

# LabsLand Electronics Laboratory: Distributed, Scalable and Reliable Remote Laboratory for Teaching Electronics

Aitor Villar-Martinez<sup>1</sup>, Lucas Ortiz-de-Zarate<sup>1</sup>, Luis Rodriguez-Gil<sup>1</sup>, Unai Hernandez-Jayo<sup>2</sup>, Javier Garcia-Zubia<sup>2</sup>, Ignacio Angulo<sup>2</sup>, Claudius Terkowsky<sup>3</sup>, Tobias R. Ortelt<sup>3</sup>, Uwe Wilkesmann<sup>3</sup>, Robert Nowak<sup>3</sup>, Stephan Frei<sup>3</sup>, Carlos Arguedas-Matarrita<sup>4</sup>, Eric Montero-Miranda<sup>4</sup>, and Pablo Orduña<sup>5</sup>

<sup>1</sup> LabsLand, Bilbao, 48011, Spain

<sup>2</sup> University of Deusto, Bilbao, 48007, Spain

<sup>3</sup> Center for Higher Education, TU Dortmund University, Germany

<sup>4</sup> Universidad Estatal a Distancia, Costa Rica

<sup>5</sup> LabsLand, St. Louis, MO 63101, USA

pablo@labsland.com

**Abstract.** Educational remote laboratories are tools that allow students to access physical equipment from any location, online. There are different systems and tools created over the years to this end both in academia and industry. One of the fields where this technology has been applied most often is the teaching of analog electronics, taught in most Engineering programs. Within this type of remote laboratories, the most popular is probably VISIR, designed at the Blekinge Institute of Technology, and which has been the source of an entire movement in the field of remote laboratories, used by many research groups worldwide. The focus of this paper is to present a novel remote laboratory called LabsLand Electronics Laboratory, which is focused on scalability through multiple copies worldwide, explaining its advantages and disadvantages.

**Keywords:** Remote Laboratories, Electronics, Online Engineering

## 1 Introduction

Educational remote laboratories are hardware and software solutions that enable students to access equipment that is located somewhere else on the Internet. Students can thus access that equipment from anywhere, anytime, similarly to how they would use it in a hands-on-lab session. These systems have been extensively used through different approaches for almost thirty years. In this line, there are many examples and classifications in the literature [1, 2]. Indeed, remote laboratories were born nearly two decades ago [3–5], and they have since been adopted in multiple fields, including Chemistry [6], Electronics [7] or Robotics, [8, 9]. One of the most common is analog electronics, taught by most Engineering programs in their first year.

Among various solutions, there is one called VISIR (Virtual Instrument Systems In Reality) [7]. One of the most popular remote laboratories in the world, it has many setups in different countries and several projects dedicated to it [10–13], Special Interest Groups and awards. Fifteen years after its first version, a vibrant international community has grown and matured.

Separately, LabsLand [14] is a global network of remote laboratories. It acts as a platform, connecting remote laboratories from *laboratory providers* internationally and making them accessible to other institutions (universities, colleges, schools, and companies). Most institutions that use LabsLand are nonetheless *laboratory consumers*, which do not share equipment but instead access laboratories of the LabsLand network through a subscription. LabsLand’s goal is to democratize access to equipment for STEAM learning and training. It includes many different types of remote laboratories including VISIR. LabsLand is a spin-off of the WebLab-Deusto research group at the University of Deusto, the first university to have a VISIR system outside the Blekinge Institute of Technology.

LabsLand has had the opportunity to collect feedback from many universities and schools using VISIR and to experience its advantages and its limitations. It has created a new Electronics Remote Laboratory that could support the same audience while reducing existing VISIR limitations. The goal of this paper is to describe this remote laboratory.

