Bulletin of the *Transilvania* University of Braşov
Series VIII: Performing Arts • Vol. 16(65) No. 2 – 2023
https://doi.org/10.31926/but.pa.2023.16.65.2.12

Symphonic Ornaments in Parametric Architecture through Music

Ehsan RONAGH[1], Mohammadjavad MAHDAVINEJAD[2],
Shaheen FARHOODFAR[3]

Abstract: *The research explores a pioneering approach to intertwining music and architecture through the development of reliefs with musical identities, inspired by Goethe's perspective that music and architecture are intrinsically linked. By employing augmented reality (AR) and QR code technology, the initiative enables a synchronized visual and auditory narrative. The methodology encompasses three pivotal sections: Firstly, Generative Design, which leverages artificial intelligence-optimized algorithms to morph numerical musical outputs into 3D geometrical patterns. Secondly, technology application, employing Pure Javascript for QR code scanning and utilizing Asp.Net 6 and Kestrel for streaming audio information. Thirdly, AR Interaction, which utilizes AR technology to offer an immersive visual and auditory experience via mobile devices. This innovative integration of music, architecture, and technology not only pioneers a new experiential journey through form and melody but also delivers an interactive, dynamic user experience.*

Key-words: *Parametric architecture, Music, Math Art, Computational Design, AI Technology, Augmented Reality*

1. Introduction

In the harmonious confluence of music and architecture, a symphony of experiential and spatial design emerges, crafting a narrative that transcends sensory boundaries and immerses individuals into a realm where auditory and visual realms coalesce.

In the realm of digital architecture, which found its roots in the 1960s and was further propelled by Computer-Aided Architectural Design (CAAD) in the 1990s, a symbiotic relationship between computer and architect has been

[1] Faculty of Engineering, Islamic Azad University, e.ronagh@gmail.com
[2] College of Engineering and Architecture, University of Nizwa, mahdavinejad@unizwa.edu.om
[3] Faculty of Information Technology, Islamic Azad University, shaheen.farhoodfar@outlook.com

established, paving the way towards a new era of architectural evolution. Since the 1970s, marking the inception of the first digital wave in the 1990s and leading to the emergence of novel typologies of buildings, architects, and design tools. Parametric architecture, characterized by its distinctive features that leverage mathematics, geometry, and design and construction tools, has ushered in a new era where designers are introduced to innovative and modern designs and construction methods (Werner 2019, 675). Today is crystal clear that mathematics reveals the hidden order of natural disorder (Arbab et al. 2022, 4; Fallahtafti and Mahdavinejad 2021, 2382; Rahbar et al., 2019; Rahbar et al., 2020). Modern architecture is deeply connected to many fields and draws inspiration from them in its design, for instance nature is source of biophilic aesthetics (Mahdavinejad et al. 2014, 4443; Eslamirad et al. 2020, 362; Goodarzi et al. 2023, 1; Kasraei et al. 2016, 312) and is an inspirational origin of contemporary design (Ranjazmay Azari et al., 2023: 5; Mansourimajoumerd 2018, 606).

This paper embarks on an explorative journey into the innovative amalgamation of music, architecture, and technology, weaving a tapestry that resonates with Goethe's profound perspective: "Music is liquid architecture; Architecture is frozen music." This research pivots on the pioneering approach of intertwining these two art forms, creating reliefs with distinct musical identities and establishing a synchronized narrative through augmented reality (AR) and QR code technology.

2. Methodology

The methodology delineated in this research is tripartite, each section pivotal in crafting a holistic approach towards integrating musical symphonies into architectural design through technological interventions. Firstly, Generative Design, which employs artificial intelligence-optimized algorithms, transmutes numerical musical outputs into intricate 3D geometrical patterns, creating a visual representation of musical notes and rhythms. Secondly, the application of technology, utilizing Pure Javascript for QR code scanning and Asp.Net 6 alongside Kestrel for streaming auditory information, forms the backbone that supports and enhances the user interaction with the musical architecture. Thirdly, AR Interaction, employing AR technology, provides an immersive visual and auditory experience through mobile devices, crafting a multi-sensory narrative that is both dynamic and interactive.

3. Literature Review

Extensive scholarly inquiries have explored the nexus between architecture and musical composition, often adopting a conceptual lens. Elements such as rhythm, accent, thematic structure, harmony, chromatic features, symmetry, and proportion serve as the constitutive principles for transmuting musical compositions into architectural forms, and vice versa. Notwithstanding, this methodological approach is bereft of a rigorous theoretical scaffold, leaving the designer to rely on subjective interpretation of the musical attributes. Conversely, research has also been conducted that focuses on the interplay between architecture and music through the prisms of form and sound physics—yielding applications of a more utilitarian nature. Findings from these studies have informed the empirical foundation of our research, summarized herein (Table 1).

Researcher	Perspective / Performance	Reference
Pythagoras Plato	The relationship between mathematics, geometry, music and architecture, and the expression of harmonious cosmic ratios	(Antoniades, 1992)
Greeks	Geometry music returned to sound	(Ching, 2007)
Adonis Georgiades	Visual or audio harmony guarantees aesthetic pleasure	(Antoniades, 1992)
Bela Bartok	The use of Pythagorean golden ratios in music	(Antoniades, 1992)
Iannis Xnakis	Emphasis on the science of geometry as a factor of adaptation of music and architecture.	(Xenakis, 2008)
Ernst Chladni	Vibrate the sand grains on the plate through the violin bow	(Chladni, 2015)
Wassily Kandinsky Paul Klee	Convert music to architecture by translating the time interval of sounds into numbers	(Jormakka, 2009)
Hans Jenny	Coined the term Cymatics to describe the acoustic effects of sound wave phenomena.	(Jenny, 2001)
Peter Christensen	Parametric software design includes numbers and ratios to generate 48 virtual forms based on Johann Bach's music	(Christensen, 2008)
Martin Wattenberg	Use arc diagrams and convert music to charts to analyze each music course	(Wattenberg, 2002)
Alessandra Capanna	remarking the idea of self-similarity in composition; Music and Architecture	(Nexus Network Journal, 2009)

Table 1**.** *The relationship between architecture and music*

4. Discussion

4.1. Generative Design Process

The intricacies of design processes within the realm of parametric architecture are encapsulated by an algorithmic approach, comprising three pivotal components: input, algorithmic process, and output. This research delineates music as the input, wherein the constituents of sound—encompassing frequency and intensity—over temporal variations, assume a paramount role. Furthermore, all algorithmic formulations are optimized utilizing ChatGPT, an Artificial Intelligence (AI) entity, culminating in an output manifested as 3D modular geometric parametric ornaments. The comprehensive simulation of the research process has been executed utilizing the Rhino software, supplemented with Grasshopper and Firefly plugins, facilitating a meticulous exploration and realization of the proposed algorithms and design methodologies. The algorithms employed within this study are elucidated as follows:

4.1.1. Nonlinear Average Frequency Spectrum Algorithm

This algorithm that can obtain a nonlinear average frequency spectrum of any music over time. Since music is formed based on sound oscillations, it has a wave structure and ups and downs; thus, it has a dynamic and non-linear nature. A specific frequency spectrum is generated in any music at any given moment. To create a single spectrum from music that generates numerous frequency spectra over time, we need to write an algorithm that calculates the average of each frequency at any given moment (Ronagh et al. 2021, 223). Through this, we can finally achieve the average frequency range of music over time by connecting them together (Figure 1).

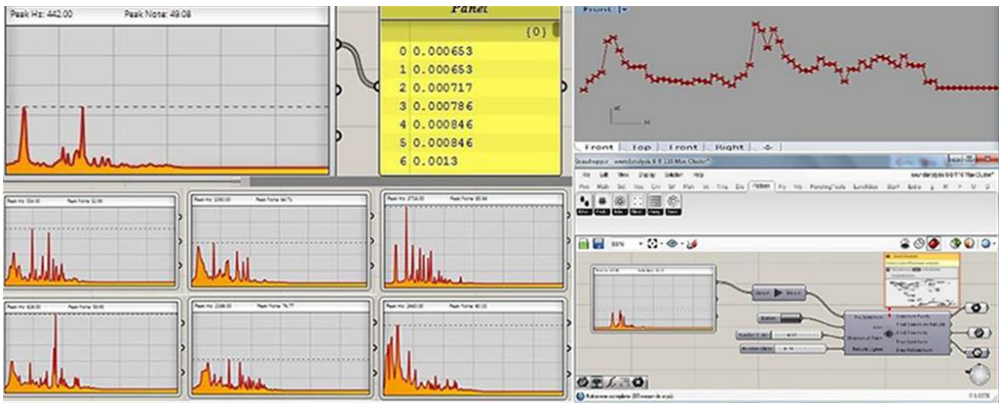

Fig 1. *Medium Frequency Spectrum Algorithm*

4.1.2. Modular Two-Dimensional Geometric Shapes Algorithms

Modular geometric patterns, underpinned by mathematical principles, can be designed parametrically, concomitant with their reproducibility. Broadly, two categories of structures can be delineated as reproducible geometric designs (patterns):

A. Regular patterns or designs (incorporating a fundamental form)

B. Combined or hybrid patterns or designs (integrating two or more fundamental forms)

Here are the geometric modular patterns clusters that have been made by coding in the Grasshopper plugin **(**Figure 2).

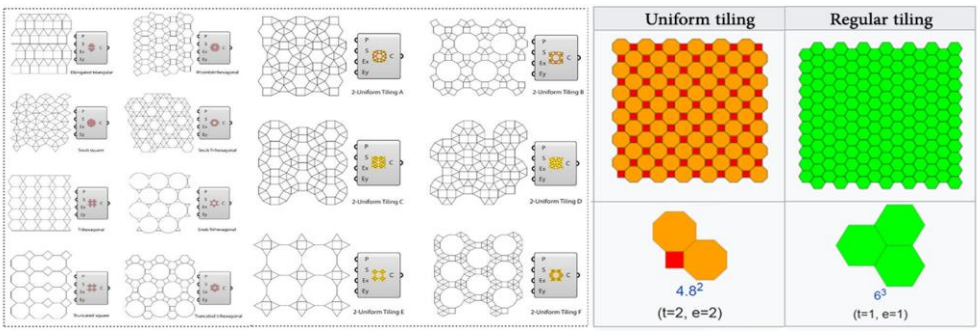

Fig 2. *Geometric modular patterns clusters (Ronagh et al. 2021, 223)*

4.1.3. Three-Dimensional Pattern Deformation Algorithm

The attractor curve is superimposed upon the created two-dimensional patterns. A coefficient of similitude, height, and a center of gravity are distinctly defined for each pattern. