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RECYKLUNG: ANGKLUNG INSPIRED MODULAR IDIOPHONE BASED ON SURFACE, BEHAVIORAL AND FUNCTIONAL MIMICRY USING RECYCLED MATERIAL

Bismo Jelantik Joyodiharjo[1*], Anugrah Sabdono Sudarsono[2], Yasraf Amir Piliang[1], Dwinita Larasati[1], Tati Suryati Syamsudin[3]

[1]Faculty of Arts and Design, Institut Teknologi Bandung, Bandung, Indonesia
[2]Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung, Indonesia
[3]School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia

Abstract. This article reports on the design process of recyklung idiophone innovation, focusing on three aspects of mimicry: surface, behavioral and functional. The tubular resonance chamber characteristics of the traditional Angklung were explored, with geometrical variations made possible through additive manufacturing methods. The idiophone rattling configuration of Angklung is primarily maintained, with improvements in modular systems to simplify the production process. Several computer-aided designs (CAD) of angklung tubes with modular configurations were developed and physical samples were subsequently created using (fused deposition modeling (FDM) rapid prototyping method and recycled PLA (Polylactic Acid) material. Furthermore, the sound characteristics of the produced samples were compared to those of the original bamboo Angklung in a sound chamber in a controlled environment. The results indicate that different forms of Angklung tubes produce distinct sound characteristics, which can enhance the creative possibility of composing new Angklung pieces.

Keywords: *Design, heritage, innovation, morphology, safeguarding, sustainability*.

*[*]**Corresponding Author:** Bismo Jelantik Joyodiharjo, Faculty of Arts and Design, Institut Teknologi Bandung, Bandung, Indonesia, Tel.: 6281221811150, e-mail: bismojo@itb.ac.id*

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1. Introduction

The angklung is a distinctive musical instrument that has been an integral part of Indonesian culture for centuries. Originating from the island of Java, the angklung is a percussion instrument composed of a varying number of bamboo tubes suspended in a bamboo frame. Each tube is tuned to a specific note and when shaken, the tubes produce a unique, resonant sound (Nugraha, 2015).

The origins of the angklung can be traced back to the 16th century, where it was used in traditional Sundanese rituals and ceremonies (Kurniawan *et al*., 2021). Over time, the angklung evolved from a spiritual instrument to a popular form of entertainment, with its melodic tones and rhythmic patterns becoming a hallmark of Indonesian music.

Angklung, a traditional musical instrument from Indonesia, has long been an integral part of the nation's cultural heritage. This unique bamboo instrument, with its distinctive rattling sound, has played a significant role in shaping the cultural identity of the Sundanese people, an ethnic group residing in the western region of Java (Arifitama & Syahputra, 2017; Sugandi & Sungkawa, 2018). This recognition also contributes to the broader goal of promoting cultural diversity and fostering intercultural dialogue, which are key objectives of UNESCO's cultural heritage initiatives (Grant, 2018).

The angklung, a traditional Indonesian musical instrument, has a fascinating history that spans its development from a rhythmic percussion instrument to one capable of playing diatonic scales. Originally, the angklung was used primarily for its rhythmic qualities, producing a distinctive rattling sound through the interplay of its bamboo tubes (Marjieh *et al*., 2024). Over time, the angklung's tuning system evolved, transitioning from the pentatonic scale commonly found in traditional Indonesian music to the diatonic scale more familiar to Western audiences (Sudarsono & Merthayasa, 2013; Marjieh *et al*., 2024). This recognition not only helps preserve angklung but also promotes its continued practice and transmission to future generations.

As a musical instrument, the development of angklung is still limited to scales and the use of bamboo as the main material. Therefore, the sound characteristics can be further developed while maintaining the method of playing the instruments. One method to develop an angklung with different sound characteristics is to explore different materials and shapes. Exploration can be achieved by implementing 3D printing technology and the concept of mimicry to explore different shapes of angklungs.

The rapid advancements in 3D printing technology have opened up new avenues for the development of innovative musical instruments. One intriguing approach is the integration of 3D printing and the concept of biomimicry, which involves the imitation of natural structures and processes to solve complex design challenges (Yang *et al*., 2018).

Additive manufacturing or 3D printing, has been a game-changer in the field of biomimicry, allowing for the creation of intricate, multiscale structures that closely mimic those found in nature (Yang *et al*., 2018). As highlighted in the literature, 3D-printing technology has enabled the fabrication of biomimetic reinforced mechanics, shape-changing and hydrodynamic structures, as well as optical and electrical devices, inspired by a wide range of natural phenomena (Yang *et al*., 2018).

The development of musical instruments using 3D printing and biomimicry can leverage these advancements to create unique and highly functional designs. For instance, the ability to mimic the complex geometries and materials of natural structures, such as the sound-producing mechanisms of various animal species, can lead to the creation of musical instruments with enhanced acoustic properties and novel tonal qualities.

Surface mimicry preserves the fundamental elements of the traditional angklung, including its tubular resonance chamber and idiophone rattling configuration, while exploring new possibilities. This approach ensured that the essential features of the instrument remained intact. The application of additive manufacturing techniques and CAD designs in the Recyklung project illustrates how conventional instruments can be modernized using contemporary production methods. This adaptation may enhance accessibility and reduce the manufacturing expenses. Employing recycled PLA material to construct angklung tubes exemplifies an eco-conscious approach to instrument creation. Studies have shown that the mechanical properties of filaments made from recycled plastic, such as polylactic acid, can be comparable to those made from virgin material (Shanmugam *et al*., 2020). Furthermore, the development of distributed recycling systems can enable the on-site production of 3D printing filament from waste plastic, reducing the energy and emissions associated with centralized recycling and transportation (Lee *et al*., 2018). This used of recycle PLA can enhance the sustainability of Angklung production and resonate with environmentally aware audiences.

The Recyklung design's incorporation of modular systems and behavioral mimicry optimizes the manufacturing process. This strategy could enable simpler maintenance, substitution or personalization of instrument components, potentially increasing longevity and versatility. The utilization of CAD and rapid prototyping demonstrates the integration of technology into conventional instrument creation, which may spark further technological progress in the development of traditional musical instruments. The functional mimicry of geometric variations in resonance tubes, which produces unique sound profiles, creates new avenues for musical composition and performance. This innovation could allow a wider range of musicians and composers to explore Angklung, possibly enhancing its popularity and significance. Recyklung innovation may support angklung conservation by achieving a balance between tradition and innovation, potentially boosting the instrument's appeal, accessibility and relevance in contemporary settings.

