BrickMusicTable: A LEGO brick-based tabletop sequencer

Merlin Waldhör
University of Vienna
Vienna, Austria
merlin@waldhoer.org

Oliver Hödl
Cooperative Systems Research Group
University of Vienna
Vienna, Austria
oliver.hoedl@univie.ac.at

Peter Reichl
Cooperative Systems Research Group
University of Vienna
Vienna, Austria
peter.reichl@univie.ac.at

Abstract

We present the *BrickMusicTable*, a prototype for a tabletop tangible user interface (TUI) for musical purposes that uses LEGO bricks. Our resulting musical instrument is a sequencer that produces sound based on visually tracked bricks placed on a LEGO ground plate. The current prototype recognises different sizes and colours of bricks and their position on the sequencer as notes. In addition, putting small coloured pins on top of these 'note bricks' enables different sound modulations. Additional brick-controlled 'sliders' allow changing the speed, pitch and volume of the sequencer. The iterative design and development process was accompanied by participating musicians, who gave feedback upon testing the prototype during development. We consider our prototype as a successful case study of novel technology and proof-of-concepts especially using a top-down camera recognition for a tabletop TUI and thus enabling new interaction techniques through stacking bricks on each other on the sequencer. At the same time the design and development process revealed different problems, but also led to possible solutions concerning illumination and a stable image analysis.

CCS Concepts

• **Applied computing** → **Sound and music computing**; Performing arts; • **Human-centered computing** → *Interface design prototyping*.

Keywords

Tabletop tangible user interface (TUI), ubiquitous multimedia, musical interaction, interface to sound mapping, LEGO bricks

ACM Reference Format:
Merlin Waldhör, Oliver Hödl, and Peter Reichl. 2024. BrickMusicTable: A LEGO brick-based tabletop sequencer. In *International Conference on Mobile and Ubiquitous Multimedia (MUM '24), December 01–04, 2024, Stockholm, Sweden.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3701571.3701592

1 Introduction

Interlocking bricks such as LEGO (the most prevalent brand) are commonly known and being used by children and adults. Also, the haptic and modular characteristics of the bricks bear a unique potential for tabletop tangible user interfaces (TUIs), which has been subject to research for various purposes and also developing new musical instruments and particularly investigating methods for musical interaction. Different brick-based interfaces for musical purposes have been examined in music education [2, 17], performance [6] and usability studies [13, 18]. Technologically, brick-based musical instruments range from robots to solely software-based concepts [1, 4]. As LEGO bricks can be considered well-known ubiquitous objects, we consider the *BrickMusicTable* a contribution to ubiquitous multimedia.

While both tabletop TUIs for musical interaction and brick-based musical instruments have been subject to research so far, there is not much knowledge on brick-based tabletop TUIs for musical purposes. Concretely, we lack knowledge on technical approaches, interaction and sound mapping techniques as well as viability and practicability as a new interface for musical expression. With our prototype, we focus on the barely investigated intersection between already investigated TUI features and aspects of LEGO brick-based musical interfaces. Thus, the question that motivates this study is: What can we learn from designing and developing a brick-based tabletop TUI for musical purposes in terms of possible solutions and limitations of the technical setup, interaction techniques and brick to sound mappings?

In the following, we start with a literature review to analyse existing approaches of brick-based TUIs as presented next in Section 2. In Section 3 we describe our methodological approach. Sections 4 and 5 present the design and prototyping process. Finally, we reflect on the outcomes of the design prototyping process of our brick-based TUI in Section 7 and the results of our case study in Section 8.

2 Related Work

2.1 Tabletop TUIs as musical instruments

Tabletop TUIs are an established kind within a broad range of new interfaces for musical expression that emerged since more than two decades. One of the earliest and probably still best known examples is the *Reactable* [15]. The *Reactable* is a tabletop TUI that uses different objects which are placed on an almost transparent surface with a projector underneath. When you put a dedicated physical object on the surface, the projection highlights how blocks can be used for modulating the sound or change the sound mappings in realtime while playing. Another more recent tabletop TUI for music is *LoopBlocks* [9]. With this sequencer, the player puts wooden cubes on a wooden board. To determine if a block is placed in a notch, photorestistors are used together with a Raspberry Pi. With this TUI, the authors studied how musical interfaces can be developed within education of children with intellectual disabilities.

MUM '24, December 01–04, 2024, Stockholm, Sweden

ACM ISBN 979-8-4007-1283-8/24/12
https://doi.org/10.1145/3701571.3701592

Another sequencer-like tabletop interface, the *muSurface* by Waranusast et al. allows placing melodies with standard music notation symbols [21]. Therefore, semitransparent note plates are put on a glass surface. Placed symbols and their positions create the resulting melody. With a complex infrared camera mounting, including a projector for screen display, the muSurface allowed children to play and learn music using visual recognition.

