maintenance areas, and zoning criteria that will allow for the addition of new equipment.

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Figure 15

Scalability path of the ventilation and environmental control system

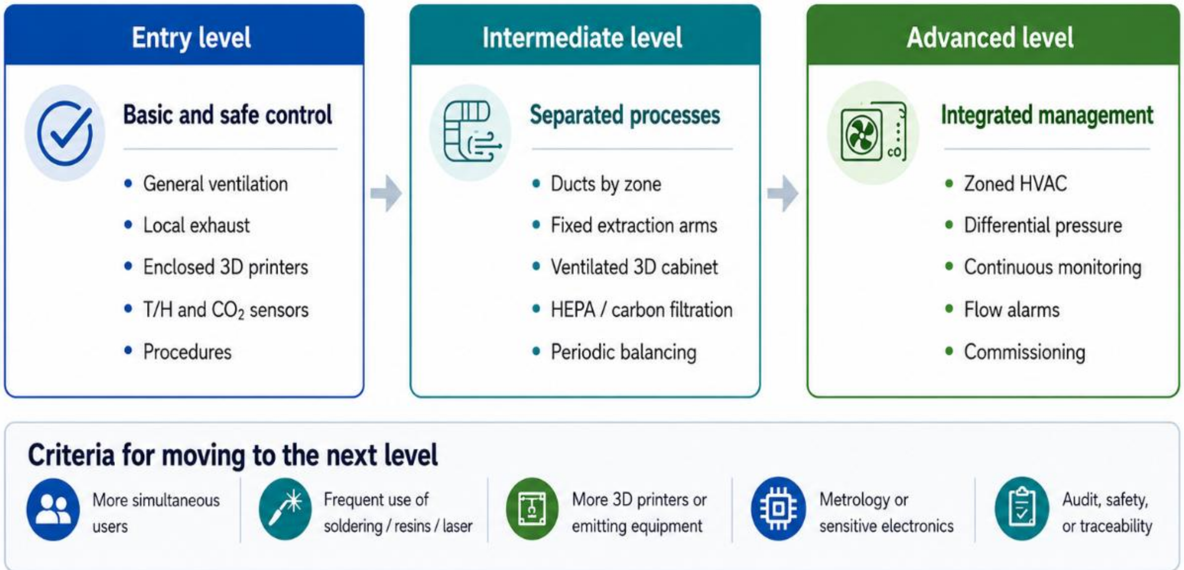

Table 26

Staged environmental infrastructure roadmap and escalation

Stage	Recommended actions
Stage 1: Entry level	General ventilation, basic sensors, portable extractors, enclosed cabinets for 3D printing, usage and maintenance procedures.
Stage 2: Growth controlled	Fixed extractor arms, dedicated ducts, extraction for multiple printers, improved filtration, flow balanced, and environmental condition monitoring.
Stage 3: Capabilities advanced	Zoned HVAC, differential pressure control, continuous monitoring, flow alarms, dedicated systems for laser/CNC/resins and periodic commissioning.
Escalation triggers	Increased users, more equipment with emissions, persistent odours, use of new materials, need for more sensitive measurements, comfort complaints, or institutional security requirements.

6.8 Specific technical references

- OSHA, Technical Manual, Section III: Chapter 3 - Ventilation Investigation: https://www.osha.gov/otm/section-3-health-hazards/chapter-3

- OSHA, Laboratory Safety: Chemical Fume Hoods: https://www.osha.gov/sites/default/files/publications/OSHAQUICKFACTS-LAB-SAFETY-CHEMICAL-FUME-HOODS.pdf
- NIOSH/CDC, Characterizing 3D Printing Emissions and Controls in an Office Environment: https://www.cdc.gov/niosh/bulletin/2018/3d-printing.html
- EPA, Indoor Air Quality: Improving Indoor Air Quality: https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality
- EPA, Indoor Air Quality Tools for Schools and Reference Guide: https://www.epa.gov/iaq-schools/reference-guide-indoor-air-quality-schools
- ASHRAE, Laboratory Design Guide, 2nd edition: https://www.ashrae.org/technical-resources/bookstore/ashrae-laboratory-design-guide-2nd-ed
- Stanford EH&S, General Ventilation Considerations: https://ehs.stanford.edu/manual/laboratory-standard-design-guidelines/general-ventilation-considerations

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7. Communication and data infrastructure

The communication and data infrastructure of an academic FabLab should be understood as a support system for research, experimental teaching, and prototype development. It's not simply about enabling internet access, but about ensuring reliable connectivity, traceability, information security, service availability, data backup, and scalability. In an advanced physics laboratory, the network might connect design workstations, data acquisition equipment, measuring instruments, 3D printers, controllers, servers, design repositories, authorised monitoring cameras, displays, environmental sensors, and institutional services.

The initial design should be austere yet well organised. A simple, poorly organised network can quickly become an operational risk: loss of design files, unbacked equipment, IP address conflicts, exposure of instruments to open networks, inability to audit changes, or over-reliance on individual computers. Therefore, even at an entry level, it is recommended to consider principles of structured cabling, logical segmentation, backups, documentation, and basic security.

7.1 General design criteria

- Prioritise wired networking for critical equipment, measuring instruments, servers, NAS, data acquisition stations, and manufacturing equipment that require stable file transfer.
- Use Wi-Fi for academic mobility, portable devices, classes, consultations, and non-critical equipment, avoiding reliance on Wi-Fi for sensitive data acquisition or process control.
- Logically separate users, lab equipment, guests, administration, and scientific storage using VLANs or equivalent policies.
- Plan for physical growth from the initial stage: ducts, conduits, patch panel, rack space, free ports, PoE capacity and data point reservation.
- Coordinate all design with the university IT office to ensure compatibility with directories, security, firewall, VPN, acceptable use policies, and institutional support.

7.2 Recommendations for an entry-level laboratory

An entry-level FabLab doesn't require a data centre infrastructure, but it does need an organised, documented, and secure network. The initial goal is to enable reliable academic work in design, lightweight fabrication, electronics, basic instrumentation, file management, and collaboration among faculty, students, and researchers.

Table 27

Baseline it network architecture, hardware components, and technical justifications

Component	Recommendation initial	Livelihood
Communications rack or cabinet	Wall-mounted cabinet or small rack with patch panel, organisers, UPS, and passive or active ventilation, depending on the load.	It consolidates the infrastructure, facilitates maintenance, and avoids improvised installations.
Managed switch	24-port 1GbE managed switch, preferably with some PoE + ports for Wi-Fi points, authorized cameras, or network devices.	It allows VLANs, port monitoring, quality of service, and orderly growth.
Cabling structured	Horizontal Cat 6 cabling as a minimum base, labeled and tested; leave double points in critical banks.	robustly supports 1 GbE and can support certain higher speed scenarios over short distances.
Network points	Double points per design station, electronics bench, instrumentation area and manufacturing zones with connectable equipment.	Reduce extensions, unauthorized switches, and insecure temporary connections.
Institutional Wi-Fi	Wi-Fi 6 or higher coverage managed by institutional IT; academic network, guests and differentiated devices.	It facilitates mobility without compromising the network of instruments or storage.
Storage	NAS or shared server with folders per project, permission control and automatic backup.	Avoid loss of designs, codes, CAD models, and experimental data.
Security basic	Institutional credentials, role profiles, antivirus/EDR, firewall, equipment updates, and change log.	It reduces the risk of intrusion, data loss, or misuse of resources.

Table 28

Suggested minimum data points

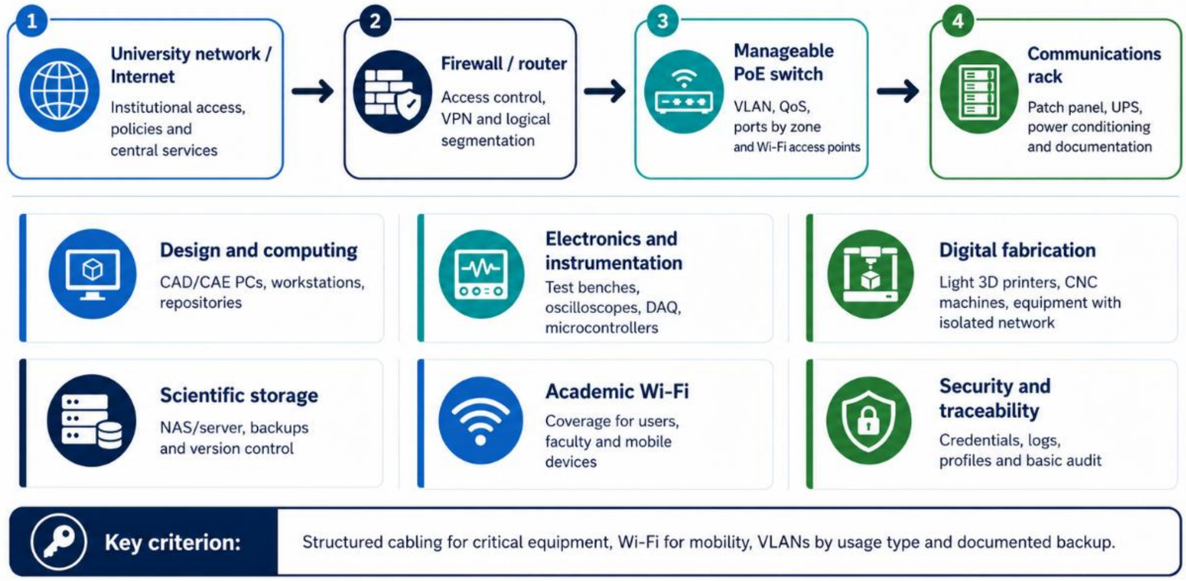
Area	Minimum network points	Observations
Design and computing	2 points per workstation	Consider an additional point for printer, screen, or temporary equipment.
Electronics and Instrumentation	2 to 4 points per bank	One point for PC/DAQ and another for instrument or controller; use static IP where appropriate.
Digital manufacturing	1 to 2 points per connectable device	Separate 3D printers, lightweight CNC machines, or lasers from common user networks.
Storage /NAS	2 points dedicated	Preferably redundant link or 10 GbE in intermediate stage.
Teaching / Meeting Area	2 to 4 points	Screen, videoconference, presentation PC or interactive whiteboard.
Wi-Fi hotspots	According to coverage study	Prefer ceiling- or wall-mounted PoE points, managed by IT.

7.3 Recommended network and data architecture

The architecture should be simple to operate, yet robust enough to separate critical functions. For the entry level, a star topology is recommended, with a central rack or communications cabinet that receives the institutional link, houses the managed switch, patch panel, and UPS, and distributes connectivity to the FabLab areas.

Figure 16

Recommended conceptual architecture for communication and data infrastructure



The architecture must be coordinated with the electrical, furniture, and security designs. Network points should be located near workbenches and metering stations, with cables avoiding crossings of walkways. It is recommended to maintain separate cable runs, respect cable bend radii, label both ends, and record each point on a plan or asset matrix.

Main elements of architecture

- Institutional link: main connection provided by the university or parent entity, with policy control, Internet access and central services.
- Firewall/ router: an institutional device or service responsible for controlling traffic, VPN, access rules and separation between segments.
- FabLab's local distribution core must support VLAN, monitoring, PoE (if powered by APs), and secure management.
- Rack or cabinet: physical space for patch panel, switch, UPS, cable organisation, documentation and future expansions.
- Data services: NAS, project server, design repository, version control, backups and synchronisation with institutional storage where applicable.

7.4 Structured cabling, network points and Wi-Fi

Structured cabling should be designed as a permanent infrastructure, not as a collection of temporary extensions or cables. For an entry-level university FabLab, Category 6 copper cabling is usually a reasonable base for workstations and benches. For links between cabinets, servers, or areas that may grow, fibre-optic or 10 GbE links should be considered, especially if large CAD files, images, sensor data, or experimental results will be transferred.

Technical cabling recommendations

- Use certified structured cabling with patch panels, wall plates, and faceplates. Use appropriate cords; avoid makeshift splices or permanently lose cables.
- Label all network points with a unique code that relates to rack, patch panel, switch port, physical zone, and intended use.
- Plan to reserve 25%-40% of free ports on the patch panel and switch for expansion.
- Separate data conduits from power cables, motors, compressors, or other sources of electromagnetic interference; follow the supplier's installation recommendations and local regulations.
- For electronics and instrumentation benches, locate network points next to regulated electrical outlets, but with physical order and clear labelling to avoid accidental disconnections.

Wi-Fi Recommendations

- Install university-managed access points, preferably Wi-Fi 6 or higher, with PoE power from the switch and channels configured by the IT department.
- Separate wireless networks: academic/institutional, guest, and FabLab devices when necessary.
- Do not rely on Wi-Fi for critical equipment control, sensitive data acquisition, large-file transfers to manufacturing machines, or equipment requiring low latency.
- Perform at least a basic validation of coverage and saturation, especially if the FabLab is in spaces with thick walls, metal structures, or equipment that generates interference.

7.5 Segmentation, security and access control

Segmentation is a relatively low-cost, high-impact measure. It allows for the separation of experimental equipment, guest users, workstations, servers, and manufacturing devices. This reduces the risk of unauthorised access, malware propagation, accidental modifications, or exposure of research data.

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Figure 17

Segmentation matrix and recommended data services

Segment	Main use	Recommended access	Minimum controls	Scalability
Administration	FabLab management, inventory, documentation	Authorized personnel	MFA/VPN, role-based permissions, backups	Integration with institutional directory
Design and computing	CAD/CAE, data analysis, and documentation	Registered users	Antivirus/EDR, repositories, quotas	High-performance workstations
Instrumentation	DAQ, oscilloscopes, sensors, test benches	Researchers and faculty	Dedicated VLAN, static IP, NTP, logs	Acquisition server and isolated network
Digital fabrication	3D printers, light CNC, connectable equipment	Authorized operators	Separate network, file control, monitoring	Job queues and traceability
Guests / teaching	Temporary access, classes, demonstrations	Internet and limited resources	Portal/credentials, client isolation	Integration with eduroam or institutional Wi-Fi
Storage / backups	NAS, repository for designs and experimental data	Project groups	Permissions, encryption, 3-2-1 copies	Redundancy and external replication

Practical rule: Do not connect experimental equipment, guest users, and scientific storage in the same logical domain.

Suggested minimum controls

- Define user profiles: FabLab administrator, teacher/researcher, authorised student, equipment operator, guest, and maintenance.
- Implement institutional authentication and, where feasible, 802.1X network access control for enterprise wired or Wi-Fi ports.
- Block or isolate unused ports and avoid unauthorised home switches or routers within the lab.
- Maintain an inventory of connected equipment: IP address, MAC address, responsible party, physical location, function, date of incorporation, and status.
- Define rules for transferring files to manufacturing equipment: allowed formats, prior review, source repository, and version traceability.
- Establish policies for sensitive data, experimental results, unpublished designs, student data, and projects with confidentiality agreements.

7.6 Research data management, storage and backups

A research-oriented FabLab generates files of diverse nature: CAD models, source code, microcontroller configurations, CNC programs, 3D printing profiles, sensor data, spreadsheets, prototype photographs, test reports, and version documentation. The data infrastructure must make it easy to access, back up, and link these files to projects, but without turning the FabLab into a cluttered repository.

Storage recommendations

- Create a folder structure by project, line of research or course, with defined responsibilities and differentiated permissions.
- Use a NAS or shared server with user control, not USB drives, as the primary repository.
- Implement automatic backup with the 3-2-1 rule as a conceptual reference: three copies, two different media or locations, and one external or institutional copy when possible.
- Maintain version-control repositories for code, parametric designs, data-acquisition scripts, and important technical documents.
- Record versions of files sent to manufacturing or printing to reproduce prototypes and correlate them with tests performed.

Instrumentation and acquisition data

Networked data acquisition systems and measuring equipment require special attention. At an entry level, a local acquisition PC with automatic backup to a NAS may suffice. At an intermediate level, an acquisition server or temporary storage with scheduled synchronisation is advisable. At an advanced level, a dedicated instrumentation network, reliable time synchronisation, redundant storage, and traceability of experimental metadata can be considered.

7.7 Progressive scalability

Scalability should be a design requirement from the outset. This doesn't mean buying all the equipment from the beginning but rather planning for future growth without having to redo the installation: rack space, spare patch panel capacity, oversized cabling, additional network points, a managed switch, and up-to-date documentation.

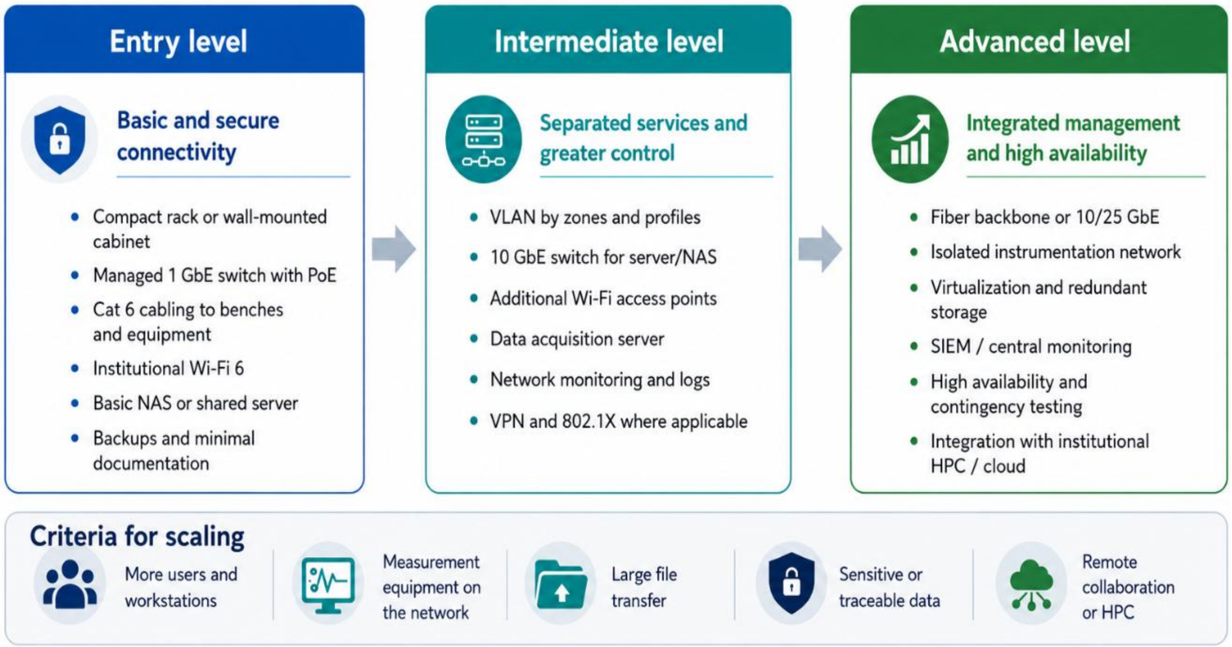
Table 29

Network infrastructure growth framework and modular expansion criteria

Level	Capabilities recommended	When climb
Entrance	GbE connectivity, institutional Wi-Fi, basic NAS, initial VLANs, port documentation, and automated backup.	FabLab beginnings, few teams, initial academic projects, light prototyping.
Intermediate	Switches with higher PoE, 10 GbE links for NAS/server, more APs, consolidated VLANs, network monitoring, and a data acquisition server.	More users, more connected devices, frequent transfer of large files or networked instruments.
Advanced	Fibre or 10/25 GbE backbone, high availability, redundant storage, isolated instrumentation network, integration with HPC/cloud, central monitoring.	Intensive research, multi-user operation, sensitive data, need for formal traceability, or advanced collaborative projects.

Figure 18

Scalability roadmap for the FabLab 's communication and data infrastructure



7.8 Recommendations for institutional coordination

- Integrate the FabLab into the university's security and support model, avoiding isolated solutions that cannot be maintained.
- Define technical responsibilities: FabLab administrator, IT support, security manager, and research line managers.
- Establish a procedure for registering network-connected equipment and for approving devices with remote access.
- Align the design with institutional policies on data, intellectual property, research, information protection, and acceptable use of digital resources.

7.9 Supporting technical references

The following references are included as a general technical framework. Final implementation must comply with local regulations, institutional policies, and selected vendor specifications.

- ANSI/TIA-568.0-E: Generic Telecommunications Cabling for Customer Premises. https://www.tiafotc.org/tia-standards-update/tia-568-0-e/
- ISO/IEC 11801-1:2017 - Information technology - Generic cabling for customer premises. https://www.iso.org/standard/66182.html
- IEEE 802.11ax-2021 - Wireless LAN medium access control and physical layer specifications. https://standards.ieee.org/ieee/802.11ax/7180/

- IEEE 802.3bt-2018 - Power over Ethernet amendment. https://standards.ieee.org/ieee/802.3bt/6749/
- IEEE 802.1X - Port-Based Network Access Control. https://1.ieee802.org/security/802-1x/
- NIST Cybersecurity Framework 2.0. https://www.nist.gov/cyberframework
- NIST SP 800-171 Rev. 3 - Protecting Controlled Unclassified Information in Nonfederal Systems and Organizations. https://csrc.nist.gov/pubs/sp/800/171/r3/final
- NIST SP 800-34 Rev. 1 - Contingency Planning Guide for Federal Information Systems. https://csrc.nist.gov/pubs/sp/800/34/r1/upd1/final

8. Technical furniture and layout

The technical equipment in an academic FabLab for advanced physics must prioritise safety, reconfiguration, project traceability, compatibility with sensitive instrumentation, and the separation of clean and manufacturing activities. Unlike a commercial FabLab, the primary goal is not to maximise customer traffic or mass production, but rather to facilitate learning, research, incremental prototype development, instrument maintenance, and student training.

