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Maker Technology and its Application in Conservation

Ir a la versión en español

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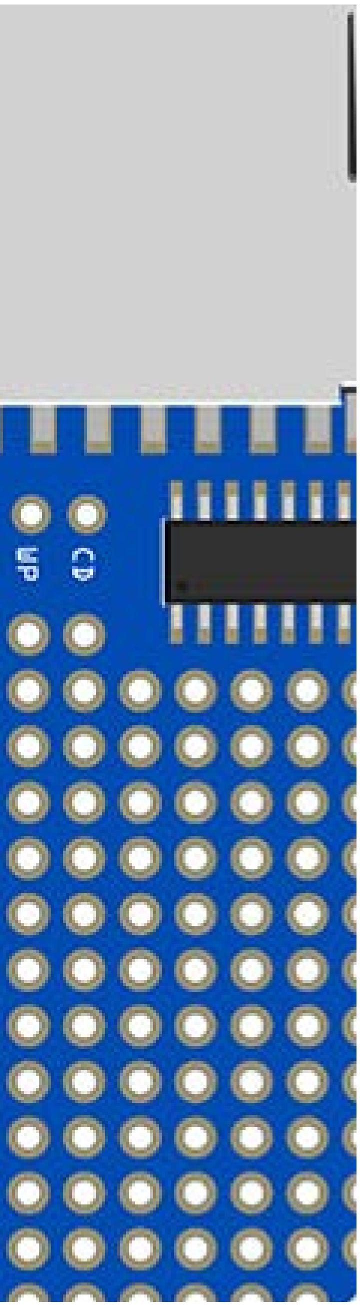

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Translated by Fernanda Andablo

ABSTRACT

This paper describes the construction of a datalogger for use in conservation, it is based on the tools and philosophy of the maker movement. The requirements of a datalogger for monitoring the environmental conditions of storage spaces for heritage collections are presented, such as: the precision and resolution of the sensor, the power source, the memory capacity, the way to access to data, durability, size, and cost.

The result is a datalogger that is 10 times cheaper and that yields identical results to a commercial one, but with significant differences in the way it is operated by the user. The applied methodology stands out as a low-cost alternative, applicable to a wide range of problems and applications in the conservation profession.

KEY WORDS

datalogger, preventive conservation, environmental monitoring, maker movement, electronics, programming

CONTEXT

The project of maker technology in conservation arises from a common problem in the archives, libraries and museums of our country: the lack of measurement instruments to monitor the environmental conditions of the collections (Subcomité de Normalización para la Preservación de Acervos Documentales

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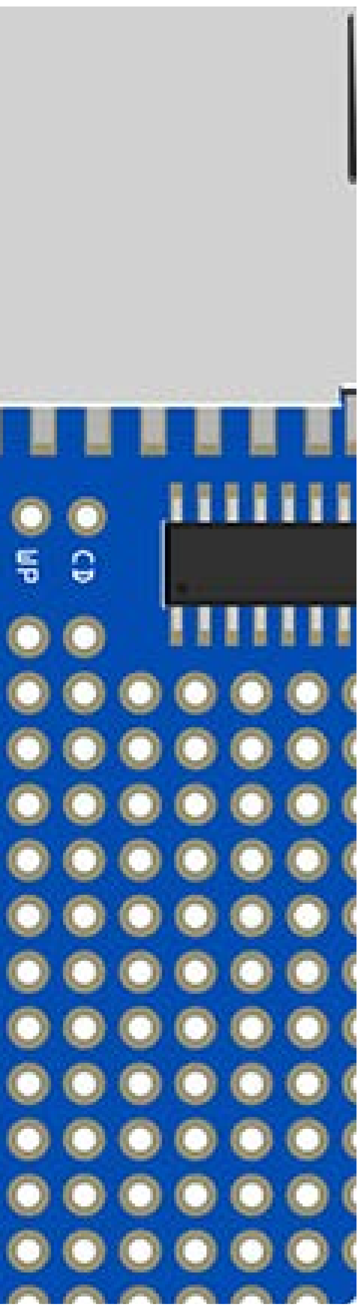

[Subcommittee for Standardization for the Preservation of Documentary Collections, in English], 2019, p. 11).

Such was the case of the Instituto de Investigaciones Artísticas (IIE) of the Universidad Nacional Autónoma de México (UNAM), which recently acquired the documentary archive from the archaeologist Laurette Sejourné, consisting on drawings, photographs, and field notes, which document the work she carried out in Teotihuacan during the middle of the 20th century. At that time, the Institute's dataloggers[1] were assigned to other areas and it was not possible to purchase additional equipment.

That fact arose the question which motivates this project. How can you build a datalogger using the methods and tools from the maker movement?

THE DATALOGGER AND ITS ROLE IN PREVENTIVE CONSERVATION

A datalogger normally records environmental factors such as the temperature (T) and relative humidity (RH), which, depending on the type of preserved cultural asset, can cause various types of deterioration. For this reason, the risk management methodology for cultural heritage (Pedersoli, Antomarchi & Michalski, 2017, p. 28) classifies them as external deterioration agents.

In the case of archival documents, particularly those of the 20th century,[2] which mainly contain paper and plastic supports, as well as various types of support elements,[3] and image-forming substances, the interaction between these constitutive materials and environmental agents can result in deterioration, since they produce physical, chemical, and biological effects (Tapia & González, 2015, p. 53), which might cause deformations, color changes, alteration in the inks, and more.

To prevent this, the internationally recommended parameters for long-term storage of these materials are a temperature of 16°C and 60% relative humidity (International Organization for Standardization [ISO], 2015, p. 6), although some of them may require more stringent conditions.

In Mexico, the norm NMX-R-100-SCFI-2018, *Acervos documentales. Lineamientos para su preservación* (*Documentary collections. Guidelines for Its Preservation,* in English), by the Subcommittee for Standardization for the Preservation of Documenta-

[1] Datalogger is a colloquially used term which refers to an electronic device with an instrument or sensor to record data over time.
[2] Handwritten and typewritten texts, printings, and photographic negatives, amongst other things.
[3] Iron gall ink, Chinese ink, printing ink, graphite pencil, etc.