Focusing on an educational approach, the *TuneTable* was developed to demonstrate how music can be programmed using specific command plates [22]. Based upon the technical concept of the *Reactable* [8], the *TuneTable* implemented a physical interface for *EarSketch* [16] - a python API that allows simplified audio programming for students. The *TuneTable* uses different symbols for playing, looping and controlling further play with so called programming blocks. Using *EarSketch* and the tangible components described, the study on *TuneTable* indicates how tabletop TUIs can be used within computer science lessons.

In a project by Jin et al. [14], who present an *Augmented Reality for Musical Programming*, a similar tangible music programming application using puzzle-piece like objects was achieved. This prototype shows a TUI using augmented reality on a mobile device without complex infrared camera mountings, leading to a much simpler technical setup.

	Year published	Uses visual recognition	Uses wired bricks or robots	Solely Software or theoretical	LEGO Specific
Reactable [15]	2005	X			
muSurface [21]	2013	X			
Mindstorms Instruments [4, 5]	2014		X		X
Composition Focused Brick Tabletop [18]	2015	X			X
Rapid Sketching TUI [10]	2015	X			X
Hitmachine [6]	2016		X		X
TuneTable [22]	2017	X			
Brick notation in primary schools [2]	2017			X	X
Ynformatics [20]	2018	X			X
Legato [1]	2019			X	X
LoopBlocks LoopBlocks[9]	2021	X			
Playel [11]	2021		X		X
AR Music Programming [14]	2023	X			
3D-Stacked bricks [3]	2023		X		X

Table 1: Overview of investigated TUI tabletop prototypes

2.2 Brick-based instruments and TUIs

Among TUIs for musical purposes, there are already some studies on brick-based TUIs. One example is a composition-focused prototype using a screen as tabletop for brick note reading and a special brick notation [18]. In this case notes are connected using transparent bricks as spaces and white bricks for note values, creating a connected plate which can be flipped to reverse the whole note sheet. Regarding hardware requirements (i.e. a tabletop screen) it is a more complex prototype with high costs, which was tested with children in music education. Compared to other tangible brick notations [2, 10, 20], however, usage of transparent bricks for spaces instead of just leaving empty spaces seems to be rare.

Although mainly evaluated with virtual bricks, Bartè et al. [2] developed and investigated a tangible LEGO-based music notation for children. Different brick colors, sizes and positions led to different properties like instrument type, note duration or note pitch. The virtual music notation could also be expressed with tangible LEGO bricks and offered a view similar to a piano roll.

A proof-of-concept study by Gohlke et al. [10] has shown that brick-based TUIs and visual recognition can be used with sliders and other note presentations for translating bricks to OSC and MIDI messages. The presented LEGO mounting frame prototype contains multiple light bulbs for illumination. The upward-facing webcam underneath a translucent LEGO plate captures the bricks placed on top.

A similar concept using video recognition was presented in a more informal environment [20]. Technically, LEGO bricks were recognised with a webcam from above.This approach used solely bricks without any positioning restrictions (i.e., without a ground plate, which binds bricks to a specific grid), but only offered a rather simple way of musical expression regardless of the bricks color or rotation. Compared to the prototype by Gohlke et al. [10] mentioned previously, this TUI exposes a less comprehensive brick-based music notation.

At last, also pure digital LEGO interfaces have been developed. The *Legato* web prototype uses a LEGO based brick notation in a digital manner, presenting notes similarly with colors and lengths in a visualization that looks like common midi note presentations [1]. The *Legato* offers a simple interface for playing notes, allowing to play chords, melodies and enabling control of playing.

2.3 Electrified brick-based TUIs

Another approach towards brick-based TUIs is using additional electronic components. Barbancho et al. [3] used electronic hardware including a Raspberry Pi for brick-based music making. Their brick notation builds upon a three-dimensional pattern: Stacking multiple blocks with copper creates different sounds. We can assume that the process of wiring bricks is more time-consuming, but issues relating to visual detection are avoided, as the copper connections offer a much more robust technical interface.

The Playel [11] is an electrified LEGO piano model turned into a functioning keyboard while maintaining almost the original LEGO model. Similarly, to the stackable brick-based approach by Barbancho et al. [3], *The Playel* is based on copper connections in combination with a micro-computer (an Arduino in this case). As a fully functional MIDI controller it can be used with various digital audio workstations or external programs.

Other musical instruments were reconstructed using LEGO Mindstorms robots[1] such as a electronic guitar model [4] or a trumpet [5]. Although these interfaces emulate real instruments, we can assume that they are limited concerning musical expressivity, missing potential important features of a music interface. The *hitmachine* by Jakobsen et al. [6] also uses LEGO Mindstorms robots and their sensors to create new musical instruments. The goal of the *hitmachine* study was encouraging children to get a deeper understanding of sound generation and how sound can be created by human interaction through constructing and performing with interfaces using different sensors and bricks. Regarding musical expressivity, the *hitmachine* provided an unique feature for note simplification to avoid

[1]https://www.lego.com/en-us/themes/mindstorms

dissonant notes. Their evaluated custom-made LEGO Mindstorms instruments also showed that musical expressivity for children is not only linked to the interface, but also the children's experiences and capabilities for interaction. This leads to boundaries in expressivity which are potentially lower than the instruments actual capabilities [13].