The recommendations described in this section are for guidance only and should be adapted to the available space, specific equipment, local regulations, institutional safety policy, electrical availability, ventilation, accessibility conditions, and risk assessment. The final furniture layout should be coordinated with the specialists responsible for the laboratory's infrastructure, safety, maintenance, and operation.

8.1 Recommendations for an entry-level FabLab

For the initial phase, it is recommended to implement modular, durable, easy-to-clean, and relocatable furniture. The initial investment should focus on multipurpose work tables, electronics benches with ESD protection, secure storage, and visual management systems. The purchase of highly specialised furniture should be reserved for when the work processes are well established.

Table 30

Suggested minimum configuration

Element	Amount of the initial referential	Characteristics techniques minimums	Main use
Work tables multipurpose	2 to 4	Metal frame, sturdy tabletop, capacity for accessories, wheels with brakes or levellers.	Assembly, testing, practical teaching and small prototypes.
ESD electronics banks	2 to 4 positions	Dissipative cover, ESD mat, grounding, top shelf, lighting, channels and local exhaust for welding.	Assembly, repair and testing of circuits and instruments.
Heavy bench of lightweight manufacture	1 to 2	High rigidity, impact/heat-resistant surface, clamp or press, and a tool board nearby.	Basic mechanical work, fitting, drilling, manual cutting and parts preparation.

Element	Amount of the initial referential	Characteristics techniques minimums	Main use
Metrology /control table	1	Rigid and stable table, away from vibration, dust and heat; clean and level surface.	Dimensional verification, inspection of parts, non-accredited internal calibrations and quality control.
Storage technical	According to the inventory	Racks, drawers, closed cabinets, labelled boxes, and areas for ongoing projects.	Order, traceability and control of tools, parts and supplies.
Whiteboards and panels	2 to 4	Whiteboard, Kanban board, shadow tool board and visible signage.	Visual management, safety, planning and teaching.

8.2 Furniture distribution criteria

- Separate the clean areas for design, computing, electronics and instrumentation from the areas where dust, noise, vibration, fumes, heat or waste are generated.
- Organise the flow from design and documentation to manufacturing, assembly, testing, control, and storage, avoiding unnecessary cross-over among people, materials, and waste.
- Keep corridors clear and visually unobstructed. As a practical guideline, consider 1.0 to 1.2 m for main circulation and no less than 0.8 m in secondary passages, adjusting to local regulations and accessibility requirements.
- Place electronics workbenches near stabilised power outlets, data network, task lighting, and welding fume extraction.
- Place heavy benches and vibrating equipment in perimeter areas, preferably on firm floors and away from measuring stations or sensitive instruments.
- Reserve a clearly identified area for prototypes in progress, samples, finished parts, and components in quarantine or pending verification.

8.3 Technical working groups

Tables should be selected according to the type of activity. For an academic FabLab, it is recommended to avoid domestic or office tables for technical activities, as they tend to have low mechanical resistance, poor stability, poor compatibility with accessories, and limited durability.

Table 31

Technical workbench specifications, dimensional criteria, and surface standards

Table type	Dimensions recommended	Surface	Requirements technicians	Observations
Multipurpose table	1.50-2.40 m long x 0.75-0.90 m deep	Phenolic, compact laminate, sealed engineered wood or industrial surface.	Rigidity, protected edges, capacity for strips, trays and drawers.	Useful for assembly, teaching, and lightweight prototyping.
Assembly table fine	1.20-1.80 m long x 0.75 m deep	Smooth, clear and easy-to-clean surface.	Good lighting, low vibration, storage for fine tools.	Suitable for small parts, sensors, brackets and simple optics.
Heavy table	1.50-2.00 m long x 0.75-0.90 m deep	Steel, engineered solid wood, or impact-resistant coating.	Reinforced structure, levellers, anchoring possibility, and vice.	It should not share an immediate area with delicate instruments.
Metrological table basic	1.20-1.80 m long x 0.75 m deep	Stone, a stable technical board or level rigid surface.	Relative vibration isolation, cleanliness, location away from heat.	For dimensional inspection and prototype verification.
Mobile auxiliary table	0.80-1.20 m long	Surface durable and washable.	Industrial wheels with brake and containment edges.	Supports internal transport and preparation of materials.

8.4 Electronics and instrumentation workbenches

Electronics test benches should be treated as clean technical areas. Circuit assembly, soldering, data acquisition, sensor testing, power supply connection, instrument maintenance, and measurement prototype development will all take place there.

Therefore, the test bench must incorporate ergonomics, electrical safety, electrostatic protection, organisation, and documentation capabilities.

- Use ESD surfaces or dissipative mats connected to a technical ground point defined by the laboratory's electrical manager.
- Include a top-shelf or modular profile for lightweight instruments: oscilloscopes, power supplies, generators, multimeters, and compact analysers.
- Include adjustable task lighting, preferably integrated into the workbench or installed above the work area without creating intense shadows.
- Include localised extraction for welding and flux work to prevent fumes from dispersing into computing or metrology areas.
- Clearly separate general power, stabilised/UPS power, and dedicated outlets for sensitive instruments, using labelling and cable trays.
- Incorporate low drawers or component carts with classification by resistor, connector, sensor, cable, module, and consumable.

8.5 Furniture for prototype manufacturing

Prototype fabrication in an academic FabLab can include 3D printing, cutting, drilling, fitting, light machining, mechanical assembly, and the fabrication of supports, shields, housings, detector parts, adapters, and experimental benches. The equipment must allow for the control of waste, vibration, heat, dust, and tool safety.

- For 3D printers, use rigid, level tables with a temperature-resistant surface; avoid unstable tables or tables with vibration transmitted by other equipment.
- For laser cutting or equipment with extraction, use furniture compatible with ducting, maintenance access, a dedicated cabinet or table, and separation from combustible materials.
- For hand or power tools, use a heavy-duty workbench with a tool board, vice, edge protection, chip container, and space for PPE.
- For mechanical prototyping work, place material storage near the workbench, but outside the immediate operating area to avoid obstructions.
- For scientific prototypes, reserve a clean final integration table for assembling mechanical parts, electronics, sensors, wiring, and documentation.

8.6 Technical storage and materials management

Storage should not be treated as secondary furniture. In an academic FabLab, the traceability of parts, tools, components, and ongoing projects prevents losses, rework, accidents, and duplicate purchases.

Table 32

Technical storage infrastructure, materials management standards, and traceability criteria

Element	Recommended use	Selection criteria	Labeled suggested
Metal racks	Materials, boxes, large parts and prototypes in progress.	Visible load capacity, stability, and anchoring are high.	Material, project, responsible party, date, status.
Drawer units technicians	Electronic components, screws, connectors, sensors and consumables.	Internal divisions, labels, partial transparency.	Component code, value, minimum quantity.
Cabinets closed	Instruments, precision tools, PPE and sensitive equipment.	Lock, access control, dust protection.	Equipment, status, responsible party, and calibration, if applicable.
Mobile carts	Shared tools and practice kits.	Wheels with brakes, trays with rims, ergonomic height.	Kit, contents, assigned area.
Shade panel	Tools manuals frequent.	Visual, durable and close to the manufacturing bench.	Tool name and defined location.

8.7 Chairs, posture and ergonomics

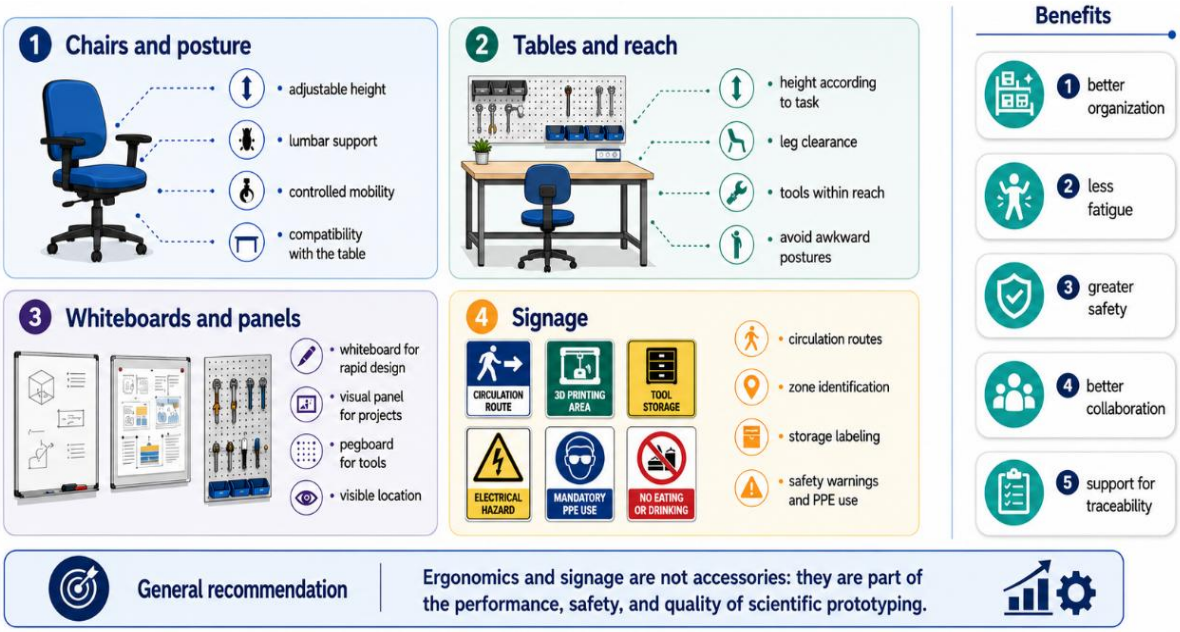
Ergonomics is critical because many design, welding, assembly, programming, documentation, and measurement activities require prolonged concentration and manual dexterity. Avoid makeshift chairs, unsupported stools, or non-adjustable office furniture when the user is performing repetitive technical work.

- Use height-adjustable chairs with a backrest, lumbar support, and a stable five-point base for design, electronics, and instrumentation workstations.
- For high benches, use technical chairs or industrial stools with a footrest ring and height adjustment; do not use low chairs in front of high benches.
- In ESD areas, consider using antistatic chairs or accessories when handling sensitive devices.
- Maintain a working height appropriate to the task: lower for heavy work, medium for general assembly, and close to the elbow for fine work.
- Use armrests only if they do not interfere with approaching the bench; for welding and simple microscopy, a technical chair without bulky armrests may be preferable.

- Promote alternation between sitting and standing work through suitable tables, active breaks, and tools located within the normal reach zone.

Figure 19

Ergonomics, visual support and signage to comply with good practices for teaching, research and safe technical work



8.8 Blackboards, panels and signage

Whiteboards and panels are not just decorative elements. In an academic FabLab, they serve functions of visual management, teaching, security, traceability, and communication among teachers, researchers, technicians, and students.

- Install a main whiteboard for experiment planning, prototype diagrams, failure discussion, and short classes.
- Use a Kanban board for projects: pending, in design, in manufacturing, in testing, stopped, completed, and archived.
- Implement a shadow panel for frequently used tools that immediately indicates their absence.
- Place signage for the following areas: ESD electronics, mechanical manufacturing, 3D cutting/printing, storage, waste, PPE, evacuation routes, and emergency equipment.
- Use safety signage with clear pictograms and brief text: mandatory use of glasses and gloves; active extraction; hot surface; electrical risk; laser; noise or moving parts, as appropriate.
- Maintain a quick procedures panel covering equipment power-on/off, cleaning, incident reporting, tool lending, and waste management.

8.9 Scalability of the furniture

Scalability must be planned from the initial stage. The most common mistake is filling the space with rigid furniture and then discovering there are no routes, outlets, clean surfaces, or storage for new lines of research. It is recommended to grow through repeatable modules rather than by accumulating isolated pieces of furniture.

Figure 20

Recommended technical furniture for entry-level FabLabs and scalability criteria

Table 33

Phased strategy

Stage	Aim	Furniture priority	Criteria for moving to the next stage
Entry level	Operate basic prototyping, practical teaching, and initial testing.	Multipurpose tables, ESD benches, basic heavy-duty benches, racks and whiteboards.	Sustained demand for projects and real saturation of stations.
Intermediate level	Separate work lines and improve safety/flow.	Electronics islands, dedicated metrology table, mobile carts, cabinets, and panels by zone.	Need to work in parallel with more users and greater complexity.
Advanced level	Support specialised research and systems integration.	Specialised benches, anti-vibration tables, custom-made furniture, and controlled storage.	High-value projects, sensitive equipment, and formal operating protocols.

8.10 Management suggestions

- Create a furniture layout plan before purchasing tables, benches, and racks. The plan should integrate power, data, ventilation, routing, security, and future expansion.
- Prioritise modular technical furniture over fixed furniture, except for heavy benches, booths or stations that require permanent stability.
- Standardise dimensions, heights, labelling colours, and classification criteria to reduce clutter and facilitate maintenance.
- Separate the furniture budget into three categories: basic operation, safety/ergonomics, and scalability.
- Document each station with a sheet: purpose, associated equipment, risks, PPE, responsible party, maintenance and usage restrictions.
- Validate the final layout with the person responsible for security, maintenance, electricity, teaching and research before physical implementation.

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9. Basic equipment

For a basic academic Fab Lab intended for prototyping, measuring instruments, and components for experiments in advanced physics and related fields, the minimum equipment must cover five capabilities: design, part manufacturing, electronic integration, measurement/testing, and documentation.

The goal is not to set up a commercial Fab Lab, but rather a functional, safe, and scalable academic laboratory. Implementation should prioritise versatile equipment for teaching and research, with relatively low operating costs and the potential for phased expansion.

- Design mechanical parts, supports, housing, adapters and auxiliary components.
- Manufacture prototypes using 3D printing, cutting, light machining and hand tools.
- Integrate electronics, sensors, microcontrollers, and data acquisition systems.
- Perform basic measurements, dimensional checks, and functional tests.
- Document designs, codes, manufacturing parameters, results, and improvements.

9.1 Minimum equipment for design and computing

Computers and design software are the backbone of any prototyping lab or FabLab, and their capabilities can be scaled to a commercial level. The following is a recommended minimum list for an entry-level academic Fab Lab.

Table 34

List of minimum equipment

Equipment	Minimum quantity	Main use
CAD workstations	2	3D design, blueprints, basic simulation and file preparation.
Support computers	2 to 4	Teaching, programming, documentation, and data analysis.
A computer dedicated to equipment	1	3D printer control, laser, CNC or data acquisition.
Projector or screen	1	Training, design review, and practical classes.
Multifunctional printer	1	Printing and scanning plans, forms and documentation.
Basic shared storage	1	Support for designs, codes, plans and results.

Suggested specifications for CAD workstations: Intel i7 or Ryzen 7 processor, 32 GB of RAM, 1 TB SSD, dedicated graphics card, and a 24-inch or larger monitor.

Minimum recommended software: FreeCAD, Fusion with an educational license if available, KiCad, LTspice, Arduino IDE, Python, JupyterLab, Cura or PrusaSlicer, LibreOffice or Microsoft Office, and Git for basic version control.

9.2 Additive manufacturing

For a basic lab, FDM 3D printing should be the priority because it is economical, versatile, and useful for mechanical prototypes. Resin printing can be considered for small, detailed parts or components that require greater dimensional accuracy.

Table 35

Additive manufacturing infrastructure framework: baseline capacity, tooling, and emission controls

Equipment	Minimum quantity	Main use
FDM 3D Printer	2	Manufacturing of supports, housings, adapters and educational pieces.
3D resin printer	1 optional	Smaller pieces of higher resolution.
Post-processing tools	1 set	Removal of supports, sanding, cleaning and finishing.
Filament kit	As needed	PLA, PETG and ABS/ASA only if there is adequate ventilation.
Cabinet or ventilated area	1	Emission, dust and odor control.

9.3 Cutting, engraving and two-dimensional manufacturing

Laser cutting is useful for quickly manufacturing panels, bases, boxes, supports, and lightweight structural elements. Special attention must be paid to fume extraction and the list of permitted materials. Not all plastics can be laser cut; some generate hazardous gases.

Table 35

Laser cutting specifications

Equipment	Minimum quantity	Main use
Desktop or medium-sized CO2 laser cutter	1	Cutting acrylic, MDF, cardboard, thin wood, templates and panels.
Smoke extraction system	1	Safety and environmental control.
Auxiliary air compressor	1	Air assistance for laser cutting.
Cutting plotter	1 optional	Vinyls, stencils, masks and labels.

9.4 Light machining and basic mechanical manufacturing

For experimental physics, this block allows for the fabrication and adaptation of simple mechanical parts: supports, bases, spacers, flanges, adapters, clamps, sample holders, and alignment elements. Starting with heavy industrial machinery is not recommended; light machining, with well-defined boundaries and safety precautions, is sufficient.

Table 36

Light machining capabilities and tooling specifications

Equipment	Minimum quantity	Main use
Desktop CNC Milling Machine	1	Small parts, plates, molds and light machining.
Bench drill	1	Precise perforations.
Mini lathe or bench lathe	1 optional	Shafts, spacers and cylindrical parts.
Bench grinder/sander	1	Adjustments and finishing of parts.
Dremel-type rotary tool	1 to 2	Cutting, grinding, polishing and adjustments.
Bank press	1 to 2	Clamping parts.
Hand tool set	1 complete set	Assembly, adjustments and maintenance.

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9.5 Electronics, sensors e instrumentation

This is the most important section if the Fab Lab will be focuses on measuring instruments. It must allow working with analog and digital signals, sensors, microcontrollers, data acquisition, and basic experimental control.

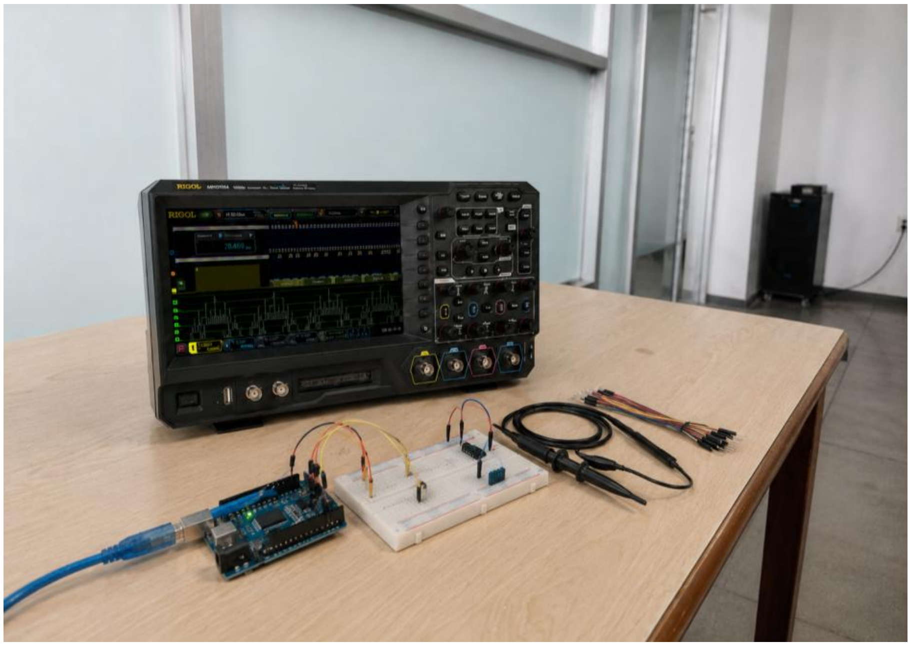
Table 37

Electronics and instrumentation infrastructure specifications

Equipment	Minimum quantity	Main use
Soldering stations	2	Circuit assembly and repair.
Hot air station	1	SMD components and rework.
Adjustable DC power supplies	2	Prototype feeding.
Digital multimeters	4	Basic electrical measurement.
Digital oscilloscope	1 to 2	Signals, sensors and electronic tests.
Function generator	1	Circuit and signal testing.
Logic analyzer	1	Digital signals and communication buses.
Breadboards and cables	Several	Rapid prototyping.
Microcontroller kits	Several	Arduino, ESP32, STM32 or Raspberry Pi Pico.
Sensor kits	Several	Temperature, pressure, light, position, acceleration, current and voltage.
Basic data acquisition system	1	Recording of experimental variables.

Figure 21

4-channel digital oscilloscope and logic analyser



9.6 Dimensional metrology and measuring tools

These instruments are necessary to verify whether the manufactured parts meet minimum dimensions, basic tolerances, and assembly conditions.

Table 38

Metrology equipment

Equipment	Minimum quantity	Main use
Digital Vernier Callipers	2 to 4	Measuring parts.
Micrometer	1 to 2	Precision measurement.
Metal ruler and set of squares	Several	Layout and verification.
Dial comparator	1	Alignment and displacements.
Digital scale	1	Weighing samples and materials.
Level, goniometer or inclinometer	1	Basic alignment.
USB Digital Microscope	1	Inspection of solders, PCBs and small parts.

9.7 Assembly, testing and experimental documentation

Documentation is key in an academic Fab Lab. Each prototype should have a record of plans, versions, manufacturing parameters, photographs, source code, test results, and observations.

Table 39
Documentation

Equipment	Minimum quantity	Main use
Robust assembly tables	2	Prototype assembly.
Electronics bank	1 to 2	Welding, testing and measurement.
Acrylic whiteboard	1	Design, classes and planning.
Institutional camera or cell phone	1	Registration of prototypes and practices.
Tripod	1	Test documentation.
Labeler	1	Identification of cables, parts and equipment.
Component organizers	Several	Resistors, sensors, screws, connectors and small parts.

9.8 Minimum essential security

Safety should not be seen as an accessory. In an academic FabLab, where there are students in training, it must be part of the initial design.

Table 40
Security

Element	Minimum quantity	Main use
Suitable fire extinguishers	According to the area	Electrical, solid or chemical fires.
Kit	1	First aid.
Portable or fixed eyewash station	1	Emergencies involving chemicals or particles.
Safety glasses	Several	Eye protection.
Work gloves	Several	Mechanical manipulation.

Element	Minimum quantity	Main use
Thermal gloves	1 pair	Hot pieces.
Masks or respirators	According to risk	Dust, fumes or vapours.
Welding extractor	1 to 2	Welding fumes.
Safety signage	Complete	Zones, risks and emergencies.
Chemical cabinet	1	Adhesives, solvents and resins.
Waste containers	Several	Plastic, metal, electronics, and chemicals.

9.9 Initial materials and supplies

Table 41
Minimum inputs

Category	Minimum inputs
3D printing	PLA, PETG, nozzles, adhesive bed and isopropyl alcohol.
Laser cutting	Thin MDF, compatible acrylic, cardboard and balsa wood.
Electronics	Resistors, capacitors, diodes, transistors, regulators, cables and connectors.
Sensors	Temperature, humidity, pressure, light, proximity, acceleration, current, and voltage.
Mechanics	Screws, nuts, washers, rods, aluminium profiles and springs.
Adhesives	Cyanoacrylate, epoxy, silicone, and double-sided tape.
Documentation	Labels, folders, usage sheets, and logbooks.

9.10 Minimum recommended equipment by priority

Table 42

Priority 1: essential to start

Area	Minimum equipment
Design	2 CAD workstations and basic software.
Manufacturing	2 FDM 3D printers.
Electronics	2 soldering stations, DC power supplies, multimeters and an oscilloscope.
Measurement	Callipers, micrometre, scale and digital microscope.
Security	Fire extinguishers, PPE, first aid kit and welding extraction.
Documentation	Shared storage, camera, and recording formats.

Table 43

Priority 2: Recommended in the first expansion

Area	Equipment
Court	Laser cutter with extraction.
Machining	Bench drill, rotary tool, press and desktop CNC milling machine.
Instrumentation	Function generator, logic analyser, and DAQ system.
Data	Basic NAS and external backup.
Teaching	Projector or screen, support computers.

Table 44

Priority 3: future growth

Area	Equipment
High resolution	Resin 3D printer.
Advanced Mechanics	Mini lathe or more robust CNC.
Advanced electronics	Improved optical microscope and complete SMD station.
Essays	Small environmental camera, basic optical bench and specialised sensors.
Management	Digital system for reservations, inventory and traceability.

10. Materials, supplies, reagents and storage

The Fab Lab must have sufficient materials and supplies to manufacture, assemble, test, and document prototypes, but without handling the volumes typical of a commercial unit. Management should prioritise four criteria: safety, traceability, chemical compatibility, and controlled academic use.

Specifically, materials and supplies should be organised by use type: additive manufacturing, cutting and machining, electronics, instrumentation, assembly, cleaning, auxiliary reagents, and waste. Chemicals should be stored according to their hazards and compatibility, always using the information provided in safety data sheets, labels, and manufacturer recommendations.

For an academic or teaching environment, it is recommended to start with low-risk, high-utility teaching materials, gradually incorporating more specialised inputs only when adequate procedures, responsible parties, infrastructure, and controls are in place.

10.1 Materials for additive manufacturing

Filaments for FDM 3D printing

For a basic academic Fab Lab, the priority filaments should be PLA and PETG. ABS, ASA, nylon, and composites should be considered for restricted or advanced use.

Table 45
Filaments 3D printing

Material	Recommended use	Considerations
PLA	Educational prototypes, casings, simple supports, and conceptual models	Easy to print; relatively low risk; not suitable for high temperatures
PETG	Housings, more resistant supports, functional parts	Greater strength than PLA; requires good ventilation
TPU	Flexible parts, shock absorbers, protectors	Requires printing experience
ABS / ASA	Temperature- and outdoor-resistant parts	Only use with the printer closed and with adequate extraction or ventilation.
Nylon	Durable mechanical parts	Hygroscopic; requires dry storage
Composite filaments	Special parts: carbon, wood, metal, etc.	They can wear down nozzles and generate particles

Resins for 3D printing

Resin printers require special care because they combine photopolymers, UV radiation, and flammable solvents. Their use should be restricted to trained personnel or students under supervision.

Table 46
Resins 3D printing

Material/Supply	Recommended use	Considerations
Standard UV resin	Small, high-resolution pieces	Requires gloves, ventilation, and careful handling.
Durable or technical resin	Small functional components	Higher cost; review safety data sheet
Isopropyl alcohol	Washing resin-printed parts	Flammable; store in a suitable cabinet
Washing containers	Cleaning parts	Labeled and with lid
UV curing chamber	Final curing of pieces	Avoid eye and skin exposure

10.2 Materials for laser cutting, engraving and two-dimensional manufacturing

Table 47

Laser cutting

Material	Recommended use	Considerations
Laser-compatible acrylic	Boxes, windows, supports, panels	Good finish; check compatibility
Thin MDF	Models, temporary supports, templates	Generates smoke; requires extraction
Cardboard	Rapid prototypes, templates	Risk of fire if used incorrectly
Balsa wood or thin plywood	Lightweight structures	Control smoke and waste
Adhesive paper / vinyl	Labels, masks, templates	Check compatibility with equipment
Permitted plastic sheets	Panels or insulators	Only if they are approved for laser use.

10.3 Materials that should be avoided or prohibited in lasers

Laser cutters must have a clearly visible list of permitted and prohibited materials. The equipment must not be operated unattended, must have fume extraction, and the cutting bed must be cleaned to prevent fires caused by residue.

Table 48

Forbidden materials

Material	Reason
PVC / Chlorinated vinyl	It can generate corrosive and toxic gases
Polycarbonate	Poor cutting quality and dangerous fumes
Fiberglass	Risk of particles and fumes
Unknown materials	Emission risk cannot be assessed
Non-certified foams	Risk of fire and irritant gases
Materials with unknown coatings	Possible release of hazardous substances

10.4 Materials for light machining and mechanical manufacturing

In experimental physics, these materials enable the fabrication of supports, adapters, sample holders, modular structures, sensor mounts, detector bases, alignment pieces, and test bench components.

Table 49

Machining materials

Material/Supply	Recommended use	Considerations
Aluminum	Supports, bases, adapters, and lightweight mechanical parts	It requires appropriate tools
Brass	Connectors, small parts, special components	Control shavings
Low-carbon steel	Simple structural pieces	More demanding machining
Acrylic	Panels, casings, windows	May break; wear eye protection
Polycarbonate	Impact-resistant parts	Machining is better than laser cutting.
POM / Delrin	Low-friction parts	Control shavings
Nylon / PTFE	Insulators, special parts	They require appropriate parameters
Aluminum profiles	Modular structures, test benches	Very useful for experimental prototypes
Metric screws	Assembly	Sort by diameter and length
Rods, shafts and springs	Simple mechanisms	Keep inventory organised

10.5 Electronic and instrumentation components and supplies

Table 50

Basic electronic components

Category	Examples
Resistors	Various trade values, accuracy 1% if possible
Capacitors	Ceramics, electrolytic, tantalum, polyester
Inductors	Basic values for filters and sources
Diodes	Rectifiers, Zener, Schottky, LED
Transistors	BJTs, MOSFETs, regulators
Integrated circuits	Operational amplifiers, comparators, timers, converters
Voltage regulators	Linear and switched
Optocouplers	Signal isolation
Relays and power modules	Load control
Fuses and protections	Prototype safety

Table 51

Sensors and modules

Sensor type	Use in physics or instrumentation
Temperature	Thermal monitoring, heat practices
Humidity and pressure	Environmental experiments
Light/photodiodes	Optics, photometry, detection
Accelerometers/gyroscopes	Mechanics, vibrations, motion
Current and voltage	Electrical instrumentation
Magnetic field	Electromagnetism
Distance/proximity	Movement, automation
Load cells	Force, weight, deformation
Radiation sensors, if applicable	Nuclear physics or radiation protection, under specific regulations

Table 52

Prototyping and connection

Input	Use
Protoboards	Quick assembly
Perforated plates	Semi-permanent prototypes
Dupont cables	Sensor connection
Coaxial cables	Fast signals, detectors, instrumentation
BNC connectors	Laboratory signals
Banana connectors	Sources and measurements
JST connectors, Molex connectors, terminal blocks	Prototype assembly
Terminals, terminal blocks and connectors	Cabling
Solder tin	Electronic assembly
Flux	Welding improvement
Desoldering the mesh and the pump	Rework
Heat shrink tubing	Isolation
Kapton tape	Thermal/electrical insulation
Electrical tape	General protection
Cable labels	Traceability

10.6 Supplies for assembly, finishing and cleaning

These supplies must be controlled because several can be flammable, irritating, or incompatible with other products.

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Table 53

Supplies

Category	Supplies
Adhesives	Cyanoacrylate, epoxy, silicone, UV adhesive
Fixatives	Threadlockers, sealants, PTFE tape
Abrasives	Sandpaper, files, abrasive sponges
Mechanical cleaning	Lint-free cloths, brushes, compressed air
Chemical cleaning	Isopropyl alcohol, contact cleaner
Lubricants	Light oil, technical grease, guide lubricant
Marked	Permanent markers, labels, engraving, label maker
Protection	Antistatic bags, plastic boxes, dividers

10.7 Classification of materials, supplies and reagents

Table 54

Functional classification

Cluster	Examples	Suggested location
Additive manufacturing	Filaments, resins, supports, and nozzles	3D printing area
Cutting and engraving	Acrylic, MDF, cardboard, wood	Flat materials zone
Machining	Metals, polymers, profiles, bars	Mechanical shelving
Electronics	Components, sensors, cables, connectors	Antistatic cabinets
Instrumentation	Sensors, DAQ modules, BNC connectors	Technical office
Assembly	Screws, adhesives, abrasives	Assembly area
Cleaning	Alcohol, cloths, cleaners	Chemical Cabinet
Security	PPE, absorbents, and a first aid kit	Signposted area
Waste	Plastic, metal, electronic, chemical	Segregation point

Table 55
Hazard classification

Risk class	Examples	Main consideration
Flammables	Isopropyl alcohol, solvents, aerosols, and some resins	Cabinet for flammable materials; keep away from heat
Irritants/sensitisers	UV resins, adhesives, flux	Gloves, goggles, ventilation
Corrosives	Some cleaners, developers, or strippers	Cabinet for corrosives
Oxidants	Special reagents, if any	Separated from organic and flammable materials
Toxins	Specific solvents, heavy metals, and certain compounds	Restricted use and mandatory SDS
Dust and particles	Sanding, machining, composite filaments	Extraction, mask, cleaning
Sharps	Blades, drill bits, metal shavings	Durable container
Electrical/electronic	Batteries, plates, cables	Short circuit prevention
Special waste	Resins, used solvents, electronics	Differentiated management

10.8 Handling and storage considerations

General handling rules

1. All materials or reagents must be identified, labelled, and recorded.
2. Substances without a safety data sheet available should not be used.
3. Users must receive induction before handling resins, solvents, adhesives, cutting tools, or fume-emitting equipment.
4. Substances and waste should not be mixed without authorisation from the Fab Lab manager.
5. Work involving vapours, fumes, or particles must be carried out with ventilation or local exhaust.
6. Eating, drinking, or storing food inside the Fab Lab is prohibited.
7. The quantities available in the work area should be minimal.
8. Containers should remain closed when not in use.
9. Expired, degraded, or unidentified substances must be withdrawn from use.
10. Incidents, spills, exposure, or misuse must be recorded.

Table 56
Storage of non-chemical materials

Material	Recommendation
3D Filaments	Store in sealed bags or dry boxes; use desiccants
Resins	Store in the original, sealed container, protected from light and heat.
Acrylics and woods	Store in a stable horizontal or vertical position; avoid moisture.
Metals	Separate by type; protect edges; prevent falls
Screws	Sort by diameter, length, and type
Electronic components	Use drawers, antistatic bags, and labelling
Sensors	Store in labelled boxes with moisture protection.
Cables	Sort by type: BNC, banana, Dupont, USB, coaxial, power
Batteries	Store separately, with protected terminals, away from heat

Table 57
Storage of chemicals and reagents

Product type	Recommended storage
Flammables	Cabinet for flammable materials, ventilated if appropriate, away from ignition sources
Solvents	Original packaging, secondary tray, lid closed
UV resins	Cool, dark, well-ventilated place with secondary containment
Corrosives	Cabinet for corrosives; separated from metals and incompatible bases/acids
Adhesives	Closed cabinet, temperature-controlled, away from heat
Aerosols	Vertical, away from heat, protected from impacts
Lubricants	Secondary tray, labelled, prevents spills
Flux and cleaners	Chemical cabinet, ventilation and SDS available

Table 58
Minimum storage area requirements

Element	Recommended requirement
Flammable materials cabinet	For alcohols, solvents, aerosols and some adhesives
Cabinet for corrosives	If acids, bases, or corrosive cleaners are used
Sturdy shelving	Anchored or stable, with a retaining rim if possible
Secondary containment trays	For liquids and reagents
Labeled	Name, hazard, date of entry, responsible
SDS available	In an accessible physical or digital format
Updated inventory	Quantity, location, expiration date and responsible party
Access control	Hazardous products under authorization
Ventilation	According to stored products
Spill kit	Absorbents, gloves, bags, signage

10.9 Waste management

Waste management should be planned from the moment materials are purchased. The Fab Lab should apply the rule: reduce, reuse, segregate, label, temporarily store, and dispose of through authorised channels.

Table 59
FabLab waste sorting

Type of waste	Examples	Recommended management
Clean plastics	PLA, PETG, printing supports	Segregate; evaluate recycling or reuse
Resin waste	Liquid resin, contaminated gloves, and cloths	Chemical waste; treat if necessary and manage as special
Solvents used	Contaminated isopropyl alcohol, cleaners	Closed, labelled container and specialised management
Wood/cardboard	Laser cutting scraps	Common or recyclable waste if it is not contaminated
Acrylic	Scraps, failed pieces	Keep separate; do not mix with chemical waste

Metal shavings	Aluminium, brass, steel	Metal container; avoid mixing with chemicals
Sanding powders	Plastic, metal, composites	Controlled harvesting; avoid dispersal
Electronics	PCBs, sensors, cables, and damaged components	Separated electronic waste
Batteries	Li-ion, alkaline, button	Special container; protected terminals
Sharps	Broken drill bits, blades, and technical needles	Rigid container
Contaminated containers	Bottles of solvents, resins, and adhesives	According to SDS and institutional regulations
Common waste	Paper, clean packaging	Recycling or regular disposal

Chemical waste management

Chemical waste must be placed in compatible, sealed, and undamaged containers with secondary containment, labelled with the contents and primary hazard. The determination of the type of waste and its final disposal must be carried out by trained personnel or by the institutional unit responsible for safety, environment, or waste management.

Table 60

Recommendations for chemical waste management

Aspect	Recommendation
Labeled	"Chemical waste", contents, date, responsible party, hazard
Compatibility	Do not mix halogenated and non-halogenated solvents if the institution keeps them separate.
Packaging	Compatible with waste, sealed, leak-proof
Secondary containment	Mandatory for liquids
Temporary area	Signposted, ventilated and with restricted access
Record	Date of generation, quantity, origin, and responsible party
Withdrawal	By environmental unit, safety or authorised manager
Prohibition	Do not dispose of solvents, resins, or heavy metals down the drain

Table 61

3D printing waste management

Residue	Management
PLA/PETG supports	Separate as clean plastic
Failed pieces	Evaluate reuse, recycling, or disposal
Contaminated filament	Separate from clean plastic
Liquid resin	Chemical waste: do not pour down the drain
Clothes with resin	Curing or disposal as special waste according to SDS
Alcohol contaminated with resin	Flammable chemical waste
Contaminated gloves	Special waste if they contain uncured resin

Table 62

Handling of electronic waste and batteries

Batteries should not be mixed with ordinary waste or stored loose, as this could cause a short circuit.

Residue	Management
Electronic boards	Collection as electronic waste
Damaged sensors	Separate and record
Cables	Reuse or recycle
Li-ion batteries	Protected terminals, fireproof container if possible
Alkaline or button cell batteries	Specific container
Recoverable components	Sort for reuse

10.10 Other relevant considerations

Table 63

Inventory and traceability

Field	Description
Internal code	Material identification
Name	Trade or technical name
Category	Filament, reactive, electronic, mechanical, etc.
Amount	Stock available
Location	Cabinet, shelf, area
Date of entry	Seniority control
Expiration date	For reagents, resins, and adhesives
Responsible	Person in charge
SDS	Available yes/no
Condition	Available, restricted, expired, low

Table 64

Colour system or labels

Suggested color	Category
Green	General use material
Blue	Electronics and Instrumentation
Yellow	Use with caution
Red	Flammable or restricted
Orange	Resins, solvents, or special chemicals
Grey	Waste or material under evaluation
Black	Prohibited or discontinued material

Table 65

Restricted or authorisation-only materials

Material/Supply	Reason
ABS, ASA, nylon, composites	Emissions, temperature, or complexity
UV resins	Chemical risk
Flammable solvents	Fire, inhalation
Acids or bases	Corrosiveness
Aerosols	Flammability and pressure
Lithium batteries	Fire/short circuit
Unknown materials for the laser	Risk of toxic gases
Special sensors or sources	Regulatory requirements
Biological, radioactive or toxic material	It should not be handled without specific institutional authorisation.

Table 66

Materials not recommended for a basic academic FabLab

Material	Reason
Large volumes of solvents	Risk and complex management
Reagents with no clear teaching use	Risk and dead inventory increase
Highly toxic substances	They require specialised infrastructure
Carcinogenic or mutagenic substances	They should be avoided except in authorised laboratories.
Radioactive sources	Only under specific regulations and licenses
Biological material	Not applicable except to authorised BioFab Lab
PVC for laser	Risk of corrosive gases
Fine metallic powders	Respiratory/fire risk
Nanomaterials	They require specialised controls

Table 67
Minimum procedures that the FabLab must have

Procedure	Purpose
Receiving materials	Verify status, SDS, labelling, and inventory
Storage	Define location, compatibility, and access
Use of resins	Control exposure, cleaning and waste
Use of solvents	Avoid fires, inhalation and spills
Use of a laser cutter	Control of permitted materials
Use of 3D printers	Filament management, emissions and waste
Waste management	Segregation, labelling, and withdrawal
Spill response	Quick and reliable response
Removal of expired materials	Controlled inventory withdrawal
Inventory audit	Periodic control of stock and expiration dates

10.11 Initial minimum stock recommendation

Table 68
Minimum stock

Category	Suggested minimum stock
PLA filament	5 to 10 kg in basic colours
PETG filament	2 to 5 kg
UV resin	1 to 2 litres, only if there is a resin printer
Isopropyl alcohol	2 to 5 litres, in a flammable materials cabinet
Acrylic	10 to 20 small or medium-sized irons
MDF/cardboard	Teaching staff for practical training
Screws	Metric kit M2, M3, M4, M5 and M6
Aluminum profiles	Small stock for assemblies
Electronic components	Assorted basic kit
Sensors	Kits by type of physical variable
Cables and connectors	BNC, banana, Dupont, USB, power

Adhesives	Cyanoacrylate, epoxy, silicone
Cleaning	Cloths, alcohol, contact cleaner
PPE	Glasses, gloves, masks according to risk

10.12 Considerations regarding materials

For an academic Fab Lab, the selection of materials should be prudent and progressive. It is recommended to start with low-risk, easy-to-handle materials with high educational value, such as PLA, PETG, compatible acrylic, MDF, basic electronic components, sensors, screws, and common adhesives.

