# Repertoire-Centred Design: Mechanical Augmentations in Digital Lutherie for Acoustic Musical Instruments

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## Abstract

Over the last century, the practice of musical instruments modification has evolved in a wide range of contexts, from early avant-garde to contemporary digital practices. More recently, research has expanded this field through instrument modifications grounded either in artistic exploration or in user-centered design, often targeting the needs of specific groups of musicians. In this paper, we present a series of mechanical augmentations for traditional instruments - theorbo, accordion, bass clarinet, and euphonium - developed using digital fabrication techniques. Drawing on second-wave HCI's focus on workplaces, we frame musicians as workers and focus on the idiosyncratic needs of specific repertoire (i.e., baroque or post-avantgarde written music). We introduce the concept of repertoire-centered design as a way to ground instrument augmentation in concrete practices and constraints of specific musical works. After presenting the idea, the design process, and the implementation of our augmentations, we discuss how our approach situates the design process within the broader ecology of musicians' working practices, supporting long term adoption in a real-world performance context.

## Keywords

repertoire-centred design, augmented instruments, digital lutherie

## 1 Introduction

Modifying instruments has been a part of the creative practices for many decades - *Baccanale* (1940) and *Sonatas and Interludes* (1948) by John Cage arguably being the most iconic examples, with increasing traction in the last years (e.g., [20, 42, 61]).

Different design approaches have been used: while often a musical has "composed" his instrument starting form one musical idea - echoing Cook's [10] "Make a piece, not an instrument or controller" -, other approaches relied on user-centered design targeting specific performers (e.g., percussive fingerstyle guitarist [29] or cajòn players [60]). These approaches led to amazing musical works; however, a design approach of augmentation based on the needs of classically trained instrumentalists who built their career as *performers* (by reading music) and not creative artists inventing new music tend to remains overlooked.

*Score based* avant-garde and contemporary music has not been so central in the NIME debate, where the term score have assumed different meaning that can greatly diverge form the idea of a set of notation printed on paper (see [30] on scores at NIME - notable exception exist, see [15]). Indeed, NIME tends to relate to contemporary music-making approaches grounded in new interfaces rather than in scores - as pointed by the name itself. Yet, addressing this population may offer challenges highly relevant for NIME, e.g., problems concerning affordability and portability.

In their chapter on embodied musical interaction, Tanaka [54] discusses how NIME research can encompass different settings, including professional settings. Drawing from the idea of the three waves in HCI (as formalized by Bødker [5]), Tanaka [54] discusses how some of his works can be related to the second-wave HCI, which address workplace, while others are more related to the third-wave HCI, thus mainly focused on leisure, art, and creativity.

Therefore, following a second-wave HCI approach, we approached instrumentalists as workers operating in a specific job environment (or ecologies). By interacting with such musicians, we understood the centrality of repertoire in defining specific needs (that could be understood as design requirements), which well represent the performers overall working ecology. As such, we devised a repertoire-centered approach to design and develop mechanical augmentations for the following instruments: theorbo, accordion, bass clarinet, and euphonium. These augmentations have been created using digital fabrication techniques (mainly 3D printing) and follow suggestions on sustainable and long-term NIME design [35]. The last of these projects has sustained a collaboration of over 4 years leading to a number of public concerts and interactions with new performers and composers, while the other three have been finalized more recently.

Throughout the paper, we discuss how focusing on *score-based* repertoire, and its influence on the design mechanical augmentations, supported their inclusion in the overall music ecologies of the performers. Overall, the main contribution of this paper is a reflection on the relationship between instrument augmentations and the professional ecology of instrumental performers. As a

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side contribution, this paper offers a number of design considerations that emerged in our work.[1]

## 2 Background

### 2.1 Instruments Modifications

Musical instruments have long undergone modification driven by practical needs, aesthetic preferences, and compositional demands [23, 25]. Instrument making can therefore be understood as a dynamic and situated practice, shaped by cultural contexts - including repertoire itself - and technological conditions [27, 39]. Beyond long-term organological evolution [14, 50], musicians have developed strategies to directly intervene on existing instruments, temporarily or permanently altering their acoustic, mechanical, or expressive behavior.

A pivotal moment can be traced in *preparations*: reversible physical modifications introduced to alter sound production. While early precedents can be traced to works such as Heinrich Biber's *Battalia* (1647), the practice was formalized in the 20th century through John Cage's prepared piano works, including *Bacchanale* (1940) and *Sonatas and Interludes* (1948), where objects inserted between strings transform timbre and response [45].

Over the years, these practices increasingly incorporated technological components, leading to *instrument augmentation* [38, 43]. Although no unified taxonomy exists, prior work has identified recurring tendencies such as augmented, feedback, and intelligent/networked instruments [20, 42, 61], or classifications based types of technologies [59].