Electrified LEGO interfaces were also evaluated in workshops at the *LEGO World Fair*, an event supported by the LEGO company itself. In a study by Jakobsen et al. [12] children were asked to build instruments with so called *Makey-Makey*[2] boards, which offer an intersection between sensors and software. Their results show several different techniques for constructing custom interfaces with children and the authors highlight the potential of creating new interfaces with LEGO materials.

Table 1 gives an overview of all TUI tabletop prototypes we reviewed and mapping the key technology and interaction technique used. As we can see, the majority of investigated tabletop TUIs is based on visual recognition, while only a few prototypes like the Playel [11] or the stackable lego bricks [3] are electrified. Even less use a solely software based or theoretical approach.

3 Methodology

We followed an iterative design and prototyping process for developing a brick-based tabletop TUI. At the beginning, we made some preliminary design decisions as outlined in Section 4. Central to the iterative instrument prototyping process was the hardware and software development (i.e. mounting concept, visual recognition of bricks, brick to sound mapping) as described in Section 5.

In parallel to the prototype development, we involved external participants through a formative evaluation in the iterative development process to get immediate feedback and new ideas for the prototype improvement and additional functionality. Overall, four hobby musicians aged between 20 to 30 with an advanced knowledge in music technology were involved in two intermediate evaluations described in Section 6.

The whole development process lasted three months and three workshops with external participants were held all 3-4 weeks to review the improved prototype. These workshops were held as a group of 3-4 in an informal setting. Each workshop started with a short instruction on the current prototype and its new features. Then each participant could play freely with the instrument for a couple of minutes. Afterwards the participants were asked to give feedback and suggest new features. In the third workshop with the most elaborated prototype, an additional information jam session was held to trial the prototype in a more realistic setting (see Figure 1).

4 Preliminary Design decisions

At the beginning we made some preliminary decision for our *BrickMusicTable* concerning the principle design and technologies we wanted to use for our brick-based TUI.

We decided to adapt the principle of using bricks as notation for music notes from existing prototypes we found in the literature [1, 2, 17]. Our physical video-based concept, i.e., mapping bricks to a digital notation map, was inspired by Gohlke et al. [10], which

[2]https://makeymakey.com

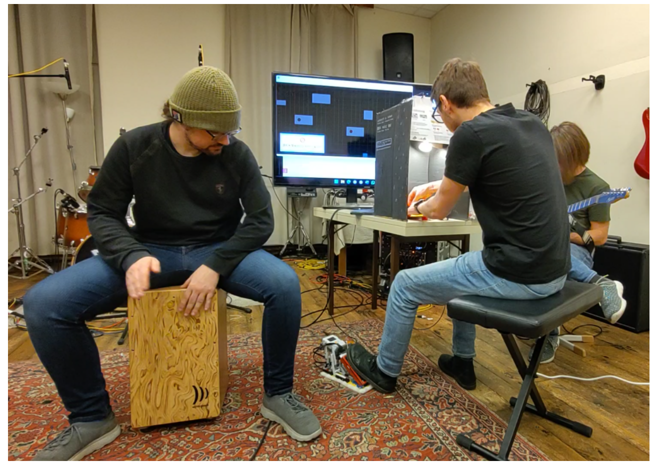

Figure 1: The instrument is tested in an informal jam session of three musicians

tracks bricks through a translucent LEGO plate from below [10]. However, we decided against a upward-facing camera approach as in [10] and instead used a top-down faced camera to avoid being limited to special translucent brick plates and also being able to use the studs on top of each brick to mount additional pieces. For the visual analysis of the plate with bricks, we used OpenCV[3] and map the recognised bricks to Open Sound Control (OSC) commands for being flexible with the sound synthesis. For the sound synthesis, we planned to use *Sonic Pi*[4], which is a widely used free software for musical purposes and eventually allows us to run our TUI on a *Raspberry Pi* in future without using an external laptop, for instance.

Finally, we included a visualisation of detected bricks on a screen for debugging purposes especially during the development of our prototype. To prevent visual detection failure when manipulating the bricks with the hands, we added a custom-made foot pedal built with the LEGO Mindstorms touch sensors. Our goal was to pause the visual analysis while the pedal is activated, but still continue the sound synthesis. By doing so, the performer's hand cannot interfere with the visual analysis while placing bricks. Otherwise, the performer's hand may cause unwanted side effects.

Figure 2 illustrates the schematic concept for our brick-based TUI following our preliminary decisions for the design and the technologies as just described.

5 Instrument prototyping

5.1 Mounting concept

Developing the *BrickMusicTable*, our brick-based TUI prototype, was an iterative process where we started to focus on the mounting concept and the visual recognition. Developing the setup that involved hardware and software was driven by trial and error through iterative implementation and testing.

We tried four different mounting concepts to achieve a satisfactory tracking the bricks on a LEGO ground plate with a webcam from the top. Figure 5 shows four concepts including the

[3]https://opencv.org
[4]https://sonic-pi.net

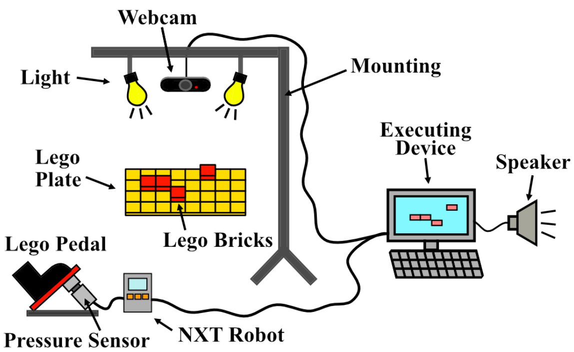

Figure 2: Schematic concept for our brick-based TUI

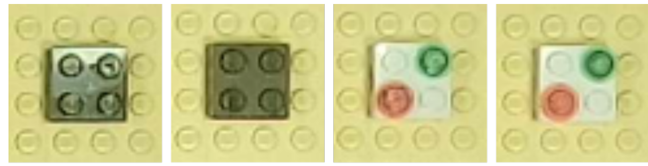

Figure 3: Comparison of original and mat lacquered bricks

final mounting setup (labelled with number 4). All three discarded mounting concepts were either lacking stability, transportability, a stable illumination or a combination of them.

The final mounting setup (labelled with number 4 in Figure 5) has four light bulbs placed on the upper side of the box. The web camera is placed inside a small box attached on top to stabilise the camera position. The camera box contains two holes: A small outlet is used for the camera USB cable and a hole is used to uncover the field of view for the camera. A 32x16 studs LEGO ground plate (ca. 25.4 x 12.7 cm) is fixed on the bottom of the cardboard box.

5.2 Visual recognition of bricks

In parallel to testing different mounting concepts, we developed and tested the visual recognition of bricks within the respective prototype. The major functionality within visual recognition, which is to identify bricks, is based on OpenCVs contour detection [19]. However, to allow a sophisticating brick detection we first needed to ensure that the captured images were pre-processed accordingly. For this, we included the Canny algorithm together with some basic blurring and morphological operations [7]. Afterwards, the generated binary image was used for rectangle detection. After the brick contours are identified, assessment of color and further processing steps are completed. Besides this visual analysis, we also used OpenCVs drawing functions for showing a low-level image and note sheet preview, which was useful for debugging reasons, but may be enhanced with future prototypes.

One challenge was a good enough illumination of the ground plate and bricks. An external varying light situation in a room, for instance through daylight and windows, decreased the visual recognition accuracy significantly. With partly closed mounting setups or using cardboard boxes as with prototypes 2, 3 and 4 in Figure 5 and additional lamps or LEDs, we achieved the best results due to a stable illumination.

We observed another issue regarding visual recognition accuracy in relation to reflection caused by the illumination. The glossy plastic material of LEGO bricks can reflect light depending on its position on the plate which leads to recognition errors. To reduce these reflections on the brick surfaces, we applied a thin layer of mat lacquer to the top of the LEGO bricks. This lead to a significant improvement of the visual recognition. Figure 3 shows the comparison of the original bricks and the same ones with a thin layer of mat lacquer.

Due to visual detection failures when manipulating the bricks with the hands, we decided to use a foot pedal for shortly pausing the visual recognition while placing bricks. We could have used any other off-the-shelf foot pedal, but developed a custom LEGO foot pedal to underline the brick-based nature of the instrument. We also tested another approach for preventing miscalculation during placing bricks using an ultrasonic sensor. We tested a LEGO Mindstorms distance sensor for detecting the human hand and pausing the recognition. However, this sensor was not accurate enough as it fluctuated too much and we discarded this idea.

The prototype code base is available on GitHub. [5]

5.3 Brick to sound mapping

The basic concept of the brick to sound mapping is that the 32x16 studs LEGO ground plate is a sequencer where the x-axis (32 studs) is the timeline and the y-axis determines the note height. In the current setting, the sequencer has 8 measures and a four-four time (8 measures x 4 studs = 32 studs). For a better orientation, we have drawn a thin line on the plate every four studs (not recognised by the visual recognition), to identify the bars more easily.

The size of a brick represents a specific duration. For instance, a 2x2 brick is interpreted as an quarter note while a 4x2 brick is interpreted as a whole note. The vertical position of the brick determines the pitch. Note, that for a better handling and for allowing multiple pins to be stacked on the brick, we use 2 studs height bricks, but the upper row of studs determines the position. Figure 4 shows a schematic illustration of the brick to sound mapping.