Reagents and chemicals should be kept to the minimum necessary. Resins, solvents, aerosols, technical adhesives, and corrosive products should be considered restricted use, with available Safety Data Sheets (SDS), compatible storage, adequate ventilation, PPE, and separate waste management.

Materials management should not be limited to inventory. It must include usage authorisation, traceability, training, waste segregation, expiration date control, and periodic safety reviews. In this way, the Fab Lab can fulfil its academic and experimental purpose without generating unnecessary risks for students, faculty, researchers, or technical staff.

11. Safety, occupational health and risk management

This chapter outlines the minimum criteria for implementing and operating an entry-level university Fab Lab for academic and scientific research, with a focus on prototyping measuring instruments, mechanical and electronic components, and auxiliary systems for advanced physics experiments and related fields. The approach is not commercially driven, but rather educational, experimental, and supportive of research projects; therefore, safety must be integrated from the initial design of the space, through equipment selection, user authorisation, and activity traceability.

11.1 FabLab Security Policy

The safety policy must stipulate that no design, manufacturing, welding, cutting, 3D printing, assembly, measurement, or testing activity will be performed without controlled conditions, trained users, and authorisation commensurate with the risk. The institutional priority must be to prevent injuries, exposures, and damage to equipment, even if this means temporarily limiting an activity or rejecting unevaluated material.

- Every user must receive induction, know the rules of the space, and accept individual responsibility for the safe use of tools, materials, and technical data.

- The equipment is classified by risk level and may be used only by authorised users or under direct supervision.
- The operation of the FabLab must be recorded through logs, checklists, incident reports, and maintenance control.
- High-risk jobs require prior evaluation, authorisation from the technical manager and, where appropriate, review by the safety committee or the institutional occupational safety and health office.

11.2 Hazard Identification

Hazard identification must be performed before operations begin and updated whenever new equipment, materials, or processes are introduced. It should cover routine and non-routine activities, student practices, maintenance, cleaning, site visits, and experimental testing.

Table 69

Hazard identification framework and risk assessment parameters

Type of hazard	Examples in an academic FabLab	Measures the initials recommended
Mechanical and cutting	Rotary tools, drills, sanding, light CNC, blades, and entrapment.	Guards, securing of parts, order, training and prohibition of loose clothing.
Electrical and thermal	Soldering, DC/AC power supplies, test benches, heating elements, batteries.	Outlets with protection, grounding, cable inspection, signage and safe disconnection.
Chemical and inhalation	Resins, solvents, adhesives, welding fumes, particles, and 3D printing vapours.	Replacement, ventilation, local exhaust, segregated storage and safety data sheets.
Optical, noise and non-ionising radiation	Laser, intense light, UV curing, compressor noise, tools and extraction.	Enclosures, appropriate lenses, barriers, measurement if applicable, and hearing protection.
Ergonomics and fire safety	Prolonged postures, handling of loads, cables, flammable materials, ignition sources.	Suitable tables, adjustable chairs, clear routes, fire extinguishers, and control of flammable materials.

11.3 Risk assessment

It is recommended to use a simple probability-and-severity matrix for each piece of equipment, activity, and area. The result should determine whether the activity is acceptable, requires additional controls, or is suspended until sufficient protection is in place. For an entry-level FabLab, the matrix can be qualitative and reviewed quarterly; as the operation scales, it should incorporate evidence from measurements, incidents, maintenance, and audits.

Table 70
Risk analysis

Activity/equipment	Main danger	Initial risk	Controls required	Residual risk
3D printing	Particulates /VOCs, hot surfaces	Half	Enclosure, ventilation, approved materials, wait before opening	Low/ medium
Welding electronics	Smoke, burns, and electricity	Half	Extractor with filter, soldering iron stand, safety glasses, training	Low
Cutting/ sanding	Projection of particles, noise	Medium/high	Guards, lenses, fastening, dust extraction, and hearing protection	Half
Laser or light CNC	Smoke, fire, entrapment, optical	High	Enclosure, interlocks, dedicated extraction, supervision, and checklist	Half
Metrology / Assembly fine	Equipment damage, ESD, postures	Low/medium	Stable table, ESD control, cleanliness, lighting and order	Low

11.4 Engineering Controls

Engineering controls should be the first line of defence because they reduce hazards at the source or prevent them from reaching the user. In an entry-level FabLab, these controls should prioritise processes that generate fumes, particles, heat, electrical energy, or mechanical movement. OSHA describes local exhaust ventilation as a system designed to capture contaminants at the source before they disperse into the work environment; NIOSH recommends ventilation, enclosures, and exhaust to reduce 3D printing emissions.

- Sufficient general ventilation and localised extraction for welding, resins, 3D printing, cutting, sanding and processes with odours or particles.
- Guards, screens, interlocks, emergency stop and physical barriers on equipment with movement, cutting, laser, heat or entrapment.
- Electrical protection through earthing, residual current devices where appropriate, overcurrent protection, labelled panels and tidy conduits.
- Stable tables, antistatic surfaces in electronics, parts clamping, spill containment and ventilated or segregated storage for compatible supplies.

11.5 Administrative Controls

Administrative controls organise work, reduce errors, and enable traceability. In a university environment, they are essential because expert users, students in training, visitors, and projects of varying technical maturity coexist.

- Written procedures by equipment and activity, with a checklist for pre-use, operation, cleaning, closure and failure reporting.
- Levelled authorisation system: observer, basic user, autonomous user, advanced operator, and supervisor.
- Logs of usage, maintenance, incidents, critical consumables and configuration changes.
- Signage for areas, routes, required PPE, restrictions, prohibited materials, and emergency contacts.
- Mandatory initial training and periodic refresher, with practical evaluation before authorising medium or high-risk equipment.

11.6 Personal protective equipment

Personal protective equipment (PPE) does not replace engineering or administrative controls, but it must be readily available, clearly marked, and selected according to the task. A generic "use everything all the time" policy should be avoided; the correct approach is to define the minimum PPE required for each activity and verify its compatibility with the actual risk.

Table 71

Personal protective equipment (PPE) matrix and activity-specific safety requirements

Activity	Minimum PPE	Additional PPE according to risk	Observations
Electronics	Safety glasses, gown/apron, ESD wristband if applicable	Fume extractor, specific thermal gloves	Do not wear loose gloves near rotation.
Manufacturing mechanics light	Glasses, closed shoes, tight clothing	Hearing protection, dust mask	Secure parts and remove loose accessories.
3D printing /resins	Glasses, compatible gloves, apron	Respiratory protection if assessment requires it.	Prefer ventilation and approved materials.
Laser /CNC	Wear appropriate safety glasses and hearing protection if applicable.	Specific PPE according to wavelength/material	Never operate without extraction and interlocks.

11.7 Fire safety

Fire prevention must be addressed from the design stage: separation of flammable materials, control of ignition sources, adequate ventilation, and the order and availability of fire extinguishers appropriate to the risks present. An academic FabLab typically combines electrical equipment, polymeric materials, adhesives, solvents, and heat sources; therefore, the number of flammable materials in the work area must be limited, and the accumulation of combustible waste must be avoided.

- Locate accessible, marked fire extinguishers selected according to the expected fire class; train staff in basic use and intervention limits.
- Keep evacuation routes clear, doors operational, emergency lighting on, and a defined assembly point.
- Store solvents, resins, and aerosols in appropriate cabinets, with minimum operating quantities and clear labelling.
- Control ignition sources: soldering irons, resistors, lasers, batteries, improvised connections, overloaded power strips, and unmaintained equipment.

- Prohibit unsupervised operation of equipment with heat generation, lasers, critical extraction or fire risk, except for formal assessment and automatic controls.

11.8 Emergency procedures

Emergency procedures should be simple, visible, and practical. The goal is not to replace the institutional emergency plan, but to adapt it to the specific scenarios of the FabLab and ensure that students and operators know how to act during the first few minutes.

Table 72

Emergency protocols and initial incident response

Event	Action immediate	Communication	Back closure
Cut, burn or entrapment	Stop equipment, apply basic first aid, and do not move if there is a serious injury.	Notify the person in charge and activate medical attention.	Record the incident and block the equipment if necessary.
Spill chemical minor	Isolate the area, use a compatible kit, ventilate, and avoid contact.	Notify and consult the safety data sheet	Dispose of waste and investigate cause
Inhalation of vapours/fumes	Remove the person to fresh air and stop the process	Seek medical attention if symptoms are present.	Review extraction, material, and authorisation
Electrical failure/fire	De-energise if safe, evacuate, and use a fire extinguisher only if trained.	Activate institutional alarm and emergency	Do not re-enter until authorised

11.9 Work restrictions

Restrictions must be explicit to prevent the FabLab from being used as an uncontrolled general workshop. In an entry-level university lab, the scope should be limited to safe prototyping, preliminary testing, and light fabrication. Authorisation for more complex processes should be contingent upon sufficient infrastructure, training, and controls.

- Prohibit unidentified materials, flammable materials in uncontrolled quantities, incompatible substances, hazardous reagents without authorisation, and processes that generate emissions without ventilation or prior evaluation.
- Restrict working alone in activities with electrical, thermal, laser, CNC, rotary tool, cutting, resin or unknown material risks.
- Establish operating hours, minimum presence of authorised personnel and safe closure criteria: equipment turned off, waste removed, surfaces cleaned and logbook completed.
- Do not allow modifications to electrical installations, extraction, guards, interlocks or control software without authorisation from the technical manager.
- Activities involving ionising radiation, radioactive sources, high voltage, extreme vacuum, special compressed gases, or hazardous chemicals should only be carried out in specialised laboratories, not as a basic activity of the FabLab.

11.10 Recommended phased implementation

Table 73

Progressive implementation roadmap and operational milestones

Phase	Priorities	Result expected
Entry level	Policy, induction, risk matrix, basic PPE, signage, welding/3D extraction, fire extinguishers, logs and evacuation routes.	Safe operation of basic tools, electronics, 3D printing, and light assembly.
Intermediate level	Permits per equipment, certified training, extraction by zone, preventive maintenance, control of supplies and internal audits.	Greater traceability, less improvisation, and enabling processes with medium risk.
Advanced level	Documented management system, environmental monitoring, commissioning of critical equipment, safety indicators and integration with institutional management.	FabLab is scalable, auditable and suitable for more complex instrumented research.

11.11 Minimum documents to be generated before operating

- FabLab usage rules and security policy signed by the responsible authority.
- Inventory of equipment with risk level, responsible party, location, electrical requirements and maintenance status.
- Hazard and risk matrix by zone, equipment and activity, updated when the process changes.
- Safe operating procedures for critical equipment and activities, with checklists.
- FabLab -specific emergency plan, location of fire extinguishers, kits, evacuation routes and contacts.
- Training records, authorisations, usage logs, maintenance, incidents and corrective actions.

11.12 Basic monitoring indicators

To justify the investment in time, human resources, and infrastructure, safety must be measurable. The following indicators demonstrate control, institutional learning, and continuous improvement: percentage of trained users, number of devices with current procedures, compliance with preventive maintenance, reported incidents and near misses, corrected findings, hours of supervised use, availability of PPE, status of extraction/ventilation, and timely closure of corrective actions.

11.13 Technical reference sources

- OSHA. Technical Manual, Section III, Chapter 3: Ventilation Investigation. Describes the components of local exhaust ventilation and its function in capturing contaminants at the source.
- NIOSH/CDC. Characterising 3D Printing Emissions and Controls. Recommends ventilation, local exhaust, and ventilated enclosures to reduce 3D printing emissions.
- National Academies. Prudent Practices in the Laboratory. Recommends adequate general ventilation, storage control, and safety equipment in laboratories.
- OSHA 1926.57 Ventilation. Establishes ventilation and extraction principles to prevent the dispersion of dust, fumes, vapours, and gases in work areas.

12. Organisation, personnel and responsibilities

FabLab's organisation should be simple at the outset, yet formal enough to ensure security, traceability, and academic continuity. A well-defined, minimal structure allows for a low-cost start, the training of responsible users, and the progressive scaling up to more complex technical capabilities without losing operational control.

12.1 Organisational structure

The organisational structure should be lean, clear, and appropriate for an entry-level FabLab. Starting with a complex structure is not recommended; however, it is essential to define responsibilities, lines of authority, authorisation mechanisms, and communication channels. The organisation must ensure that the space functions as an academic platform supporting courses, theses, research projects, and the development of scientific prototypes.

Recommended minimum structure:

- FabLab Manager: functional authority of space; approves guidelines, prioritises academic use, coordinates with the host unit or laboratory and ensures institutional alignment.
- Technical Manager or Coordinator: manages daily use, verifies safety conditions, schedules equipment, controls inventories, records incidents, and provides technical support to users.
- Area or team leaders: teachers, researchers or technicians designated for specific team groups, such as electronics, 3D printing, lightweight manufacturing, instrumentation or storage.
- Authorised users: people trained and registered to use equipment or defined areas, according to their level of training and the risk of the activity.
- Safety committee or technical committee: a small group that reviews procedures, incidents, incorporation of new equipment, permitted materials, and improvement needs.

Table 74

Organizational structure, functional roles, and decision-making authority

Role	Main function	Designation suggested	Decisions that can take
FabLab Manager	Operational management and academic prioritisation	Lecturer, principal investigator, or head of laboratory	Approve usage, internal policies, and escalation
Coordinator technical	Daily operations, support and security	Specialised technician or responsible professional	Authorise users, schedule equipment, and stop unsafe activities
Area Managers	Supervision of equipment or processes	Designated teachers, technicians or researchers	Validate procedures and conditions of use
Users authorized	Use of equipment according to training	Students, thesis writers, teachers, researchers	Operate authorised equipment and report malfunctions
Security Committee	Risk review and continuous improvement	Manager, coordinator, security institutional	Review incidents, materials, and new processes

At an entry level, one person can fulfil more than one role, provided that the responsibilities are clearly defined and documented. As the FabLab grows, it is recommended to separate the functions of administration, technical operation, security, and user support.

12.2 Profile of the technical manager

The technical manager is key to ensuring that the FabLab is not just a collection of equipment, but a well-organised system supporting research and teaching. Their profile should combine technical skills, safety awareness, management abilities, and a willingness to support users with varying levels of experience.

Minimum technical skills:

- Practical knowledge of basic digital manufacturing: 3D printing, file preparation, material selection, basic calibration and preventive maintenance.
- Safe handling of light hand and power tools, workbenches and assembly areas.

- Knowledge of basic electronics and instrumentation: soldering, power supplies, multimeters, oscilloscopes, sensors, microcontrollers, wiring and ESD good practices.
- Ability to interpret plans, CAD models, simple electrical schematics, connection diagrams and technical requirements of prototypes.
- Criteria for identifying mechanical, electrical, thermal, chemical, ergonomic, fire and particle, fume or vapour exposure risks.

Management and support skills:

- Organise usage schedules, logs, inventory of tools, consumables, spare parts and technical documentation.
- Train or induct new users, explain usage restrictions, and verify that activities are carried out within approved procedures.
- Support project planning by helping to define scope, materials, timelines, technical limitations, and safety requirements.
- Coordinate preventive maintenance, troubleshooting, minor purchases, material storage, and low-risk waste disposal.
- Maintain communication with teachers, researchers, students, institutional maintenance, occupational safety, and information technologies.

Table 75

Operational competencies, entry requirements, and scalability criteria

Dimension	Entry requirement	Scalability criterion
Training	Technician, high school graduate or professional with practical experience in laboratory, electronics, manufacturing or instrumentation.	Specialisation in digital manufacturing, metrology, laboratory safety or scientific infrastructure management.
Experience	Safe use of tools, basic equipment, documentation and user support.	Management of complex equipment, planned maintenance, quality control and advanced traceability.
Security	Knowledge of PPE, signage, basic lockout/tagout procedures, ventilation, electricity, and incident response.	Ability to lead risk matrices, work permits, and internal audits.

12.3 FabLab users

Users must be classified according to their institutional affiliation, experience, training level, and type of activity. This classification allows for access control, permission assignment, equipment protection, and ensures that the FabLab is used for academic and research purposes. No user should operate equipment or processes for which they have not been trained or authorised.

Recommended user rating:

- Researchers and teachers: lead projects, courses, theses or research activities; can request use of equipment, propose processes and assume responsibility for projects.
- Students and thesis students: participate in courses, internships, theses or projects; they must operate under authorisation, prior training and supervision proportional to the risk.
- Technicians and support staff: perform functions of operation, maintenance, support, preparation of materials, inventory control or assistance in projects.
- Users in training: they do not yet have full authorization; they can only perform demonstration activities, guided practice, or low-complexity tasks.
- Visitors and external parties: They enter for the purposes of observation, induction, demonstration or authorised academic collaboration; they must not displace the university purpose or turn the FabLab into a commercial service.

Table 76

Suggested authorisation levels

Level	Scope	Examples of activities	Condition minimum
Level 0: Visitor	Observation or induction only.	Tour, talk, demonstration.	Income accompanied and registered.
Level 1: User essential	Use of clean areas and low-risk tools.	CAD design, file preparation, simple assembly.	General induction approved.
Level 2: user operational	Use of specific low- or medium-risk equipment.	3D printing, basic soldering, electronics benches.	Team training and registered authorisation.
Level 3: user advanced	Specialised or higher risk activities.	Lightweight CNC, laser, sensitive instrumentation, complex prototypes.	Technical evaluation, supervision and approved procedure.

The authorisation must be personal, non-transferable, and limited to specific equipment, schedules, and activities. It must be suspended in cases of unsafe use, failure to follow procedures, deliberate damage to equipment, unauthorised entry, or use of prohibited materials.

12.4 Responsibilities

The distribution of responsibilities avoids ambiguity and reduces operational risks. In an academic FabLab, responsibilities should focus on safety, equipment maintenance, prototype traceability, research continuity, and responsible student training.

Table 77

Distribution of responsibilities

Actor	Responsibilities main	Evidence or records minimum
Administrator or person in charge	Define internal policies, approve priorities, coordinate resources, validate escalation, report needs, and ensure academic alignment.	Work plan, internal rules, usage reports, review minutes.
Coordinator technical	Open and close the space, check security, manage reservations, train users, check equipment, control inventories, and stop unsafe activities.	Logs, checklists, training records, failure reports.
Equipment operators or managers	Ensure proper use of assigned equipment, verify parameters, supervise practices, support basic maintenance, and update procedures.	Operating procedures, equipment checklist, maintenance log.
Users	Use only authorized equipment, comply with regulations, report failures and incidents, clean the area, document prototypes, and respect material restrictions.	Usage log, design files, project log, incident report if applicable.
Project Managers	Define prototype objectives, materials, risks, timeline, deliverables, student supervision, and validation criteria.	Project sheet, risk matrix, test results, technical report.
Maintenance / IT / Security	Support facilities, data network, electricity, ventilation, fire extinguishers, inspections, corrective actions and institutional regulatory compliance.	Work orders, maintenance reports, inspection evidence.

Recommended minimum operating rules:

- Every project must have an identified person in charge, a brief description of the prototype, and a basic risk assessment before starting manufacturing or testing.
- Critical equipment must have an assigned person in charge, a procedure for use, a logbook, and a record of preventive or corrective maintenance.
- Students must work within the framework of a course, thesis, internship, project, or authorisation from a responsible teacher/researcher.
- Use outside of regular hours, working alone, and higher-risk activities should be restricted or subject to express authorisation.
- The operation should be reviewed using simple indicators: trained users, projects served, incidents, equipment failures, hours of use, and improvement needs.

12.5 Organisational scalability criteria

As the FabLab incorporates more users, higher-risk equipment, or more complex projects, the organisation must evolve. Growth shouldn't be limited to purchasing equipment; it also requires greater operational control, technical support, maintenance, training, and documentation.

Table 78

Organisational scalability

Growth situation	Adjustment organizational recommended	Justification
More users and courses	Extend hours, formalise reservations, and create authorisation levels.	Avoid saturation, improvised use, and conflicts between teaching and research.
Teams further complex	Assign responsibilities per team and require specific procedures.	It reduces damage, accidents, and dependence on a single person.
Increased production of data or prototypes	Strengthen documentation, traceability, repositories, and version control.	It facilitates reproducibility, internal transfer and continuity of theses/projects.

Materials or processes with higher risk	Activate safety committee and work permits.	It allows you to review risks before incorporating new processes.

13. Implementation of FabLabs in the EL-BONGO Physics project

Implementation status and evidence framework

The EL-BONGO Physics partner institutions are implementing their FabLabs from different starting points and are currently at different stages of development. Some facilities are operational, others are undergoing installation or commissioning, and some remain in the planning stage. The institutional descriptions in this chapter follow a common structure covering location, physical infrastructure, functional areas, equipment status, current activities, documented developments, implementation experience, and next steps.

Table 79

Comparative implementation status based on the institutional information currently available.

Institution	Country	Status	Area	Capabilities
UNMSM	Peru	Initial implementation	9.3 m x 2.3 m (about 21.4 m^2)	Instrumentation, laser cutting, electronics and complementary heavy machining
UIS	Colombia	In consolidation	5.0 m x 2.6 m (13 m^2)	Additive manufacturing, PCB preparation, electronics and documented prototypes
USFQ	Ecuador	Operational laboratory; PCB capability in commissioning	HS-516 (Lab Leopard): 6.28 x 4.34 m (27 m^2); HS-519: 2.42x 3.09 m (7.5 m^2)	Detector instrumentation, 3D printing, electronics characterisation and PCB milling
USAC	Guatemala	Installed; operational laboratory	6.4 x 10.5 m (67.2 m^2)	Instrumentation, laser cutting, electronics, signal generation, FPGA testing and reported fabrication areas.

Institution	Country	Status	Area	Capabilities
UAN	Colombia	Installed: Operational laboratory	26 m^2	3D printing, PCB routing, soldering and NI ELVIS instrumentation
ESPOCH	Ecuador	Installed; operational laboratory	6 m x 6 m (36 m^2)	Digital fabrication, laser cutting, electronics and seismic instrumentation
UES	El Salvador	Installed; operational laboratory	4.5 m x 4.5 m (about 20 m^2)	PCB fabrication, electronics assembly, FPGA, 3D printing and testing
UNAH	Honduras	Initial implementation	4.2 m x 3.7 m (about 15.5 m^2)	PCB routing, 3D printing, electronics, FPGA and instrumentation
UFG	El Salvador	Installed; Initial implementation	5.13 m x 3.63 m (about 18.6 m^2)	Electronics, FPGA, PCB routing, 3D printing and instrumentation
UCV	Venezuela	Planning initial phase	70 m^2 planned	Electronics and fabrication lines for physics and seismic-risk applications
USB	Venezuela	Planning / initial phase	100 m^2 planned	Electronics and fabrication lines for physics and seismic-risk applications

13.1 Fab Lab at Universidad Nacional Mayor de San Marcos - Perú

Institutional context and purpose

The Faculty of Physical Sciences at the Universidad Nacional Mayor de San Marcos (UNMSM) has a long-standing capacity for scientific instrumentation development through the Research Group in Physical Instrumentation and Applications (INFISA) and associated laboratories for electronic instrumentation, nuclear instrumentation, electronic assembly, additive manufacturing, and mechanical construction. Under EL-BONGO Physics, these activities are being brought together within a FabLab framework to shorten the transition from design to fabrication, assembly and experimental testing.

Location, implementation status and physical infrastructure

The FabLab is being implemented in a 9.3 m x 2.3 m room, corresponding to an approximate working area of 21.4 m^2. The room is equipped with air conditioning, a stabilised electrical power line, grounding and computing resources for computer-aided design.

Figure 22

UNMSM FabLab room during the implementation stage, showing computing and initial prototyping equipment.

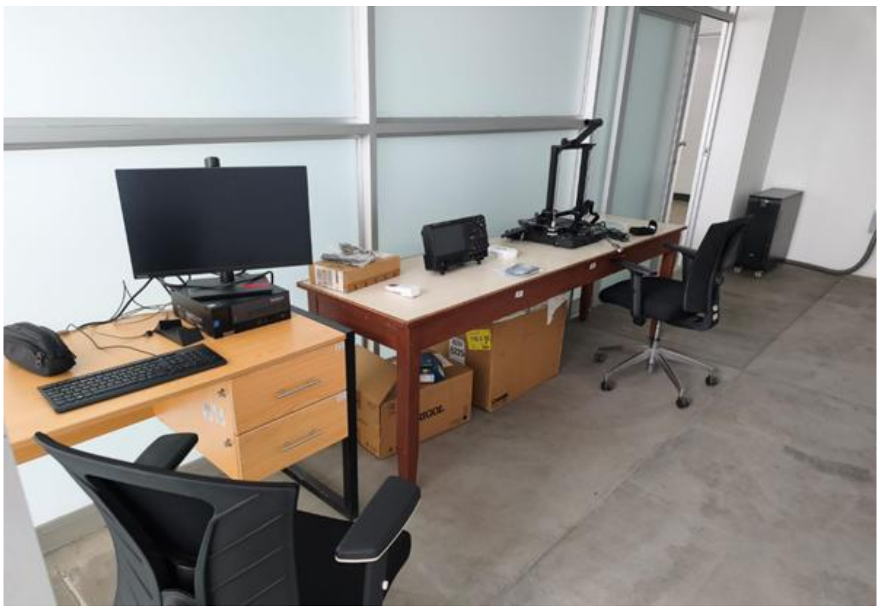
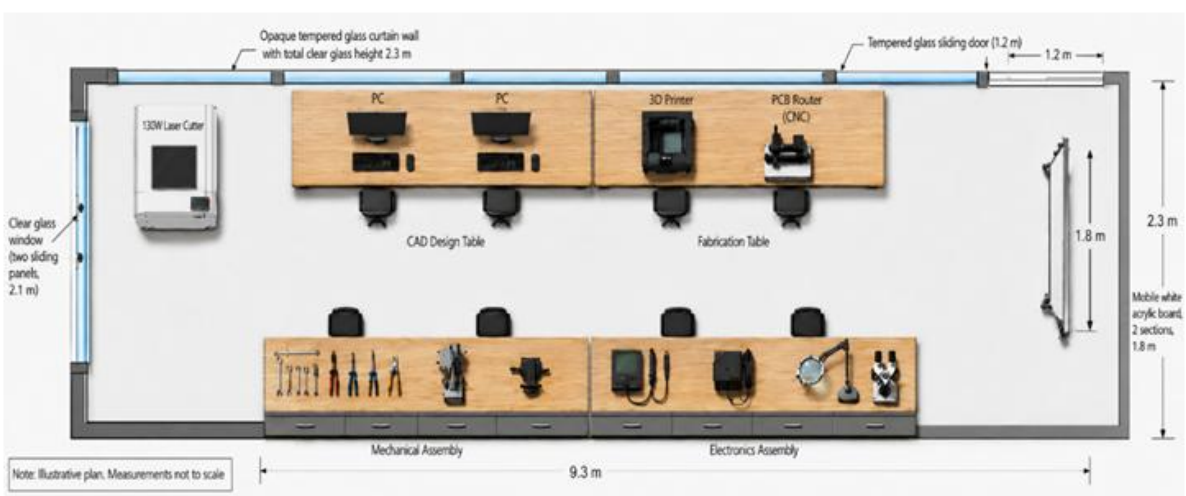


Figure 23

Approximate floor plan of the UNMSM FabLab. The drawing is intended as a functional representation and should be updated if the final layout changes.



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Functional areas

The UNMSM FabLab is organised around six complementary functional areas that connect computer-aided design, digital fabrication, electronics, assembly and experimental integration. These areas are complemented by the Nuclear Instrumentation Laboratory and the Mechanical Workshop of the Faculty of Physical Sciences when specialised instrumentation or heavy machining is required.

Table 80

Functional areas, available infrastructure and main activities of the UNMSM FabLab

Area	Available infrastructure	Main activities
Computer-aided design and documentation area	Computer equipment and CAD workstation within the air-conditioned FabLab space, supported by a stabilised electrical line and grounding	Mechanical and electronic design, preparation of drawings and PCB layouts, modelling of parts and enclosures, bills of materials and technical documentation
3D additive manufacturing area	Bambu Lab 3D printer	Fabrication of supports, housings, adapters, sample holders, bases and auxiliary components for scientific instruments and experimental setups
Printed-circuit-board fabrication area	CNC router acquired for PCB manufacturing	Routing and preparation of prototype PCBs for detectors, power supplies, data-acquisition systems and instrumentation modules
Laser-cutting area	Existing 80 W CO2 laser cutter with a maximum working area of approximately 60 cm x 40 cm	Cutting of acrylic, polymers, thin wood and other compatible lightweight materials for panels, enclosures, templates and prototype structures
Electronic assembly and instrumentation area	Installed Rigol four-channel, 200 MHz mixed-signal oscilloscope; digital microscope, reflow station and two FPGA development boards acquired through the project	Soldering, inspection, integration and electrical testing of electronic circuits, detector modules, power supplies, acquisition systems and scientific instrumentation

Funded by the European Union

Mechanical assembly, experimental and integration area	Assembly space within the FabLab, complemented by the Faculty Mechanical Workshop with a 1 m parallel lathe (1.5 HP) and a universal milling drill (1.5 HP)	Assembly and adjustment of complete prototypes; machining of aluminium, iron and steel components; fabrication of metal enclosures, Faraday cages, structural supports, vacuum chambers and pressure chambers

Equipment and operational status

Table 81

Equipment for the UNMSM FabLab and its complementary laser-cutting capability

Equipment	Model/specification	Qty	Status	Main use
Mixed-signal oscilloscope	Rigol, 4 channels, 200 MHz	1	Received and installed	Signal acquisition and electronic testing
PCB CNC router	CNC9018 PRO	1	Received, in process of installation	Printed circuit-board fabrication
3D printer	Bambu Lab P1S	1	Received and installed	Additive manufacturing
Digital microscope	ANDONSTAR	1	Received and installed	Inspection of PCB tracks and solder joints
Reflow soldering station	PUHUI T962	1	Received and installed	SMD assembly
FPGA development board	Digilent Nexys A7	2	Received and installed	Digital acquisition, timing and control
CO_2 laser cutter	80 W; maximum area 60 cm x 40 cm	1	Existing complementary equipment	Cutting and engraving of lightweight materials

Current activities and developments

The FabLab is complemented by the Nuclear Instrumentation Laboratory and the Mechanical Workshop of the Faculty of Physical Sciences. The workshop includes a 1 m parallel lathe rated at 1.5 HP and a 1.5 HP universal milling drill. These machines support parts made from aluminium, iron and steel that are outside the safe or practical scope of a compact FabLab.

Figure 24

80 W CO_2 laser cutter

Figure 25

Semi-automatic machine tools in the Faculty mechanical workshop

Two documented developments illustrate this complementary model: an anodised aluminium enclosure for a programmable 2 kV high-voltage power supply and a vacuum chamber for charged-particle detection. Both required machining capabilities beyond lightweight digital fabrication.

Figure 26

Programmable 2 kV high-voltage power-supply assembly in its machined enclosure.

Figure 27

Machined vacuum chamber for charged-particle detection

Implementation experience, constraints and next steps

The UNMSM experience shows that a FabLab for scientific instrumentation should not be expected to contain every manufacturing process. Compact digital-fabrication and electronics capabilities are most effective when they are connected to institutional workshops that can safely perform heavy machining, manufacture structural supports, prepare grounded enclosures and build vacuum or pressure components.

13.2 Fab Lab at Universidad Industrial de Santander - Colombia

Institutional context and purpose

The FabLab at the Universidad Industrial de Santander (UIS) is a digital-fabrication laboratory in the process of consolidation. It supports EL-BONGO Physics, Grupo Halley and LIDeRA - Laboratorio de Investigación para la Detección de Radiación y Astropartículas. Its purpose is to design, fabricate, integrate and test low-cost scientific prototypes for experimental physics, astroparticles, geophysics and electronics.

Location, implementation status and physical infrastructure

The facility is located in the upper area of the Human Sciences Building, with three working zones and installed equipment.

Figure 28

General view of the FabLab UIS, including workstations, storage and electronics bench space

Table 82

Functional areas for the FabLab UIS

Area	Available infrastructure	Main activities
General work area	Three workstations with desks and chairs	Conceptual design, technical-guide review, preliminary CAD modelling, documentation, analysis and practice planning
3D-printing area	Bambu Lab P1S, Creality and Creality Ender-3 S1 printers	Fabrication of supports, housings, bases, mounts, angular structures and prototype components
Electronics area	WEGSTR CNC, electronics hot plate, soldering station, ANDONSTAR microscope, Rigol instruments and NI ELVIS III	PCB preparation, soldering, inspection, sensor integration, testing, repair and adjustment

Figure 29

Additive-manufacturing area equipped with Creality and Bambu Lab printers

Equipment and operational status

Table 83

Equipment at the FabLab UIS

Equipment	Model	Qty	Status	Main use
3D printer	Bambu Lab P1S	1	Installed	Additive manufacturing
3D printer	Creality Ender-3 S1 Pro	1	Installed	Additive manufacturing
3D printer	Creality Ender-3 S1	1	Installed	Additive manufacturing
PCB CNC router	WEGSTR	1	Installed	PCB preparation and light routing
Electronics hot plate	946C	1	Installed	SMD assembly and repair
Soldering station	Sugon A9	1	Installed	Manual assembly and repair
Digital microscope	ANDONSTAR	1	Installed	PCB and component inspection
DC power supply	Rigol DP811A	1	Installed	Controlled power for tests
Mixed-signal oscilloscope	Rigol MSO5204	1	Installed	Analogue and digital signal analysis
Function generator	Rigol DG852	1	Installed	Generation of test signals
Educational workstation	NI ELVIS III	1	Installed	Circuit design, acquisition and instrumentation

Current activities and developments

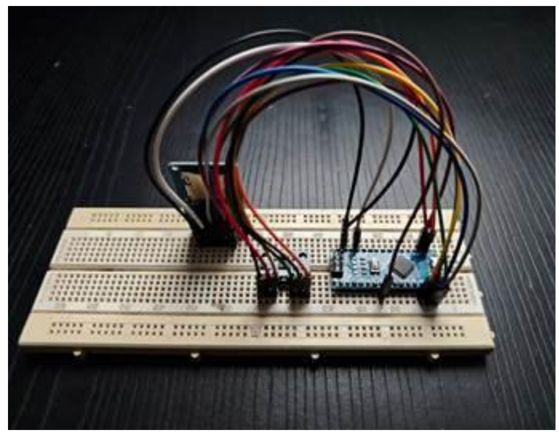
The FabLab UIS has developed two prototypes that combine digital fabrication, mechanics, electronics and experimental instrumentation. The first is a MEMS accelerometer system for recording vibrations in a scale structure, including Arduino-based acquisition and a mounting configuration. The second is a 3D-printed angular support for coupling two MuNRa muon detectors in coincidence, enabling measurements at different relative angles and supporting studies of the angular dependence of atmospheric-muon flux.

Figure 30

Angular support for a MuNRa Hodoscope

Figure 31

MEMS accelerometer prototype for vibration recording



For teaching, the facility supports the complete prototype cycle: defining an experimental need, designing a mechanical or electronic solution, fabricating parts, assembling circuits, acquiring data and documenting the final system. For research, it provides local capacity for iterative modification during experimental campaigns.

Implementation experience, constraints and next steps

The UIS case demonstrates the value of organising a compact laboratory around a real workflow rather than around isolated equipment. Its strongest documented feature is the connection between manufacturing resources and concrete experimental prototypes. The next consolidation stage should formalise equipment-use procedures, material inventories, maintenance logs, authorisation levels and shared repositories for CAD, firmware, raw data and analysis scripts.

13.3 Fab Lab at LEOPARD Laboratory from Universidad San Francisco de Quito - Ecuador

Institutional context and purpose

The LEOPARD Laboratory at Universidad San Francisco de Quito (USFQ) is developing an in-house capability for designing, building and customising scientific instrumentation. The laboratory is progressively moving from the assembly and adaptation of commercial systems toward local fabrication of detector electronics by combining experimental physics, electronic engineering and computing. The FabLab was initially equipped through LA-CoNGA physics and expanded through EL-BONGO Physics.

Location, implementation status and physical infrastructure

The principal laboratory activities are carried out in room HS-516, which contains student workbenches and the instrumentation station. The DGSHAPE / Roland MODELA MDX-50 PCB milling system is installed in room HS-519 in coordinated shared use with the Electronics programme.

Figure 32

General view of the LEOPARD Laboratory in HS-516, showing student workbenches and the instrumentation station.

Functional areas

The spatial organisation of the LEOPARD FabLab is presented below using the same structure adopted for the UIS FabLab, for consistency across the institutional sections.

Table 84

Functional areas, available infrastructure and main activities of the LEOPARD FabLab at USFQ

Area	Available infrastructure	Main activities
Design, data and technical documentation area	Student workstations in room HS-516; workstation used for the local CosmicWatch event dashboard; control laptop for the PCB milling system; Ultimaker Cura software for preparing 3D-printing jobs	Preparation of detector and PCB designs, configuration of fabrication jobs, monitoring and visualisation of cosmic-ray data, analysis of experimental results, and preparation of technical documentation
Electronics instrumentation and characterisation area	Keysight EDU instrumentation bench with EDUX1052A 50 MHz digital oscilloscope, EDU33212A 20 MHz two-channel waveform generator, EDU34450A 5.5-digit bench multimeter and EDU36311A triple-output programmable DC power supply, complemented by an auxiliary Wanptek supply	Characterisation and debugging of detector front-end electronics; pulse-shape inspection; gain, threshold and noise measurements; SiPM characterisation; photon-spectroscopy practices; and hands-on instrumentation training
PCB fabrication and light-machining area	DGSHAPE/Roland MODELA MDX-50 PCB milling system (PCB-50) installed on a dedicated support bench in room HS-519, with control laptop.	High-resolution routing of prototype PCBs for detector front-end and data-acquisition electronics, including LAGO-family designs; fabrication of student circuit boards; validation of existing PCB designs; and light machining of small mechanical parts
Additive-manufacturing area	Artillery Genius FDM 3D printer with an adjacent workstation using Ultimaker Cura slicing software	Fabrication of detector enclosures, mounts, supports and other mechanical parts for scientific instruments and student projects; production of the enclosure used for the CosmicWatch-type muon detector

Detector assembly and experimental-integration area	Student workbenches in room HS-516; CosmicWatch-type scintillator muon detector; plastic scintillator panels with SiPM readout; bias and amplification boards; data-acquisition electronics; and an existing LAGO_RP_DP eight-channel front-end-board design	Assembly and testing of cosmic-ray detectors and data-acquisition circuits; integration of electronics with 3D-printed enclosures; characterisation of scintillator and SiPM response; continuous event monitoring; and support for teaching and research in astroparticle physics
Seismic sensing and environmental monitoring area (in preparation)	Raspberry Shake seismic sensor received in July 2026 and held in room HS-516	Installation and use of the seismic sensor for teaching, environmental monitoring and research activities after reception, documentation and commissioning

Equipment and operational status

Table 86

Equipment for the LEOPARD Laboratory

Equipment	Model/specification	Qty	Status	Main use
PCB milling system	DGSHAPE / Roland MODELA MDX-50 (PCB-50)	1	Installed and functional; awaiting supplier training	High-resolution PCB routing and light machining
FDM 3D printer	Artillery Genius	1	Operational	Enclosures, mounts and mechanical parts
Digital storage oscilloscope	Keysight EDUX1052A, 50 MHz, 1 GSa/s	1	Operational	Pulse and signal characterization
Waveform generator	Keysight EDU33212A, 20 MHz, 2-channel	1	Operational	Electronic test signals
Bench multimeter	Keysight EDU34450A, 5.5-digit	1	Operational	Electrical measurements
DC power supply	Keysight EDU36311A, triple-output programmable	1	Operational	Detector and circuit power

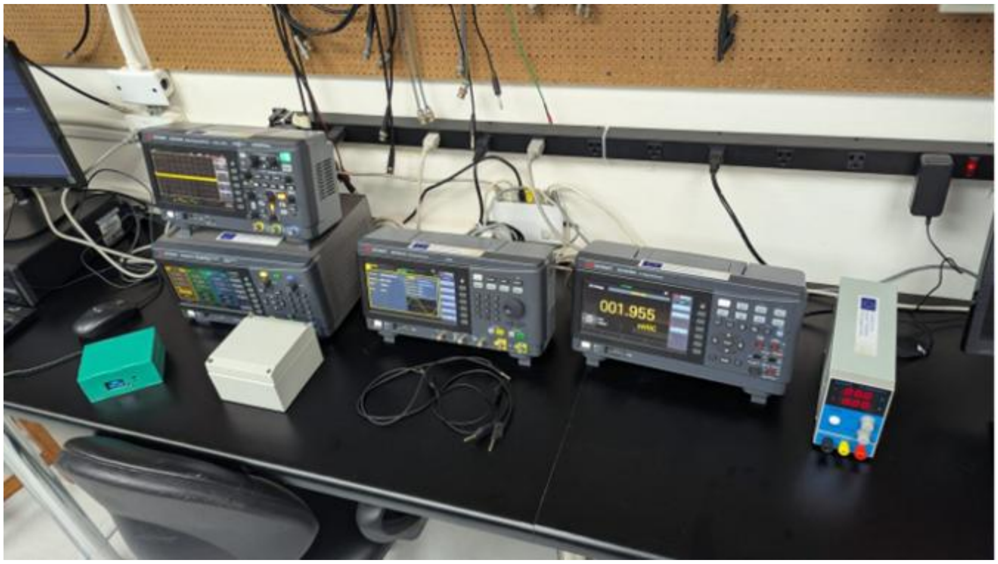
Auxiliary DC power supply	Wanptek bench supply	1	Operational	Auxiliary testing
Seismic sensor	Raspberry Shake	1	Received, installation pending	Seismic monitoring and geophysics

Current activities and developments

The instrumentation bench is used to inspect pulse shapes, adjust gain and thresholds, measure noise and train students in experimental electronics. Under LA-CoNGA physics, the laboratory contributed to the consortium's scientific-instrumentation module, which was delivered jointly across partner institutions using shared remote-laboratory infrastructure. In total, 27 master's students from the participating universities completed the instrumentation course during 2022 and 2023. The FabLab also supports student and research work in cosmic-ray detection and co-directed doctoral research on cosmic-ray methods for soil-moisture estimation in collaboration with UIS.