## 2 Background

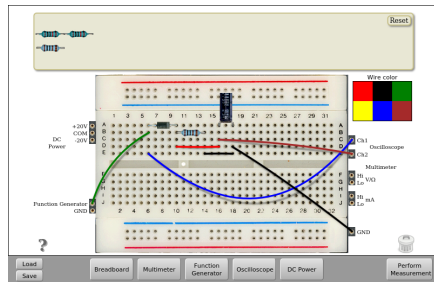
### 2.1 VISIR Remote Laboratory

The VISIR Remote Laboratory is a leading remote laboratory in the field of electronics originally designed by the Blekinge Institute of Technology, under the leadership of the visionary Ingvar Gustavsson<sup>6</sup>. There are different types of extensions and adaptations in the literature [15–17]. From a *technical software perspective*, VISIR is divided into the following components:

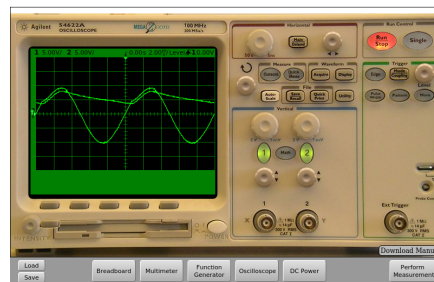
- The *VISIR client* (the web user interface): students can build their own circuits by dragging and dropping components (e.g., resistors, capacitors, etc. see Figure 1a) and configure the instruments (see Figure 1b). This client was originally developed in Flash. In 2012, both the Blekinge Institute of Technology and researchers at the University of Deusto (some of which are now in LabsLand) started building jointly a new version in HTML5, currently in use.
- The *Measurement Server*: Programmed in C++, it receives client requests and relies on an allow-list of combinations representing the circuits that may be built to validate or refuse them. If validated, it resolves the relay combination to dynamically build the circuit and forwards it to the Equipment Server.

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<sup>6</sup> <https://www.youtube.com/watch?v=jTyrklrA5FE>

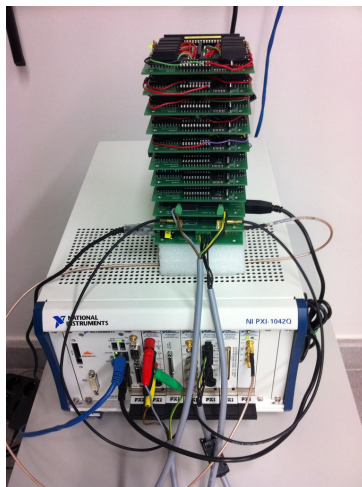


(a) VISIR breadboard

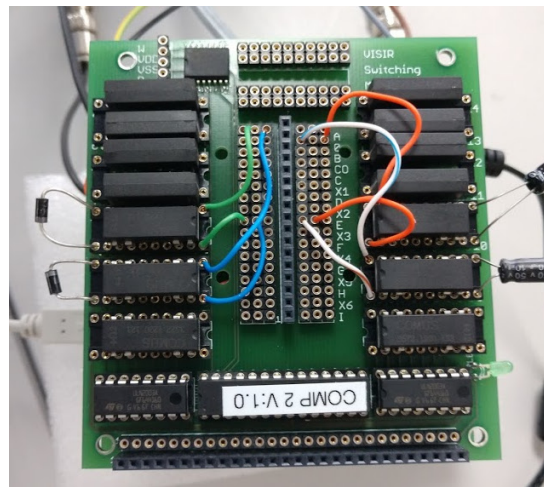


(b) VISIR oscilloscope

Fig. 1: Part of the VISIR [7] web user interface displaying the breadboard and oscilloscope respectively.



(a) VISIR setup



(b) VISIR Components board

Fig. 2: VISIR [7] setup at the University of Deusto and a sample board.

- The *Equipment Server*: LabView-based, it receives validated requests from the Measurement Server and physically builds the circuits by configuring the National Instruments PXI equipment and by setting the relays properly in the switching matrix, controlled by Microchip PIC microcontrollers.

From a *technical hardware perspective*, VISIR is divided in the following components (see Figure 2):

- The National Instruments PXI equipment (see Figure 2a), typically connected to a Windows computer through an MXI cable. It has all the instruments: oscilloscope, power supply, up to two multimeters and function generator.

- The switching matrix, manufactured and sold by Blekinge Institute of Technology staff, which has a set of boards (see Figure 2b) that physically build the circuits and connect the instruments (through the instrument boards) and the components (through the component boards).

