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New Additions to the Guitar Family: Lego and Automatic Microtonal Guitars

ABSTRACT

One of the modern classical guitar's biggest strengths is also one of its biggest weaknesses. The instrument depends on an equal temperament fretboard system that has lent itself to brilliant repertoire and ease of production, yet this same fretboard system does not lend itself to perfectly tuned notes and tuning systems not found in Eurocentric classical music. Many guitarists and luthiers have sought a fretboard system that marries the benefits of equal temperament with the rich possibilities of just intonation and other tuning systems. This paper presents two new fretboard designs and discuss their role in the history of guitar fretboard construction. Our first design is a fully functional fretboard made from the popular toy 'Legos' and solves many of the problems that previous designs had, including ease of use and production, affordability, and versatility. Our second design is a one-string prototype for an automatic (automated) fretboard that would allow performers to switch tuning systems instantly at the press of a button.

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Introduction

Today's standard guitar is a 12TET[1] (12 tone equal temperament) instrument that works much like a piano. Pitches on the guitar and piano are tempered (modified from their pure form) and fixed into place (permanently in the case of standard guitars without moveable frets) (Duffin, 2007: 38). The advantage of 12TET tuning is pitches that are consistently usable in the context of any of the 24 major and minor keys of Western harmony (Field, 2008: 12). This means that the 12TET tuning system allows for key modulation, ease of collaboration with other Western instruments, and ease of manufacturing guitars since the precise measurements of their fret locations are standardized to remain in 12TET tuning. This system has some disadvantages as well, most notably the inability to play the natural tones (ratios) in just intonation, the inability to play the tuning systems of Renaissance and Baroque era such as meantone and well temperaments, and the inability to play tones found in other styles of music such as Turkish *makam* music or Balinese *Gamelan* music because of the unchangeable nature of a fixed-tone (fixed-fret) instrument (Field, 2008: 15-16). Guitarists and luthiers have made many attempts to expand the tuning system possibilities of the guitar over the years by either altering the layout of the fixed-frets, or providing ways to change the location of frets, yet there is still room for improvement. In order to help improve on this lineage of guitar fretboard development, our multi-discipline team consists of engineers and musicians in Istanbul designed and built two new fretboard designs. The first design is a Lego fretboard that uses easy-to-move Lego pieces as the basis to achieve new fret positions. The second design uses electronics to move guitar frets into new positions automatically. These designs offer new solutions and new ways of thinking to overcome the design limitations of the past.

Brief History of the Microtonal Guitar

The first innovations in microtonal guitar were adaptations designed to play either in just intonation or to correct the intonation problems of the 12TET guitar. The first 'Enharmonic Guitar' was designed by Thomas Perronet Thompson and constructed in London in 1829 by luthier Louis Panormo. This guitar used a system of hundreds of small holes in which frets could be inserted (Button, 1984: 248). In 1845 in Paris, luthier René

[1] 12TET will be used throughout to refer to a system in which an octave is divided into 12 equal tones. Also known as 12EDO (equally divided octave) and equal temperament.

Lacôte created the '*Guitare à Tempérament Réglable*' ('Adjustable Temperament Guitar'). The frets on this guitar were individually mounted onto long blocks of ebony and could be adjusted slightly (Schneider, 2015: 61). In Stuttgart in 1911, luthier Paul Kochendorfer built a guitar designed by Otto Paret. This complicated design contained a mechanism allowing for the adjustment of multiple frets simultaneously using levers fixed on the side of the guitar (Schneider, 2015: 187).