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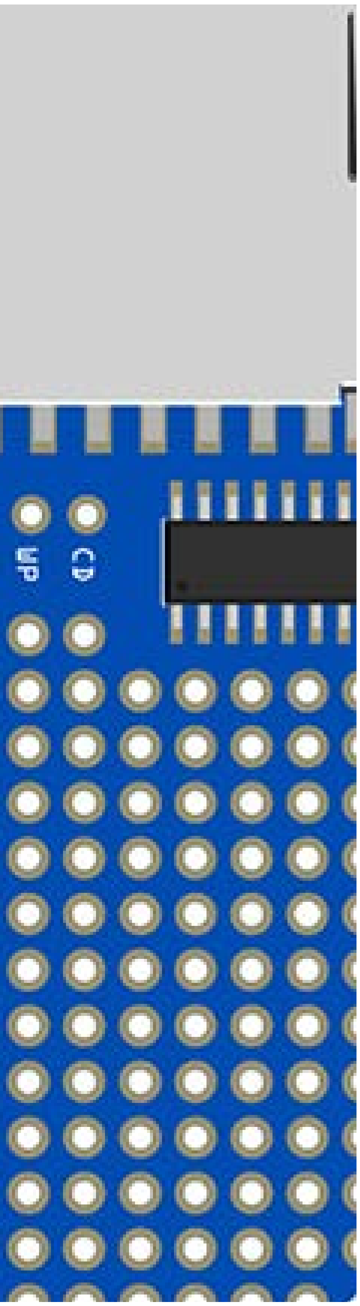

ry Collections (2018, p. 38) proposes actions to create a cycle of continuous improvement for monitoring and environmental control. In this, the datalogger fulfills a double function. Initially, it allows to characterize the environmental conditions of an area throughout a certain time. Later, it makes possible the permanent evaluation of the implemented control strategies.

Many projects have explored the use of new and accessible technologies, such as the *Internet of Things*[4] and *open-source software* for monitoring the environmental conditions of cultural assets. In one of such projects, researchers from Yale University (Londero et al., 2016) demonstrated the feasibility of using the internet of things to monitor the levels of visible radiation received by a set of miniatures painted with watercolor during their exhibition: a network of very small wireless sensors was prepared, because of their size, they could be placed inside the showcases to record, visualize, and send the data to a cloud storage service. The conclusions of the project show that with this technology it is possible to make customized low-cost devices, which are also easier to use than commercially available dataloggers.

In another project, the *Centro de Fotografía de Montevideo* (Uruguay, Photography Center of Montevideo, in English) has set up a data visualization panel for real-time monitoring of the environmental conditions of the photographic archive (Centro de Fotografía Montevideo, 2020) that uses the open-source software[5] Grafana (Grafana Labs, 2023). This software has a variety of graphs and statistical metrics to show the values of relative humidity, temperature, preservation index, and time weighted preservation index,[6] from the different storage and work areas. Thus, it is possible to obtain a complete overview of the performance of environmental control equipment, such as chillers and dehumidifiers, to respond immediately in the event that the parameters are outside of the established range.

[4] They are smart objects for home use that have sensors, processing capacity and interconnection that are used to automate tasks of daily life.

[5] It is the type of permission or license with which the software, hardware or some other type of creation is made available to all people so that it can be used without restrictions by other people and even companies, with the sole condition of citing the original authors and redistribute the improvements they make using the same permission (Open Knowledge Foundation, 2020).

[6] Known collectively as Preservation Metrics®, the Preservation Index and Time Weighted Preservation Index are quantitative measures of the environment, developed by the Image Permanence Institute (IPI) of the Rochester Institute of Technology (RIT) for faster and easier management (eClimateNotebooks *Fundamentals,* 2019a).

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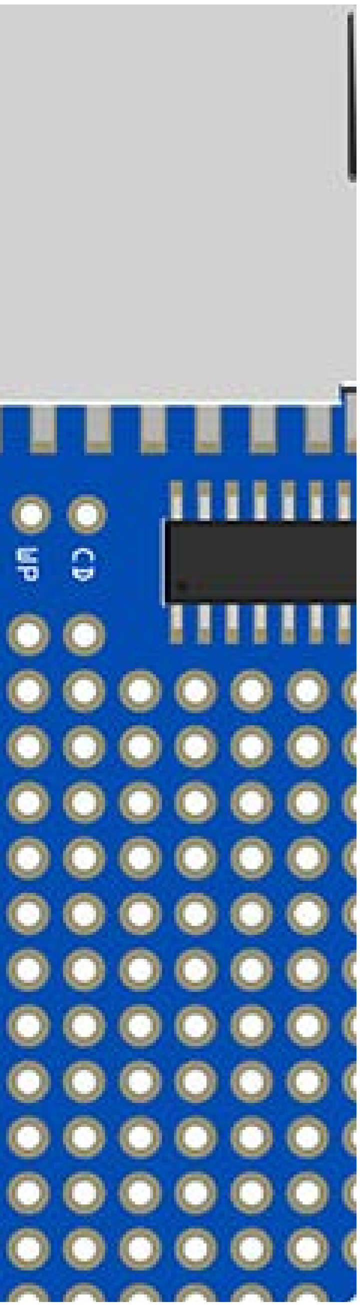

MAKER PHILOSOPHY AND TOOLS

The project from the *Centro de Fotografía Montevideo* complements the previous ones, using the proposals from the maker movement—technological and digital extension of the "do-it-yourself (DIY)" movement—, which is based on the manufacture or adaptation of electronic devices to solve problems and attend to necessities of daily life.

This movement responds to a philosophy that proposes to provide people with greater technological autonomy, through the development of creativity, collaborative learning and the free exchange of information for the common good; it also proposes alternatives to the excessive consumption of commercial products designed to be obsolete in a short time and, instead, to seek for the creation and reuse of economical and ecologically sustainable personalized devices (Gutiérrez, 2018).

Some of the tools that maker technology relies on are electronics, programming, and 3D design and printing. It is also common to use microcontrollers and single board computers,[7] such as Arduino® and Raspberry® Pi boards, which can be connected to a wide variety of sensors and actuators[8] to extend their functionality in fields such as art, science, and education, among others.

Arduino® is a platform based on open-source hardware and software that is easy to learn and use. On the one hand, it consists of development boards with a microprocessor, memory, and input and output connections to interact with other components. On the other hand, it consists of a program to write the instructions that the microcontroller will execute; the programming language used is a simplified version of C++.[9]

A great advantage of the Arduino® platform is that it allows projects to be developed in a modular way, that is, starting initially with the most basic functions and later, if required, more functionalities can be added. This is possible thanks to the existence of a great variety of additional modules which incorporate sensors and actuators, which are generally accompanied by libraries or small programs that add specific functionalities and simplify the code

[7] These are complete computers integrated into a single small-sized circuit, functionally simple, but with sufficient performance to be used in teaching young people and children (Kuss et al., 2018).
[8] A sensor is a device capable of detecting physical or chemical magnitudes, such as temperature, light intensity, inclination, humidity, movement, pH, and more. Conversely, an actuator is a device that receives instructions from a microcontroller and generates an action which allows a task to be completed. Some examples of actuators are motors, leds, hydraulic or pneumatic pumps, relays, digital or thermal cameras, screens, amongst others.
[9] Coming from C language, its main characteristic is the ability to work with objects.

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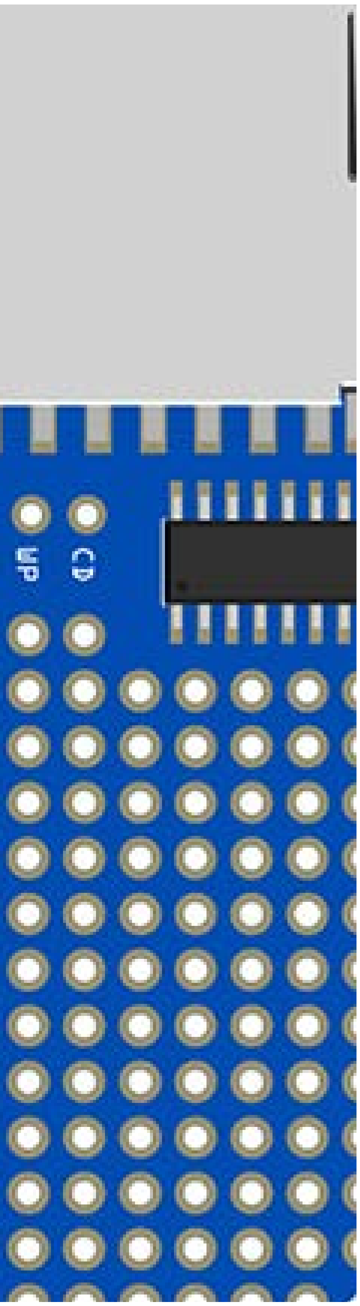
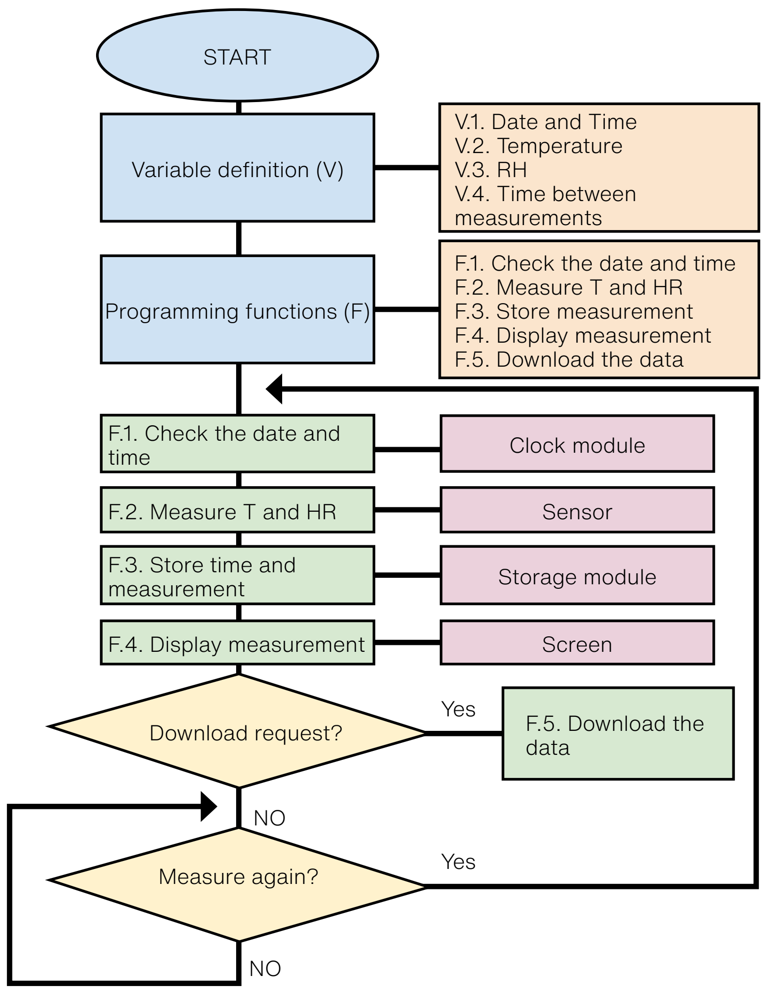


writing. Because of this, the approaches of the maker philosophy were considered a viable option to solve a specific need for the conservation of collections.

DATALOGGER PERFORMANCE AND CHARACTERISTICS

The Subcommittee for Standardization for the Preservation of Documentary Collections defines datalogger as an "electronic device which records and stores the values of environmental conditions through its own or externally connected sensors" (2018, p. 4).[10] Its operation is divided into two phases: initially, a configuration phase, in which the microcontroller is programmed with the variables[11] and functions that it must execute; the second is when the data measurement and recording functions are executed from time to time and users interact with the datalogger (Figure 1).

FIGURE 1. Flow of operation of a datalogger (Scheme: Gustavo Lozano, 2023).



[10] Editorial translation. All quotes and description of terms where the original text is in Spanish are also editorial translations.
[11] A variable is a reserved space in memory intended for storing certain data.

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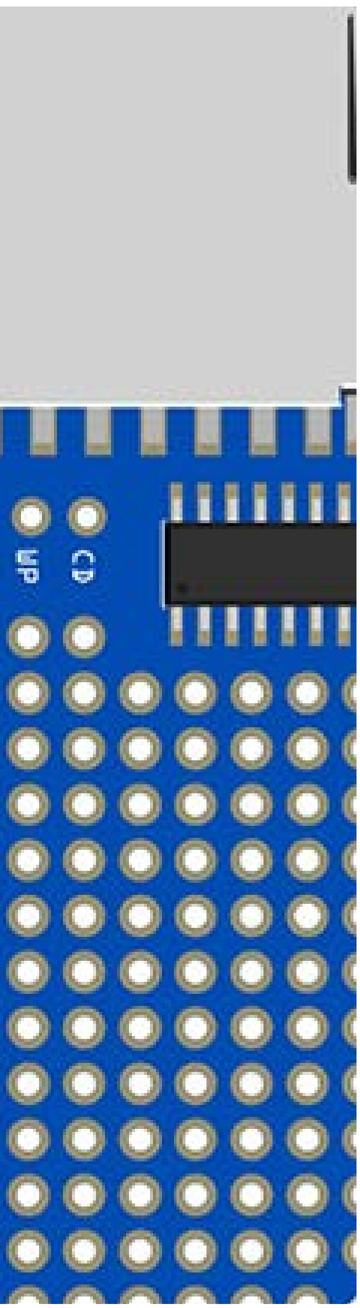

As specialized users, conservators expect a datalogger to be reliable, durability, and affordable at the same time (Arenstein & Alderson, 2011). Reliability is mainly related to the technical specifications of the datalogger, such as accuracy and resolution. While, in terms of durability, both the useful life and the availability of technical service are considered, primarily for the calibration or replacement of the sensor. Finally, accessibility has to do with price, a factor that defines whether you can have one or several devices; it is common for a medium-sized institution to require between five and ten dataloggers. Some of the desirable characteristics for measuring tools for the conservatory area are detailed below.