Besides offering a general pattern for creating melodies or chords, the basic brick notation does not allow further modulation of the sound. Therefore, we developed further possibilities for sound modulation. The colour of a brick determines an instrument type. For example, a white brick represents piano sound, a red brick a kalimba sound, etc.

Additionally, bricks can be extended with coloured pins (cf. Figure 3). A green pin transposes a note up by an octave and a red pin transposes a note down by an octave. Black pins increase the volume of a note. The position of the pin on the brick and the number of pins does not matter, multiple pins of the same color lead to the same result. However, multiple pins of different color can be applied to one brick (cf. Figure 3).

Another interaction technique is brick rotation which changes a sound effect. The effect type is currently set fixed in program code

[5] https://github.com/waldhoer/brickmusictable

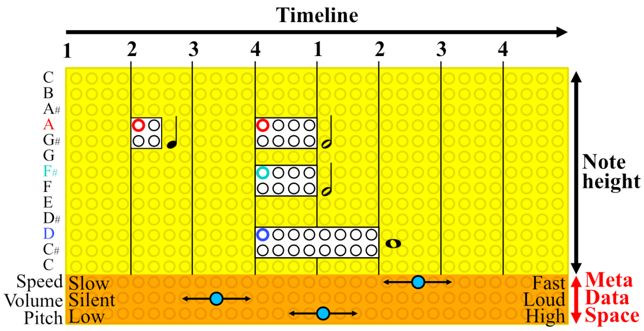

Figure 4: Schematic harmony in D major on the 32x16 LEGO ground plate

but could be expanded. Due to simplicity a basic wobble effect was chosen. The degree of the rotated brick determines how much the effect will be applied: While a slightly rotated brick (e.g., 20 degrees) only has a small impact, a 60 degree rotated brick, for instance, will have a strong effect amount. As bricks cannot be simply rotated on the ground plate a round pin is required to be clipped underneath its bottom center.

The three lowest rows on the plate are reserved for so called metadata pins. Each row represents a horizontal slider for a specific value: speed, volume and pitch of the whole sequencer. Placing a pin on a row further left will decrease the respective value and further right will increase the value. Without pins in either of these rows, default values are used. The colors of these pins are not recognised and used.

Both mappings, to put additional pins on top of the bricks and to use lower rows as slider for sequencer options, were ideas of musicians we included in the iterative prototype development. The mapping of rotation was added without peer feedback to broaden the range of interaction methods. Currently, rotating a brick causes a simple tremolo effect.

For demonstration purposes and to get a better impression of how the MusicBrickTUI works, there is a video available which explains the functionality and demonstrates the instrument's sound capabilities. [6]

6 Formative evaluation

We included four testers aged between 20 and 30 in a formative evaluation during the prototype development who attended between seven and twelve years education on musical instruments (i.e. drums, guitar, bass guitar and saxophone). All of them were hobby musicians and skilled in playing at least one musical instrument. They were hired through one author's near musical milieu. The formative evaluation itself happened in two steps.

For the first evaluation step, we showed our prototype to each of the three testers separately. The test session included an introduction of the instrument concept in general and how to play it. Each tester had about ten minutes for playing and interacting with the instrument. Afterwards each of them were asked to give feedback and suggest new interaction methods for the brick notation and

[6]https://youtu.be/pTw-Q8GOd1w

Feedback received	Implemented
Using fixated rotation values for different sound effects	No
Adding volume- or accent bricks above or next to a note brick	Yes
Dedicated space on the ground plate for meta data (e.g., general volume or speed) reserved to be used in combinations with semantic-associated pins or bricks	Yes
Using rotation of bricks as glide between two notes	No
Using pins on bricks for accents or octave shifting	Yes
Allowing vertical bricks to be split into multiple bricks	No
Another foot pedal used for octave switching	Yes
Adding visual marks for note height on or next to the ground plate	Yes
Adding visual marks for beats on or next to the ground plate	Yes
Improving the display shown while pressing the foot pedal	Yes
Fixing bugs regarding brick rotation	Yes
Usage of a semi-open box as mounting	Yes
Improving foot pedal quality	Yes
Mark note lengths on bricks	Yes

Table 2: Overview of feedback received during the evaluation

handling. To get a broad range of results, the sessions were held without specific questionnaires, intending for the testers to provide feedback more freely. We structured and prioritised the feedback from all three in relation to general feedback and feedback on new interaction methods. Table 2 shows all suggested improvements and new interaction methods. Due to time and resource limitations of this study, we could not consider all improvements and interaction techniques, but focused on the most important ones as indicated in the rightmost column of Table 2.

The second evaluation happened after three weeks when all prioritised features were implemented. The testers included in this round were the same three and an additional tester. The reason for contribution of the fourth additional participant was a sudden dropout before the first evaluation. To enable the fourth interested person to contribute, it was still involved within the second evaluation. This evaluation step was held as a group workshop with all four testers. The reason for a group setting instead of another round of individual tests was to bring all ideas and feedback together at once this time for having a discussion among all testers.