The next wave of innovation came from new divisions of the octaves on the guitar. Previously 12TET was the norm, but innovators soon began using the 24TET guitar (quartertone guitar) which became one of the more popular designs. In 1927, Augusto Navarro suggested new equally tempered guitars such as 15TET, 29TET or 31TET (Schneider, 2015: 171-172). While these designs do provide new microtonal possibilities, they also become more difficult to play as guitars with greater octave divisions leave less space in between frets for guitarists to place their fingers. These extra frets also create a lot of notes that will not be needed in any practical circumstance**.** Many guitarists have solved this by removing the unnecessary frets. However, this still does not allow for the subtle adjustments needed to play *makam*s or just intonation. Another solution came from the American composer Harry Partch in 1940s. He repositioned all the frets on his 'Adapted Guitar #1' to match the ratios called for in his piece 'Barstow's premiere in 1941. In the 1970s, Tom Stone created the 'switchplates' guitar design allowing performers to easily remove the fretboard and replace it with various different fret configurations.[2] This system works well for quick changes, but it is limited by the number of fretboards that must be designed and built. At least one version of this idea is still in production today.[3] A popular recent solution has been to affix 'fretlets' (small frets) to 12TET fretboards with tape. These temporary frets can be taped precisely onto the fretboard fixing the intonation of certain notes. While this does provide a level of precision not achieved by permanently fixed frets, it is still not a perfect solution because the standard 12TET frets cannot be moved and will sometimes block an area of the fretboard where a fret could be added with tape. It is more precise if individual frets can

[2] The patent was entitled "Fretted musical instrument with detachable fingerboard for providing multiple tonal scales" numbered US4132143A (https://patents.google.com/patent/US4132143).
[3] Microtone Guitars LLC founded by Michael Kudirka can be found here https://www.microtoneguitars.com/

be precisely moved into position without the need to add additional frets for every microtone.

To this end, there have been many movable-fretted microtonal guitar designs, such as those by René Lacote, Daniel Friederich, and Walter Vogt. Tolgahan Çoğulu designed a moveable fret guitar entitled 'Adjustable Microtonal Guitar' in 2008, which was built by luthier Ekrem Özkarpat. The distinguishing feature of the 'adjustable microtonal guitar' is that the frets can be added or removed from the fretboard individually without effecting the other frets. The previous designs by Lacote, Friederich, and Vogt require all the frets to be moved in order to add additional frets from the side of the fretboard. Çoğulu's design won first prize in the 2014 Guthman Musical Instrument Competition at Georgia Tech University USA.

Lego Microtonal Guitar

The team who designed and built the Lego microtonal guitar consists of Tolgahan Çoğulu, Atlas Çoğulu, and Ruşen Can Acet. During the project Selçuk Keser provided sponsorship and assistance with 3d printing. While playing with Legos in 2017, Tolgahan Çoğulu's 7-year-old son Atlas Çoğulu came up with the idea of building his father's adjustable microtonal guitar fretboard. In this prototype, he put Legos into the fret positions accordingly.