Precision is the degree of reproducibility of a measurement (National Instruments Corp., 2020). Although an ideal sensor should always respond with the same value to the same magnitude, this is not the case. All sensors have an error range considered acceptable depending on their application; generally, the error is more pronounced at the extremes of the measurement range. Precision expresses the difference that there may be between the measurement and the actual magnitude, therefore, the lower this value, the higher the quality of the sensor. For use in conservation, an accuracy of +–2°C in temperature and +–3% in relative humidity is considered adequate (Arenstein & Alderson, 2011).

For its part, resolution refers to the minimum change of the physical magnitude detectable by the sensor; generally, it is expressed as tenths or hundredths of the unit of measurement. For a conservatory datalogger, a resolution greater than 0.1°C and 0.1% relative humidity is not necessary (Arenstein & Alderson, 2011).

The useful life of a datalogger depends on the battery that powers it and the stability of its sensor over time. In the older dataloggers the batteries are not rechargeable—in the most modern ones they are—and have a length of between one and three years, depending on the frequency of data download and the use of the screen. The batteries that most dataloggers use are unconventional and can be hard to come by; moreover, to replace them it is necessary to remove screws or force snaps to open the device, which sometimes discourages users from changing those for new ones.

Likewise, the sensors suffer degradation, which affects their response over time and it is caused, among other factors, by extreme temperature conditions, chemical agents, vibrations, electromagnetic fields, and electric currents that damage their components.

Because of this, calibration is important, which is the comparison between a given sensor and a calibration standard. The standard can be a measuring device whose precision is known, or an

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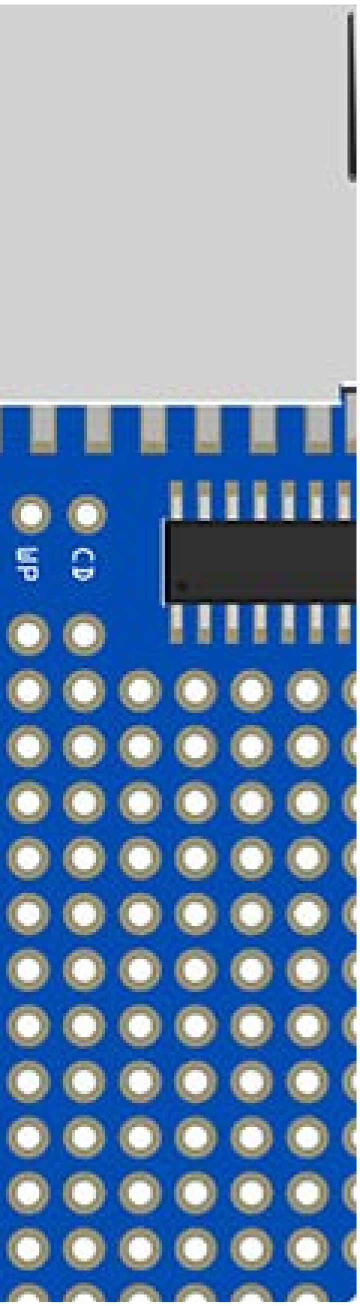

instrument which generates the quantity that is sought to be measured in a controlled manner. The most renowned dataloggers and sensors manufacturers perform the calibration as part of the quality control of their products and issue a certificate that specifies the sensor's serial number, the comparison results, the methodology used, the date and the period of validity or the guarantee of those results. When the certificate exceeds the validity period, the sensor has to be calibrated again, and in case the precision or resolution exceeds the acceptable error parameters, it must be replaced. In practice, recalibration and replacement of the sensor almost never take place, either because the manufacturers do not offer the service, because of the complications represented by sending the datalogger to another country, or because of its high cost, which is around one third part of a new datalogger. As a result, there are devices that are no longer reliable or simply stop working after a few years.

Finally, regarding the cost of a new datalogger, there are a variety of options, ranging from 3,000 to 11,000 pesos,[12] which depends on the quality of the components, the brand, and the versatility of the functions it offers. Thus, **reliability**, **durability** and **accessibility** are the categories of analysis used to evaluate the result of this project.

METHODOLOGY

Datalogger Components and Construction

The datalogger proposed here seeks to meet both the technical requirements and the problems described in the previous section. Its components are listed below, such as the characteristics of each one of them are (Figure 2).

The Arduino® platform was chosen for its construction, and the board used was the Arduino Uno®, which is the simplest and most common one: it has a modest processor and memory, but enough for most of the simplest projects. Its size is 6.8 x 5.3 cm, it weighs 25 g, and it counts with 14 input and output ports for the connection of sensors, actuators and external modules; a USB type B port to connect to the computer, and a 7-12 volt power connection.

[12] In the text, all prices are expressed in Mexican pesos and do not include the cost of shipping. The prices correspond to the month of January 2023. The current exchange rate is 1 dollar for 18.77 Mexican pesos. The price of the EL-USB-2 model from the Easy Log© brand at University Products, a supplier in the United States, is 3,000 (Data Logger with USB and LCD Display, n.d.) and the price of the HOBO MX101 from the brand ONSET© with the Mexican supplier *Editorial Marco Polo* is 11,000 (Marco Polo, 2020).

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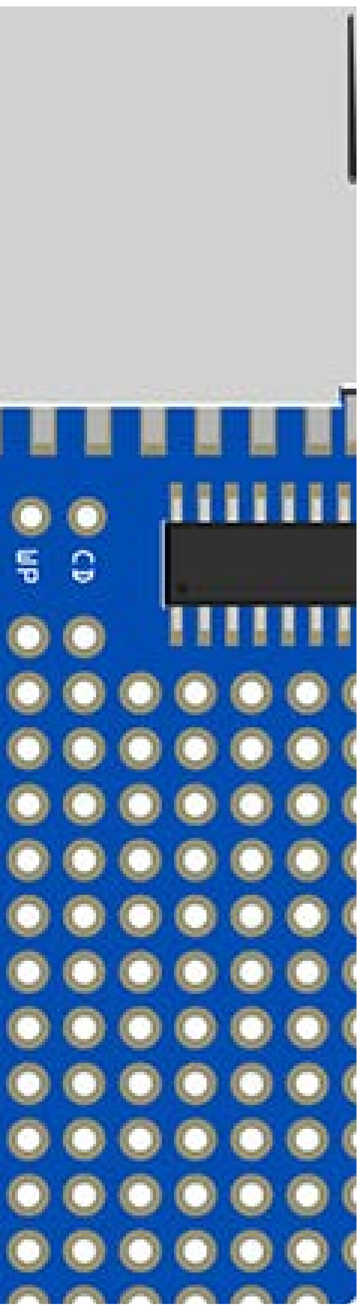

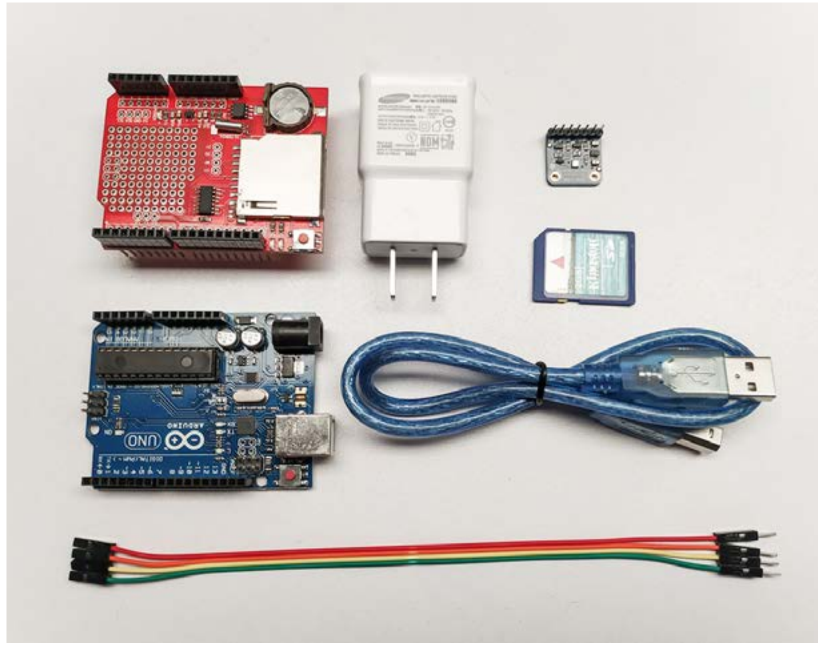

FIGURE 2. Datalogger components (Photograph: Gustavo Lozano, 2023).

Being an open-source hardware, there are many boards on the market from different manufacturers at very different costs. In general, their quality and operation are adequate. The minimum cost is 150 pesos with a USB cable included, and it can be found in stores specialized in electronic components and tools.

Also, in regards to the sensors, the offer of manufacturers and prices varies, but, in this case, it is very important to use only those which comply with the previously described characteristics. The specifications of a sensor can be found in its technical data sheet. However, it is common for some manufacturers to report information that sensors cannot achieve in real life. Such is the case of the accuracy of the relative humidity in the DHT11 and DHT22 sensors, which is reported with a value of +–5%, but in its real performance it can be up to +–9%. Therefore, although they are accessible and economical, their use for conservatory applications is not recommended.

Instead, what is recommended is the Bosch® brand sensor, model BME280 (Humidity Sensor BME280, n.d.), or, ideally, the Sensirion® brand, model SHT85 (SHT85 Humidity and temperature sensor, n.d.), which is from the same family as the humidity sensor using the PEM2 datalogger manufactured by the Image Permanence Institute (IPE) (eClimate Notebook, 2019b). Although there are variants of these two sensors, the easiest to use are those that implemnt the I2C communication protocol, which is a digital connection channel using 4 wires, two to provide power and two for data transmission. These sensors operate between 3.3 and 5 V,

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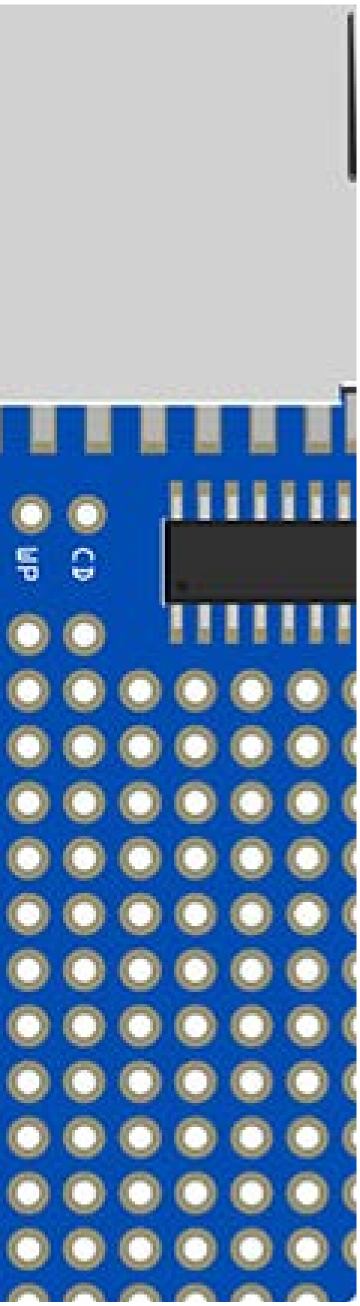

and are mounted on a module that is easy to plug and play. The cost of the first is 400 pesos[13] and the second, 800 pesos.

The next two components are closely related: the storage and clock modules. The first provides the Arduino® with a non-volatile memory[14] to store the information of the measurements made by the sensor, while the second serves to save the date and time of each measurement. Both modules provide the microcontroller with a better functionality than the one it has from its origin, and although they can be purchased separately, in this case, it is proposed to purchase them in a single component, called the datalogger shield,[15] which integrates the clock circuit and a module for reading and writing SD or microSD cards. The cost is 200 pesos, with an 8 GB card included.

Finally, it is required to feed power to the board and the rest of the components. It was decided to do it through the USB port, using a cell phone charger with a 5 V and 1 A USB A output. In this way, if there are no electrical contacts available in the space where the datalogger will be placed, it can be connected to a high-capacity power bank, whose charger costs around 100 pesos.

For this project, it was decided not to incorporate a screen for data visualization, because of the higher energy consumption that it demands, which makes it difficult to power it by means of an external battery, and also, because with the use of the SD card, downloading and visualizing the data is practically immediate (Figure 3).

The connections that must be made between the components are to couple the board with the shield and connect the sensor through its SDA and SCL ports, which in the Arduino Uno® correspond to outputs A4 & A5. In addition, power must be provided to the sensor through the VCC and GND ports. For all this, Dupont cables of the female-male type were used, although, for greater security, they can be weld.

Code

First, it is necessary to install the Arduino® IDE software (Arduino, 2020), which will allow communication between the board and the computer. The code is divided into three parts: the libraries and variables part, the configuration part, and the cycle part. Because

[13] It is very important to purchase these components from a renowned supplier, such as Mouser Electronics and Newark, which have locations in the United States and Mexico.

[14] It means that the information is not lost when disconnecting the electrical power.

[15] A shield is similar to a module; the difference is that it is not connected by means of a cable but is assembled on the Arduino board through the input and output ports.

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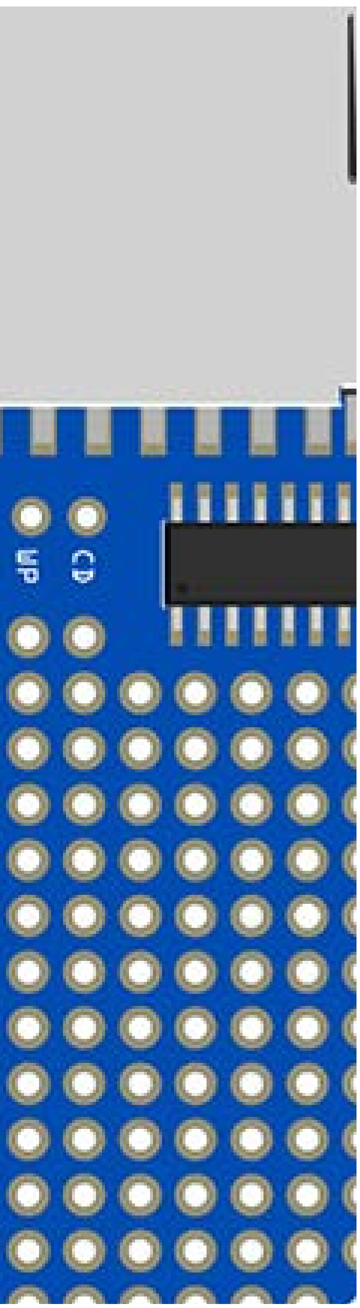

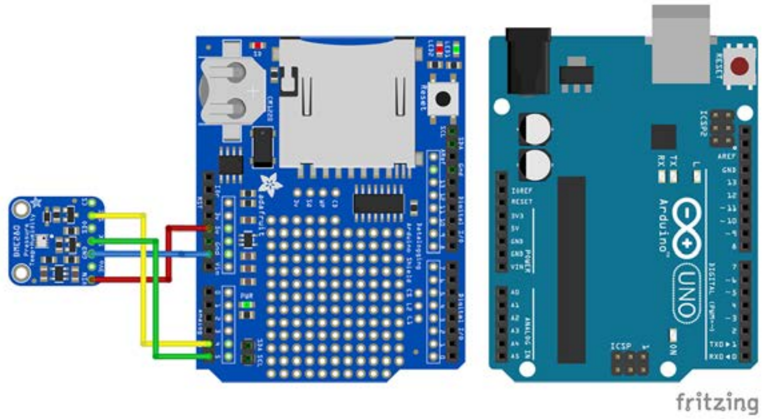

FIGURE 3. Connection Scheme made in the *Fritzing* Program (Scheme: Gustavo Lozano, 2023).

of the length of the code, here it is only described in a general way. The full version can be downloaded from the GitHub repository of this project,[16] where a step-by-step guide to construct a fully functional datalogger is also provided.

The first section of the code is where the libraries required by the different modules are imported, the variables that will store the data to be used are defined, and the objects that allow interaction with the different modules are instantiated.[17] The second section initializes the previously created objects. Finally, in the third section the functions are defined and executed in a continuous cycle.

The datalogger performs a measurement every 30 seconds and stores the data in a text file in CSV format.[18] These are stored according to the following structure: year/month/day hour: minute: second, RH, value, T, value. In this data, the date and time are expressed numerically in 24-hour format, and the relative humidity values and temperature consist of numbers with two decimal places (Figure 4). Finally, after waiting for the predefined time, the cycle of measuring and storing the data gets repeated.

After some initial tests to verify the correct operation of each one of the components, the datalogger was installed in the space where the Sejourné fund is temporarily located, and since august 2019 it has recorded its environmental conditions (Figure 5).

[16] Two years of continuous operation at the time of writing this text.
[17] In programming it is the action of creating a particular object from a general model.
[18] File format for comma separated values; it can be opened from any spreadsheet program or text editor.

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FIGURE 4. Execution code and output text (Capture: Gustavo Lozano, 2023).

FIGURE 5. Installed Datalogger (Photograph: Gustavo Lozano, 2023).

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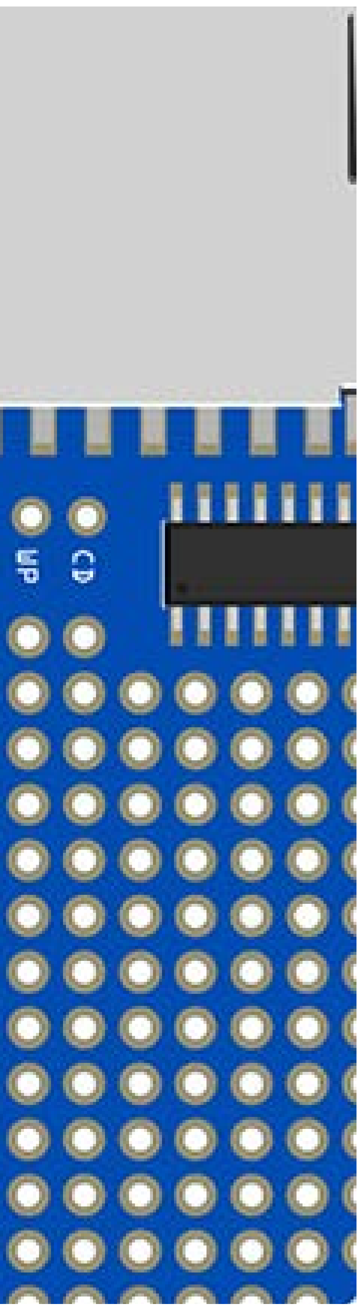

RESULTS

The datalogger information is downloaded monthly and the data is imported from the CSV file into an Excel® spreadsheet. Thus, it generates a table in which the rows correspond to each measurement point, and the columns to the values of date and time, relative humidity, and temperature. With this information, lineal charts were made, and they gathered the following information: the minimum temperature in degrees centigrade is 19.8, the maximum is 26, and the average is 24.7, with a standard deviation of 0.6. This means that, although in general there are few fluctuations, the area is very hot, probably due to its orientation, in a southerly direction. Regarding relative humidity, the minimum measurement was 36% and the maximum 63%, with an average of 44.8%, and a standard deviation of 2.9%. This means that, although the area is not especially humid, there are extreme fluctuations in short periods of time. This is because the area has windows and walls adjacent to the exterior; these characteristics affect the stability of internal conditions (Figure 6).