Although new interaction methods were suggested, in general less feedback was given than in the first interview round. We suppose this decrease in feedback is connected to the creative workflow of the participants. As the participants already gave much feedback in the first round, the pool of ideas is potentially smaller in the second evaluation. Additionally, the prototype used within the second evaluation offered less room for technical feedback, as many inputs on bugs and errors were already resolved.

7 Reflection

One of our preliminary design decision for the *BrickMusicTable* was the downwards-facing camera approach for enabling more interaction techniques with bricks. Compared to tabletop TUIs using

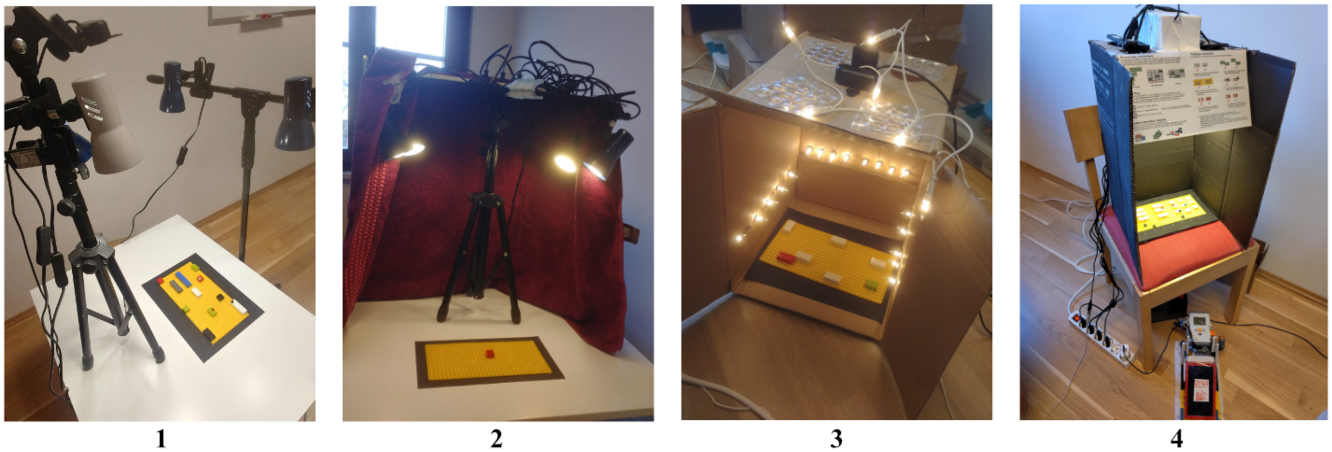

Figure 5: Different preliminary mounting prototypes

an upwards-facing camera, our top-down approach indeed offered more and simpler options for using stacked bricks (i.e., with small coloured pins) and enabling more expressivity without requiring special hardware wiring as in other prototypes [3, 10]. Although, musical expressivity is currently still limited and offers less possibilities than other brick- and sensor-based musical interfaces [13]. However, the *BrickMusicTable* allows a performer to play different sounds within the sequencer by using coloured bricks. Also, expressivity can be easily extended, however, by mapping more coloured pins to new sound modulation options. Another way would using different shapes of bricks (e.g., round bricks, square pins) which multiply the options for musical expressivity. In any way, further interaction methods can be added easily and software-based and existing mappings can be exchanged without much effort adapting the OSC commands.

A disadvantage of the top-down camera recognition is clearly the risk of unwanted sound modulation when manipulating bricks with the hands between the camera and the ground plate. Our approach of using a foot pedal works in principle, but is less convenient and performer friendly as it requires an additional action while playing and pauses the interaction for a few seconds. For instance, using a distance sensor or a software-based analysis could do this automatically, but they would also require more effort in developing them.

Related to the disadvantages of using a foot pedal is an increased delay due to pausing the visual recognition for a few seconds. Other prototypes seem to offer more accurate results in terms of brick mapping robustness. Similarly, other prototypes capture and map bricks or objects in general using an infrared camera [8, 18, 21, 22]. Our solution requires more effort within resolving lightning issues and is rather prone to visual errors. However, with further investment we assume that most current visual difficulties could be solved by enhancing the visual recognition of our implementation. While usage of an infrared camera may resolve the difficulties we faced within our implementation, usage of an ordinary web camera offers a much simpler application. Thus, concerning the visual recognition technique we observed that our approach exhibits more issues relating brick mapping accuracy, but it offers more fine-grained interaction techniques, compared to the prototype by Barbancho et al. [3] or LoopBlocks [9]. An infrared camera would not allow the visual recognition of different colours of bricks and pins put on top of bricks, for instance.

