Probatio 1.0: collaborative development of a toolkit for functional DMI prototypes

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ABSTRACT

Probatio is an open-source toolkit for prototyping new digital musical instruments created in 2016. Based on a morphological chart of postures and controls of musical instruments, it comprises a set of blocks, bases, hubs, and supports that, when combined, allows designers, artists, and musicians to experiment with different input devices for musical interaction in different positions and postures. Several musicians have used the system and based on these past experiences, we assembled a list of improvements to implement version 1.0 of the toolkit through a unique international partnership between two laboratories in Brazil and Canada. In this paper, we present the original toolkit and its use so far, summarize the main lessons learned from musicians using it, and present the requirements behind, and the final design of, v1.0 of the project. We also detail the work developed in digital fabrication using two different techniques: laser cutting and 3D printing, comparing their pros and cons. We finally discuss the opportunities and challenges of fully sharing the project online and replicating its parts in both countries.

Author Keywords

digital musical instrument, functional prototyping, prototyping toolkit, design process

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts; •**Human-centered computing** → *Interaction devices;*

1. INTRODUCTION

Probatio (Latin word for "test, experiment, trial"), currently, in its version 1.0, is a functional prototyping toolkit for creating digital musical instruments (DMI) [13]. Two main questions guide its design:

- *How to provide structured and exploratory paths for generating new DMI ideas?*
- *How to reduce the time and effort needed to build functional DMI prototypes?*

The first question is related to the large number of combination possibilities of inputs and outputs in the DMI conception that can yield to creative paralysis [9]. The second question addresses the plethora of skills that one should possess to develop a functional prototype of a DMI.

We consider that, in the musical instrument design context, the functional prototype is vital to perform a more accurate evaluation of musical interactions as it immediately allows for experimenting with the results of someone's idea. In short, Probatio "aims to provide designers with directions for conception, as well as to narrow the gap between idea and prototype" [2, 3].

To address the first question, Probatio embeds the concept of *instrumental inheritance* [2], which is a collection of physical structures or playing techniques that a new instrument "borrows" from existing instruments. Designing a novel DMI then amounts to choosing postures and controls from the morphological chart (cf. Figure 1).

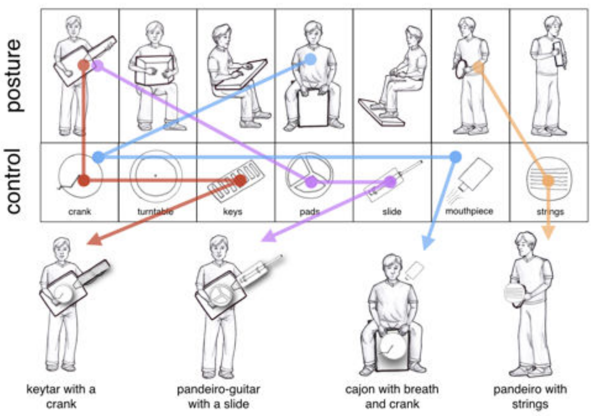

Figure 1: Morphological chart [4] based on instrument inheritance [2]: splitting existing instruments into parts and recombining them. Drawings by Giordano Cabral.

About the second question, the system encapsulates tech-

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nical details of physical structure, electronics, and programming in the form of pre-defined blocks and bases. These parts allow designers, musicians, and artists to experiment with postures and controls intuitively by just combining pieces and experiment with the system's response in real-time and immediately obtain a functional DMI.

2. ORIGINAL TOOLKIT

In this section, we discuss the original Probatio toolkit, revisit the results of its evaluation with musicians and performers [3, 2], and technical limitations that constrain a broader use of this version.

In its version 0.2, Probatio consisted of thirteen blocks, three bases, one hub, and multiple supports for holding blocks in place. With the toolkit, the musicians could experiment different ways of controlling and holding the DMI prototype (cf. Figure 2)[1].

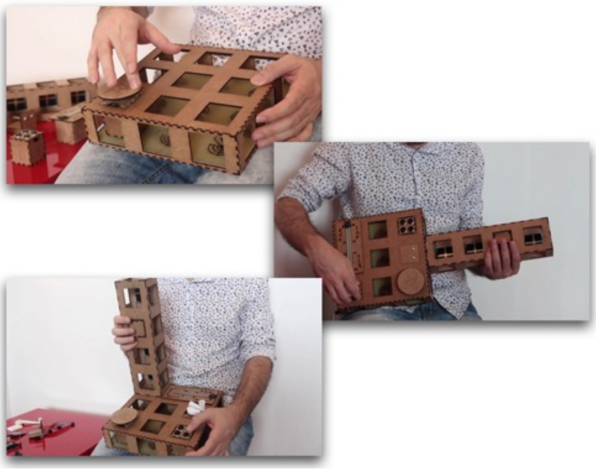

Figure 2: Example of a possible combinations of blocks and bases in Probatio v0.2.