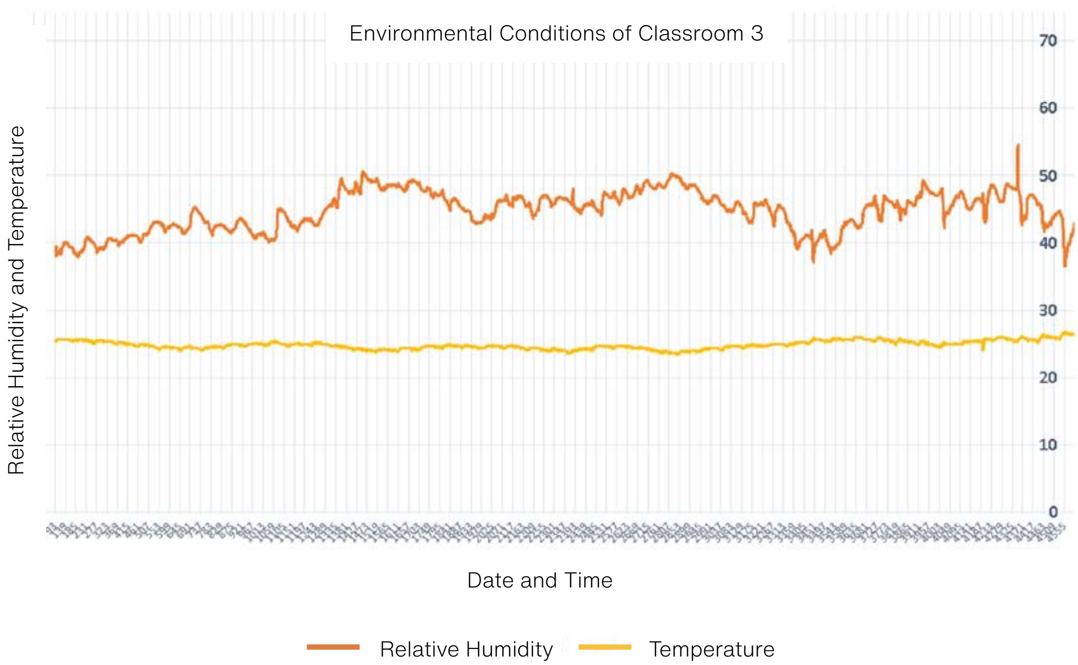

FIGURE 6. Chart Results (Chart: Gustavo Lozano, 2023).

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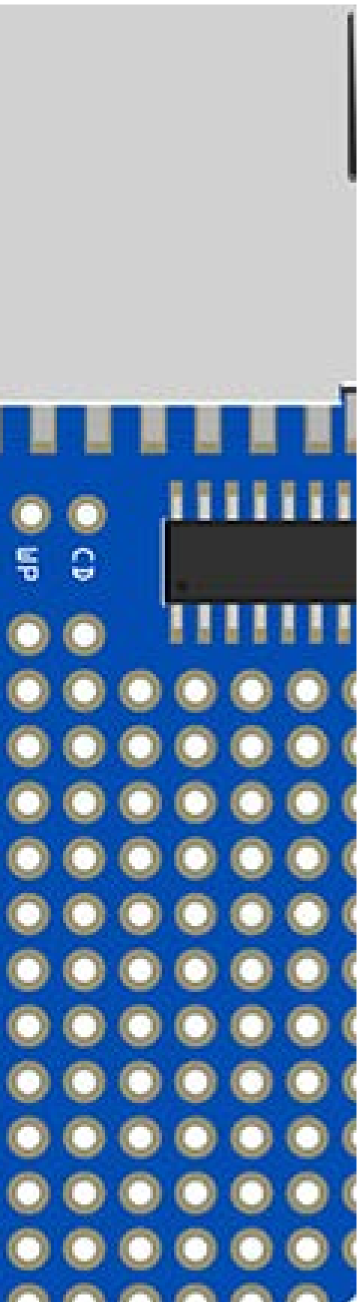

Based on this evidence, it can be concluded that this area does not have the recommended environmental conditions for the long-term storage of textual, graphic, and photographic documents. Thus, it can be argued that it is necessary to equip and condition the area to provide the required environmental conditions, or else move the fund to an area with more suitable conditions for its conservation.

Regarding the reliability, durability, and accessibility of the datalogger, the following can be concluded.

The sensor is the most important component and a good part of the reliability of this datalogger relies on it. By using a sensor with a good quality, excellent accuracy, and resolution, this home datalogger has an equivalent performance to that of the aforementioned commercial dataloggers, for a tenth fraction of its cost. In this case, although the sensor will have to be calibrated or replaced after three years, doing it in the home device is extremely simple—anyone can take care of it—, at a significantly lower cost, so it can be said that its durability will be longer. It is also valid to say that this datalogger is more accessible, since its total cost is 800 pesos, using the Bosch® BME280 sensor, which must be imported. Even though this increases the cost, the rest of the components necessary for its construction have a low cost and each can be purchased locally.

Another aspect of accessibility is the ease of its construction. This is relatively simple due to the small number of components used. Perhaps the most complex aspect is to replicate the programming code, although it is not strictly necessary, since with the code shared here it is possible to reproduce a fully functional datalogger.

One of the approaches of the maker movement is the iterative work. This refers to the creation, use, and continuous improvement of projects in order to enhance their operation and expand their capabilities. Therefore, the greatest advantage of this datalogger is the possibility of modifying, improving, and repairing it in a simple way. Its modular design allows easy replacement of any damaged component, making it both economically and environmentally sustainable.

There are some improvements that can be implemented: adding a low consumption screen to view the measurements in real time; include a battery module to use the device in places where there is no electrical connection; incorporate a wireless communication module that allows alerts to be sent when humidity or temperature exceed certain limits; or add more sensors to measure other

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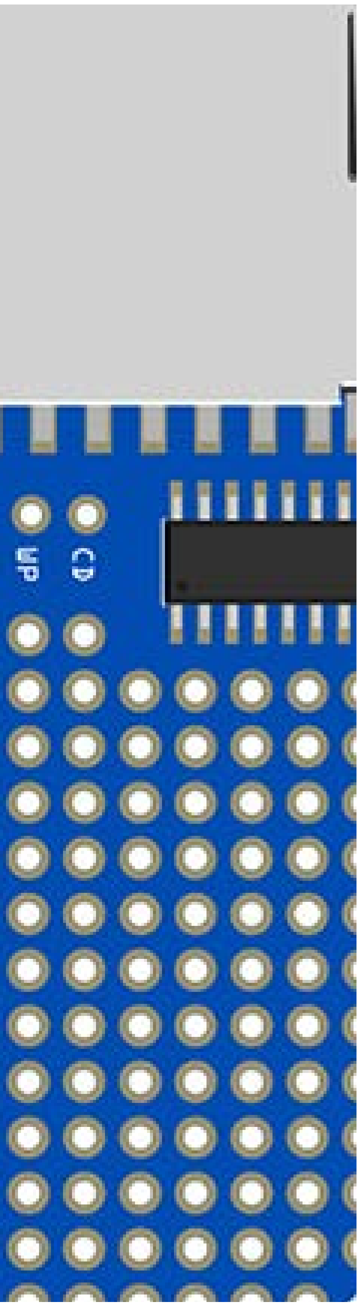

agents of deterioration, such as visible lighting, UV radiation, or solid or gaseous contaminants.

This datalogger also has disadvantages, which need to be mentioned. The most important is that, unlike the commercial ones, which have a manufacturer's guarantee, the person who builds it must have the willingness and time to supervise its operation, and to investigate and solve possible errors and unforeseen events that may arise. Constant monitoring is key for the purposes of use and management of this type of implementation.

CONCLUSIONS

This project demonstrates that, based on the approaches of maker technology, it is possible to build a reliable, durable, and accessible datalogger, which can be used in the conservation of cultural assets. The manufacturing process can be replicated by other conservators with an interest in the subject, obtaining a device with an excellent cost/benefit. For this project, various sources of information were consulted, including academic articles, web pages, and video tutorials. The author also participated in a practical workshop on Arduino®. A large amount of information on this subject is available on the internet in different languages, degrees of depth, formats, and duration, so any user can find options for their specific needs.

The tools and philosophy of the maker movement offer an enormous range of possibilities in very diverse fields of application. However, one must not fall into the extreme of technological solutionism. Not all existing needs can be solved through electronic or digital devices. In the practice of restoration, there is a tradition of importing and adapting tools from other disciplines and trades, but they are mostly manual, which do not require an electrical connection, batteries, or internet connection, and this is why they are enormously useful for us.

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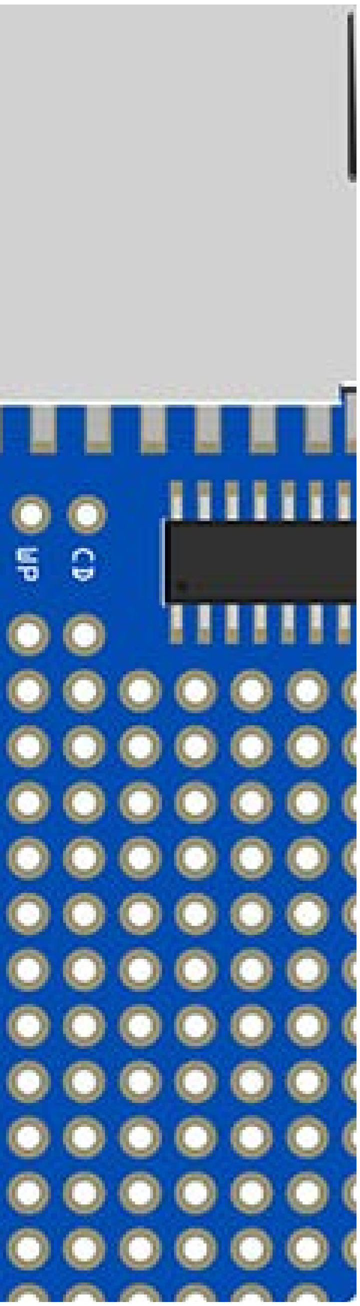

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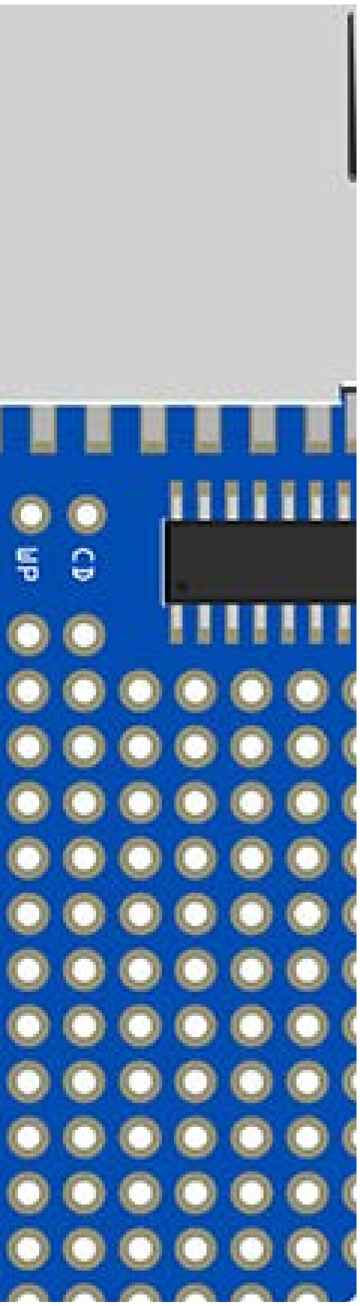

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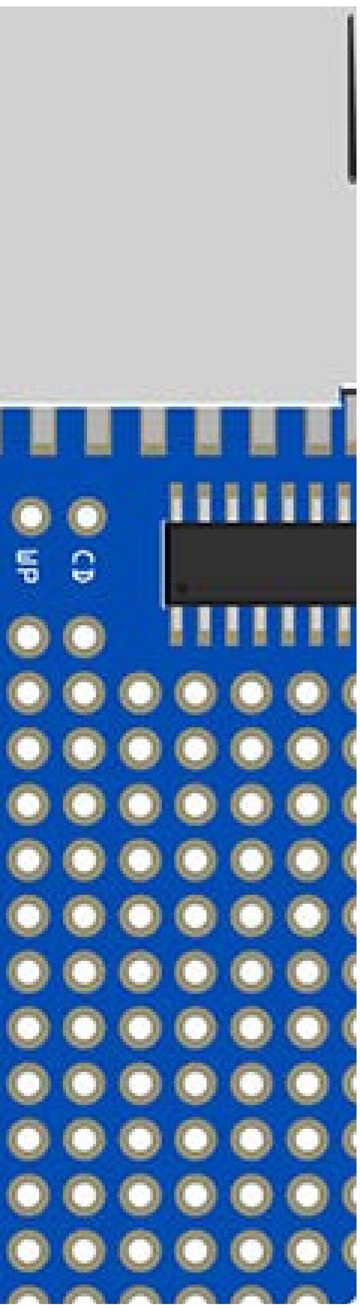

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Graduated in Restoration from the *Escuela Nacional de Conservación, Restauración y Museografía* (ENCRyM, National School of Conservation, Restoration and Museography) and specialist in Photography Conservation from the George Eastman Museum and the Image Permanence Institute (IPI). He is responsible for the conservation of the documentary collections of the IIE and a professor of the bachelor's degree in Archives Administration and Document Management, both at UNAM. He is a member of the Documentary Preservation Seminar, the Research Group on the Conservation of Photographic Heritage, and the Subcommittee for Standardization for the Preservation of Documentary Collections. His main interests are focused on the application of techniques and methods of analysis and digital transformation for the conservation, study, and spreading of historical documentary collections.

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