We found that using a semi-open cardboard box reduces external light interference significantly, leading to more reliable image analysis. However, this sight barrier makes it hard or rather impossible for others than the performer to see when, where and which bricks are placed. An additional visualisation on a screen or projection could display the video captured by the camera or visualising bricks as in [1]. An alternative could be a simple mounting concept only using a camera on a tripod as in [20] and our first tested mounting concept (see Figure 5). However, this lacks a quick instrument setup, requires calibration every time and makes the instrument vulnerable to varying light situations which all apply when thinking of performances.

Regarding usability, the *BrickMusicTable* offers a simple, yet explanation-requiring, TUI as the feedback from the testers showed. Compared to more apparent imitating instrument models, we assume, it requires more time to study the instructions to play the *BrickMusicTable*. For instance, playing an electric LEGO model guitar [4] or *The Playel* [11] may be more straightforward as they both resemble commonly known instruments. However, compared to the tangible music programming prototypes by Jin et al. [14] and Xambó et al. [22], we assume the *BrickMusicTable* offers a more apparent interface. This would need further studies for confirmation though.

In contrast to the *muSurface* [21], where only the melody can be set, our prototype enables configuring multiple sound properties like effects or volume. While the simple interaction method of the prototype by Waranusast et al. [21] is possibly more appropriate for music education, our applied range of musical expression is more likely to be appropriate for live performances. This has to be investigated in depth, though, which brings us to the limitations and future work in this regard.

A current limitation is that our prototype has only been evaluated with hobby musicians in an informal setting rather than involving professional artists and testing the *BrickMusicTable* in a real performance. Moreover, the current mapping is quite ordinary or traditional musically speaking. At this point, involving musicians experienced in more avant-garde electronic music could add new yet unconsidered brick to sound mappings.

In terms of future work, the current prototype must be improved to be used in an actual performance. Firstly, the cardboard box is still quite fragile and could be replaced with a wooden box similar to a cajon, but with one side fully open. Secondly, an additional visualisation showing the inside of the box and the brick-based interface needs to be added for an external spectator-oriented projection.

8 Conclusions

Developing a new interface for musical expression realised as a tabletop TUI using LEGO bricks and reflecting on this process led to new insights into how such a ubiquitous multimedia TUI may be designed. Our top-down camera visual recognition approach enabled new interaction methods like using stackable LEGO pins for additional sound modulation options. At the same time, we observed difficulties regarding the light illumination for a reliable image analysis and unwanted interferences. Our final prototype within a cardboard box resulted in a stable system which benefits transportability and quick setup, but requires an additional visual feedback channel, e.g., on an external screen or projection, for other musicians and the audience to follow the actual playing and manipulation of bricks inside the box by the performer. However, as a case study of novel technology and proof-of-concept, our approach was successful with the next step of making the *BrickMusicTable* ready to be tested in an actual performance.

Acknowledgments

This work was supported in part by the Austrian Science Fund (FWF) under Grant 10.55776/WKP126. We also want to thank the participating musicians of the band Liquid Air and Manuel Helscher for their contributions within the development process of the prototype.

References

[1] Adriano Baratè, Luca Andrea Ludovico, and Davide Andrea Mauro. 2019. A Web Prototype to Teach Music and Computational Thinking Through Building Blocks. In *Proceedings of the 14th International Audio Mostly Conference: A Journey in Sound* (Nottingham, United Kingdom) *(AM '19)*. Association for Computing Machinery, New York, NY, USA, 227–230. https://doi.org/10.1145/3356590.3356625

[2] Adriano Baratè, Luca A. Ludovico, and Dario Malchiodi. 2017. Fostering Computational Thinking in Primary School through a LEGO®-based Music Notation. *Procedia Computer Science* 112 (2017), 1334–1344. https://doi.org/10.1016/j.procs.2017.08.018 Knowledge-Based and Intelligent Information & Engineering Systems: Proceedings of the 21st International Conference, KES-20176-8 September 2017, Marseille, France, urlhttps://doi.org/10.1016/j.procs.2017.08.018 .

[3] Ana M. Barbancho, Lorenzo J. Tardón, and Isabel Barbancho. 2023. Building music with Lego bricks and Raspberry Pi. (2023). https://doi.org/10.1007/s11042-023-15902-z.

[4] Daniele Benedettelli. 2014. LEGO EL3CTRIC GUITAR. https://robotics.benedettelli.com/lego-guitar/.

[5] Daniele Benedettelli. 2018. LEGO MINDSTORMS MIDI trumpet. https://robotics.benedettelli.com/lego-trumpet.

[6] Kasper buhl Jakobsen, Marianne Graves Petersen, Majken Kirkegaard Rasmussen, Jens Emil Groenbaek, jakob winge, and jeppe stougaard. 2016. Hitmachine: Collective Musical Expressivity for Novices. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Queensland Conservatorium Griffith University, Brisbane, Australia, 241–246. https://doi.org/10.5281/zenodo.1176038 https://doi.org/10.5281/zenodo.1176038.

[7] John Canny. 1986. A Computational Approach to Edge Detection. (1986). https://perso.limsi.fr/vezien/PAPIERS_ACS/canny1986.pdf.