2.1 Evaluation of Earlier Versions

Since its development, twenty-five musicians with diverse backgrounds participated in evaluation sessions of Probatio [3, 2]. The evaluation methods comprise video analysis focusing on instrumental interaction analysis [8], comparative questionnaires, interviews that were processed using thematic analysis [1], and coding methods such as structural coding and emotion coding [15]. One of the main results of the qualitative analysis of data gathered in these sessions was the emergence of three user profiles:

- *Builder*, who was interested in building each detail of their instrument and who wanted freedom for choosing sensors and placing them on desired specific positions;
- *Experimenter*, who demands rapid responses from the system and focus on combining existing elements to reach interesting interactive results;
- *Virtuoso*, who wants to develop playing techniques with existing controllers.

Probatio seemed better suited for the experimenters. For this profile, the number of elements, and the toolkit's fast and straightforward connection appear as essential aspects. Furthermore, the results of the quantitative evaluation presented an increase of cycles of mounting and testing when using Probatio if compared to a generic sensor toolkit [2]. These results suggest that the use of a pre-defined structure and easy connections allowed for more cycles of experimentation, which is welcome in creative prototyping.

This advantage nevertheless comes with a cost in the form of the limited grid-style format of the base and the size of the blocks, which both influence the minimum resolution of the controls, i.e., how close together they can be placed, as well as the pre-determined mapping and sound synthesis possibilities in each block.

Furthermore, some physical features interfered in the production time of blocks and bases. The assembly of bases and blocks demanded artisan-detailed work, which made the process long. This centralized high-skilled work resulted in only a few blocks and bases being produced. This exacerbated production time directly affected the diversity of possible combinations.

The evaluation process also highlighted some system malfunctions and technical bugs requiring the presence of a developer to correct these issues during the process. Thus, it was not possible to allow for a more intimate use of the toolkit by the participants since its use was restricted to a time-limited session. We believe this limitation constrained our understanding of the system's creative and engagement potential.

3. EXPERT PERFORMANCE WITH RESPONSIVE DEVICES

Despite its limitations, Probatio became a fundamental building block in the ongoing 5-year research project "Responsive Devices and Systems for Expert Musical Interaction", led by Marcelo Wanderley and funded by the Natural Sciences and Engineering Research Council of Canada which addresses two main questions: a) *how to design responsive, reliable interfaces for musical interaction?* and b) *how do musicians develop expertise in their interaction with such novel interfaces?*

The project is divided into three main steps:

- *Design of proof-of-concept functional prototypes.* Using Probatio, musicians are asked to choose interaction metaphors and iteratively build functional prototypes (cf. Figure 1). Musicians are interviewed at each step of prototype development, and the designs are cataloged in terms of the types of inputs used and the primary musical interaction metaphors proposed.
- *Development of advanced prototypes.* Three to five most innovative devices from the various prototypes produced in the first step will be re-created to present a more organic integration of its various parts using digital manufacturing technologies [7] and improved gesture acquisition design [12].
- *Evaluation of long-term musical interactions.* In the 3rd step, musicians have the opportunity to perform with the advanced prototypes for several weeks or months, allowing them to develop and practice performance techniques with the devices. A methodology for the evaluation of musical interaction with the prototypes is adapted from recent works, e.g., [6, 11, 14, 16], with the goal of *better understanding how musicians develop long-term musical expertise with DMIs.*

3.1 Collaborative Development

The effort to build Probatio v1.0 is a collaboration between two universities of two countries in different hemispheres: Brazil and Canada. Different from software devel-

[1]Youtube Demo: `youtu.be/_kTkg6RyL3k`

opment, which can seamlessly be shared due to the immaterial essence of the code, online collaborative design, and development of a physical and functional toolkit present challenges. Thanks to digital fabrication techniques such as laser cutting, 3D printing, and PCB manufacturing, digital representation of tangible artifacts can be shared online, allowing cooperation from geographic distances, but many assembly aspects remain to be solved locally. Therefore, in order to keep the team at the same pace, all the steps should be well documented and presented in a focal sharing point website. Probatio project is open source and under Creative Commons BY-NC-SA 4.0 license.

4. PROBATIO V1.0

Distinct from the previous version, where the objective was to validate the idea of a toolkit for prototyping DMIs, our goal with version 1.0 is to use the toolkit in the context of DMI conception for reaching non-modular versions of instruments that will be evaluated in longer periods with musicians in different countries, as explained in section 3.

4.1 Requirements for v1.0

Based on the project's objective and the results from previous versions, we defined the following requirements for version 1.0:

1. Due to the collaborative nature of the project, the toolkit's fabrication must consider available materials and manufacturing techniques in different countries conforming to the same centralized model (for instance, it is expected that blocks and bases made in different countries should work interchangeably);
2. Considering fabrication, the toolkit should be easily assembled also easily adaptable to specific situations.
3. The system must be stable and, where possible, recover from errors without compromising the user interaction;
4. The system should still be plug-and-play and maintain its quick and easy approach for combining blocks and bases;

4.2 Physical Structure

In this section, we describe the architecture of Probatio v1.0, as illustrated in Figure 3.

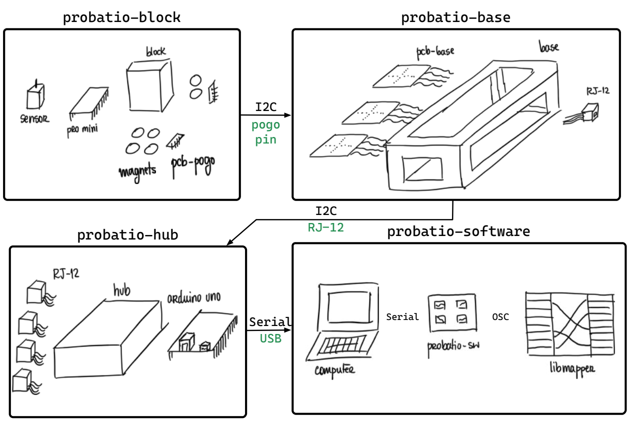

Figure 3: Probatio's architecture, showing the various components of the toolkit v1.0.

Probatio-block. The basic element of interaction was inspired by control units of existing instruments in the form of a *quasi cube* of 50 mm x 50 mm x 56 mm (lateral size, depth, height) in its most basic realization. It encapsulates the sensor(s) and the microcontroller (cf. Figure 4).

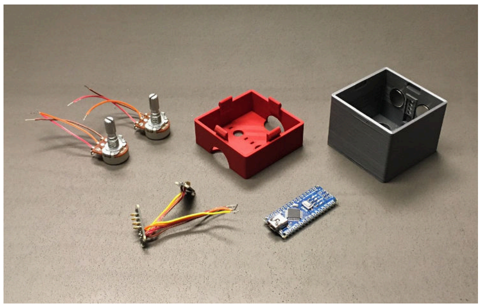

Figure 4: Example of an open block showing sensors (two pots), microcontroller, and pogo-pcbs with pogo pins.

Probatio-blocks translate user gestures into digital data and transmits it through the communication bus. Magnets fix the blocks in place and force spring-loaded (pogo) pins to be in contact with the *probatio-base*. The pins are grouped in a *pcb-pogo*, and each block has two boards (one for bottom connections and one for side one). Blocks can assume different sizes following the rule of being multiples of 50mm width x 50mm length. The height is constant at 56mm. For instance, a *2x2 probatio-block* would measure 100mm x 100mm x 56mm.

Probatio-base. A component inspired by ways of holding instruments and where the blocks sit, cf. Figure 5.

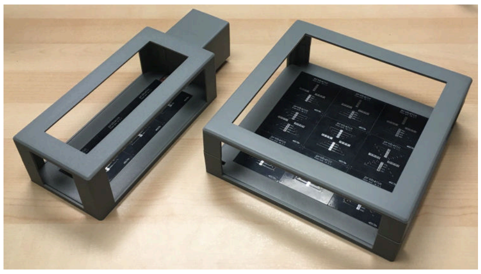

Figure 5: Examples of two bases.

The bases provide the fundamental structure of the built prototypes. They expand the communication bus to their slots, with rules of dimension similar to the blocks, and allows the blocks to be connected vertically and laterally (cf. Figure 6).

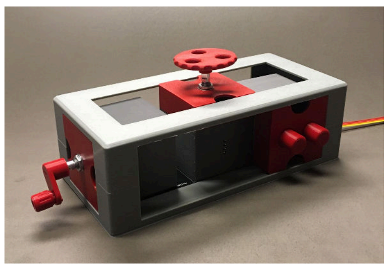

Figure 6: Assembly of blocks using a 1x3 base. Note the vertical and lateral positions of the blocks, which are kept in place by magnets in the block bottom and the pcb-base.

Each slot is composed of a *pcb-base* (cf. Figure 7) that expands the communication bus.

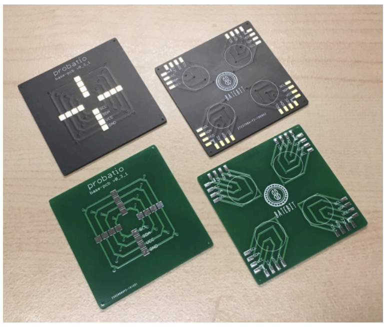

Figure 7: Photo of pcb-bases. Top row was designed by the group in Brazil. The bottom row was designed in Canada. Both are functionally equivalent based on the same centralized and shared design model.

Probatio-support. The elements related to the physical structure and used to hold blocks in place or make the fit more firmly.

Probatio-hub. The central processing unit that gathers sensor data from each block via the I^{2}C serial communication protocol consolidates the data and transmits to the computer through a serial connection.

Probatio-software. The computer-side piece of the system is responsible for making the connection between the physical toolkit with mapping software (e.g., libmapper [10] clients such as webmapper [17]) and sound-related programs such as Digital Audio Workstations, Virtual Studio Technology.

4.3 Materials and Digital Fabrication

We developed the previous version of Probatio using laser cutting with medium-density fiberboard (MDF). The benefits of engineered MDF include low cost, consistent dimensions across the axes, and rigidity. However, due to health safety issues in some countries, this material is not recommended for laser cutting due to the emission of formaldehyde [5], so new fabrication strategies had to be devised for version 1.0.

In terms of digital fabrication, laser cutting is based on 2D subtractive manufacturing, in which Z-axis details are constrained by the material thickness. This is often excessively limiting for designing objects.

4.3.1 PLA and plywood

Based on the limitations of MDF, we decided to use 3D printing as our primary digital fabrication technique and polylactic acid (PLA) as the standard material. Although 3D printing is a slower manufacturing process when compared to laser cutting, it can reproduce, with adequate levels of resolution, the details modeled in a CAD or digital prototyping software. Concerning the material, PLA has become popular in the 3D printing community because it is in the class of biodegradable plastics and presents good finishing quality and strength. Due to its popularity, good quality PLA is available in many countries with consistent printing properties along with affordable printer costs.

Although we are using 3D-printed PLA as our primary material, we consider that there is an essential cultural hook that is associated with wooden pieces with existing instruments, and this resemblance and aesthetics could resonate with musician users' expectations. Therefore, we have also experimented with laser cutting of plywood. For that matter, the previous MDF-version models were adapted to 3D models using digital prototyping software such as Autodesk^{TM}Fusion 360.

Figure 8 presents the sketch of a 3D-printed block that relies on four snap fits on the inner sides to fix the top and the bottom parts together. To close the blocks made of MDF or plywood, we rely on gluing the parts together, which makes the maintenance difficult. On the other hand, using 3D printed snap fits, we can easily update the blocks.

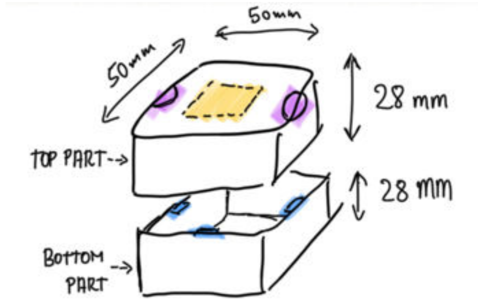

Figure 8: Sketch of the 3D printed block with snap fits positions and handles.

4.3.2 Parametric design

In parametric design, the designer defines a set of rules that guide the model generation. By manipulating numerical parameters, one can obtain different instances of a certain class of objects. This versatility resides in the middle ground between conforming to standards and also allowing for adaptation for specific necessities. For collaboration, it is vital to maintain the centralized model between the teams and also to allow adaptation for specific needs, for example, the number of sensors or sensor sizes. Therefore, parametric design suits our project well since we expect that blocks and bases designed in different countries should work interchangeably. In version 1.0, it is straightforward to change the dimension of blocks and bases (cf. Figure 9), and also generate different block tops.