The laboratory has three special features compared to most remote labs in the literature. Firstly, its user interface (see Figure 1) resembles accurately students conduct Electronics labs in hands-on-lab sessions, by dragging and dropping components, and configuring real instruments. It is a realistic and effective user interface. Secondly, despite concurrent access, students feel they have full control over the laboratory. Students spend most of the time building the circuits, configuring instruments, and analyzing results. When they request to take a measurement the request is sent to the *Measurement Server*, which will concurrently send it to a FIFO queue in the *Equipment Server* and iteratively conduct them and return the results, eventually arriving back at the user interface. For example, if 10 students request one measurement each at the exact same time (even if there are 50 more students using the same lab who are not yet requesting a measurement because they are building the circuit still), and each measurement takes around 200ms to be processed, then the first student will get the result in 200ms, the second one in 400ms, and the tenth one in two seconds. Since students only see their own results the user experience and throughput of the laboratory are very remarkable. In the current open-source implementation of the Measurement Server for Windows (the one used in all the institutions that authors are aware of) of VISIR, the limit of concurrent students with an open session is 60. The time per measurement request is typically suggested to be low to avoid long queues when using the laboratories, although there are experiences in UNED (Spain) of using VISIR in a single-student mode [18] precisely to support long measurements. Thirdly, VISIR is highly flexible and supports most types of circuits. Institutions that own a VISIR system can configure (and typically do so) VISIR for their needs [19], customizing circuits. For example, one university might use a particular set of components (e.g., 10 resistors of 10k, 1k, 470, two inductors, four capacitors and two diodes) in a particular order (e.g., being able to connect only some of these components to each other), whereas another university might use a completely separate set of components.

Furthermore, different articles have analyzed the usage of VISIR showing how effective the laboratory is from the pedagogic perspective [20] or from maintainers' point of view [21].

## 2.2 Usage of VISIR in LabsLand

LabsLand<sup>7</sup> is a global network of remote laboratories, spin-off of the University of Deusto (Spain). LabsLand's goal is to democratize access to STEM laboratories worldwide by sharing equipment through remote laboratories across institutions. These laboratories include Physics [22, 23], Chemistry [6], Robotics

<sup>7</sup> <https://labsland.com>

[8], Engineering and Digital Design [24, 25]. In the LabsLand network, there are three types of institutions:

- *Lab provider*: institutions that are sharing their equipment or co-create laboratories that are available in the network.
- *Lab consumer*: institutions that access the laboratories of the *lab provider*.
- *Lab prosumer*: institutions that are both *lab provider* and *lab consumer* at the same time. Most *lab providers* are in this category.

So as to make access to laboratories available at scale, LabsLand needs to guarantee to the *lab consumers* (majority of the network users):

- *Scalability*: making sure that there are enough copies of the same laboratory so students may access without having to wait too much to use the laboratory.
- *Trust*: making sure that available laboratories work predictably. This implies that (1) if a copy of the lab is not working, it must be automatically removed from the pool and (2) the configuration of each pool of copies of a laboratory must be the same.

As discussed, VISIR is available in the LabsLand network and is managed in multiple locations [26–28]. However, after analyzing experiences involving thousands of students (including a class of one thousand *concurrent* students) from various institutions and countries, LabsLand needed to make certain changes in VISIR: An optional cache was added to the LabsLand version of the remote laboratory. Before performing any measurement, it will try to look it up in a cache of previously performed measurements. If the exact same circuit with the same configuration was previously tested, the student will obtain a cached measurement result. Several measurements are stored for each measurement request. Even if students perform the same measurement multiple times, they will get different results. The cache is optional (students can disable it) and users are made aware of it. It is very useful to maintain low response times for high numbers of concurrent users, as typically in a class most students will perform similar circuits and successful cache lookups are thus common. The limit of 60 concurrent students was removed. Altogether with the cached version, LabsLand-managed installations of VISIR currently support 200 concurrent students per setup and additional tools to verify the state of the relays. Through them, it is possible to verify if the laboratory is fully working and to reduce the maintenance time it takes to locate damaged relays and components.

Through its experience of using VISIR over the years, and after different adjustments, adaptations, and initiatives, LabsLand reached the conclusion that VISIR is an extremely useful and flexible tool for *lab providers*, and for their direct communities. A *lab provider* can create their own customization, and if another university which is in contact with the *lab provider* suggests a change, they might be able to perform the change, and they can use it. If there is a maintenance issue (e.g., a part of the equipment breaks), direct communities might be communicated and they might be able to find workarounds to the problem.