Sensor-based augmentation remains prevalent in NIME, (e.g.,[3, 21] or systems for plucked strings and winds [47, 48]. Actuator-based systems inject sound into an instrument's resonant structure, from acoustic transducers [22] to dedicated devices such as magnets [33] or DRMMR [6], with hybrid approaches establishing feedback loops through combined actuation and software processing [6, 22, 44, 62].

### 2.2 Design practices, approaches, and methods

Instrument modification has been approached in multiple ways within the NIME literature. In this section, we draw on research on Digital Musical Instruments (DMIs) more broadly, as many of these considerations can be assumed to apply both to augmented acoustic instruments and to DMIs in general. The practice of designing and building DMIs is commonly referred to as *digital lutherie* [1, 19]. Recent work has explored digital lutherie as a means of intervening on acoustic instruments through small, reproducible mechanical modifications. In parallel, research on instrument making has highlighted how even minimal physical adjustments can lead to substantial perceptual consequences. For instance, Armitage [1] demonstrate that small construction differences in violins significantly affect playing response, underscoring both the sensitivity of acoustic instruments to mechanical intervention and the importance of a tacit, practice-based knowledge.

Digital lutherie prototyping is often carried out using fabrication techniques such as Fused Deposition Modeling (FDM) 3D printing, laser cutting, and CNC milling [35, 63]. In many of these cases, the design process begins "starting with a concept or goal in mind" [49], while other studies have noted how instrument augmenters may focus primarily on the technology itself rather than on musical practice [42]. Another approach is offered by Gurevich, who proposed a "repertoire-driven approach to creating NIMEs," to design NIMEs, drawing inspiration from avant-garde electroacoustic works [15].

Motivations for digital lutherie are often creative or compositional in nature for many sub-communities within NIME, echoing long-standing arguments that making an instrument can itself be understood as a form of composition [24, 31, 57]. Perry Cook's notion of "make a piece, not an instrument," [10] along with perspectives discussed, for istance, by Lucier, Tanaka, and Magnusson [24, 26, 53], reflects a recurring trend within our community. This orientation is also evident in empirical studies: Morreale and colleagues, in their work on design for longevity [41], observed that the majority of DMIs are designed primarily for their authors' own use.

Other approaches have instead involved participants and target populations through workshops, hackathons [11], idiographic processes [17], and co-design [55]. In these cases, participant involvement typically occurs through discussions, informal testing, and hands-on experimentation with sketches and early prototypes, supporting the evaluation of ergonomic compatibility, technical feasibility, and acoustic side effects [18].

An illustrative example is provided by Martelloni [29], who report on a workshop focused on augmenting guitars that originated from collaboration with fingerstyle percussive performers. This attention to specific user populations in professional performance contexts resonates with perspectives from second-wave HCI. In their chapter on embodied musical interaction, Tanaka [54] frames NIME research as encompassing professional settings alongside leisure and artistic practices, drawing on the distinction between second- and third-wave HCI as formalized by Bødker [5]. Following this perspective, the present paper addresses professional instrumentalists as workers with needs emerging from their job practice, adopting a practice-based research approach developed in close collaboration with instrumentalists

From the early interactions with the instrumentalists we understood how repertoire was central. Inspired by Gurevich's repertoire-driven approach, we reflected on how instrumental repertoire can be a source for understanding performers' needs and as a foundation for instrument augmentation. While we acknowledge that new compositional ideas (from composers) and instruments making (from luthiers) have been linked and mutually influenced for centuries, today, score-based music is largely performed on instruments whose assets remained stable for centuries, furthermore - in the domain of digital fabrication - score-based repertoire tends not to be the central focus.

### 2.3 Longevity, reuse, and repertoire

Within NIME, the discussion on DMIs longevity suggests possible ways to improve the current situation. Several authors have noted that many projects presented at NIME conferences are used only a few times - if not just once - before becoming debris, partly due to the pressure to produce a large amount of output [12, 37]. This has led to the coinage and use of the term "disposable instrument" [9]. To foster longevity, Calegario emphasized the importance of documentation [8], discussing the challenges of replicating NIME projects and providing guidelines for producing replication-driven documentation. Bin [4] also addressed this

[1]The augmentations have been designed and developed by the first author who retains the intellectual properties of the devices per se. The second author contributed with the academic grounding and the conceptualization of *repertoire-centered design* approach, all the author contributed to the paper.

issue, proposing five strategies for documenting NIME projects: Collaborative, Ongoing, Flexible, Open, and As complete as we can make it.

Recent NIME papers have explored ways to increase the longevity of DMIs with different forms of reuse [32], for example by: 1) promoting the development of modular and long-lasting instruments [7]; 2) proposing design solutions aimed at preventing breakage, enabling repair, and open-sourcing the outcomes of the design process to support future hacks and redesigns [36]. Other approaches have highlighted how updating [52, 58] and complementing [46, 56] editing NIME can support longevity [32], while others actively try to create repertoire for new DMIs [13] or augmented instruments [34] working around the idea of community.

Overall, the issue of longevity can be related to the "problem of the second performer" [32, 34], which is deeply linked with the issue of lack of repertoireisation. As such a focus on repertoire can have an impact on longevity which we will discuss in the end of the paper.

## 3 Methodology

This research follows a practice-based methodology - aligned with approaches articulated by Gurevich [15]. The work developed through ongoing design activity situated within real musical contexts, allowing repertoire, performance needs, and instrumental constraints to actively shape the research process. The authors of this paper acted as designers–researchers, working in close collaboration with instrumentalists who are part of an extended network of long-term musical collaborations. As such, these musicians were not recruited for a formal co-design study; instead, interactions emerged naturally as part of our daily musical lives and over time through rehearsals, performances, informal discussions, and compositional consultations. All these interactions started with informal conversations about limits of the instruments.

Rather than adopting a structured co-design methodology, the researchers embedded themselves within the instrumentalists' usual musical practices. Observations, conversations, and iterative exchanges were documented through self-reflective notes. As such rather than starting from a theoretical framework or design aim, the focus on repertoire emerged organically from practice.

## 4 New Artifacts

### 4.1 Theorbo

The theorbo is a plucked string instrument developed in Italy during the 16th century. It features a distinctive double-neck design: an extended neck hosting a set of long, unfretted bass strings, coupled with a shorter one with a fretted fingerboard. The theorbo combines a lightweight and fragile body with a long and comparatively heavy neck. Weight already represents a critical parameter in the instrument's ergonomics; therefore, any modification must be carefully tailored to avoid negatively affecting the player's physical comfort and performative control.

#### *4.1.1 The drone tuner - Fig. 1a.*

**Repertoire-related issues.** The limited number of drone strings creates constraints in terms of available tonalities. Pieces in different keys normally require retuning the drones, leading to long pauses between works; moreover, due to the instrument's size, tuning necessitates repositioning it and laying it on the stage floor. This issue arises both in Baroque repertoire (for example, in pieces drawn from the same manuscript, such as *Pièces en G majeur* and *Pièces en D majeur* from the *Besançon Vaudry de Sayzenay* manuscript), and in contemporary theorbo repertoire (such as the sequence of *Monarca* by Giovanni Bertelli and *Fiato* by Filippo Perrocco). In addition, pieces such as *Com'esser può ch'io viva* from Kapsberger's *Libro III di Chitarrone* require up to eleven drone strings to accommodate chromatic bass lines, whereas a standard theorbo has only six diatonic drones. Therefore, enabling fast and easy retuning of the drones would both make it possible to perform such repertoire and simplify transitions between pieces.

**The Device.** The drone tuner is composed of three main elements: a gear system acting directly on the strings, a bicycle brake cable as a transmission element, and a foot pedal that actuates the mechanism by pulling the cable. As a primary control interface, the pedal is designed around a wheel mounted on its pivot axis. The brake cable wraps around the wheel and is tensioned through pedal motion. The cable then runs to the main mechanical unit, mounted on the extended neck section for the drone strings. The gear mechanism is attached on a custom 3D-printed mount featuring a rail system, allowing the device to be aligned with different drone strings. The brake cable is attached to a spring-loaded linear rack that drives a gear stack composed of a spur gear at its base and a 45° bevel gear at the top. This bevel gear engages with a second one with the same slope, coupled to a cam mechanism. The cam features an indented slot designed to accommodate the string and, when actuated, presses the drone against a 3D-printed counter-cam made of a softer material, effectively fretting the string at a new pitch.

**Design Challenges.** The long neck of the instrument implies an inherent unbalanced asset, therefore the design of the drone tuner requires a careful evaluation of weights. Excluding cable and pedal, the device totals 20g, which is a tolerable amount to be managed.

#### *4.1.2 Bender - Fig. 1b.*

**Repertoire-related issues.** Theorbo repertoire often requires the use of alternative temperaments, such as *Just Intonation* or Werckmeister tuning; however, due to the fingerboard structure and the presence of gut frets, intonation cannot remain fully constant or precise across the entire range of the instrument. Additionally, some contemporary compositions - e.g., *YCERTPB-NITA* (2025) by Mauro Lanza - require performers to produce microtonal pitches even on instruments with fixed intonation, such as plucked string instruments.

**The Device.** The bending device is designed to provide bending, vibrato, and extended timbral effects on the fretted strings of the theorbo. It is installed between the bridge and the lower end of the soundboard, where it is anchored to the shoulder-strap pin. The device is further secured to the bridge via 3D-printed blocks. Inspired by lever mechanisms found in lap steel guitars[2], the device allows the performer to intervene directly on one or more strings through a single control surface. An adjustable 3D-printed pad positioned beneath the lever presses the string toward the soundboard, thereby modifying pitch. In addition, different pad materials can be employed to also influence timber response and articulation, extending the expressive range of the instrument.

[2]https://en.wikipedia.org/wiki/Lap_steel_guitar

**Design Challenges.** As the string tension of the theorbo - from ~2 to 4 kg - is quite low compared to other string instruments, the soundboard is traditionally thin and fragile, with the bridge directly glued without any mechanical reinforcement. Consequently, any device interacting with the soundboard must carefully account for these structural constraints. To address this, the lever is anchored to a wide plate that distributes mechanical forces over a larger surface area. Additionally, the bridge attachments are fabricated in a softer material chosen to minimize localized stress.

(a) (b)

**Figure 1: Theorbo devices: (a) the drone tuner installed with its pedal; and (b) the bender on the bridge.**

## 4.2 Accordion

The accordion is a compact and enclosed instrument, designed with a space-efficient internal layout: each side of the bellows contains reed blocks and narrow mechanical linkages that activate the voices of the individual registers. This dense configuration makes modification challenging, as there is very limited room to accommodate additional components, and only a few suitable areas for attaching additional elements. The sole part of the internal mechanism that can be accessed without interfering with the primary controls is the air button located on the left side of the instrument, which allows the bellow to be compressed without producing sound. By contrast, interventions involving the external controls - such as the keyboard and the bass buttons - are less complex and more common, as they are similar to those found on other keyboard-based instruments.

### *4.2.1 Pedalboard - Fig. 2a.*

**Repertoire-related issues.** Accordion repertoire may require capabilities beyond the standard instrument. Pieces readapted from the later baroque tradition (e.g., Venetian repertoire for organ from the 18th century) may demand specific timbral registers not available on standard instruments, or a wider range, while contemporary compositions - such as those written by Conrado del Rosario, or for Duo XAMP, an accordion duo that performs with custom-built instruments - may additionally call for microtonal pitches or prepared reeds. Potential solutions involve transposition or timbre masking, but sometimes a second instrument is strictly required, which implies higher costs and portability concerns. Thus, we developed a low-cost device constituting an affordable solution to these issues.

**The Device.** The pedalboard is derived from a vintage Farfisa 5220 pedal unit, from which all the electronics have been removed. The original pedal covers have been replaced with 3D-printed pedals incorporating articulated joints designed to accommodate the new mechanical system. A custom 3D-printed *cassotto* is mounted onto the pedal unit and fitted with a reed block connected to an air tube. Two independent sets of arms and pushrods are used to actuate the reed block, opening/closing the chambers. Each pushrod is directly coupled to its corresponding pedal via 3D-printed ball joints, resulting in a smooth and direct mechanical response. On the accordion, the bass grille has been replaced with a custom 3D-printed grille, allowing a tube to exit the bellows and redirect airflow to the *cassotto*. The tube is secured to a custom connection block designed to keep the air button permanently open for a continuous airflow. Through this modification, the instrument retains its original paraphonic articulation while extending it to a third *cassotto*, introducing an additional set of voices controlled by the pedalboard.

**Design Challenges.** The challenges in implementing an external pedalboard concern both mechanical design and airflow management. Mechanically, a reliable system inspired by the internal keyboard mechanism connects rocker arms to pushrods with carefully calculated slopes. This arrangement ensures that each reed opens and closes correctly when actuated by the pedals. The *cassotto* must be kept as compact as possible to maintain sufficient pressure. Additionally, the connection block on the instrument must be precisely tailored to guarantee a continuous, controlled airflow to the external reed block.

### *4.2.2 Drone Block - Fig. 2b.*

**Repertoire-related issues.** In both baroque and avant-garde repertoire, accordion players are sometimes required to sustain certain notes during performance. Common solutions, such as pen caps or tape, are often unreliable and inconvenient for live use due to their fragility.

**The Device.** The drone block is designed to fit over one key on the right side of the accordion, forming a small shield that interlocks with the two adjacent keys. Its ring-shaped end allows it to be worn during performance, giving the musician the ability to quickly place it on a key to engage it, or remove it when no longer needed.

**Design Challenges.** Designing this device does not require specialized knowledge; the key aspect is to tailor it precisely to the instrument's key layout, taking into account both horizontal pitch spacing and vertical key action.

## 4.3 Bass Clarinet

Like other clarinets, the bass clarinet features a compact and narrow key layout. However, its extended lower register - and consequently its larger physical size - requires longer levers and a wider spatial distribution of keys for both hands. Due to its complexity and wide range, the bass clarinets is equipped with set of keys that actuates the same holes and mechanism redundant for both hands. Bass clarinets descending to low C (sounding B♭) also include a dedicated set of keys for the lowest notes on the rear of the instrument, typically actuated by the right thumb.

**Repertoire-related issues.** New repertoire, especially from the avant-garde, demands greater endurance from instrumentalists than earlier literature. Techniques like circular breathing are sometimes required for wind instruments. Alongside these techniques, new gestural demands must also contend with the existing mechanical layout of the instrument: the instrument itself already features redundancies in its set of keys, but for the smallest ones—actuated by weaker fingers (e.g., the pinky) or

(a) (b)

**Figure 2: Accordion devices: (a) the pedalboard connected to the *cassotto* with the air-tube; and (b) the small drone block pressing a key.**

those requiring more movement along the tube—there are fewer possibilities for redundancies.

#### *4.3.1 F# Trill Extension - Fig. 3a.*

**The Device.** Due to multiple redundancies in its key system, the bass clarinet - like other members of the clarinet family - offers several fingerings and keys that produce the same pitch. Some of these keys extend into regions accessible to both hands, as sometimes required in avant-garde repertoire.

However, the performer in their practice encountered the need play this note faster, more efficiently for less fatiguing trill gestures. This lead to the idea of an extension lever (for the F# key), that could be operated with the right hand solely. Since in the standard instrument the F# key is one of the lowest left-hand keys, extending it toward the right-hand area requires minimal mechanical modification and allows both hands to access the same key without altering the instrument's original key layout or hand position.

**Design Challenges.** The available space between the left-hand keys is extremely limited, and any added component must remain thin and tightly integrated to avoid interference with adjacent keys. This extension required a 3D scan of the original key geometry in order to obtain precise measurements for attachment. Additionally, the mounting mechanism needed to balance structural robustness with mechanical delicacy, ensuring reliability under the speed and repetition of trill gestures.

#### *4.3.2 Low-A Key - Fig. 3b.*

**Repertoire-related issues.** Avant-garde compositions for solo bass clarinet like *Transelefantico* (2022) by Matteo Bergamin, or even transcribed literature (e.g., from cello or bassoon repertoire) require a wider range especially in the lower register. Bending and lip pressure are common used techniques to avoid these mechanical and performative problems, transpositions or register changes are also deployed, often as a compromise between feasibility and sonic result.

**The Device.** The low-A key extends the instrument's lower range by one semitone. Its design relies on an additional tone hole located on the bell section at the bottom of the instrument, a feature not present on all bass clarinets and primarily intended to ensure timbral stability across the full register. When this hole is closed, the instrument produces a low-A; when left open, it allows the instrument to maintain consistent timbre and intonation in all other playing positions.

The key mechanism extends from the middle section of the instrument to its lower end and is actuated by the palm of the left hand. The lever is situated to the left of the pinky finger keys, so that the player can actuate it without changing the left-hand position. A spring-loaded mechanism leaves the hole open to ensure timbral stability in all other positions, and converts the performer's pressing gesture into a key-closing action, while a felt pad ensures proper sealing of the tone hole.

**Design Challenges.** Integrating an additional key into the already dense and narrow key layout of the bass clarinet is a delicate task, as both attachment points and effective leverage are severely constrained. Furthermore, reliable coverage of the tone hole requires precise alignment between the instrument's segments, as the key mechanism is mounted on the main tube while the corresponding tone hole is located on the bell section. Most mechanical enhancements acting on the main mechanisms of the instrument must be positioned alongside its dense system of keys and levers, and any structural addition must preserve the native mechanics while remaining easily mountable and removable. Unlike brass instruments, whose valves and tubing can often be removed and reinstalled without affecting performance, clarinets require precise regulation after any intervention, making non-invasive and reversible attachment essential.

(a) (b)

**Figure 3: Bass clarinet devices: (a) the F# trill extension; and (b) the low-A key.**

## 4.4 Euphonium

As the devices have been presented in a previous work [28], the following provide an overview; readers interested in further details can refer to the former publication.

#### *4.4.1 Trigger Lever - Fig. 4a.*

**Repertoire-related issues.** Being a closed continuous tube from the embouchure to the bell, any preparation on the euphonium's main pump affects the whole system (e.g., *Ahora Van a Ver...* (2024) by Matteo Cenerini). While working on preparations for the euphonium, we found that many composers decided to use the second valve for preparation. This, however, results in a reduced range due to the loss of one semitone transposition, particularly in the lower register [2], requiring compositional strategies to work around this constraint. Beyond the avant-garde repertoire, the euphonium sometimes requires a wider range and different articulation possibilities when playing transcriptions from other instruments (e.g., trombone, French horn, and bassoon).

**The Device.** The trigger lever extends the intonation range of the compensation trigger (primarily used to correct pitch discrepancies inherent in certain harmonics and valve combinations) up to a semitone. The native trigger is controlled on the front of the euphonium, moving a slide of the main pump on the back of the instrument: our design extends this control with a longer lever, providing a wider range of movement. This extension (a) provides a new lower position for every harmonic, thus enabling for new phrasing; (b) permits alternative fingering for some pitches (having now redoundacies with the second valve action); (c) allows actual glissandos (usually done with lips at the embouchure); (d) eases the preparation of the second valve, which can be then used as a switch between two different assets (e.g., mechanically augmented and prepared).

**Design Challenges.** Such a device needs to be fast responsive without any backslash or unwanted noises. The space in which we had to operate is very narrow, so the new lever had to be mounted as a shield on the previous one. This ensures the most direct and strong connection with the trigger actuation. The new lever that extends from the main arm has to be firmly attached to the slide as well. For a strong and easily-adjustable connection between the lever and the slide, we adapted an RC-car spare suspension arm; in addition, by designing a custom shield with a 3D-printed gasket, we have also been able to create a mounting system that does not damage the instrument while keeping a strong connection with the mechanism. This shield allows also the old arm to be installed, so the switching between native and extended asset can be done in seconds.

#### 4.4.2 *Microtonal Valve - Fig. 4b.*

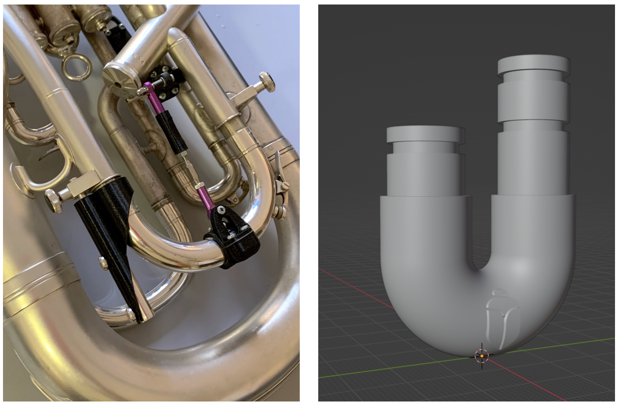
**Repertoire-related issues.** In many pieces, especially from the last century, microtonal intonation is used to enrich the tonal variety of melodic and harmonic material (e.g., Giacinto Scelsi's *Maknongan* (1976); Luigi Nono's *Post-Prae-Ludioum n.1 per Donau* (1987)). However, musical instruments have historically evolved to standardise their pitch production around equal temperament. Some instruments - such as strings or the trombone - can freely explore microtonal nuances thanks to their continuous intonation systems, but for the majority this is not the case: on the euphonium, the compensation trigger has been integrated into the instrument's mechanics precisely to address intonation discrepancies. More broadly, microtonal pitch production on brass instruments relies heavily on embouchure and lip pressure, which places additional physical stress on the player and constrains both accurate intonation and articulation possibilities.

**The Device.** The microtonal tube changes the transposition of the second valve from a semitone to a quarter-tone, enabling the instrument to access full 24-EDO transpositions. This device requires the instrument to be equipped with the trigger lever, in order to keep the semitone transposition.

**Design Challenges.** The design of such a tube depends on the measure of the instrument: the diameter of the valve and the length of the tube are the main parameters to take into account to achieve a correct microtonal transposition. As for the material, PETG has been chosen due to its resistance to water and humidity. In the design, we also integrated slots of o-ring to act as gaskets for the inserted parts.

#### 4.4.3 *New repertoire emerged post hoc.*

Over the last four years of development with the euphonist, we had the opportunity to work with many composers—ranging from students to established professionals—in a variety of settings (e.g., workshops, masterclasses, rehearsals, concerts). In all these scenarios, the instrument was presented and played in its mechanically augmented configuration. Composers expressed interest in the new possibilities of writing for an instrument capable of a wider register and finer articulation nuances. Even when a composition did not specifically require the mechanical augmentations, the performer reported feeling comfortable playing with the extended setup, highlighting the ease of navigating different ranges and articulating various techniques. As a result of this sustained use, the repertoire has grown considerably, with many pieces now explicitly calling for these mechanical augmentations (e.g., *Proiettili di Pace* (2024) by Graziano Riccardi, and *HCYBLT* (2025) by Daniel Puerto).



**(a)** **(b)**

**Figure 4: Euphonioum devices: (a) the trigger lever installed on the instrument; and (b) a rendering of the microtonal valve.**

## 5 Discussions

### 5.1 A Framework to Ecological Account from Repertoire

Starting from the repertoire in design of NIME technology is not a complete novelty as it was proposed by Gurevich [15]. However, pairing it with a design process that accounts for instrumental performers as workers - inspired by the second wave HCI [5, 54] - allowed us to situate our design within the broader ecology of musical labour. By retrospectively analysing our work as common in design based NIME reseacrh (e.g., [36]), we identified a set of recurring elements that we organise in a two-axis diagram (see Fig. 5). One axis describes the nature of the element involved, distinguishing between musical aspects and material aspects, while the other axis identifies the human actors involved, distinguishing between the performer-as-worker in one dimension and their collaborators in the other. These distinctions emerged from the observation that performers are rarely isolated individuals, but are embedded in a professional ecosystem composed of multiple specialised figures - as already discussed in previous studies on music ecologies (e.g., [16, 51]). We propose that this model may support other designers in more systematically accounting for the full performative ecology when pursuing repertoire-centred design interventions.

Considering material aspects first, our cases highlight different forms of material agency distributed across this ecology. At one end, performers themselves often possess substantial expertise in maintaining, repairing, or modifying their instruments. This is particularly evident among brass players, including the one involved in our case studies, for whom actions such as adjusting valves or introducing mutes are common in their established practice. In these situations, our devices did not significantly alter existing workflows; rather, they aligned with and extended them. In other cases, such as the accordion, performers are accustomed to relying on specialised craftspeople/luthiers and technicians for maintenance and repair, reflecting the instrument's higher mechanical complexity compared to brass instruments. By leveraging this existing ecosystem, we were able to design and iterate rapidly and effectively. Notably, we avoided building components such as a windchest from scratch, which would have required forms of craftsmanship distinct from those supported by digital fabrication. We integrated our devices into established material practices (i.e., accordion players collaborate with craftsmen for fixing the instrument).

On the musical axis, repertoire itself constitutes a central design resource. Repertoire comprises not only a collection of scores, but also a set of embodied and situated practices already mastered by the musician. As such, it provides a concrete starting point for design by foregrounding recurring problems, constraints, and opportunities for improvement encountered in everyday performance. Closely related to this are composers, with whom performers - particularly those regularly engaged in contemporary music, as was the case for all our collaborators - maintain active professional relationships.

Based on our long-term collaboration with the euphonist, we support that these composers encounter the tools produced in performance contexts and are often motivated to explore them creatively in their own work. This dynamic is directly related to the question of longevity and will be further analysed in terms of how it contributes to the emergence of new repertoire over time in the next section. We acknowledge that other actors - such as concert organisers and institutions - play an important role in enabling an instrument, or in our case a device, to be used in real performance contexts (and discussed later). However, in this section, we intentionally focus on actors who are directly involved with the device and its immediate integration into practice.

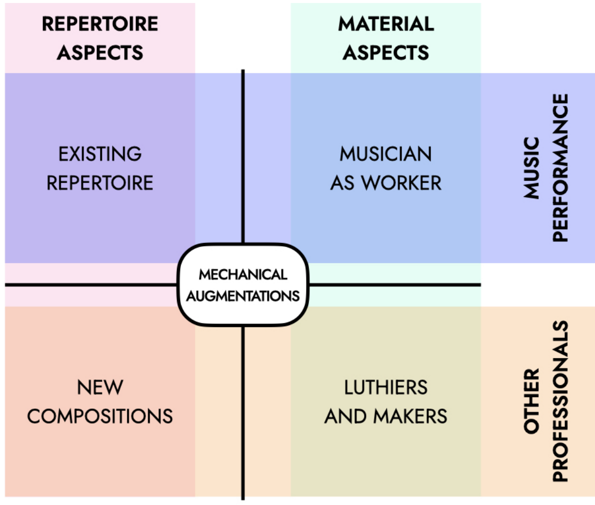



**Figure 5: The two axis diagram showing the ecology system.**

## 5.2 Repertoire-Centred Design, Longevity and Communities

We now expand the scope of our reflection, considering the overall ecology of a musician's working environment and how it relates to longevity and community. The issue of longevity has repeatedly emerged within the NIME community [13, 32, 36, 41]. It has been discussed in relation to the emphasis on novelty and the technopositivist ideology that dominates both scientific discourse and the structures of funding, calls, and evaluation criteria [4, 32, 40].

However, we argue that the problem of reuse and longevity cannot be reduced solely to systemic pressures for newness. Instead, it is also deeply connected to the artistic identity of many DMIs. One contributing factor is that many NIMEs are conceived less as instruments and more as artworks in themselves - "pieces" rather than musical tools, to echo Cook's distinction [10]. In these cases, the instrument primarily expresses the artistic idea of its creator. As such, finding a second performer or composer willing and able to adopt an existing NIME often proves difficult, suggesting that reuse is not only a technical or institutional issue, but also an aesthetic and cultural one [34]. By contrast, other NIMEs more clearly function as instruments in a traditional sense, opening up new musical affordances that enable the emergence of repertoires beyond the original designer-performer. While examples such as the Magnetic Resonator Piano [33], as well as examples like the T-Stick [13], differ from our design principle as they primarily open broader sonic territories, in both these cases the issues of community of composers have been addressed and they illustrate how instruments designed with broader performative potential can support multiple composers and performers. In both of these cases, the inventors/researchers actively collaborated with composers to expand the creative possibilities of the instruments and build a repertoire as well as a community.

Our approach addresses community of composers form a different perspective, as it proposes a repertoire-centred design, rather than primarily aiming to open up entirely new musical possibilities; this perspective focuses on facilitating the performance of existing repertoire. In framing musicians as workers and musical performance as a working environment, we draw inspiration from second-wave HCI [5] - that has already influenced Tanaka and Parkinson on interfaces for blind-producers [55], which are treated as tools rather than artistic artifacts. This perspective foregrounds integration into established practices.

Among the four case studies presented, the euphonium-based system is the one with the longest development and adoption timeline, spanning approximately four years (the first years detailed in a dedicated publication [28]), whereas the other systems have been developed in a shorter amount of time (two years for the bass clarinet, one year for the accordion, and six months for the theorbo). In this case, the performer initially adopted our devices because they made the practical work of performing repertoire easier and more reliable. Over time, this integration into everyday practice led to broader uptake. By leveraging on her usual ecology of work connections (artistic directors and organisers of concerts, festivals and other musical venues), the performer continued to work and naturally showcase the devices in different contexts (from classes/workshops to concerts and festivals). Indeed, these augmentations did not change her practice in its essence (i.e., technical readers remained the same). Simply, the devices were included in an existing musical practice. As such, we propose that it can facilitate longevity.

We observed that our approach can facilitate the development of a community around it; in this sense, we observed a process similar to the one with the Magnetic Resonator Piano [33] and the T-stick [13]. The main distinction with these two works, however is that these interactions with other composers did not occur with us, rather naturally emerged in the professional ecology of the performers. For instance, in the case of the euphonium, composers encountered the system through performances and naturally began writing works that explicitly accounted for these devices, while students of the collaborating performer expressed interest in adopting the system themselves. This pattern of dissemination did not emerge from an explicit strategy or effort in creating a community from the authors of this paper, but rather from the fact that the design was embedded within a stable and well-established performative practice. By aligning with an existing instrumental technique and repertoire, the system was able to generate new performances, attract additional performers, and stimulate compositional activity (more than 15 pieces have been written for this asset in the last three years - many of which detailed here [28]) that leveraged the new affordances introduced by the devices. From this element, we support that our proposed repertoire centered approach to designs complements the aforementioned approaches to build communities.

### 5.3 Limitation

We want to highlight that while our approach directly addresses the conditions under which instruments are adopted, it was intentionally less exploratory compared to other instrument augmentations and it produced less sonic variety compared to other experimental design paradigms. Future research could investigate design processes capable of more organically blending repertoire-centered and exploratory approaches, potentially reconciling longevity with innovation in NIME practice.

## 6 Conclusions

This paper introduced *repertoire-centered design* as an approach to mechanical instrument augmentation, grounded in the constraints of written repertoire and in the professional ecology of performers-as-workers. Through a series of digitally-fabricated devices designed for four case instruments (theorbo, accordion, bass clarinet, and euphonium), we showed how repertoire can act as a practical driver for requirements, shaping lightweight, reversible, and performance-ready devices. We argue that designing from repertoire supports long-term adoption, as it aligns with existing techniques, workflows, and collaborations (e.g., between luthiers, instrumentalists, and composers), and can foster repertoire growth and community uptake over time.

This proposed perspective invites future NIME research to consider repertoire not only as an outcome, but as a concrete starting point for instrument design.

## 7 Ethical Standards

The first author is a freelance professional who commercially offers devices similar to those described in this manuscript. However, the authors do not consider this to constitute a conflict of interest. The primary focus of the present study is not the validation, performance evaluation, or promotion of the devices themselves, but rather the methodological and developmental process that led to their design and implementation.

The research was conducted through a reflective analysis of the authors' own professional practice. All interpretations were developed independently of any commercial considerations.

Photographs of performers using the final devices were taken with their consent. All musicians involved were aware that the authors were conducting research on this topic and that the devices were also developed for potential commercial purposes.

The authors declare that there are no other financial, commercial, or ethical issues that could be construed as a potential conflict of interest.

As none of the author is a native English speaker, we relied on AI-tools to refine the text including synthax, grammar, and spelling.

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