[8] Smilen Dimitrov, Marcos Alonso, and Stefania Serafin. 2008. Developing block-movement, physical-model based objects for the Reactable. (2008). https://www.nime.org/proceedings/2008/nime2008_211.pdf.

[9] Andreas Förster and Mathias Komesker. 2021. LoopBlocks: Design and Preliminary Evaluation of an Accessible Tangible Musical Step Sequencer. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Shanghai, China, Article 3. https://doi.org/10.21428/92fbeb44.f45e1caf

[10] Kristian Gohlke, Michael Hlatky, and Bram de Jong. 2015. Physical Construction Toys for Rapid Sketching of Tangible User Interfaces. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 643–648. https://doi.org/10.1145/2677199.2687900

[11] Oliver Hödl. 2024. An Electronic Engineering Approach for Turning a Lego Brick Piano into a Musical Instrument. *IEEE Access* 12 (2024), 51319–51329. https://doi.org/10.1109/ACCESS.2024.3386361 https://doi.org/10.1109/ACCESS.2024.3386361.

[12] Kasper Buhl Jakobsen, Majken Kirkegaard Rasmussen, and Marianne Graves Petersen. 2015. Framing open-ended and constructive play with emerging interactive materials. In *Proceedings of the 14th International Conference on Interaction Design and Children* (Boston, Massachusetts) *(IDC '15)*. Association for Computing Machinery, New York, NY, USA, 150–159. https://doi.org/10.1145/2771839.2771855

[13] Kasper Buhl Jakobsen, Jeppe Stougaard, and Marianne Graves Petersen. 2016. Expressivity in Open-ended Constructive Play: Building and Playing Musical Lego Instruments. In *Proceedings of the The 15th International Conference on Interaction Design and Children* (Manchester, United Kingdom) *(IDC '16)*. Association for Computing Machinery, New York, NY, USA, 46–57. https://doi.org/10.1145/2930674.2930683

[14] Qiao Jin, Danli Wang, Haoran Yun, and Svetlana Yarosh. 2023. Shape of Music: AR-based Tangible Programming Tool for Music Visualization. In *Proceedings of the 22nd Annual ACM Interaction Design and Children Conference* (Chicago, IL, USA) *(IDC '23)*. Association for Computing Machinery, New York, NY, USA, 647–651. https://doi.org/10.1145/3585088.3593872

[15] Sergi Jordà, Martin Kaltenbrunner, Günter Geiger, and Ross Bencina. 2005. THE REACTABLE*. *Proceedings of the International Computer Music Conference.* http://hdl.handle.net/2027/spo.bbp2372.2005.172 .

[16] Scott McCoid, Jason Freeman, Brian Magerko, Christopher Michaud, Tom Jenkins, Tom Mcklin, and Hera Kan. 2013. EarSketch: An integrated approach to teaching introductory computer music. *Organised Sound* 18, 2 (2013), 146–160. https://doi.org/10.1017/S135577181300006X https://doi.org/10.1017/S135577181300006X.

[17] Jennifer Müller, Uwe Oestermeier, and Peter Gerjets. 2017. Multimodal interaction in classrooms: implementation of tangibles in integrated music and math lessons. In *Proceedings of the 19th ACM International Conference on Multimodal Interaction* (Glasgow, UK) *(ICMI '17)*. Association for Computing Machinery, New York, NY, USA, 487–488. https://doi.org/10.1145/3136755.3143018

[18] Uwe Oestermeier, Philipp Mock, Jörg Edelmann, and Peter Gerjets. 2015. LEGO music: learning composition with bricks. In *Proceedings of the 14th International Conference on Interaction Design and Children* (Boston, Massachusetts) *(IDC '15)*. Association for Computing Machinery, New York, NY, USA, 283–286. https://doi.org/10.1145/2771839.2771897

[19] OpenCV. 2024. Imgproc.findContours - OpenCV 3.4.20 Java documentation. (2024). https://docs.opencv.org/3.4/javadoc/org/opencv/imgproc/Imgproc.html.

[20] Paul Wallace. 2018. Lego Music - Ynformatics. https://ynformatics.com/2018/lego-music-tangible-user-interface/.

[21] Rattapoom Waranusast, Arin Bang-ngoen, and Jeerapa Thipakorn. 2013. Interactive tangible user interface for music learning. In *2013 28th International Conference on Image and Vision Computing New Zealand (IVCNZ 2013)*. 400–405. https://doi.org/10.1109/IVCNZ.2013.6727048 https://doi.org/10.1109/IVCNZ.2013.6727048.

[22] Anna Xambó, Brigid Drozda, Anna Weisling, Brian Magerko, Marc Huet, Travis Gasque, and Jason Freeman. 2017. Experience and Ownership with a Tangible Computational Music Installation for Informal Learning. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (Yokohama, Japan) *(TEI '17)*. Association for Computing Machinery, New York, NY, USA, 351–360. https://doi.org/10.1145/3024969.3024988