However, non-direct users (e.g., *lab consumers* who are not related to any *lab owner* and just want to use the laboratory) can suffer if they use circuits that are only available in one *lab provider*: they might not *scale* given that the circuits are in a single *lab provider* and they might not be *trustworthy*, as in case of maintenance in the *lab provider* they might not have the laboratory available when they need it. Trying to solve this problem, LabsLand configured a subset of experiments common to the different *lab providers*<sup>8</sup>, but it uses most of 10 VISIR component boards, and it leaves little flexibility for the *lab providers* to build their own circuits. For this reason, LabsLand decided to start the work presented in this contribution. The goal is to create a new electronics remote laboratory focused on the LabsLand usage that can provide a good experience to both *lab providers* and *lab consumers*: providing a supported set of available circuits common to all the setups, while allowing *lab providers* to be creative and create their own new circuits, which might be later adopted by a wider audience of *lab consumers* if adopted by more *lab providers* in new upgrades that can be easily shipped and installed.

### 3 System Design

This section describes the system design of the LabsLand Electronics Laboratory presented in this article. The LabsLand Electronics Remote Laboratory is composed of the following elements, as seen in Figure 3:

- *LabsLand Cloud*: in the LabsLand cloud (in Amazon Web Services) there will be certain elements, such as the equivalent to the *Measurement Server* in VISIR.
- *LabsLand HIVEs*: each university will have one *HIVE* which represents the entire laboratory in the university.
- *LabsLand Electronics Remotified Node (LERN)*: each *HIVE* has multiple *LERNs*. Each *LERN* has its own instruments, and its own boards (explained in Section 4).

This design supports the following flow:

- Students connect to the LabsLand Electronics Laboratory in the cloud, and perform the measurements from there. By default, each session will randomly establish a preference to use a *HIVE* of a *lab provider* in the beginning of the session. The logo of that *lab provider* will be shown. When they perform a request, the requests will go to *LERNs* in that *HIVE*. However, if that *HIVE* is overloaded, the measurements will also be added in other *HIVEs* and will wait for the first one to complete the task, updating the logo accordingly.
- An exception to this are *Lab providers*: they have priority access over their own resources in case of a queue being formed. They will typically use only their own equipment, but if the equipment is offline or the load of their own users is high, their students might get also measurements from other setups, unless a specific circuit only available in their setup is used.

<sup>8</sup> <http://labsland.com/pub/docs/experiments/electronics/en/index.html>

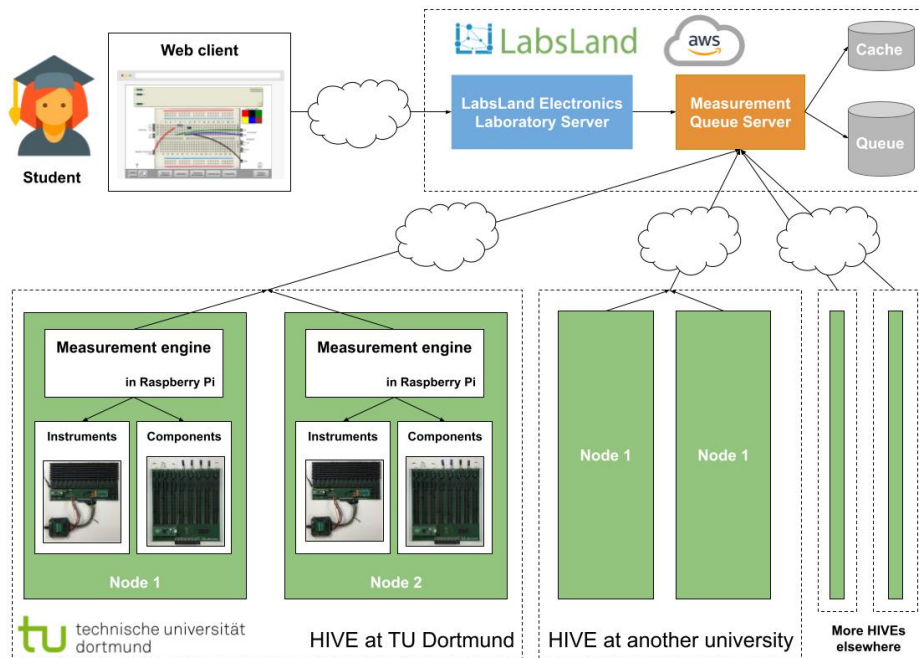


Fig. 3: Architecture of the LabsLand Electronics Laboratory.