2. The Potential of Additive Manufacturing in the Development of Musical Instruments

Additive manufacturing, also known as 3D printing, has emerged as a transformative technology in various industries, including the development of musical instruments (Ramesh *et al*., 2024). This innovative approach offers unique opportunities to create customized and highly specialized musical instruments that can expand the creative potential of musicians and composers (Huang *et al*., 2014).

Additive manufacturing presents several advantages over traditional manufacturing methods, particularly in the realm of musical instrument design and production. One key advantage is the ability to fabricate complex geometries and intricate structures that would be challenging or even impossible to achieve using conventional manufacturing techniques. This opens up new avenues for the design of aerophones, such as wind instruments, as well as idiophones and chordophones, where the shape and internal structure of the instrument can significantly impact its acoustic properties and tonal quality.

A great example of a 3D-printed aerophone is a saxophone (Robertson, 2014). Others include trumpets (Thimmesch, 2015) and experimental wind instruments developed in collaboration with Autodesk Research and Dartmouth College (Saunders, 2016). While not strictly musical instruments, 3D-printed bat heads used in wind tunnels to study aerodynamics (Matisons, 2015) also demonstrate the technology's application to aerophone-like structures.

3D-printed chordophones are less common than aerophones, but they do exist. While I don't have specific examples readily available, technology definitely has the potential to create unique stringed instruments. Imagine a 3D-printed violin with an intricate lattice structure for enhanced resonance (Kasha & Kasha, 1982) or a customized guitar body designed to perfectly fit a musician's form. The ability to create complex geometries with 3D printing (Dunai *et al*., 2020) opens up exciting possibilities in this domain.

Idiophones produce sound through the vibration of the entire instrument. One example of a 3D-printed idiophone is a voice sculpture (Strauss, 2013), created from a 3D-printed representation of sound waves. Although not traditional musical instruments, 3D-printed models of the human vocal tract (Bushwick, 2020; Howard, 2017) can also be considered idiophones, as they produce sound through their own vibration when air is passed through them. These examples highlight the versatility of 3D printing in creating diverse instruments.

Furthermore, additive manufacturing allows for the integration of advanced materials and engineered structures within instrument design (Jared *et al*., 2017). The use of lattice structures, for example, can enhance the acoustic properties of musical instruments by optimizing sound absorption and resonance characteristics (Li *et al*., 2023). This customization and optimization of material and structural properties can lead to the development of instruments with enhanced performance, improved playability and unique tonal characteristics.

3. Shape and Form, Surface Mimicry

Nature has long been a source of inspiration for designers, who have sought to emulate the intricate and often elegant forms found in the natural world. Biomimicry, the practice of learning from and then imitating natural designs, processes and systems, has become an increasingly popular approach in the built environment, offering the potential to enhance sustainability and even generate regenerative solutions (Verbrugghe *et al*., 2023).

At the heart of biomimicry lie the concepts of shape and form, which are inextricably linked to the surface textures and patterns observed in nature. Biomimicry in architecture often begins with a fascination for the aesthetic qualities of natural forms, leading designers to incorporate biomorphic shapes and patterns into their creations (El-Zeiny, 2012). However, the true essence of biomimicry goes beyond mere surface mimicry, requiring a deeper understanding of the underlying biological principles and processes that give rise to these captivating natural forms (El-Zeiny, 2012).

The study of form and function begins with the shape of the physical object of the angklung. Understanding modularity based on the basic shape of the material used (bamboo) and the relationship between the two-sized resonant tubes and the structural frame. In the design process, Surface Mimicry can be employed as an alternative approach by utilizing the role and similarity of objects based on their familiarity with their shapes. In contrast to behavior and functional mimicry, the perspective on surface mimicry emphasizes the visual similarity of objects rather than their actions and functions (Joyodiharjo *et al*., 2024).

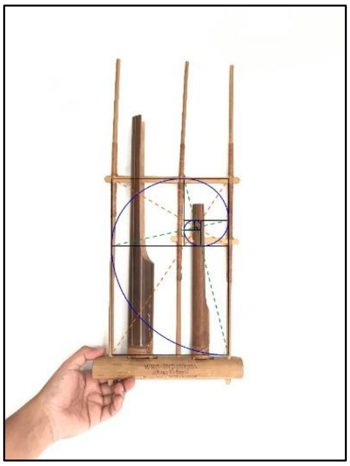

Figure 1. Golden ratio and configuration of Angklung

The original Angklung composition generally consists of a set of bamboo tubes, ranging from two to multiple in quantity, carefully chosen for their diverse lengths. The tubes were hung vertically in a robust bamboo framework. The frame is usually rectangular or trapezoidal in shape, offering stability and enabling the pipes to resonate freely (Nugraha, 2015).

This exploration could involve analyzing how the unique properties of bamboo, such as its natural hollowness and segmented structure, inform the modular design of resonant tubes and structural frames. Investigations into additive manufacturing techniques may reveal innovative ways to replicate or enhance the acoustic properties of bamboo using recycled plastics, potentially leading to more sustainable and customizable musical instruments. Additionally, the study could examine how 3D printing technology allows for precise control over the dimensions and internal geometries of the resonant tubes, potentially optimizing their acoustic performance beyond what is achievable with traditional bamboo craftsmanship. Exploration of the golden ratio in angklung tubes presents a fascinating avenue for enhancing the instrument's design and acoustic properties. This ancient mathematical concept, found throughout nature and art, could potentially revolutionize traditional Indonesian musical instruments. To fully understand the potential impact of applying the golden ratio in angklung design, it is essential to consider several key aspects of this innovative approach:

1. Applying the golden ratio to tube dimensions and spacing: By calculating and implementing the golden ratio in the length, diameter and spacing of bamboo tubes, researchers can optimize the instrument's resonance and tonal quality. This precise arrangement could yield a more harmonious sound. The golden ratio can determine ideal tube lengths, creating a balanced frequency set and adjusting spacing to enhance resonance and minimize interference.

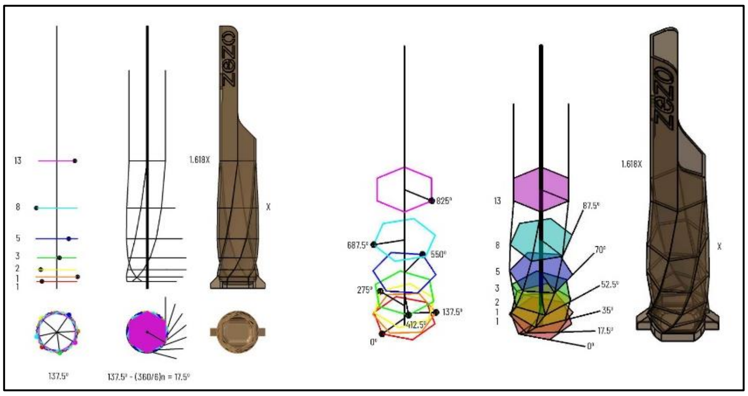

Figure 2. Golden angle and fibonacci sequence applied in the design process

2. Investigating its influence on resonant frequencies: The golden ratio may affect the fundamental frequencies and overtones of each tube. Thorough analysis may uncover new ways to fine-tune pitch and timbre. Researchers can explore how it influences harmonic series, potentially leading to richer tonal qualities and unique scales or tuning systems.

3. Incorporating it into the frame structure: Applying the golden ratio to the angklung's supporting frame can enhance both the structural integrity and acoustic properties. Frame dimensions and placement of support bars and joints, designed

according to golden ratio proportions, may optimize stability and sound projection, reduce vibration damping and enhance resonance.

4. Developing a modular system based on golden ratio proportions: A standardized modular design system can streamline manufacturing and ensure consistency across different angklung sets, facilitating easier maintenance and replacement of components. A modular system with interchangeable parts that maintain golden ratio proportions could allow customization while preserving acoustic integrity, leading to more efficient production and reduced costs. Additionally, smaller details, such as sound hole placement, can benefit from the golden ratio application.

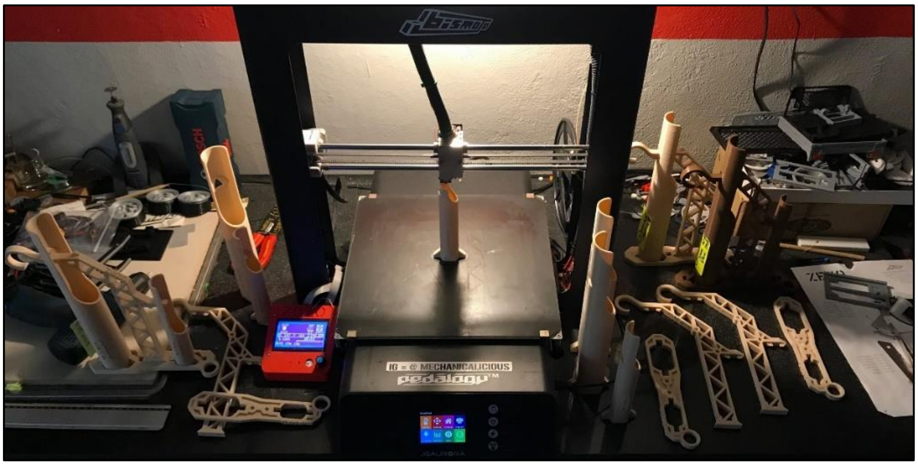

Figure 3. Recyklung creation with Additive Manufacturing

5. Resonant tube placement experiments: Positioning the resonant tube according to the golden ratio may enhance the instrument projection and tonal quality. Thorough experimentation can improve the sound and volume. Researchers should explore how sound holes, size, shape and location based on the golden ratio principles influence resonance and sound dispersion, potentially leading to angklung designs with better projection and tonal balance.

Figure 4. Alternative materials in Recyklung

6. Material distribution in 3D printing: Utilizing the golden ratio in 3D-printed angklung production could optimize the weight, strength and acoustic properties. Applying the golden ratio to internal structures may create lightweight and durable parts with superior acoustics, integrating multiple materials within a single component to enhance performance. Rigorous testing was required to validate these design changes.
7. Comparative acoustic tests: Rigorous testing comparing traditional and golden ratio-based angklung designs is crucial for measuring improvements in sound quality and performance. Tests should include frequency analysis, sound pressure level measurements and blind listening by experienced musicians. Long-term studies can be used to assess the durability and stability of new designs.

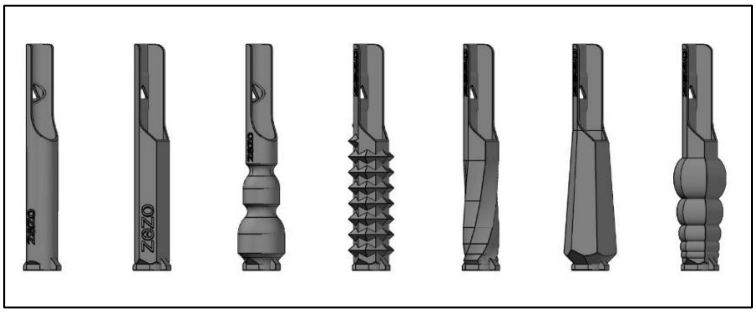

Figure 5. Recyklung tubes variations Figure 9. (a) tube, (b) hexagonal, (c) botol, (d) sisik, (e) twirl, (f) kendi, (g) limas, (h) ular

8. Visual aesthetics enhancement: In addition to acoustic benefits, the golden ratio can enhance the instrument's visual appeal, increasing its attractiveness to musicians and audiences. The golden ratio can guide the proportion of decorative elements, creating a harmonious visual balance, elevating the angklung's status as a musical instrument and a work of art and increasing its cultural and commercial value.
9. Scalability for different instrument sizes: Applying the golden ratio to various angklung sizes can create a cohesive and harmonious range of instruments, ensuring acoustic benefits across the entire family. This exploration might lead to new angklung variants with unique tonal characteristics, expanding the musical possibilities of the instrument. Collaboration across disciplines is essential for a comprehensive approach to this study.
10. Collaboration with experts for comprehensive research: A multidisciplinary approach involving musicologists, acousticians, mathematicians and traditional angklung craftsmen would ensure a thorough exploration of the potential of the golden ratio in angklung design. This collaboration could bring together diverse perspectives and expertise, leading to innovative solutions that honor the instrument's cultural heritage while enhancing its capabilities. The involvement of traditional craftsmen is crucial for preserving the essence and playing techniques of traditional angklungs. Systematic implementation of these considerations could significantly advance the angklung design and performance, reshaping the instrument's future.

The systematic implementation of these considerations could potentially lead to significant advancements in the design and performance of angklungs. By combining traditional craftsmanship with modern mathematical principles and technology, researchers and instrument makers may unlock new possibilities for this beloved

Indonesian instrument, potentially enhancing its global appeal and preserving its cultural significance for future generations.

Although traditional angklung design has been cherished for generations, incorporating the golden ratio into its construction offers an intriguing opportunity to enhance its capabilities without compromising its cultural essence. This approach could potentially bridge the gap between ancient wisdom and modern scientific understanding, creating an instrument that honors its roots while embracing innovation.