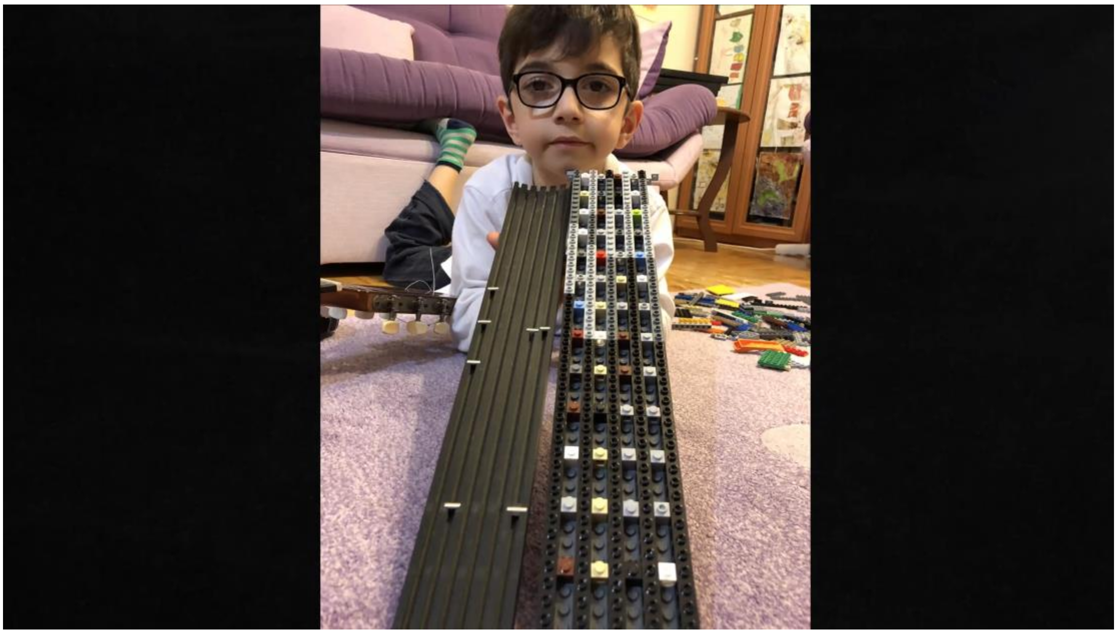

Figure 1. First Lego fretboard, created by Atlas Çoğulu (Tolgahan Çoğulu, Personal Archive)

This prototype led to the idea of using Lego pieces for both the frets and the fretboard, allowing the microtonal fretboard problem to be solved from a new angle. This idea bears a resemblance to the mechanism behind the first microtonal guitar design the 'Enharmonic Guitar'. After examining all known Lego guitars in 2018, none could be found that included a fretboard constructed out of Lego; in addition, all previous Lego guitars used standard 12TET fretboards, which limited them to one tuning system by default.

Baseplate

There were two main design and manufacturing problems present at the beginning of the project. First, original Lego pieces had to be attached to the fretboard, and second, Lego frets had to be designed that could function like standard guitar frets while also being placed and removed easily by the performer. Ruşen's engineering goals for the Lego microtonal guitar project were to design a system that was easy to replicate, easy to construct, easy to use, and minimalist in design.

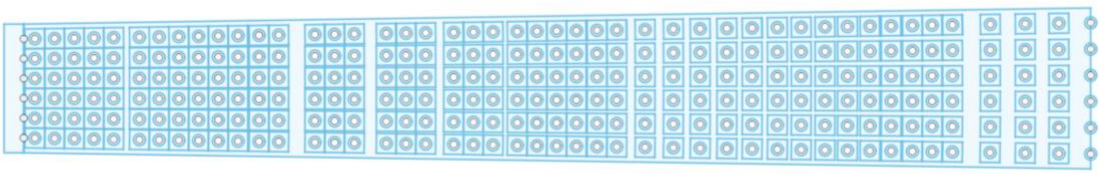

Figure 2. 2D view of Lego fret system (Tolgahan Çoğulu, Personal Archive)

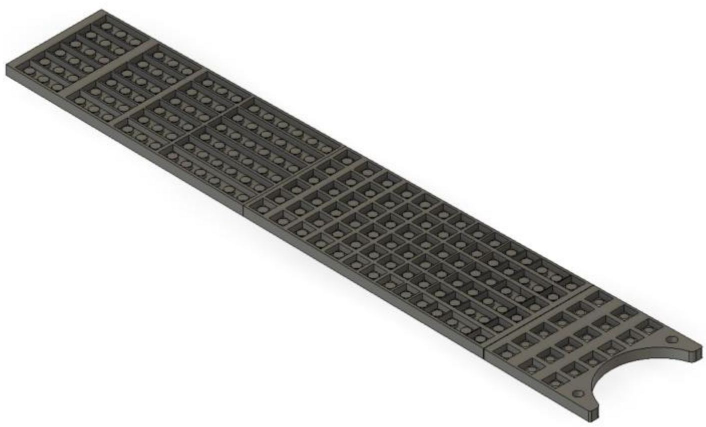

Figure 3. 3D model of the baseplate (Tolgahan Çoğulu, Personal Archive)

The fretboard and fret system were designed to fit a standard size classical guitar and 2D modeled. Lego studs were located between 12TET fret locations. Each Lego line was aligned with the string angle determined by the nut. The top priority was to implement the correct 12TET studs into the 3D model. After the 12TET studs were positioned correctly, 24TET studs and further divisions were added wherever possible. More studs were able to fit in-between the 12TET studs in the lower register of the guitar due to the wider 12TET fret spacing in this register. After all fret positions were defined, a 3D printable baseplate was designed such that original Lego pieces could be inserted precisely. The baseplate was divided into four parts in order to make 3D printing easier. PLA and PET-G materials were used for 3D Printing.

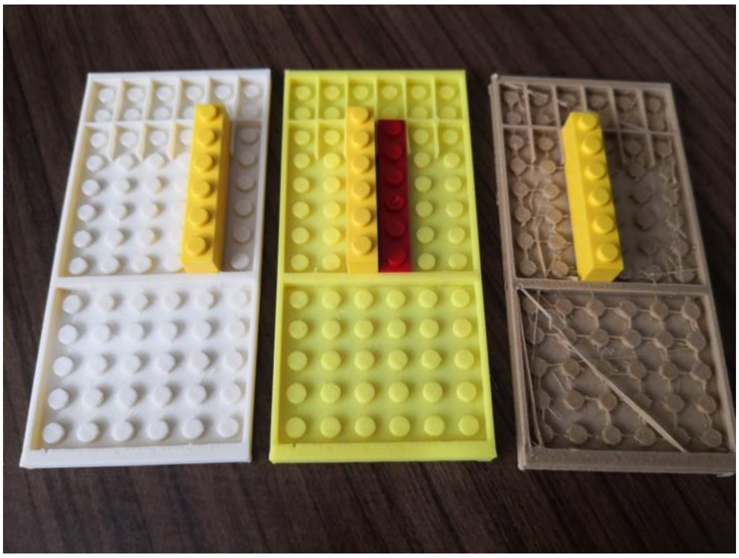

Figure 4. Some 3D printed trials (Tolgahan Çoğulu, Personal Archive)

Frets

The first fret design idea was to insert metal fret rods into original single 1x1 Lego blocks and use them as microtonal frets. Building these frets was time-consuming, and the result was unstable because they were made by hand and not done precisely. Therefore, 3D printing technology had to be used for these parts as well. The process of modeling different fret shapes was relatively straightforward, and the first frets were prepared in only a couple of hours. Engineer and maker Selçuk Keser contributed to the project by printing these frets and calibrating the sizes to fit tightly on Legos.

Figure 5. Fret designs (Tolgahan Çoğulu, Personal Archive)

Manufacturing

The previously inserted Legos and fretboard were removed in the workshop. The guitar's neck was reconstructed and get ready for 3D printed baseplate. Then, the baseplate was glued on the guitar's neck. The guitar's bridge and nut were re-built and adjusted accordingly.

Figure 6. Neck reconstruction, and application of baseplates (Tolgahan Çoğulu, Personal Archive)

Figure 7. First Lego microtonal guitar (Tolgahan Çoğulu, Personal Archive)

Figure 8. The final version of Lego microtonal guitar (Tolgahan Çoğulu, Personal Archive)

Developments After Creating The First Fully Functional Prototype

During an interview with *bağlama* player Sinan Ayyıldız, he suggested designing new frets raised at the sides or other points rather than in the center, which increased the number of achievable microtones (Sinan Ayyıldız, personal communication, February 12, 2021). Since many tuning systems including *makam* tunings need many microtones to be performed correctly, it is important to have as many options for fret placement as possible within the design limits; now, all tuning systems are possible with the right fret shapes. Having several fret design shapes allows for full control of fret placement while maintaining the ease-of-use set as an engineering goal for the project.

Figure 9. Fret idea suggested by Sinan Ayyıldız (Tolgahan Çoğulu, Personal Archive)

The next unexpected development came from a YouTuber and instrument builder who uses the name Simon the Magpie,[4] who was inspired by our design. He built his own Lego bass neck utilizing our ideas and innovated on the original design by using smooth-top original Lego bricks to create fretless zones on his bass guitar. Upon seeing this further innovation, Tolgahan used the smooth Lego bricks for some frets and played a *Rast Taksim* in the video entitled *Some Frets are Fretless Guitar*.[5] This is the first known instance involving a hybrid fretted/fretless guitar. Previous hybrid designs, such as the design below by Ibanez, have involved a split fretboard that renders some strings fretless and others fretted.

[4] The video can be found at the following link: https://youtu.be/yWWYRfVhytw
[5] The video can be found at the following link: https://youtu.be/ktBHjDu_4To

Figure 10. Ibanez SR AS7 bass guitar with split fretboard, showing 3 fretless strings and 4 fretted strings (Hermanny, 2017)

The Lego guitar's hybrid design is completely different, targeting only specific frets on specific strings for fretless notes.

Figure 11. Example of a smooth Lego brick being used on only one string and one fret (Tolgahan Çoğulu, Personal Archive)

Post-Creation Period

After the creation of the Lego Microtonal Guitar, Tolgahan discovered that the easily added frets can be positioned in ways to teach music theory on the guitar. By adding only the frets needed for specific scales, it is easy for students to learn different scale patterns. The first test of this pedagogy idea can be seen in the video[6] where a middle-school conservatory student in Istanbul had learned 18 different scales (four of which are microtonal) in two guitar lessons. Tolgahan plans to do further experiments with Lego colors and placement in relation to pedagogy.

The Lego microtonal guitar received a lot of attention via media coverage and Youtube views. Currently the video *Lego Microtonal Guitar* has over 1 million views on Youtube, and there is a video that includes footage of renowned American guitarist Kaki King playing the guitar.[7] The design received the People's Choice Award at the 2021 Guthman Musical Instrument Competition hosted at Georgia Tech University USA (the same award won by Tolgahan in 2014). After receiving this award, Atlas and Tolgahan were featured in Turkish news in both print and in TV segments for CNN Turkey and NTV. The Lego guitar also received international press in the *New York Times* and in the French publication *Les Explorateurs*.

A distinguishing feature of using Legos on the guitar is that anyone in the world can potentially participate in the design process because of Lego's standard sizes, ease of use, and availability. For example, players can use any colors they want for any frets and even cover the soundboard with Lego bricks and change their guitar's color. Working in conjunction with 3D print technology, both the guitar construction process and the fretboard modification processes can be done from anywhere in the world.

Automatic Microtonal Guitar

The team who designed and constructed the first Automatic Microtonal guitar consisted of Tolgahan Çoğulu, Selçuk Keser and Batuhan Başar. In 2014, Tolgahan began to think about automizing his manually working adjustable microtonal guitar. His dream was for all the frets to move to the desired locations of any tuning systems in any key at the press of a button. He started collaborating with Dr. Zeki Yağız Bayraktaroğlu and Dr. Bülent

[6] The video can be found at the following link: https://youtu.be/4LqfqW4gL5E
[7] The video can be found at the following link: https://youtu.be/rPCEImSfCwc

Bölat from Istanbul Technical University's mechanical engineering department. After a few trials with horizontal moving frets, they changed plans and began experimenting with vertical moving frets because they were unable to find an ideal activation mechanism. They 3D-printed modules which had 6 frets and planned for 100 modules to play as many tuning systems as possible; however, after a few years, the project came to a halt due to lack of funding.