- Each measurement request by the student will be added to a set of global queues in the cloud. Each *LERN* will be automatically assigned a request that will be processed and the result will be sent back to the cloud.

The advantages of this architecture are:

1. Reliability: if a student is using a particular HIVE (e.g., the LERNs of a particular university) and suddenly that equipment stops being available (e.g., power outage, maintenance, upgrades in progress...), the student automatically will be using other HIVEs transparently.
2. Performance: by being able to reallocate students from different HIVEs, the queue in each *LERN* will be kept shorter than if once assigned to a particular setup, the student was always there.
3. Long measurements: inside a HIVE, it will be possible to configure that one *LERN* processes slower requests. This way, students using long measurements can be using a *LERN* without saturating the queues with long measurements. Students taking long measurements may have to wait longer than usual, but students requesting normal fast measurements will not be so affected because there will be a subset of the *LERN*s that is always fast.
4. Flexibility: it is still possible for *lab providers* to set up circuits.

## 4 Results

This section analyzes the hardware implementation of a particular *LERN*. A complete *LERN* can be seen in Figure 4, although the lid of the chassis (with a camera incorporated) is not displayed. The first LabsLand HIVE in the world will be deployed in TU Dortmund (Germany) in the first quarter of 2023.

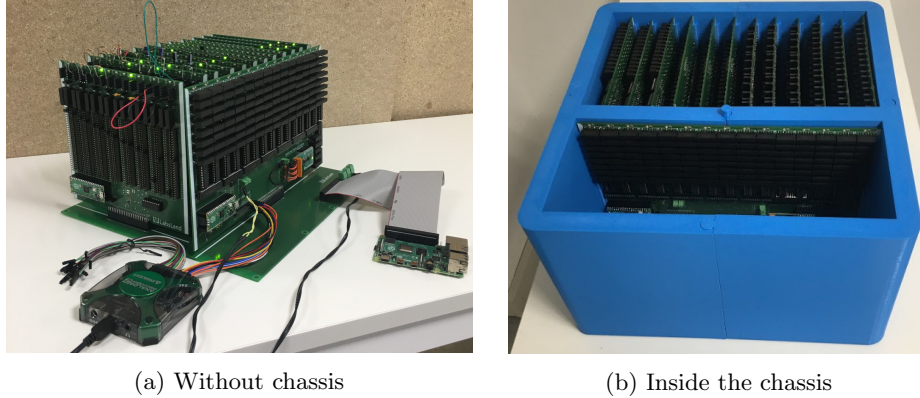
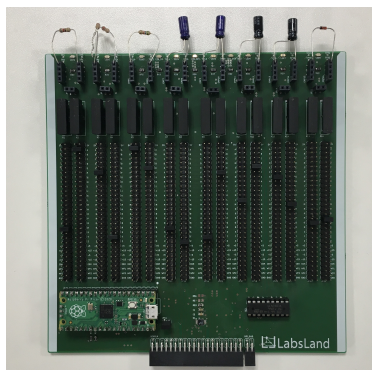


Fig. 4: Overview of a LERN

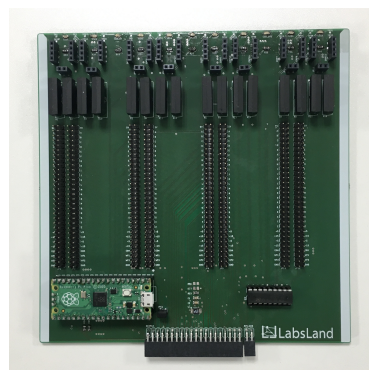
A *LERN* is composed of different boards. Each board is designed for a different purpose.