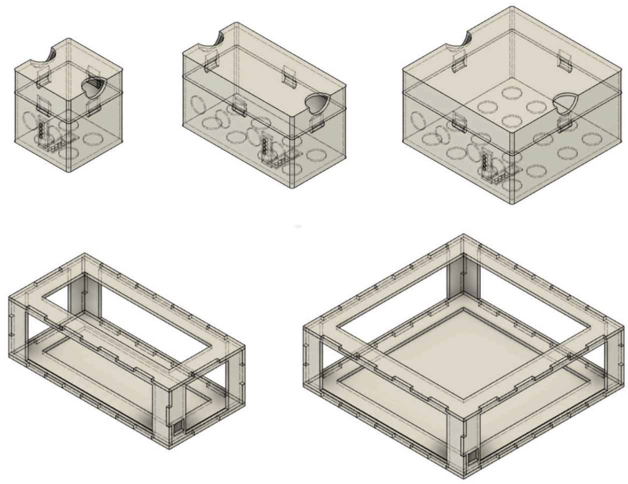

Figure 9: Parametric design of the blocks and bases

5. EXAMPLES OF V1.0 BLOCKS AND ASSEMBLY

So far, we have designed seven different blocks presented in Figure 10. From top to bottom, left to right, the blocks are the following: *crank*, implemented with a rotary encoder;

dual pistons, continuous spring-loaded buttons using hall effect sensors and magnets; *dial disc*, also using a rotary encoder; *tap*, built attaching a piezo on the inner top wall; *joystick*, one potentiometer for horizontal axis and another for vertical axis; *dual pots*, two rotary potentiometers with knobs; *dual buttons*, two momentary buttons (the only discrete value block, with the top of the block color-coded in orange). All the blocks have been modeled and are ready for 3D printing. The assembly process is fully documented, so they can be easily replicated. For more information related to the project, refer to its website[2] and repositories[3].

Figure 10: 3D printed *probatio-blocks*. From left to right upper row: crank, dual pistons, dial, dual buttons (in orange). Bottom row: piezo tap, joystick, dual potentiometers

Finally, Figure 11 presents an assembly with both 3x3 and 1x3 bases containing the above mentioned seven blocks and dummy blocks used for structural support only. We defined a color code by using red tops for blocks with continuous inputs, orange for discrete inputs, and grey tops for structural blocks (i.e., dummy blocks).

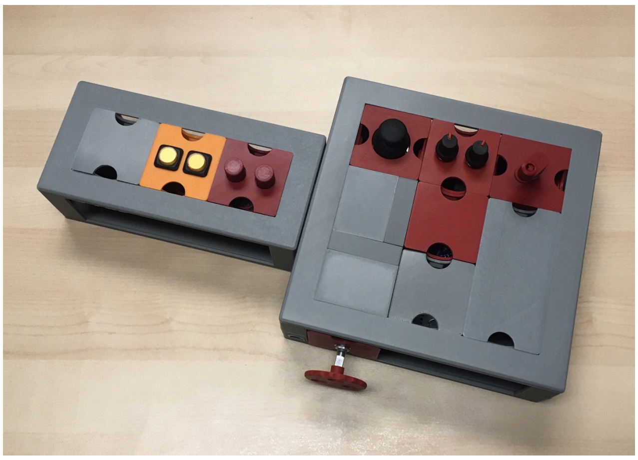

Figure 11: Two Probatio bases assembled with blocks. Red blocks provide continuous inputs, the orange one hosts two discrete buttons. Grey blocks are dummy blocks to keep the structure in place.

6. CONCLUSIONS

This paper introduced version 1.0 of the Probatio toolkit for prototyping digital musical instruments. After reviewing the goals and design choices behind the original toolkit, we reported on the use of the previous version by 25 musicians, highlighting the three main profiles of users as well as the usefulness of Probatio as a tool to foster experimentation if compared to generic sensor toolkits.

We then discussed in detail the requirements and the inter-institutional, international collaboration in the implementation for Probatio v1.0. The needs for a clear specification of manufacturing and assembly were put forward, derived from its use as a building block in a long-term project to understand the development of musical expertise with DMIs.

We believe that this interdisciplinary project will be essential to carry out longitudinal studies on the development of musical expertise with DMIs. This kind of long-term study is seldom attempted given the difficulty in finding motivated performers to spend the required time to develop expertise, the elusive notion of expertise itself, the multifaceted nature of digital devices, and the fast evolution of technology and its impact on performance. With tools like Probatio, we expect to contribute to reducing the time and effort from ideas to a working DMI prototype, helping the overall study process.

[2]http://probat.io

[3]https://github.com/probatio

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