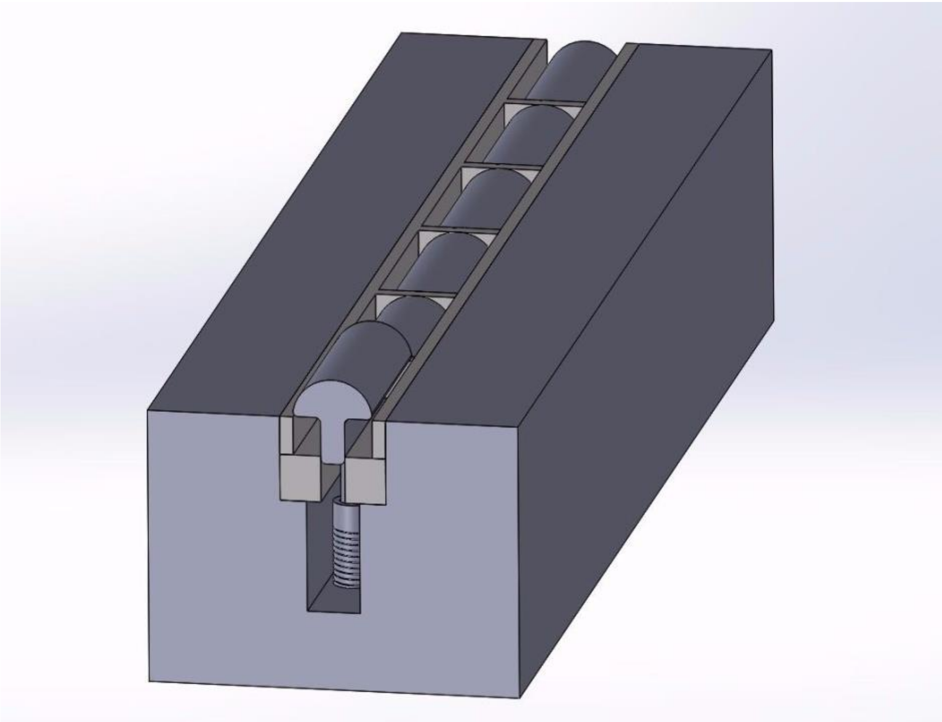

Figure 12. Previous design for vertically-moving frets (Tolgahan Çoğulu, Personal Archive)

In 2019, Tolgahan received research funding from Istanbul Technical University for a project entitled *The Design and Production of the Automatic Microtonal Guitar*. In 2020, engineer and maker Selçuk Keser, came up with an idea for horizontally moving frets. In 2021, they completed a one-string prototype on which 12 frets on the first string can be moved automatically to 10 different tunings (12TET, *Rast, Hüseyni, Uşşak, Sabâ, Segâh, Karcığar, Hüzzam*, KGLW and Pelog Selisir).

The Design

The system consists of a microcontroller, motor driver, linear servo motor, OLED display, rotary encoder and a power adapter. The system was prototyped for 12 frets on one string. In the system one micro linear servo-type motor was used for each fret that needed to be moved horizontally.

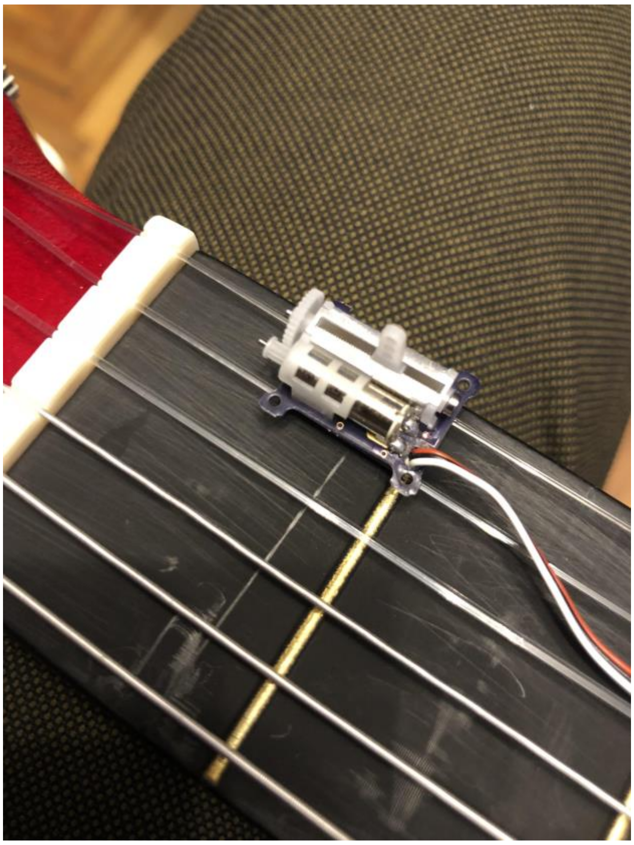

Figure 13. Linear servo-type motor on the standard classical guitar fretboard (Tolgahan Çoğulu, Personal Archive)