The application of the golden ratio to angklung design could also spark renewed interest in the instrument among the younger generations, potentially ensuring its continued relevance in contemporary music scenes. By demonstrating how mathematical principles can be applied to traditional art forms, this research could inspire interdisciplinary studies and foster a deeper appreciation of the intersection of science, mathematics and cultural heritage.

Furthermore, the insights gained from this exploration could potentially be applied to other traditional instruments, opening new avenues for research and development in ethnomusicology and instrument design. This could lead to a broader movement to apply mathematical principles to enhance and preserve cultural artifacts, potentially revolutionizing the field of musical instrument conservation and innovation.

As research in this area progresses, it is crucial to maintain open dialogue with the Indonesian musical community and cultural custodians. Their input and approval will be essential in ensuring that any modifications to angklung design respect its cultural significance and traditional playing techniques. This collaborative approach could serve as a model for responsible innovation in traditional arts, demonstrating how modern scientific principles can be applied to enhance cultural heritage while preserving core values and identity.

4. Configuration and Usage, Behavioral Mimicry

The development of musical instruments has long been a subject of fascination for both musicians and technologists. One particularly intriguing aspect of this field is the concept of modularity, which has the potential to revolutionize the way we approach instrument design and construction. By embracing a modular approach, designers can create instruments that are not only highly customizable but also better suited to the individual needs and preferences of musicians (Livingston, 2000).

At the heart of this modular design concept is the idea of behavioral mimicry, which involves observing and emulating the natural interactions between musicians and their instruments. This approach recognizes the importance of the body in musical performance, acknowledging that the physical relationship between the musician and the instrument is a crucial component of the overall musical experience.

Researchers have highlighted the significance of this embodied musical activity, noting that the dynamic interaction between the musician and the instrument involves a complex interplay of action and passion, as well as the interplay of body image and body schema (Kim, 2020). This understanding has led to the development of modular instruments that are designed to seamlessly integrate with the musician's physicality.

Modularity is one of the main constraints of this design. As an experimental tool in research, resonant tubes must be created, tuned and changed quickly and easily without changing other parameters. With 3D printing, tubes can be precisely fabricated with different thicknesses, lengths, proportions and materials. Modularity is a built-in design that is the main feature. With only two bolts, the product can be disassembled, tubes can be changed and put back together easily. This modular design approach enables researchers to rapidly iterate and test various configurations of resonant tubes, allowing for efficient experimentation and optimization of acoustic properties. The ability to easily swap out different 3D-printed tubes with precise specifications facilitates systematic exploration of how subtle changes in geometry and material composition affect sound production. Furthermore, this flexibility in design and assembly could potentially lead to the development of novel bamboo-inspired instruments or acoustic devices with enhanced performance.

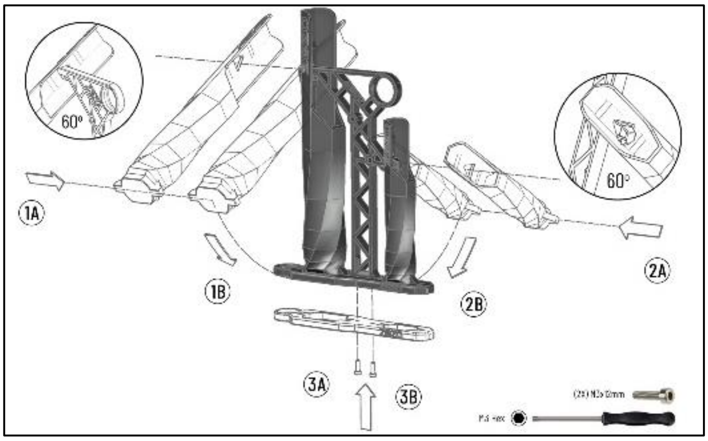

Figure 6. Modular Assembly of Recyklung

Recyklung innovation maintains a modular design that allows for easy assembly, disassembly and changing of the tubes. This modularity preserves the basic playing technique, while improving ergonomics through easier maintenance and customization. The modular approach enables players to adapt the instrument to their specific needs and preferences, potentially reducing the physical strain during extended playing sessions. This design feature also allows for quick replacement of damaged or worn-out parts, ensuring that the instrument remains in an optimal playing condition without requiring extensive repairs or replacements.

The traditional idiophone rattling configuration of the angklung is primarily maintained in the recyklung design. This preserves the fundamental playing technique and ergonomics of shaking or tapping an instrument. By retaining this configuration, players can continue to use familiar movements and gestures, minimizing the need to relearn and reducing the risk of developing new physical stress points. The preservation of this configuration also ensures that the unique timbre and sound characteristics of the angklung are maintained, allowing players to produce authentic traditional sounds while benefiting from the improved ergonomics.

The frame structure of the recyklung design retains a frame structure similar to the traditional angklung, which provides stability and allows the tubes to resonate freely. This maintained the ergonomic playing position. The frame structure supports the weight of the instrument, distributes it evenly and reduces the physical burden on players. This design element is crucial for maintaining proper posture and minimizing fatigue during prolonged performance. The frame structure also serves as a protective element, shielding the delicate bamboo tubes from direct impact and potentially extending the lifespan of the instrument.

The vertical arrangement of the tubes, consistent with the traditional angklung design, contributes to the ergonomic playing technique. Vertical orientation allows for natural arm and hand movements, reducing the risk of repetitive strain injuries and enabling players to maintain a comfortable playing position for extended periods. This arrangement also facilitates easy visual identification of the tubes, allowing players to quickly locate and play the desired notes without awkward body movement or excessive eye strain.

Recyklung design continues to use two tubes, preserving the multi-note playing capability and the associated ergonomics. This configuration allows players to access different notes without significant changes in their body position, thereby promoting efficient and comfortable playing techniques. The multitube setup also enables a more balanced distribution of the playing effort across different parts of the instrument. This design feature supports complex musical arrangements and allows for a wider range of musical expressions, without compromising player comfort.

Figure 7. Ratling of Recyklung

The basic method of producing sound by shaking or tapping the instrument is retained, maintaining the ergonomic playing technique of the traditional angklung. This preservation of the fundamental sound production method ensures that players can continue to use familiar muscle memories and movements, reducing the risk of developing new physical strains or discomfort associated with learning drastically different techniques. The consistency in the sound production method also allows experienced angklung players to transition seamlessly to recyklung, maintaining their skill level and musical proficiency.