Figure 33

Keysight EDU instrumentation bench in HS-516. The green enclosure houses a CosmicWatch-type muon detector



Three recent developments document the laboratory workflow. A CosmicWatch-type scintillator muon detector was assembled and placed in a 3D-printed enclosure; it streams event count, rate, SiPM amplitude, dead time, temperature and pressure to a local dashboard. Light-tight scintillator panels and SiPM readout electronics are used to characterise detector response. The group also co-developed the LAGO_RP_DP 8-channel frontend and signal-conditioning board, which has so far been fabricated externally and provides a validation target for the milling system.

Figure 34

CosmicWatch-type detector and live event dashboard

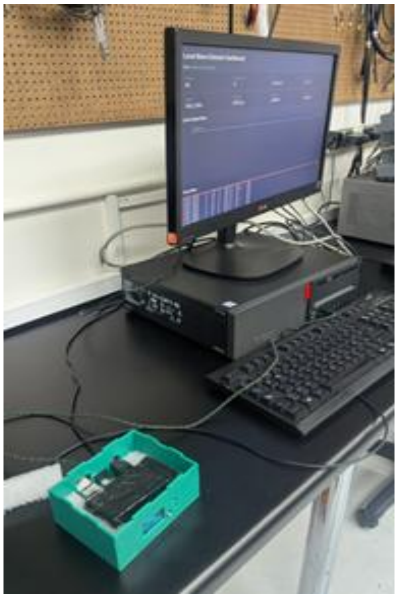
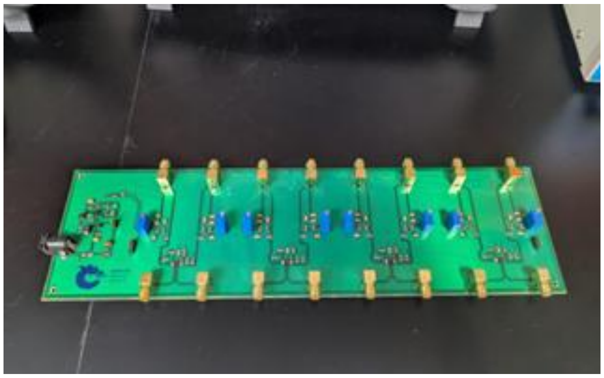


Figure 35

LAGO_RP_DP eight-channel front-end board co-developed at LEOPARD

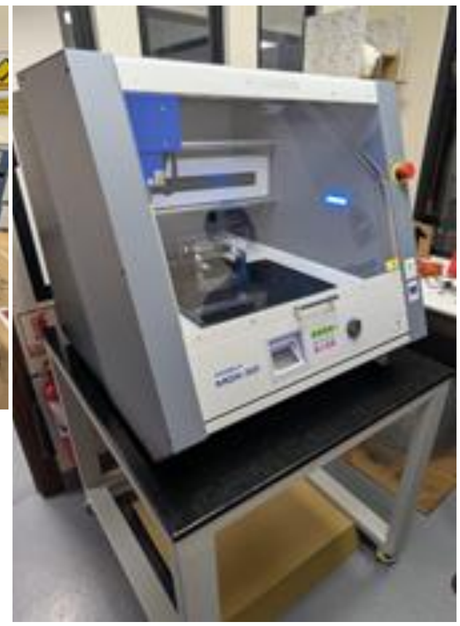


PCB milling capability

The PCB-50 is a benchtop three-axis CNC milling system with an automatic tool changer. It was received at USFQ in February 2026 and installed on a dedicated support bench in June 2026, once the bench had been fabricated and the site prepared. The system powers up and all functions respond correctly. No milling trials have yet been carried out, since operator training with the supplier is still pending and additional tooling required specifically for PCB routing may need to be procured. Colleagues from the Electronics Engineering (IEE) programme, who share the room, are following the process, and the first trials are expected in the opening weeks of the coming semester. The intended role of the system is to shorten the circuit design, build and test cycle for detector front-end and data-acquisition electronics, including LAGO-family designs.

Figure 36
Staff configuring a milling job during commissioning

Figure 37
MODELA MDX-50 installed on its dedicated bench in HS-519



Implementation experience, constraints and next steps

The USFQ experience shows how a FabLab can mature around a research-specific workflow. Existing detector assembly, 3D printing and electronic characterisation created immediate demand for in-house PCB fabrication. Commissioning the milling system is therefore not an isolated acquisition: it completes a sequence that already has users, designs and validation targets.

13.4 FabLab at Universidad de San Carlos de Guatemala - Guatemala

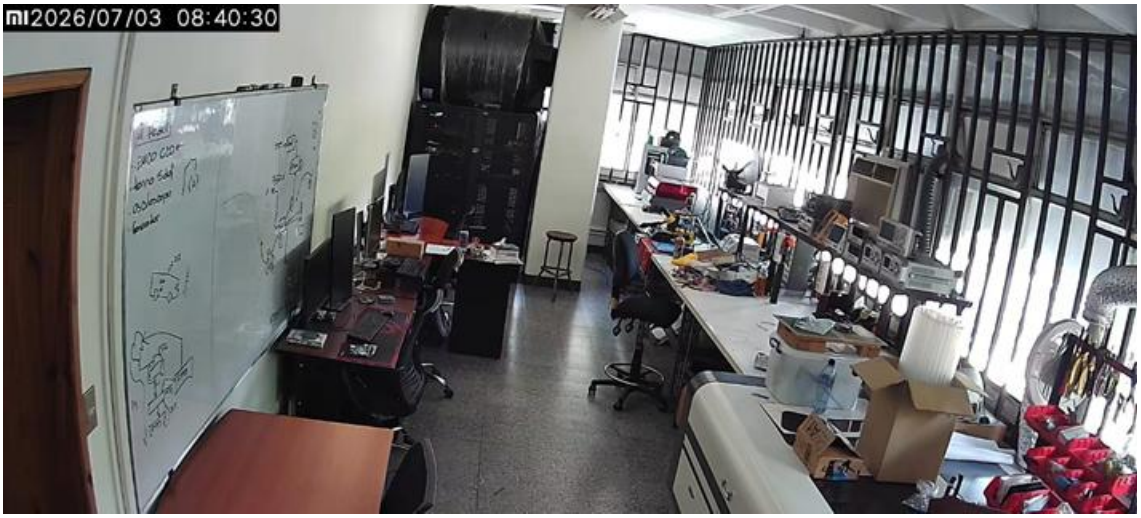
Institutional context and purpose

The Universidad de San Carlos de Guatemala (USAC), is the only public university of Guatemala. USAC has a constitutional mandate to promote higher education, scientific research and technological development. Within this institutional framework, the School of Physical Sciences and Mathematics (ECFM) has progressively strengthened its research and technological capabilities since its creation in 2015. Through collaborations with international scientific initiatives and research networks, the School has developed expertise in scientific instrumentation, detector development, electronics, embedded systems, data acquisition, and high-performance computing for applications in astrophysics, particle physics, geophysics, and environmental monitoring. The establishment of the FabLab at the School of Physical Sciences and Mathematics is intended to complement and expand these capabilities by creating a specialized environment dedicated to the design, fabrication, testing, and validation of scientific instrumentation.

Location, implementation status and physical infrastructure

Figure 38

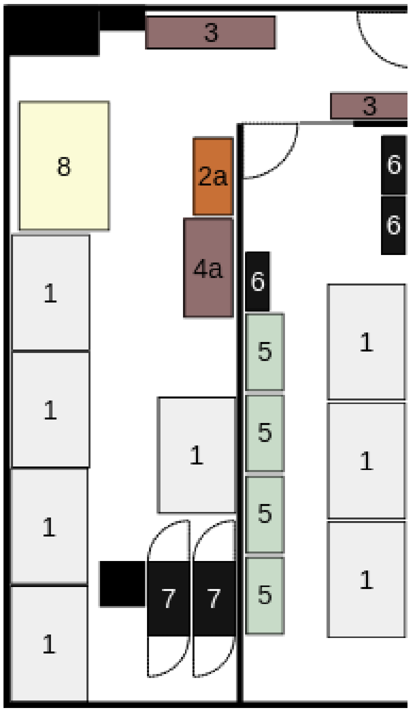
Laboratory space presented in the main institutional document as the FabLab at USAC



The FabLab is located in the building T-1, Laboratory 1 of the ECFM in the Central Campus of the university in Guatemala City. It is divided in two spaces of ~ 11 x 3.5 m. The distribution of the spaces is as shown in Figure 13.4.2.

Figure 39

Laboratory distribution of the two spaces of the FabLab at USAC.



The infrastructure includes: Air-conditioned workspace to ensure stable operating conditions for electronic equipment, high-speed network connectivity supporting collaborative development and remote access, Computer workstations equipped with CAD, electronics design, programming, and data analysis software, dedicated workbenches for electronics assembly, testing, and instrumentation development, modular furniture that allows rapid reconfiguration according to teaching or research activities and storage cabinets for electronic components, tools, and fabrication materials.

Functional areas

The USAC FabLab presents six functional areas. The table below follows the same structure used for the UIS FabLab, distinguishing the infrastructure currently documented from the main activities associated with each area.

Table 86

Functional areas, available infrastructure and main activities of the USAC FabLab

Area	Available infrastructure	Main activities
3D digital additive-manufacturing area	Specific installed equipment and operational status are not documented in the information currently available	3D modelling and fabrication of supports, housings, adapters, bases and lightweight components for teaching and scientific prototypes
Printed-circuit-board fabrication area	PCB fabrication equipment, model, quantity and operational status are not documented in the information currently available	Design, routing or milling, preparation and verification of prototype PCBs for electronics, sensors and instrumentation systems
Laser-cutting and lightweight digital-fabrication area	Laser-cutting equipment and supporting extraction infrastructure are not documented in the information currently available	Cutting and engraving of compatible lightweight materials for panels, enclosures, templates and prototype structures
Electronic assembly, digital systems and testing area	Signal generator received through the EL-BONGO Physics project and shown in use; Digilent Nexys A7 FPGA development board shown in functional testing; other bench equipment is not documented	Generation of test signals, basic circuit verification, FPGA development and functional testing, electronic assembly and preliminary validation of instrumentation modules
Mechanical assembly and prototyping area	Workbenches, hand tools, mechanical equipment and current operational status are not documented in the information currently available	Mechanical assembly, adjustment and integration of supports, enclosures, electronic modules and complete experimental prototypes
Computer-aided design and engineering-simulation area	Computer workstations, CAD or simulation software and current operational status are not documented in the information currently available	Preparation of mechanical designs, PCB layouts, engineering simulations, drawings, bills of materials and technical documentation

Equipment and operational evidence

Table 87

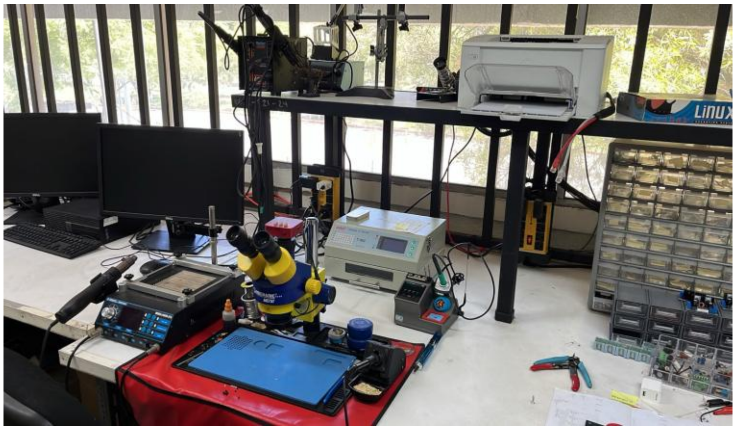
Equipment explicitly evidenced in the information currently available for USAC

Equipment	Model	Qty	Status	Main use
Signal generator	Rigol DG852	1	Operational	Electronic test-signal generation
FPGA development board	Digilent Nexys A7	2	Function test documented	Digital-system and FPGA training
Micro Soldering Station	SUGON A9210	1	Operational	Precision soldering of electronic components
Reflow Soldering Oven	PUHUI T962	1	Operational	Reflow soldering of surface mount device

Figure 40
Signal generator received through EL-BONGO and shown in use

Figure 41
Functional test of a Nexys A7 FPGA development board

Figure 42
Micro soldering station and reflow soldering oven received through EL-BONGO in operational use



Current activities and developments

The FabLab at the ECFM has the initial infrastructure completed, core fabrication and electronics equipment has been installed, and the laboratory is progressively integrating research, teaching, and outreach activities.

Current developments focus on establishing the FabLab as a multidisciplinary center for scientific instrumentation and digital fabrication, supporting both institutional research projects and regional collaborations within the EL-BONGO Physics network. An important ongoing activity of the FabLab is the implementation of the EL-BONGO instrumentation practices, which have been successfully adopted and developed by local undergraduate and master students.

Implementation experience, constraints and next steps

The implementation of the FabLab has demonstrated the feasibility of establishing a specialized scientific fabrication laboratory within a public university in a resource-constrained environment.

The implementation had several challenges. The laboratory operates within a limited physical space, requiring careful organisation of workstations and equipment to accommodate multiple activities. As with many public universities, financial resources for laboratory expansion and equipment acquisition remain limited, making it necessary to prioritise investments and maximise the use of available infrastructure. In addition, administrative procedures and institutional constraints can occasionally slow equipment acquisition and infrastructure improvements.

Another challenge has been ensuring continuous accessibility to the laboratory. Although the School has consistently supported the initiative, access to university facilities has been affected by internal institutional situations beyond the project's control, temporarily limiting laboratory operations and the continuity of research and training activities. These experiences have reinforced the importance of flexible planning and efficient resource management. Despite these constraints, the FabLab has established a solid foundation for future growth.

The ongoing implementation demonstrates that high-quality scientific instrumentation can be designed, fabricated, and maintained locally using modern digital fabrication technologies combined with open-source hardware and software.

13.5 Fab Lab at UAN Detector Laboratory - Colombia

Institutional context and purpose

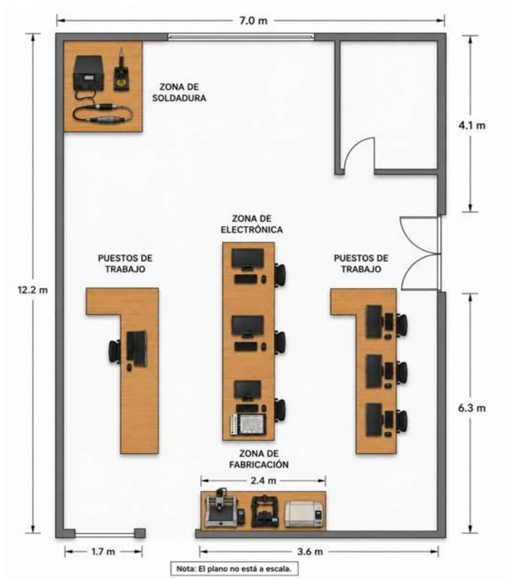
The FabLab forms part of the Detector Laboratory of Universidad Antonio Nariño (UAN), Circunvalar campus in Bogotá, and is associated with the High Energy Physics research group. It is being consolidated as a digital fabrication and scientific prototyping environment for mechanical parts, circuit substrates, electronic assembly, and instrumentation practices.

Location, implementation status and physical structure

The Detector Laboratory has a total area of 85 square meters divided into areas dedicated to teaching and research. For the FabLab, there are three functional areas: digital fabrication; electronics and soldering; and computing, instrumentation and prototyping. The total area devoted to the FabLab comprises around 30 % of the total area of the laboratory. The Figure shown below is a scheme of the Laboratory with the aforementioned functional areas. A description of each area is presented in Table 13.1.5

Figure 43

Functional layout of the UAN Detector Laboratory FabLab, including soldering, electronics, fabrication, and work areas. The plan is not to scale



Functional areas

As already mentioned, the UAN FABLAB is divided into three areas; each area is located in a zone with the environmental conditions required for optimal operation.

Table 88

Functional organisation for the UAN Detector Laboratory FabLab

Area	Available infrastructure	Main activities and function
Digital fabrication	Creality Ender 3-S1 and WEGSTR CNC router	FDM parts, mechanical components and PCB routing
Electronics and soldering	Reflow oven, electronic hot plate, ERSA soldering station and rotary tool	SMD and through-hole assembly, rework and light finishing
Computing, instrumentation and prototyping	Computer, NI ELVIS III and prototyping board	Circuit design, simulation, testing and electromechanical integration

The table shown above has a description of each area, the available infrastructure and the main function of the area is also presented.

Equipment and operational status

The equipment that the UAN Laboratory got as a part of the EL_BoNGO is already installed and most of the equipment is operational, with only the FPGA testing boards waiting to be included in future lectures under designing. Pictures of the equipment and the dedicated areas described above are shown below.

Figure 44

General view of the UAN digital-fabrication and electronics area, including the hot plate, reflow oven, CNC router and 3D printer

Figure 45
Computing and NI ELVIS III instrumentation workstation

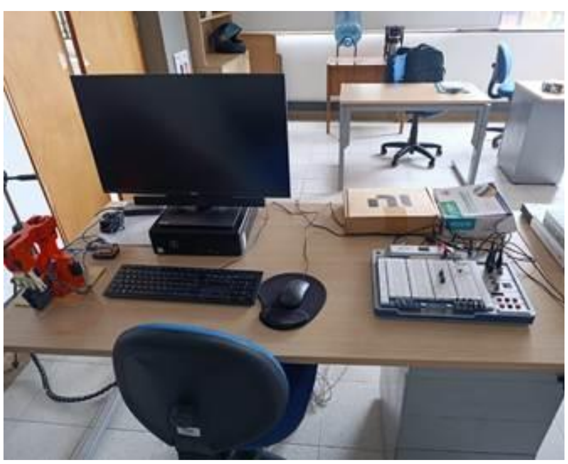


Figure 46
Manual soldering and light-finishing station

A more detailed description of the equipment together with its operational conditions are shown in the table below.

Table 89

Equipment installed at UAN

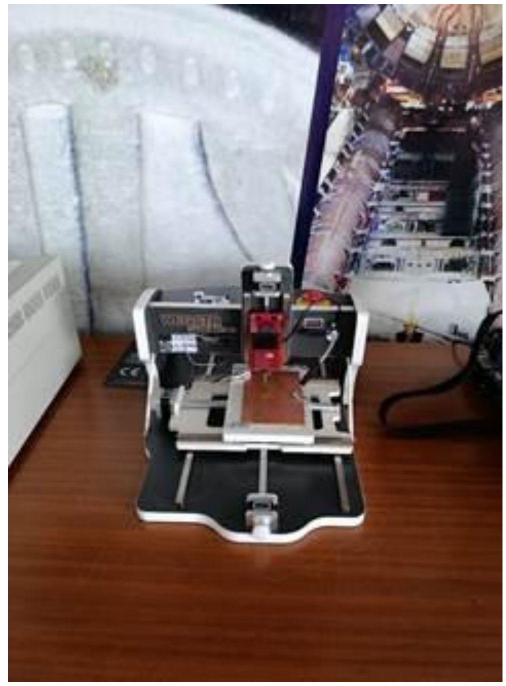
Equipment	Model	Qty	Status	Main use
3D printer	Creality Ender 3-S1	1	Operational	FDM parts and prototypes=
PCB CNC router	WEGSTR	1	Operational	PCB routing and precision milling
Reflow oven	Puhui T-962A	1	Installed	SMD reflow soldering
Electronic hot plate	Soiiw 946C+	1	Installed	Preheating and controlled soldering
Soldering station	ERSA I-CON 2	1	Operational	Manual SMD and through-hole soldering
Rotary tool	Dremel 300	1	Operational	Light mechanical finishing
Instrumentation workstation	NI ELVIS III	1	Operational	Circuit design, simulation and testing
FPGA development board	Digilent Nexys A7	2	Function test documented	Digital-system and FPGA training

Figure 47

Creality Ender 3-S1 used for 3D printing

Figure 48

WEGSTR CNC router used for PCB preparation



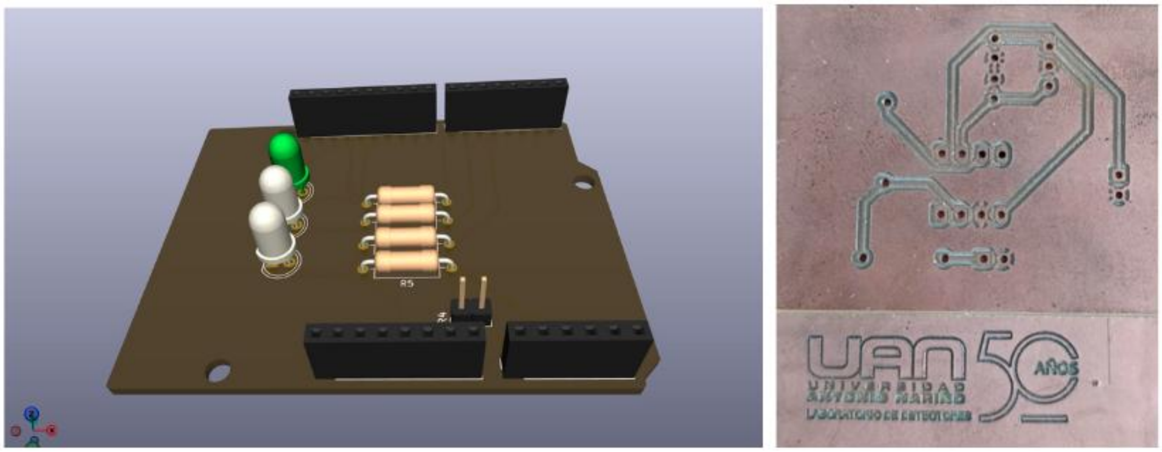
Current activities and developments

The documented configuration shown above supports FDM fabrication, PCB routing, manual and reflow soldering, circuit simulation, electronic testing and light mechanical adjustment. One of the first tasks developed at the UAN FABLAB with the equipment mentioned above was using FDM fabrication to adapt structures to laboratory equipment already presented at the lab, with the goal of using these materials for new research and to store some scintillators. Some of the FDM printed at the UAN FABLAB are shown in the pictures below.

Figure 49
3D printed elements

In addition to 3D printing the FABLAB UAN has been working in electronics design and PCB production. One example of the work performed at the UAN is a basic circuit used to convert audible signals coming from a geiger detector to digital signals to be acquired by an Arduino UNO.

Figure 50
Electronic design and drilled PCB



Implementation experience, constraints and next steps

UAN illustrates a compact workflow that places fabrication, soldering and instrumentation in the same laboratory. Following the philosophy of the FABLABs the UAN is using the equipment obtained through the project to adapt old lab material to be used in new research projects. In addition, new capabilities in prototyping are under development at the Lab. The next step is to make a full prototyping chain including the use of the reflow soldering.

13.6 Fab Lab at Escuela Superior Politécnica de Chimborazo – Ecuador

Institutional context and purpose

ESPOCH participates in Erasmus+ CBHE 101179251 - EL-BONGO Physics. Under Work Package 2, it has established a FabLab to strengthen research, digital fabrication and scientific instrumentation. The institutional report dated June 2026 documents equipment reception, space adaptation, preliminary installation and institutional inventory registration.

Location, implementation status and physical infrastructure

The FabLab is installed on the ground floor of the Faculty of Mechanics laboratory building in an area of approximately 6 m x 6 m (36 m^2). Adaptations included painting and refurbishment, zebra blinds, electrical connections for specialised equipment, fabrication worktables, metal storage cabinets, a desktop control computer, a UPS for acquisition-system continuity, a display and projector for training, and space for collaborative work.

Figure 51

General view of the adapted 36 m^2 ESPOCH FabLab

Figure 52

General view of the adapted 36 m² ESPOCH FabLab

Functional areas

Based on the institutional implementation report, the ESPOCH FabLab can be organised into six complementary functional areas. The classification below follows the same structure used for the UIS FabLab and reflects the equipment received, the physical adaptations completed, and the activities currently supported or planned within the 36 m^2 facility.

Table 90

Functional areas, available infrastructure and main activities of the ESPOCH FabLab

Area	Available infrastructure	Main activities
Digital fabrication and machining area	WEGSTR/WEGSTER three-axis CNC milling machine; Bambu Lab P1S 3D printer with AMS; Fastler S PRO laser cutter; dedicated fabrication worktables	Additive manufacturing of supports, housings, adapters and prototype components; CNC machining or PCB-related routing; laser cutting and engraving of compatible lightweight materials; preparation and adjustment of parts for scientific prototypes
Electronics assembly and PCB prototyping area	SUGON A9 microsoldering station; Puhui T962 reflow station; Andonstar AD246S-M digital microscope; electronic components and storage cabinets	Manual and reflow soldering of electronic assemblies; inspection of solder joints, PCB tracks and small components; repair, rework and integration of instrumentation electronics

Electronic instrumentation and signal-analysis area	Rigol MSO5204 oscilloscope; Rigol DG852 Pro function generator; Rigol DP811A DC power supply; Rigol PLA2216 logic probe	Generation and measurement of analogue and digital signals; power and validation of prototype circuits; sensor-response analysis; timing, trigger and logic-signal testing; preliminary troubleshooting of electronic systems
Seismic instrumentation and data-acquisition area	Raspberry Shake RS4D strong-motion seismograph; desktop computer for equipment control; UPS support for acquisition continuity	Recording and analysis of ground-motion or vibration data; operation of seismic-acquisition activities; preservation of data acquisition during short electrical interruptions; development of teaching and research activities related to geophysics
Design, training and collaborative-work area	Desktop control computer; multimedia screen and projector; collaborative tables and seating; controlled lighting with zebra blinds	Computer-aided design and preparation of fabrication files; equipment-control activities; technical training, demonstrations and collaborative work by students and researchers; review and documentation of prototype projects
Technical storage and support-services area	Metal cabinets for tools and electronic components; adapted electrical connections for specialised equipment; lighting, secure storage and general room infrastructure	Organised storage of tools, components and supplies; preparation of equipment for use; protection of materials and accessories; support for safe circulation, maintenance and orderly laboratory operation

Equipment and operational status

Table 91

Equipment received for the ESPOCH FabLab

Equipment	Model	Qty	Status	Main use
Three-axis CNC milling machine	WEGSTR	1	Operational	PCB and precision routing
Microsoldering station	SUGON A9	1	Operational	Fine soldering and rework
Digital microscope	Andonstar AD246S-M	1	Operational	PCB and component inspection

3D printer with AMS	Bambu Lab P1S	1	Operational	Additive manufacturing
Laser cutter	Fastler Series S PRO	1	Operational	Cutting and engraving
Reflow station	Puhui T962	1	Operational	SMD assembly
Strong-motion seismograph	Raspberry Shake RS4D	1	Received, installation pending	Seismic monitoring
Mixed-signal oscilloscope	Rigol MSO5204	1	Operational	Signal analysis
Function generator	Rigol DG852 Pro	1	Operational	Test-signal generation
DC power supply	Rigol DP811A	1	Operational	Controlled prototype power
Active logic probe	Rigol PLA2216	1	Operational	Digital-logic analysis

Figure 53
CNC router prepared for installation and testing

Figure 54
Bambu Lab P1S additive-manufacturing system

Figure 55
Fastler Series S PRO laser cutter installed in the ESPOCH FabLab

Current activities and developments

The documented activities comprise receipt and technical verification of equipment, adaptation of the physical space, preliminary installation and registration in the institutional inventory. The resulting environment is configured for digital fabrication, electronics, scientific instrumentation, prototype development and collaborative training.

Implementation experience, constraints and next steps

The ESPOCH case demonstrates that equipment acquisition must be accompanied by work on space, electricity, furniture, storage, computing, power continuity and training infrastructure.

13.7 Fab Lab at Universidad de El Salvador -El Salvador

Institutional context and purpose

The FabLab of the School of Physics, Faculty of Natural Sciences and Mathematics at the Universidad de El Salvador (UES), was implemented to strengthen experimental training, applied physics, electronics, digital prototyping and scientific instrumentation. The laboratory is intended as an interdisciplinary environment in which students, faculty and researchers can move from conceptual design and simulation to fabrication, assembly, testing and preliminary validation.

Location, implementation status and physical infrastructure

The laboratory facility has been provided with a versatile array of resources for digital manufacturing, electronic design, and scientific prototyping. This technical environment includes professional-grade measurement instruments, tools for PCB fabrication, FPGA development platforms, stations for electronic assembly, and additive manufacturing systems.

A subset of these resources is already integrated into the practical sessions of the BONGO scientific instrumentation course. Specifically, the mixed-signal oscilloscope, the waveform generator, and the programmable DC source are actively employed in exercises related to signal characterisation, circuit analysis, and measurement techniques. These implementations grant students direct experience with professional instrumentation, significantly enhancing the practical dimension of the physics curriculum.

The remaining systems—comprising the PCB CNC router, digital inspection microscope, FPGA boards, reflow oven, microsoldering station, SMD hot plate, and 3D printing equipment—are slated for deployment during the current academic cycle. These tools will support the evolving practical activities of the BONGO project, broadening training capabilities in areas such as embedded architectures, rapid prototyping, and the fabrication of specialized scientific components.

Functional areas

The FabLab supports undergraduate and graduate training in embedded systems, digital signal processing, FPGA design, PCB routing, additive manufacturing and electronic integration. It is also described as a cross-cutting platform for projects in physics, astronomy, astrophysics and engineering, with capabilities for custom electronic architectures, mechanical prototyping, printed-circuit fabrication and electronic-system characterisation.

Equipment and operational status

Table 92

Main equipment listed for the UES FabLab

Equipment	Model	Qty	Status	Main use
PCB CNC router	CNC WEGSTR	1	Avaible	Rapid PCB fabrication
SMD hot plate	Soiiw; 110 V; 850 W	1	Avaible	SMD placement and soldering
Microsoldering station	SUGON A9-210	1	Installed	Precision soldering and rework
Digital microscope	Andonstar AD246S-M	1	Avaible	PCB and solder-joint inspection
FPGA development board	Digilent Nexys A7-100T	2	Avaible	FPGA and embedded-system design
Reflow oven	PUHUI T-962	1	Avaible	Automated SMD reflow
3D printer	Bambu Lab P1S	1	Avaible	Mechanical parts and enclosures
Mixed-signal oscilloscope	Rigol MSO5204	1	Avaible	Analogue and digital measurements
Waveform generator	Rigol DG852 Pro	1	Installed	Electronic excitation and tests
Programmable DC supply	Rigol DP811A	1	Installed	Stable experimental power
Active logic probe	Rigol PLA2216	1	Installed	Digital-logic debugging

Current activities and developments

These resources will support practical activities associated with the educational objectives of the BONGO project, particularly in PCB design and fabrication, embedded systems, digital electronics, rapid prototyping, additive manufacturing, and scientific instrumentation.

In parallel, the School of Physics is completing the preparation of a permanent facility specifically designed for the FabLab. Once operational, this dedicated space will provide an integrated environment for teaching, research, and technological development, enabling the full deployment of the laboratory's capabilities and expanding opportunities for undergraduate training, scientific instrumentation projects, and interdisciplinary collaboration.

Looking ahead, the FabLab is expected to become a central resource for experimental education within the School of Physics, supporting laboratory-based instruction, undergraduate research projects, prototype development, and collaborations with national and international partners. By combining modern digital fabrication technologies with professional electronic instrumentation, the laboratory will help strengthen local capacity in scientific instrumentation and innovation in El Salvador.

Figure 56

Hands-on instrumentation session at UES using oscilloscopes, signal generation and regulated power resources

Implementation experience, constraints and next steps

A primary challenge identified during the initial setup phase involves the current laboratory location. While the technical resources are functional and ready for operation, the permanent facility is undergoing definitive renovations to ensure an environment specifically optimised for electronic assembly and digital prototyping. This transitional stage restricts the simultaneous execution of multiple activities and the deployment of the entire equipment inventory.

In the upcoming period, the School of Physics intends to finalise the physical infrastructure, allowing for the complete integration of acquired systems into the academic curriculum. This laboratory will function as a central resource for students participating in the EL-BONGO modules, offering specialised practical training in printed circuit routing, embedded architectures, rapid prototyping, and the construction of advanced measurement systems.

As a subsequent objective, the institution plans to implement an internship initiative focused on geophysical sensing. Within this framework, participants will utilise the laboratory's capabilities to design, assemble, and validate instruments for field experiments. Such a project aims to strengthen the link between experimental research and technological innovation, expanding opportunities for professional development and interdisciplinary cooperation among students.

Ultimately, the facility is envisioned as a stable institutional platform supporting scientific inquiry and technology transfer within the university. This enabling infrastructure will help consolidate local expertise in digital manufacturing and instrumentation, fostering meaningful collaboration with national and international networks in physics, engineering, and related scientific fields.

13.8 Fab Lab at Universidad Francisco Gavidia - El Salvador

Institutional context and purpose

The Universidad Francisco Gavidia (UFG) participates in the EL-BONGO Physics project through the development of a FabLab resource base for scientific prototyping. The equipment is available for electronic instrumentation, digital and FPGA design, additive manufacturing, printed circuit board fabrication, electronic assembly, and microscope-assisted inspection.

Location, implementation status and physical infrastructure

The FabLab equipment is housed in the specialised laboratory area of Building D at Universidad Francisco Gavidia. The facility covers an area of more than 15 square meters and is divided into different work areas, with the equipment arranged according to its function.

Figure 57

Functional layout of the UFG Laboratory (FabLab), including the functional work areas. The plan is not to scale

Functional areas

The UFG FabLab is organised around the following functional areas:

Table 93

Functional areas for the Universidad Francisco Gavidia FabLab

Area	Available infrastructure	Main activities
Electronic instrumentation area	Rigol 200 MHz four-channel digital oscilloscope; Rigol DP811A DC bench power supply; active logic probe; Rigol DG852 Pro 30 MHz function generator.	Signal acquisition and analysis, controlled power delivery, generation of test signals, digital-logic monitoring and validation of electronic circuits.
Digital design and FPGA area	Two Digilent Nexys A7 FPGA development boards.	Digital-system design, implementation of acquisition and control logic, timing applications, trigger development and embedded-system training.
Manufacturing and prototyping area	Bambu Lab P1S 3D printer.	Additive manufacturing of supports, housings, adapters, prototype components and educational parts.
Electronic fabrication and assembly area	SUGON A9 210 microsoldering station; Puhui T962 reflow station; Soiiw 110 V, 850 W SMD hot plate.	Manual soldering, microsoldering, SMD thermal processing, reflow assembly, repair and rework of prototype electronic modules.
Metrology and inspection area	Andonstar AD246S-M digital microscope with HDMI output.	Visual inspection of PCB tracks, solder joints, connectors, microcomponents and small mechanical parts.
PCB fabrication area	WEGSTR CNC router for printed circuit boards.	Routing and milling of prototype PCBs and preparation of electronic substrates for scientific-instrumentation projects.

Equipment and operational status

The institutional source provides the following consolidated equipment list. Because received, installed and pending items are presented together, the individual operational status of each item is not inferred.

Table 94

Functional areas for the Universidad Francisco Gavidia FabLab

Equipment	Model / specification	Qty	Status	Main use
Digital oscilloscope	Rigol; 200 MHz; four analogue channels	1	in implementation	Signal acquisition, waveform analysis and electronic testing
Function generator	Rigol DG852 Pro; 30 MHz; two channels	1	in implementation	Generation of sine, square, ramp and pulse test signals
DC bench power supply	Rigol DP811A; 0-40 V; 5-10 A; 200 W	1	in implementation	Controlled DC power for prototype circuits and instrumentation
Active logic probe	PLA2216	1	in implementation	Monitoring and analysis of digital logic signals
PCB CNC router	WEGSTR	1	in implementation	Routing and milling of prototype printed circuit boards
SMD hot plate	Soiiw; 110 V; 850 W	1	in implementation	Controlled heating for SMD assembly and repair
Microsoldering station	SUGON A9 210	1	in implementation	Fine soldering, rework and repair of electronic assemblies
Digital microscope	Andonstar AD246S-M; HDMI output	1	in implementation	Inspection and documentation of PCBs and small components
FPGA development board	Digilent Nexys A7	2	in implementation	Digital acquisition, timing, trigger and control development
Reflow soldering station	Puhui T962; 110 V; 800 W	1	in implementation	Reflow soldering of surface-mount components

3D printer	Bambu Lab P1S	1	in implementation	Additive manufacturing of prototype components

Figure 58
Rigol 200 MHz four-channel digital oscilloscope documented for electronic-instrumentation activities

Figure 59
Rigol DP811A DC bench power supply documented for controlled prototype testing

Figure 60
Rigol DG852 Pro 30 MHz function generator documented for electronic testing

Figure 61
Digilent Nexys A7 FPGA development board documented for digital design and control applications

Figure 62

Bambu Lab P1S 3D printer documented for additive manufacturing and prototyping

Figure 63

SUGON A9 210 microsoldering station documented for electronic assembly and rework

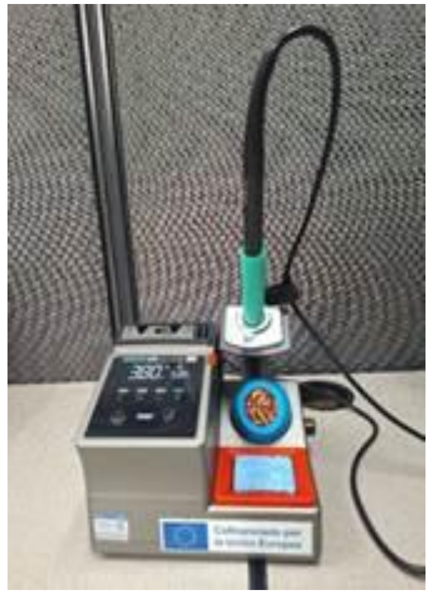


Figure 64

Puhui T962 reflow station documented for SMD assembly workflows

Figure 65

SMD hot plate documented for controlled thermal processing

Figure 66
Andonstar AD246S-M digital microscope with HDMI output documented for inspection and metrology support

Figure 67
WEGSTR CNC router documented for printed circuit-board fabrication

Current activities and developments
A central component of EL-BONGÓ Physics is the development of a regional network of digital fabrication laboratories, or FabLabs, across participating universities. These spaces are equipped with scientific measurement instruments and digital fabrication tools to support practical training, experimentation, and the development of scientific solutions. Their purpose is to complement virtual instruction with hands-on activities that allow students to design, build, test, and improve prototypes related to the project's four scientific areas.

The FabLabs also provide a shared environment for collaboration among students, lecturers, researchers, and technical staff. Through workshops, guided laboratory activities, and project-based learning, participants can strengthen their skills in scientific instrumentation, data acquisition, electronics, programming, and digital manufacturing.The second semester, expected to begin between July and August 2026, will broaden the academic programme through a series of specialized eight-week micro-courses. Eligible participants will also have the opportunity to undertake funded research internships at partner institutions during the final quarter of 2026.

Implementation experience, constraints and next steps
The next steps will focus on completing the installation and operational setup of the FabLabs, training academic and technical personnel, and developing common protocols for the safe and effective use of equipment. The project will also work to incorporate FabLab-based activities into courses, internships, research projects, and collaborative initiatives among partner universities. In the longer term, the network is

expected to become a sustainable regional platform for scientific experimentation, open innovation, interdisciplinary training, and the development of locally relevant technological solutions.

13.9 Fab Lab at Universidad Nacional Autónoma de Honduras - Honduras

Institutional context and purpose

The School of Physics of the Faculty of Sciences at the Universidad Nacional Autónoma de Honduras (UNAH) is implementing a FabLab oriented to the design, fabrication, integration and preliminary validation of scientific instrumentation. The initiative is intended to strengthen local capabilities in computer-aided design, printed-circuit-board prototyping, additive manufacturing, electronics assembly, mechanical integration, data acquisition and embedded-system development. The facility supports a transition from the exclusive use of commercial scientific equipment towards the development, adaptation and documentation of internal technological solutions for teaching, experimental physics and related scientific fields.

Location, implementation status and physical infrastructure

The UNAH FabLab is being implemented in a 4.2 m x 3.7 m room, corresponding to an approximate working area of 15.5 m^2. The available institutional information documents air conditioning, a stabilised electrical power line and grounding for the safe operation of electronics, instrumentation and digital-fabrication equipment.

The room provides a compact starting point for an entry-level academic FabLab. Its current arrangement combines equipment benches, computing space, storage and user circulation within a limited area; consequently, clear zoning and controlled access are particularly important as the laboratory progresses from installation to regular operation.

Figure 68

General view of the UNAH FabLab implementation room, showing the principal workbench and installed equipment

Figure 69

Computing and electronics workstation used for documentation, programming and prototype preparation

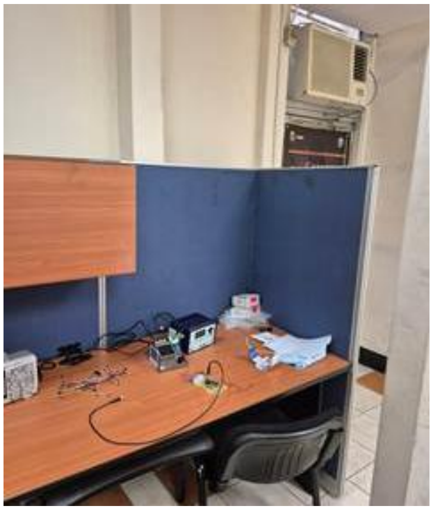


Figure 70

Storage and computing area supporting the organisation of supplies, equipment and technical work

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Figure 71

Electronics and instrumentation bench used for signal acquisition, testing and prototype validation

Functional areas

Based on the institutional equipment record and the photographic documentation, the UNAH FabLab is organised around the following complementary functional areas:

Table 95

Functional areas for the Universidad Nacional Autónoma de Honduras FabLab

Area	Available infrastructure	Main activities
Instrumentation and signal-analysis area	Rigol four-channel 200 MHz mixed-signal oscilloscope; electronics and instrumentation bench; computing resources.	Signal acquisition, validation of sensor responses, timing analysis, waveform inspection and electronic testing.
PCB-prototyping area	CNC router for printed-circuit-board manufacturing.	Fabrication of prototype boards for instrumentation, sensors, interfaces and control electronics.
Additive-manufacturing area	Bambu Lab 3D printer.	Rapid fabrication of supports, housings, adapters, educational modules and experimental components.
Inspection and documentation area	Digital microscope with HDMI/display output; computing workstation.	Inspection of solder joints, PCB traces, connectors, microcomponents and small mechanical parts; photographic and technical documentation.
Electronic assembly and SMD-processing area	Reflow soldering station, SMD hot plate and microsoldering station.	Assembly of surface-mount components, controlled heating, fine soldering, repair and prototype rework.
Embedded-systems and control area	FPGA development boards.	Development of digital acquisition, timing, trigger, communication and control systems.
General work, storage and training area	Workbenches, stools, cabinets, computing space and nearby teaching-laboratory facilities.	Preparation of practices, collaborative assembly, user training, storage of equipment and supervised demonstrations.

Equipment and operational status

The following equipment has been acquired within the framework of the EL-BONGO Physics project and it is available at UNAH.

Table 96

Equipment inventory and documented status for the Universidad Nacional Autónoma de Honduras FabLab

Equipment	Model / specification	Qty	Status	Main use
Mixed-signal oscilloscope	Rigol; four channels; 200 MHz	1	Received and installed; item-level commissioning not documented	Signal acquisition, timing analysis and electronics testing
PCB CNC router	Router CNC para PCBs modelo WEGSTR	1	Received and installed; item-level commissioning not documented	Printed-circuit-board prototyping
3D printer	Bambu Lab	1	Received and installed; photographic operation documented	Additive manufacturing of prototype components
Digital microscope	HDMI/display output	1	Received and installed	Inspection and documentation of PCB and small components
Reflow soldering station	Modelo T-962, S/N: X004DBEEI7	1	Received and installed	Surface-mount electronic assembly
FPGA development boards	FPGA Trainer X2, Modelo NEXYS-A7-100T	1	Received and installed	Digital acquisition, timing, trigger and control development
SMD hot plate	Hot Plate SMD, Modelo POWER-850W	1	Received and installed	Controlled heating for SMD assembly and repair

Microsoldering station	Modelo SUGON-09	1	Received and installed; practical use photographically documented	Fine soldering, repair and electronic assembly

Figure 72

Electronic assembly workstation with soldering and support equipment

Figure 73

SMD hot plate used for controlled heating during assembly, prototyping and repair processes.

Figure 74

CNC router installed for printed-circuit-board prototyping

Figure 75

Puhui T962 reflow station used for surface-mount electronic assembly

Figure 76

Digital microscope with display output for inspection of solder joints, PCB traces and small components

Figure 77

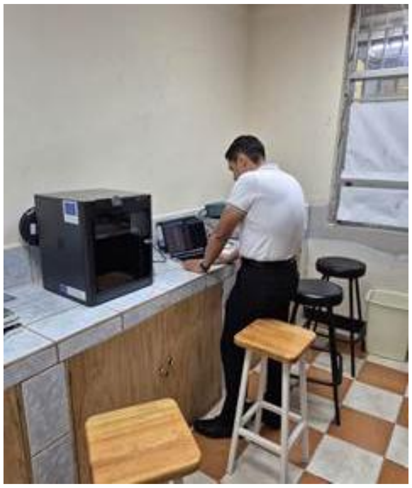
Bambu Lab 3D printer supporting the fabrication of supports, housings and experimental components

Figure 78

I*nitial operation of the additive-manufacturing equipment at the UNAH FabLab*

Figure 79

User performing setup and inspection activities on the 3D printer



Current activities and developments

The practical training and demonstration activities involve students, faculty and researchers. These activities connect electronics, sensors, signal acquisition, PCB preparation, additive manufacturing and instrumentation, allowing participants to observe and practise the sequence from experimental requirement to assembly, measurement, documentation and iterative improvement.

Figure 80
Experimental device prepared for a practical demonstration activity

Figure 81
Participants working in groups during a hands-on scientific-instrumentation session

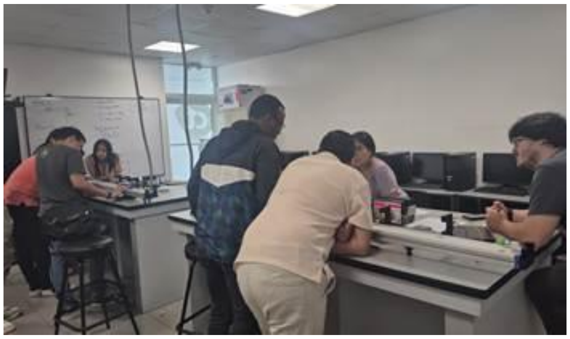


Figure 82
Group activity carried out at the laboratory workbenches

Figure 83
Practical demonstration aligned with hands-on scientific-instrumentation training

Figure 84

Microsoldering and electronic-assembly practice at the UNAH FabLab

Figure 85

Close-up of a practical electronics testing and measurement activity

Implementation experience, constraints and next steps

The initial experience at UNAH demonstrates that a compact FabLab can provide useful academic infrastructure when its equipment is aligned with real teaching and research requirements. The current configuration establishes an initial local capacity for electronics, PCB prototyping, digital fabrication, inspection and data-acquisition development, while creating a basis for progressive growth towards more specialised scientific instrumentation.

The limited floor area requires careful separation of additive manufacturing, PCB work, soldering, instrumentation, storage and user circulation. The next implementation stage should consolidate equipment-use procedures, access rules, maintenance logs, authorised-material lists, user-training records and a shared repository for design files, firmware, raw data, analysis scripts and technical documentation.

13.10 Fab Lab at Universidad Central de Venezuela (UCV) - Venezuela

Institutional context and purpose

The proposed FabLab at Universidad Central de Venezuela (UCV) is conceived as a bridge between basic scientific training and active participation in research projects. Its academic and scientific purpose is to support work in high-energy physics, astroparticles and seismic-risk analysis, while enabling students to progress from theoretical understanding to the design, construction and preliminary validation of experimental measurement systems. The concept prioritises open and adaptable instrumentation rather than exclusive dependence on closed commercial equipment.

Location, implementation status and physical infrastructure

The institutional concept assigns approximately 70 m^2 to the planned UCV facility. The planned infrastructure includes stabilised electrical power, protective grounding, UPS support for sensitive instruments, air conditioning for environmental stability, functional zoning, ventilation and cleaning provisions. The layout is expected to separate electronics and fabrication activities while supporting a progressive transition from introductory training to advanced experimental work.

Functional areas

The table below translates these worklines into functional areas using the common format adopted for the EL-BONGO Physics institutional sections.

Table 97

Functional areas documented or planned for the UCV FabLab

Area	Available infrastructure	Main activities
Design and training area	Planned CAD workstations and training resources for 3D printing.	Introductory CAD training, preparation of mechanical parts, design-file development and transition from conceptual requirements to manufacturable components.
Electronics characterisation area	The current implementation phase prioritises electronic measurement instrumentation, including digital oscilloscopes and signal generators.	Characterisation of components and circuits, waveform observation, test-signal generation and preliminary validation of electronic subsystems.

Electronic assembly and testing area	A specialised assembly and testing zone is planned. Future resources include Puhui reflow ovens and soldering and integration tools.	Soldering, electronic assembly, subsystem integration, inspection, rework and functional testing.
Scientific measurement, control and data-reading area	Planned integration of radiation and seismic sensors, control systems and data-reading resources.	Measurement of radiation and seismic phenomena, integration of control electronics, data acquisition and interpretation of experimental signals.
Digital fabrication and PCB prototyping area	Future expansion includes Bambu Lab or Creality 3D printers and equipment supporting PCB prototyping and experimental integration.	Additive manufacturing, PCB routing or milling, fabrication of supports and adapters, and integration of mechanical components into scientific experiments.

Equipment and operational status

Table 98

Equipment and implementation status reported for the UCV

Equipment	Model/ specification	Qty	Status	Main use
Digital oscilloscope	Rigol; four channels; 200 MHz	1	Received and installed; item-level commissioning not documented	Signal acquisition, timing analysis and electronics testing
Function generator	Rigol DG852 Pro; 30 MHz; two channels	1	Installed	Generation of controlled test signals
DC bench power supply	Rigol DP811A; 0-40 V; 5-10 A; 200 W	1	Installed	Controlled DC power for prototype circuits and instrumentation
3D printer	Ender III	1	Installed	Additive manufacturing of prototype components

3D printer	Bambu Lab P1S	1	To be installed	Additive manufacturing of prototype components
Soldering station	SUGON A9 210	1	To be installed	SMD assembly
Reflow soldering station	Puhui T962; 110 V; 800 W	1	To be installed	Reflow soldering of surface-mount components
Digital microscope	Andonstar AD246S-M	1	To be installed	SMD assembly
FPGA training board	NEXYS	2	To be installed	Digital circuit development platform

Current activities and developments

As the UCV site is currently in the initial acquisition phase, activities are primarily focused on the technical reception and verification of the first electronic measurement instrumentation package. Current efforts are directed toward establishing the "Electronics Line," prioritizing the characterization of components and circuits using the newly received Rigol digital oscilloscopes and function generators. This stage serves as a pedagogical bridge, moving students from theoretical basic training toward the hands-on design of measurement systems for Astroparticles and Seismic Risk analysis. Initial documentation efforts are underway to define the workflow that will eventually integrate these sensors into concrete scientific applications.

Implementation experience, constraints and next steps

The primary constraint at UCV is the transitional status of the laboratory infrastructure, as the project is still moving through the procurement and installation cycle. The 70 m^2 allocated space requires final architectural adaptations to meet EL-BONGÓ standards, specifically regarding stabilized electrical power lines, protective grounding, and functional zoning to separate the future fabrication and electronics lines. The immediate next steps involve the installation and commissioning of the remaining equipment, including the Bambu Lab 3D printers and specialized soldering stations. Following installation, the focus will shift to CAD training for digital fabrication, enabling the local production of custom mechanical supports and PCB prototypes for experimental integration.

13.11 Fab Lab at Universidad Simón Bolívar (USB) - Venezuela

Institutional context and purpose

The proposed FabLab at Universidad Simón Bolívar (USB) is conceived as a bridge between basic scientific training and active participation in research projects. Its academic and scientific purpose is to support work in high-energy physics, astroparticles and seismic-risk analysis, while enabling students to progress from theoretical understanding to the design, construction and preliminary validation of experimental measurement systems. The concept prioritises open and adaptable instrumentation rather than exclusive dependence on closed commercial equipment.

Location, implementation status and physical infrastructure

The institutional concept assigns approximately 100 m^2 to the planned USB facility. The exact campus location, building, room and present construction or installation status are not documented in the information currently available. The planned infrastructure includes stabilised electrical power, protective grounding, UPS support for sensitive instruments, air conditioning for environmental stability, functional zoning, ventilation and cleaning provisions. The layout is expected to separate electronics and fabrication activities while supporting a progressive transition from introductory training to advanced experimental work.

Functional areas

The table below translates these worklines into functional areas using the common format adopted for the EL-BONGO Physics institutional sections.

Table 99

Functional areas documented or planned for the USB

Area	Available infrastructure	Main activities
Design and training area	Planned CAD workstations and training resources for 3D printing.	Introductory CAD training, preparation of mechanical parts, design-file development and transition from conceptual requirements to manufacturable components.
Electronics characterisation area	The current implementation phase prioritises electronic measurement instrumentation, including digital oscilloscopes and signal generators.	Characterisation of components and circuits, waveform observation, test-signal generation and preliminary validation of electronic subsystems.

Electronic assembly and testing area	A specialised assembly and testing zone is planned. Future resources include Puhui reflow ovens and associated soldering and integration tools.	Soldering, electronic assembly, subsystem integration, inspection, rework and functional testing.
Scientific measurement, control and data-reading area	Planned integration of radiation and seismic sensors, control systems and data-reading resources.	Measurement of radiation and seismic phenomena, integration of control electronics, data acquisition and interpretation of experimental signals.
Digital fabrication and PCB prototyping area	Future expansion includes Bambu Lab or Creality 3D printers and equipment supporting PCB prototyping and experimental integration.	Additive manufacturing, PCB routing or milling, fabrication of supports and adapters, and integration of mechanical components into scientific experiments.

Equipment and operational status

Table 100

Equipment and implementation status reported for the USB

Equipment	Model/ specification	Qty	Status	Main use
Digital oscilloscope	Rigol; four channels; 200 MHz	1	Received and installed; item-level commissioning not documented	Signal acquisition, timing analysis and electronics testing
Function generator	Rigol DG852 Pro; 30 MHz; two channels	1	Installed	Generation of controlled test signals
DC bench power supply	Rigol DP811A; 0-40 V; 5-10 A; 200 W	1	Installed	Controlled DC power for prototype circuits and instrumentation
3D printer	Ender III	1	Installed	Additive manufacturing of prototype components

3D printer	Bambu Lab P1S	1	To be installed	Additive manufacturing of prototype components
Soldering station	SUGON A9 210	1	To be installed	SMD assembly
Reflow soldering station	Puhui T962; 110 V; 800 W	1	To be installed	Reflow soldering of surface-mount components
Digital microscope	Andonstar AD246S-M	1	To be installed	SMD assembly
FPGA training board	NEXYS	2	To be installed	Digital circuit development platform

Current activities and developments

Current developments at USB center on the operational planning for a 100 m^2 facility designed to support research in High Energy Physics and geophysics. Activities are presently concentrated on the verification of received electronic equipment to ensure it meets the requirements for high-sensitivity measurements. The site is preparing its "Scientific Measurement and Control" area, where the initial focus will be the integration of data-reading resources for radiation phenomena. Academic planning is also in progress to align the use of the new FPGA training boards with existing research lines in experimental physics.

Implementation experience, constraints and next steps

The main implementation challenge for USB is the definitive physical adaptation of the 100 m^2 area to support the simultaneous operation of clean electronics benches and "dirty" fabrication zones. As the site is in the initial phase, it must overcome the logistical constraints of the acquisition process while ensuring UPS support and air conditioning are ready for the installation of sensitive instrumentation. The next steps include the formalization of access protocols and the commissioning of the PCB prototyping area. Once the base infrastructure is stable, USB will initiate the "Fabrication Line," incorporating 3D printing and laser cutting to transition from basic training to the development of complete experimental prototypes for complex physics experiments.

14. Conclusions and recommendations

14.1 Conclusions

- The FabLab network currently being implemented through the El BONGO project is enabling the exchange of information and experiences, thereby complementing the capabilities available within the participating institutions' laboratories. The equipment was selected based on the specific conditions and needs of each institution. To date, all institutions have received the requested equipment and are at various stages of installation and commissioning. Prototypes designed and built in one laboratory can be replicated, improved, and adapted to the needs of other laboratories, facilitating collaboration in the design and development of functional prototypes. Coordinated efforts among the FabLabs ensure the sustainability of instrument development, research, and human resource training.
- All these FabLabs serve a facilitating role and do not operate as isolated laboratories. Their primary value lies in building institutional capacity to design, manufacture, adapt, test, and document experimental solutions that support research, teaching, and practical training—doing so in a decentralized and collaborative manner by sharing the strengths of more experienced laboratories with those possessing fewer capabilities.
- An entry-level implementation has been selected, as it is both technically feasible and practical. This approach allows for a low-risk start, reasonable scope for user training, controlled investment, and near-immediate results. Consequently, the decision was made to acquire versatile equipment that can be installed in compact spaces using standard furniture. This minimizes investment in complex infrastructure without compromising scalability or future growth.
- Scalability must be designed from the outset. Future growth should not depend on ad hoc adjustments; provisions must be made for space, energy, ventilation, data, storage, security, and maintenance.
- The management priority should not be purchasing more equipment but ensuring safe and sustainable operation. Each piece of equipment must be accompanied by proper installation, responsible personnel, procedures, training, maintenance, supplies, waste management, and usage guidelines.
- Functional zoning is a critical requirement. Separating design/computing, electronics, manufacturing, assembly, measurement, storage, and waste reduces risks, improves traceability, and prevents interference with sensitive activities.
- Occupational health and safety must be prerequisites for operation. The FabLab should only begin operations with an approved safety policy, risk matrix, signage, PPE, engineering controls, clearly defined emergency routes, and work restrictions.

- Technical documentation is an integral part of the FabLab product. Plans, models, bills of materials, logs, manufacturing parameters, test records, and versions are essential for reproducibility, project continuity, and institutional learning.
- Success will depend on both governance and infrastructure. The existence of a technical lead, access rules, authorisation levels, a security committee or body, and coordination with infrastructure, IT, and maintenance will be crucial for its sustainability.

14.2 Recommendations for decision making

- Approve a phased implementation. Start with a minimum functional package: CAD design, FFF 3D printing, basic electronics, assembly, simple metrology, storage, security, basic ventilation, data network, and reconfigurable furniture.
- Define the initial scope based on real projects. Before acquiring equipment, compile an initial portfolio of research, teaching, and thesis needs to prioritise capabilities that will generate immediate use.
- Assign a technical lead from the design stage. Operation should not be left to occasional users; a person or team responsible for security, inventory, training, maintenance, and project support is required.
- Condition the purchase of new equipment on maturity criteria. Scale up only when there is sustained demand, trained users, approved procedures, an operating budget, electrical/environmental capacity, and evidence of academic impact.
- Establish a competency-based access model. Not all users should have access to all equipment. It is recommended to classify users into trainees, authorized users, operators, and project managers.
- Implement performance indicators from the outset. Measure usage hours, trained users, projects served, documented prototypes, available equipment, incidents, completed maintenance, and costs avoided through in-house manufacturing.
- Integrate the FabLab into existing institutional services. The data network, security, waste management, maintenance, purchasing, inventory, intellectual property, and occupational safety must be aligned with university policies.
- Avoid commercial uses in the initial phase. The laboratory must first consolidate itself as an academic and scientific platform; any future external service should be evaluated through a specific institutional policy and without affecting the educational mission.

14.3 Recommended decision criteria

Table 101

Strategic decision criteria and minimum operational requirements

Management decision	Executive criteria	Minimum recommended condition
Approve initial investment	Academic and scientific relevance	Existence of projects, courses or lines of research that require recurring prototyping.
Enable the space	Safety and functionality	Zoning, safe circulation, energy, ventilation, data, storage and basic signage.
Buy equipment	Utility and sustainability	Intended use, assigned responsible party, procedure, maintenance, supplies and training.
Authorize operation	Risk control	Risk matrix, security policy, PPE, logs, emergencies and authorised users.
Scale capabilities	Proven demand	Usage indicators, projects served, documented limitations, and operating budget.
Incorporate complex processes	Operational maturity	Dedicated extraction, engineering controls, trained personnel, maintenance, and safety approval.

14.4 Executive implementation roadmap

Table 102

Phased execution roadmap, strategic priorities, and progression criteria

Phase	Management priority	Expected result	Evidence to move forward
Phase 1: Preparation	Designate responsible party, validate space, define initial project portfolio, risk matrix and operating budget.	Approved scope and defined minimum installation conditions.	Implementation plan, initial inventory, layout, responsible parties, and timeline.
Phase 2: Start-up	Install basic equipment, furniture, power, ventilation, data, security and initial training.	FabLab operational for basic prototyping, electronics, 3D printing and light assembly.	Trained users, active logs, procedures and maintenance records.
Phase 3: Consolidation	Measure usage, document prototypes, adjust procedures, attend to projects, and strengthen technical support.	Sustained use in courses, theses, and research projects.	Impact indicators, equipment availability, time reductions, and documented improvements.
Phase 4: Scaling	Incorporate new equipment or processes only if there is demand, security, and institutional support.	Advanced capabilities integrated without compromising safety or sustainability.	Technical-economic report, risk assessment and institutional approval.