Modules were 3D printed on the motor shaft to imitate the frets. When the player selects a preset position setting, a signal sent to the motor moves each fret along the shaft in accordance with the correct microtones. The minimum and maximum positions that each shaft can move is expressed between the numbers 0 - 100. The point where the fret position should be according to the *makam*s was determined numerically in advance. The stored information containing the fret positions is defined by the Arduino Mega 2560 and sent to the PCA9685 servo motor driver, which can drive twelve different motors separately at the same time. The task of the motor driver is to transfer the electrical power from the power adapter to the servo motors according to the signal from the Arduino.

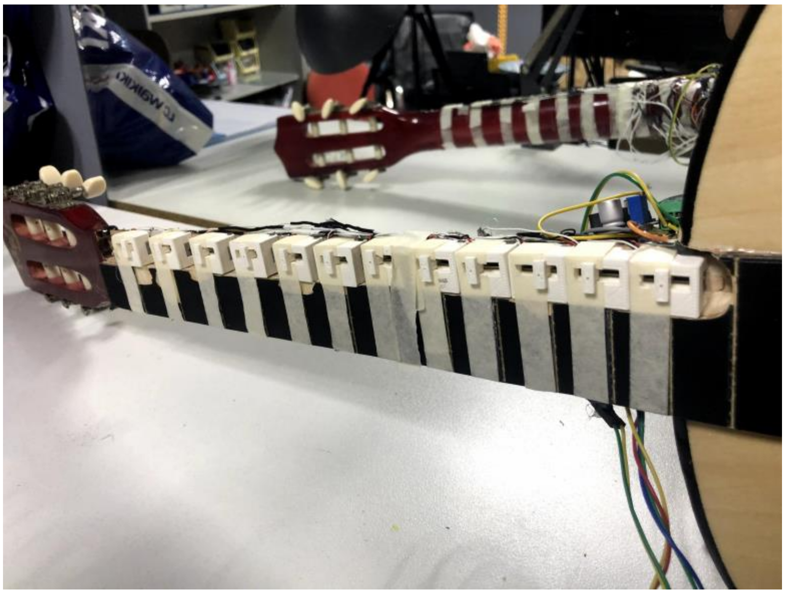

Figure 14. Modules installed into the fretboard (Tolgahan Çoğulu, Personal Archive)

Apart from motion control, there is an OLED screen and a rotary encoder that creates the user interface in the system. The *makam*s defined on the Arduino are displayed on the OLED screen and the encoder is rotated clockwise or counterclockwise to choose between the *makam*s.

Figure 15. OLED screen and the rotary encoder (Tolgahan Çoğulu, Personal Archive)

In order to apply the preference, the player presses an encoder which directs the motors to set the frets in the correct position. Each *makam* name displayed on the screen represents data sets that hold motor positions. When a player makes a selection from the interface, the position information of that *makam* is sent to the motors and the motors maintain their positions and ensure that the frets are in the correct location to produce the desired tone.

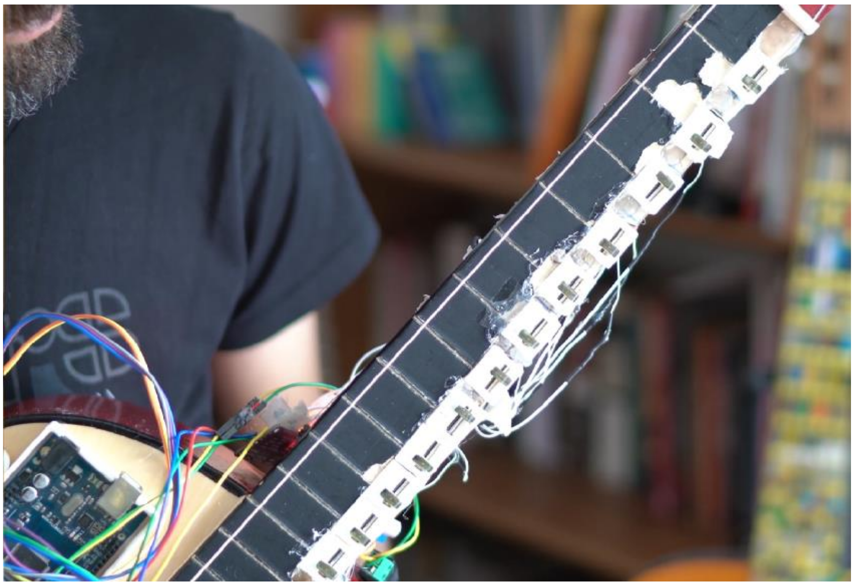

Figure 16. One-string prototype of the automatic microtonal guitar (Tolgahan Çoğulu, Personal Archive)

The project resulted in a working prototype and a YouTube video which was used to ask for additional funding and new designs from around the world.[8] This prototype changes tunings faster than any other fretboard design in history, however at the conclusion of the project no further potential to expand beyond one string exists. Therefore, the team hopes this idea will be a catalyst to continue designs in this area, now that they have proved it is possible. At the time this paper was written no serious funding or design offers have been submitted. Tolgahan has reached out to several friends in hopes of collaborating on a new vertical design. Although Tolgahan is happy with the results of this first trial guitar, ultimately he believes that the vertical design holds more potential for future projects.

Conclusion

Two teams of innovative guitar players and engineers have developed two unique guitar fretboard designs that fit neatly into the lineage of luthier innovation that came before them. The 'Automatic Microtonal Guitar' is the first ever guitar of its type, a system that uses electronics to move frets into various configurations quickly. The prototype

[8] Video can be found here https://youtu.be/zbbyikFthEc

demonstrates the potential of using new ideas and technology to overcome the problems and limitations of the guitar fretboard. While this idea continues to incubate in the prototype phase, the ‘Lego Microtonal Guitar’ is already finding its home within the history guitar fretboard construction. With the creation of the Lego microtonal guitar, the modern microtonal guitar journey has returned to its roots in 1829 with an independent design resembling the first known iteration of microtonal guitar. By using two types of easily configurable (custom designed) Lego pieces as frets, any reasonable configuration of microtones can be achieved by placing these frets on the studs as they are spaced on the fretboard baseplates. 3D-print technology enables the existence of such a guitar as well as its accessibility by people around the world without the time-consuming manufacturing processes that previous designs required. The world’s most popular instrument has joined forces with the world’s most popular toy, the potential for transforming guitar education and increasing engagement with world music communities are some of the most exciting things on the horizon for the microtonal guitar future.

REFERENCES

Button, Stewart W. (1984). “The Guitar in England 1800-1924” PhD. Dissertation, University of Surrey, Surrey: United Kingdom.

Duffin, Ross W. (2007). *How Equal Temperament Ruined Harmony (and Why You Should Care).* New York: W.W. Norton and Company.

Field, Anthony (2008). “Tuning the Classical Guitar: A Commentary and Guide” Masters Thesis, The University of Melbourne, Melbourne: Australia.

Hermanny, Franck, (2017) Ibanez SR AS7 Ashula II TEASER - 7-string fretted/fretless hybrid bass. (screenshot) Retrieved from https://youtu.be/KEireRFmy7Q on 14th April 2022

Schneider, John. (2015). *The Contemporary Guitar*. Lanham: Rowman and Littlefield.