Modular system improvement: Recyklung innovation incorporates improvements to modular systems to simplify the production process. This can potentially enhance ergonomics by making it easier to assemble, maintain and customize. The improved modularity may allow for quicker adjustments to suit individual player preferences, potentially reducing physical discomfort and enhancing overall playing experience. These improvements could also lead to more standardized parts, facilitating easier replacements and repairs, which, in turn, contributes to the instrument's longevity and consistent performance.

The use of recycled materials in recyklung design may contribute to ergonomic improvements. For instance, lighter materials can reduce the overall weight of an instrument, making it easier to handle and play for extended periods. Additionally, carefully selected materials might provide a better grip or tactile feedback, enhancing the player's control and comfort. The use of recycled materials also aligns with sustainability goals, potentially making the instrument more environmentally friendly, without compromising its ergonomic benefits.

The modular nature of recyklung design likely allows for greater customization options. This can include adjustable frame heights, interchangeable tube sizes, or variable tube spacing. Such customization possibilities can significantly enhance ergonomics by allowing players to tailor the instrument to their body size, arm length and playing style, potentially reducing physical strain and improving overall comfort. The ability to customize the instrument also caters to players with specific physical needs or limitations, making the angklung more accessible to a diverse range of musicians.

The maintenance ergonomics of the simplified modular design of the recyklung may improve the ergonomics of instrument maintenance. Easier assembly and disassembly can reduce the physical effort required for routine maintenance tasks such as cleaning or replacing individual components. This aspect of ergonomics is often overlooked but can significantly impact long-term usability and player satisfaction with the instrument. Improved maintenance ergonomics can also encourage a more regular upkeep, potentially extending the lifespan of the instrument and maintaining its optimal sound quality over time.

Educational ergonomics: Recyklung modular design may offer ergonomic benefits in educational settings. The ability to easily assemble and disassemble an instrument could facilitate hands-on learning experiences, allowing students to understand the instrument's construction while developing proper handling and playing techniques. This educational aspect can contribute to better ergonomic practices in the early stages of learning. Modular design also allows for gradual complexity in learning, where students can start with simpler configurations and progressively add more tubes as their skills improve, ensuring a comfortable and ergonomic learning curve.

Acoustic considerations: While focusing on ergonomics, recyklung design likely considers the acoustic properties of the instrument. The arrangement and design of the tubes, as well as the choice of materials, should be carefully considered to maintain or enhance traditional angklung sounds. This acoustic optimization, combined with ergonomic improvements, ensures that players can produce high-quality sounds with minimal physical effort, contributing to both musical excellence and player comfort.

Easy disassembly could allow for more compact storage and transportation, reducing physical strain on musicians who need to carry their instruments to different performance venues. This aspect of ergonomics extends beyond playing, to include the overall handling and management of the instrument in various contexts.

The ergonomic improvements and modular nature of recyklung may make it more adaptable to different musical styles and contexts. This versatility could allow players to use the instrument in various musical genres without compromising their physical comfort, potentially broadening the appeal and applicability of angklung in contemporary music scenes. Recyklung innovation may contribute to the long-term health of players by maintaining and improving the ergonomic aspects of traditional angklung design. Reduced physical strain and improved playing comfort could potentially decrease the risk of repetitive stress injuries or other music-related health issues, allowing musicians to enjoy playing the instrument for many years without a significant physical toll.

While introducing new materials and manufacturing techniques, recyklung design appears to maintain the core ergonomic principles of traditional angklung playing. These innovations focus on enhancing modularity, customization and production efficiency while preserving the fundamental playing technique and ergonomic considerations that have made the angklung a beloved and enduring musical instrument. These improvements may contribute to a more comfortable, adaptable and sustainable version of angklung, potentially broadening its appeal and ensuring its continued relevance in both traditional and contemporary musical contexts. Recyklung's design philosophy seems to strike a balance between honoring traditional craftsmanship and embracing modern innovation, resulting in an instrument that respects its cultural heritage while addressing the needs of contemporary musicians. This approach not only preserves the essence of the angklung, but also paves the way for its evolution and adaptation to changing musical landscapes and player requirements.

Furthermore, ergonomic improvements in recyklung design could have broader implications for the preservation and promotion of traditional music. By making the instrument more accessible, comfortable to play and adaptable to various contexts, it may encourage more people to learn and continue playing angklung. This could contribute to the preservation of cultural heritage and transmission of traditional musical knowledge to future generations.

5. Sound Characteristic, Functional Mimicry

The sound properties of the recyklung were evaluated in a semianechoic chamber to reduce the impact of room reverberation. The angklung sound was captured using a BSWA MPA414 measuring microphone connected to the BSWA MC3022 data collection hardware. The data-gathering device was linked to a laptop using a USB cable and the sound was recorded using Audacity 3.4. The angklung sound was captured 1 m in front of the angklung. This method resembles prior investigations on the acoustic characterization of pentatonic angklungs (Sudarsono & Merthayasa, 2013).

Figure 8. Sound analysis process of Recyklung

Angklung sounds are characterized using many techniques, including frequency and psychoacoustic analyses. The purpose of frequency analysis is to determine the timbre of the sound by identifying its pitch and overtone. The analysis was performed using the REW program. The psychoacoustic analysis was conducted using the characteristics of loudness, roughness and sharpness. The Mosquito toolkit is utilized for the extraction of psychoacoustic characteristics.

Analysis of the timbre is performed based on the frequency response of the sound generated from different angles. A comparison was also made with the standard bamboo angklung. The frequency responses of the different angklungs are shown in Figure 9 and shows that the 3d-printed angklungs have different sound characteristics compared to the angklungs made of bamboo. This result indicates the possibility of 3d-printed angklung to create new sound characteristics.

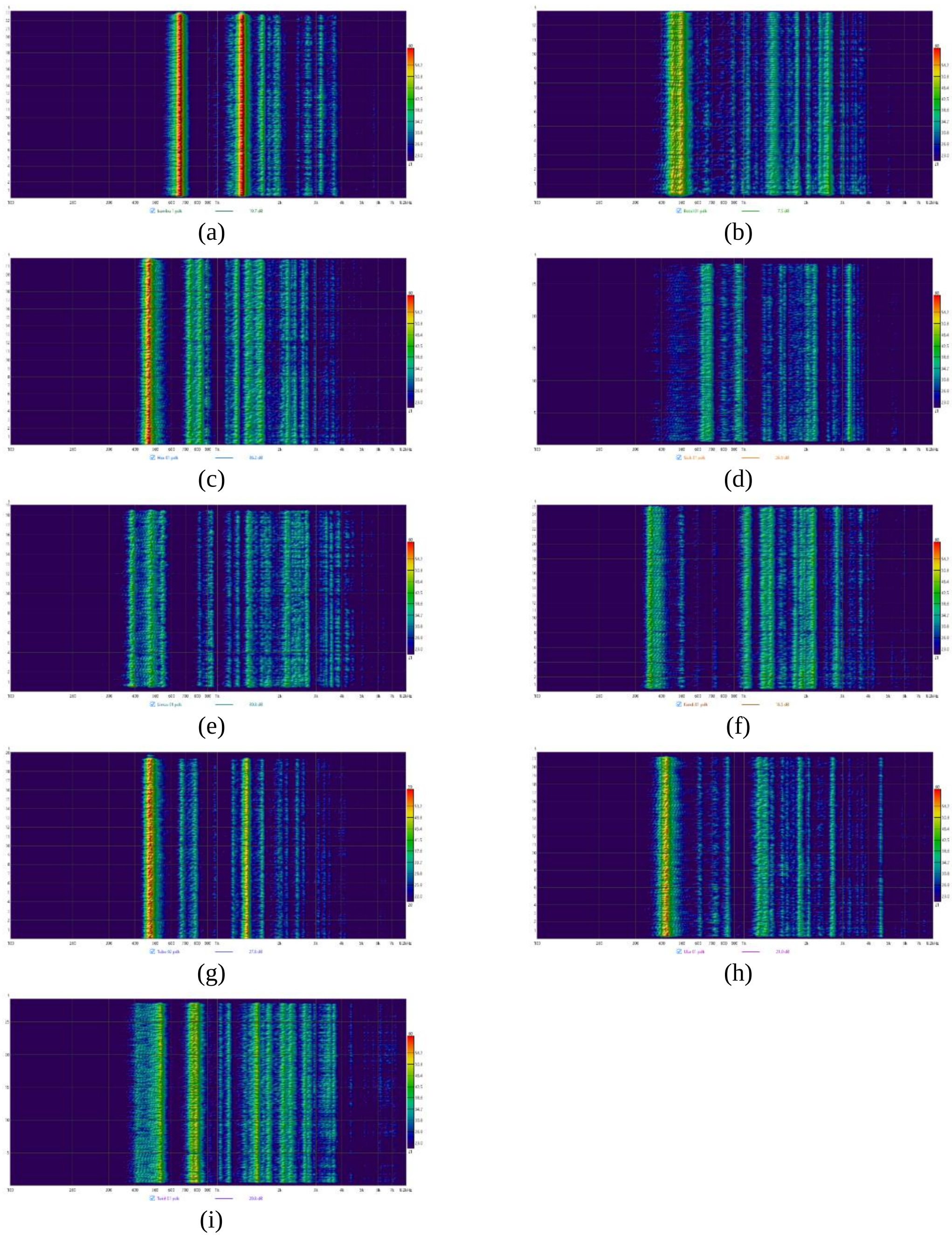

Figure 9. Sound characteristics of (a) Angklung bamboo, (b) 3d print bottle, (c) 3d print hexagonal, (d) 3d print sisik, (e) 3d print limas, (f) 3d print kendi, (g) 3d print tube, (h) 3d print ular, (i) 3d print twirl

Table 1 shows the pitch and overtone from different angklung. The angklung made using bamboo has distinct characteristics compared with the 3d-printed angklung. The angklungs made using bamboo mainly represent the pitch of each tube. The sound of the small tube was one octave higher than that of the large tube. This characteristic does not occur in a 3d-printed angklung. This result indicates that the 3d-printed angklung has different sound characteristics compared to the angklung made of bamboo. Therefore, the 3d-printed angklung is not intended to replace the existing angklung but to create a new sound of the angklung.

Table 1. Pitch and Overtone

	3D print Sisik	3D print Tube	3D print Bottle	3D print Hex	3D print Kendi	3D print Limas	3D print Twirl	3D print Ular	Angklung Bamboo
fo	1	1	1	1	1	1	1	1	1
f1	1.17	1.45	1.10	1.60	1.41	1.23	1.25	1.46	1.78
f2	1.38	1.66	1.34	1.78	1.67	1.40	1.86	1.73	2.00
f3	1.86	2.08	1.47	1.92	2.05	2.13	2.46	1.99	2.52
f4	2.21	2.54	1.76	2.41	2.93	2.42	2.69	2.23	2.71
f5	2.50	2.97	1.98	2.68	3.54	2.97	3.22	2.83	2.91

Further analysis was performed based on the psychoacoustic parameters (Zwicker & Fastl, 2013): loudness, sharpness and roughness. Loudness represents the subjective perception of how loud a sound can be heard by humans. A higher loudness level makes the perceived sound louder. Sharpness refers to the perception of harsh, unpleasant and high-frequency sounds. The sharpness value tended to increase with higher frequency components. Roughness is a measure of the perceptibility or annoyance of a sound, as perceived by the human ear and is related to the temporal characteristics of the sound. A higher roughness value indicates a more annoying sound.

Understanding these psychoacoustic parameters and their relationship to the acoustic properties of musical instruments is essential for developing comprehensive models of instrument analysis and evaluation. By incorporating these factors, researchers and musicians can gain deeper insights into the factors that contribute to the perceived quality and expressiveness of musical instruments, ultimately enhancing the understanding and appreciation of musical performance (Parise *et al*., 2014; Piazza *et al*., 2018).

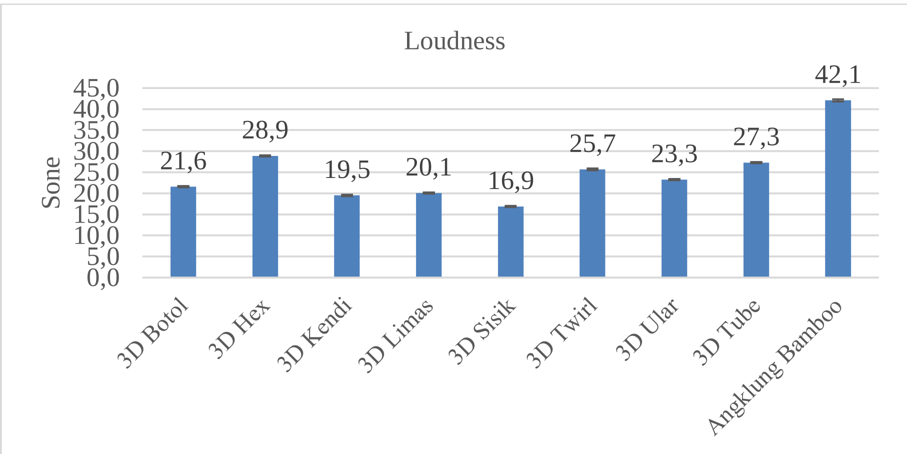

Figure 10. Loudness

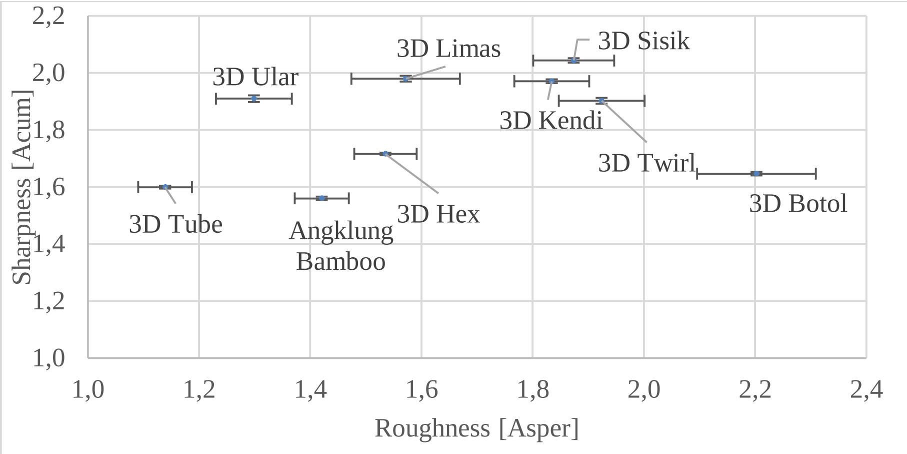

Figure 11. Roughness

The loudness data are shown in Figure 10. In general, a bamboo angklung is significantly louder than a 3d-printed angklung. The loudness of the 3d-printed angklung varies between 16.9-28.9 sone while the angklung made of bamboo can achieve a loudness of 42.1 sone. This result shows the limitations of the 3d-printed angklung which the sound is not as loud as the angklung made of bamboo.

The measurements of the roughness are shown in Figure 11. The sharpness parameter varies between 1.6-2 Acum while the roughness parameter varies between 1.1-2.2 Asper. The angklung made using bamboo still had the lowest sharpness, indicating a less high-frequency component compared to the 3d-printed angklung. An interesting finding was shown in the roughness value. The 3d-printed angklung with the shape of the tube and snake had a lower value of roughness compared to the angklung made on bamboo, indicating a more pleasant sound in terms of sound roughness.

The results from frequency and psychoacoustic analysis indicated that the 3d-printed angklung enables us to create new sounds of the angklung. The 3d-printed angklung still cannot mimic the sound of the original angklung made of bamboo, indicating that the development of 3d printer angklung is not a threat to the existing angklung. The 3d-printed angklung cannot produce sound as loud as the original angklung. However, two samples of the 3d-printed angklung can produce sound with less roughness compared to the original angklung. A lower roughness value corresponds to a more pleasant sound of the angklung.

This finding suggests that 3D-printed angklungs can potentially be used to create new musical compositions or arrangements that incorporate unique tonal qualities. Further research and development of 3D printing technology may lead to improvements in sound production and volume, potentially bridging the gap between traditional and modern angklung manufacturing methods. Additionally, the reduced roughness in some 3D-printed samples opens up possibilities for creating angklungs with smoother and more refined tones that could appeal to different musical preferences or applications.

6. Conclusion

The past, present and future of art and design are evolving constantly. Industrial revolution 4.0, such as Additive Manufacturing or 3D printing, is used to enhance the local wisdom tradition in the explorative design of traditional heritage Angklung idiophone. The indirect impact involved is the exploration of traditional Angklung, not as a musical instrument, but as a functional product with a biomimicry approach.

With the method of rapid prototyping, this project of design and art finds a balance within aspects of modularity, ergonomic usability, repeatability, precision, ease of production and efficiency. Based on the local wisdom in agricultural tradition, there are biomimicry functions and patterns that can be emulated with respect to nature and sustainability. The result is a design of a modular angklung that is suitable for the exploration. This study shows that exploration of different shapes can create angklungs with different sound characteristics, which can be further developed to enrich the existing angklung sound.

The results from frequency and psychoacoustic analysis indicated that the 3d-printed angklung enables us to create new sounds of the angklung. The 3d-printed angklung still cannot mimic the sound of the original angklung made of bamboo, indicating that the development of 3d printer angklung is not a threat to the existing angklung. The 3d-printed angklung cannot produce sound as loud as the original angklung. However, two samples of the 3d-printed angklung can produce sound with less roughness compared to the original angklung. A lower roughness value corresponds to a more pleasant sound of the angklung.

This finding suggests that 3D-printed angklungs could potentially be used to create new musical compositions or arrangements that incorporate unique tonal qualities. The ability to produce angklungs with different material properties and structural designs through 3D printing opens a wide range of possibilities for sound experimentation and innovation in traditional Indonesian music. Musicians and composers could explore novel soundscapes by combining traditional angklung sounds with distinct timbres produced by 3D-printed instruments, leading to the creation of hybrid musical styles that blend ancient traditions with modern technology.

Further research and development in 3D printing technology may lead to improvements in sound production and volume, potentially bridging the gap between traditional and modern angklung manufacturing methods. As 3D printing techniques continue to advance, it may become possible to create angklungs with more complex internal structures or to utilize materials that more closely mimic the acoustic properties of bamboo. This could result in 3D-printed angklungs that not only match but potentially surpass the sound quality of traditionally crafted instruments while offering greater consistency and customization options.

References

Arifitama, B., Syahputra, A. (2017). Cultural heritage digitalization on traditional sundanese music instrument using augmented reality markerless marker method. *Journal of Computer Technology and Systems*, *5*(3), 101-105. https://doi.org/10.14710/jtsiskom.5.3.2017.101-105

Bushwick, S. (2020). 3-D printing gives voice to a 3,000-year-old mummy. https://www.scientificamerican.com/article/3-d-printing-gives-voice-to-a-3-000-year-old-mummy/

Dunai, L., Novak, M. & García Espert, C. (2020). Human hand anatomy-based prosthetic hand. *Sensors*, *21*(1), 137. https://doi.org/10.3390/s21010137

El-Zeiny, R.M.A. (2012). Biomimicry as a problem solving methodology in interior architecture. *Procedia-Social and Behavioral Sciences*, 50, 502-512. https://doi.org/10.1016/j.sbspro.2012.08.054

Grant, C. (2018). Intangible cultural heritage. Produced by the United Nations Educational, Scientific and Cultural Organization (UNESCO). 2003-2018. In English, French and Spanish. *Yearbook for Traditional Music*, 50, 249-251.

Howard, D.M. (2018). The vocal tract organ: A new musical instrument using 3-D printed vocal tracts. *Journal of Voice*, *32*(6), 660-667. https://doi.org/10.1016/j.jvoice.2017.09.014

Huang, Y., Leu, M.C., Mazumder, J. & Donmez, A. (2015). Additive manufacturing: Current state, future potential, gaps and needs and recommendations. *Journal of Manufacturing Science and Engineering*, *137*(1), 014001. https://doi.org/10.1115/1.4028725

Jared, B.H., Aguilo, M.A., Beghini, L.L., Boyce, B.L., Clark, B.W., Cook, A., ... & Robbins, J. (2017). Additive manufacturing: Toward holistic design. *Scripta Materialia*, 135, 141-147. https://doi.org/10.1016/j.scriptamat.2017.02.029

Joyodiharjo, B.J., Piliang, Y.A., Sidarta, N.P., Larasati, D. & Syamsudin, T.S. (2024). Utilization of bamboo waste for preschool musical toy with surface mimicry approach. *Serat Rupa: Journal of Design*, *8*(1), 1-18. https://doi.org/10.28932/srjd.v8i1.6478

Kasha, M., Kasha, N. (1982). Applied mechanics and the modern string instrument - Classical guitar. *The Journal of the Acoustical Society of America*, 71, S26-S26. https://doi.org/10.1121/1.2019302

Kim, J.H. (2020). From the body image to the body schema, from the proximal to the distal: Embodied musical activity toward learning instrumental musical skills. *Frontiers in Psychology*, 11, 101. https://doi.org/10.3389/fpsyg.2020.00101

Kurniawan, S.Y., P, T.A.S. & Prestiliano, J. (2021). Realtime board game design to preserve traditional Central Javanese musical instruments using soundtrack and tile placement mechanics. *Nirmana*, *19*(2), 74-83. https://doi.org/10.9744/nirmana.19.2.74-83 (In Indonesian).

Lee, D., Lee, Y., Lee, K., Ko, Y. & Kim, N. (2019). Development and evaluation of a distributed recycling system for making filaments reused in three-dimensional printers. *Journal of Manufacturing Science and Engineering*, *141*(2), 021007. https://doi.org/10.1115/1.4041747

Li, X., Chua, J.W., Yu, X., Li, Z., Zhao, M., Wang, Z. & Zhai, W. (2024). 3D-printed lattice structures for sound absorption: Current progress, mechanisms and models, structural-property relationships and future outlook. *Advanced Science*, *11*(4), 2305232. https://doi.org/10.1002/advs.202305232

Livingston, H. (2000). Paradigms for the new string instrument: digital and materials technology. *Organised Sound*, *5*(3), 135-147. https://doi.org/10.1017/s1355771800005045

Marjieh, R., Harrison, P.M., Lee, H., Deligiannaki, F. & Jacoby, N. (2024). Timbral effects on consonance disentangle psychoacoustic mechanisms and suggest perceptual origins for musical scales. *Nature Communications*, *15*(1), 1482. https://doi.org/10.1038/s41467-024-45812-z

Matisons, M. (2015). 3D printed bat models yield new scientific discoveries about flight. https://3dprint.com/50207/3d-printed-bat-models/

Nugraha, A. (2015). Traditional sundanese angklung: Intangible, cultural heritage of humanity, its application and contribution to the birth of Indonesian angklung. *Journal Awi Laras*, *2*(1), 1-23. https://doi.org/10.31227/osf.io/v94c8 (In Indonesian).

Parise, C.V., Knorre, K. & Ernst, M.O. (2014). Natural auditory scene statistics shapes human spatial hearing. *Proceedings of the National Academy of Sciences*, *111*(16), 6104-6108. https://doi.org/10.1073/pnas.1322705111

Piazza, E.A., Theunissen, F.E., Wessel, D. & Whitney, D. (2018). Rapid adaptation to the timbre of natural sounds. *Scientific Reports*, *8*(1), 13826. https://doi.org/10.1038/s41598-018-32018-9

Ramesh, M., Niranjana, K., Bhoopathi, R. & Rajeshkumar, L. (2024). Additive manufacturing (3D printing) technologies for fiber-reinforced polymer composite materials: A review on fabrication methods and process parameters. *e-Polymers*, *24*(1), 20230114. https://doi.org/10.1515/epoly-2023-0114

Robertson, A. (2014). Here's what a 3D-printed saxophone sounds like. https://www.theverge.com/2014/8/5/5971131/heres-what-a-3d-printed-saxophone-sounds-like

Saunders, S. (2016). Autodesk research collaborates with dartmouth college to design and 3D print free-form wind instruments. https://3dprint.com/158647/3d-printed-wind-instruments/

Shanmugam, V., Das, O., Neisiany, R.E., Babu, K., Singh, S., Hedenqvist, M.S., ... & Ramakrishna, S. (2020). Polymer recycling in additive manufacturing: An opportunity for the circular economy. *Materials Circular Economy*, *2*(1), 1-11. https://doi.org/10.1007/s42824-020-00012-0

Strauss, P. (2013). 3D printed voice sculpture. https://theawesomer.com/3d-printed-voice-sculpture/260590/

Sudarsono, A.S., Merthayasa, I.G.N. (2013). Acoustic analysis from pentatonic angklung. In *Proceedings of Meetings on Acoustics*, *19*(1), 035078. https://doi.org/10.1121/1.4799452

Sugandi, D., Sungkawa, D. (2018). The preservation of angklung through art studios in Ujungberung. In *IOP Conference Series: Earth and Environmental Science*, *145*(1), 012146. https://doi.org/10.1088/1755-1315/145/1/012146

Thimmesch, D. (2015). 3D printed trumpet looks great but needs some fine-tuning. https://3dprint.com/41360/3d-printed-trumpet-project/

Verbrugghe, N., Rubinacci, E. & Khan, A.Z. (2023). Biomimicry in architecture: A review of definitions, case studies and design methods. *Biomimetics*, *8*(1), 107. https://doi.org/10.3390/biomimetics8010107

Yang, Y., Song, X., Li, X., Chen, Z., Zhou, C., Zhou, Q., & Chen, Y. (2018). Recent progress in biomimetic additive manufacturing technology: From materials to functional structures. *Advanced Materials, 30*(36), 1706539. https://doi.org/10.1002/adma.201706539

Zwicker, E., Fastl, H. (2013). *Psychoacoustics: Facts and Models*, 22. Springer Science & Business Media.