- **2-legged Component Board (2LCB)**: The purpose of the 2LCB (see Figure 5a) is to allow the connection of multiple 2-legged components. In this case, each board supports a maximum of 8 components. Through the relays and the selection jumpers, it is possible to configure the connection of each leg of the installed component with the different existing interconnection points.
- **Energy Storing Component Board (ESCB)**: The 2LCB mentioned in the previous section is valid for all components that do not store energy. Those that can store energy, such as coils and capacitors, require a different board that incorporates an extra connection to a discharge circuit. This allows these components to be safely discharged and ready for use in a new circuit. The ESCB (see Figure 5b) allows for the connection of up to 4 2-legged components and also allows for the configuration of a specific discharge network in parallel with the component.
- **General Purpose Component Board (GPCB)**: The GPBC board (see Figure 6a) allows the connection of the rest of components that have more than 2 connection legs, such as transistors or IC's, for example. The board allows up to 20 connection pins to be connected to the node. These 20 pins can be distributed among different components. An interconnection





(a) The 2LCB board allows the connection of up to 8 2-legged components.

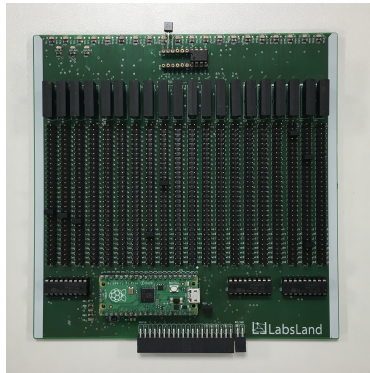


(b) The ESCB board allows the connection of up to 4, 2-legged, energy-storing components.

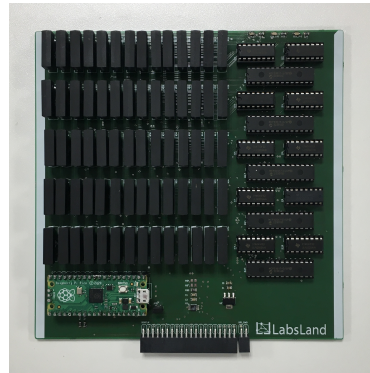
Fig. 5: ESCB and GPCB boards

connection example could include in one PCB two 3-pin transistors, an 8-pin IC, a 4-pin diode bridge, and a 2-pin resistor.

- **Shortcuts Board (SB)**: The SB board (see Figure 6b) is different from those mentioned above. In this case, the purpose of the board is to allow the interconnection of the different components in the different boards with each other and with the instruments. This forms the interconnection matrix that allows the creation of concrete electronic circuits, joining the components located on the previously mentioned PCBs.
- **Instruments Board (IS)**: The IS board (see the front board in Figure 4) allows the interconnection of the different components with the control and measurement elements. As control elements, two two-channel power supplies (+5V and -5V, and +15V and -15V) and a function generator, also two-channel are added. As measurement elements, it includes a two-channel oscilloscope and a multimeter capable of taking voltage, current, capacitance, and resistance measurements. Thanks to the switching matrix and the switching system of the instruments, it is possible to incorporate the control and measurement elements at any point in the circuit, either in series or in parallel.
- **LabsLand Specific Component Board**: In addition to the generic boards presented above, LabsLand integrates its own Specific-purpose component boards to make them compatible with the configurations that are required for its consumers. This way, this design combines the flexibility for *lab providers* with the support of a wide range of circuits and scalability for the *lab consumers*.
- **Motherboard (MB)**: The purpose of the motherboard (MB) is to be able to plug each of the previous boards in a similar way to the PCI boards in a regular computer, or in other remote laboratories [29].



(a) The GPBC board allows the connection of any type of electronic components to the VISIR.



(b) The SB board allows the interconnection of the different internal VISIR nodes with each other.

Fig. 6: The GPBC and SB boards

## 5 Conclusions

This article presented the first version of the LabsLand Electronics Remote Laboratory, developed by Labsland, a spin-off of the University of Deusto (Spain). LabsLand's overarching goal is to democratize access to STEM laboratories worldwide by sharing equipment through remote laboratories across institutions. A remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university. Students and teachers can use them as if they were in a traditional hands-on lab session, but online. The starting point for the new development of an electronics remote laboratory is the many years of experience with the VISIR remote electronics laboratory, which has also been available via Labsland for many years and whose main strengths and limitations were discussed. The article then described the most important steps of the new system design, through which some technical limitations of VISIR can be overcome. This is intended to increase and improve reliability, scalability, distribution, performance, and flexibility for everyday use of digitized high-quality electronics experiments in instructional laboratories in order to democratize access to Analog Electronics equipment. The LabsLand Electronics Remote Laboratory will be first deployed at TU Dortmund (Germany), which will be available in the LabsLand network.

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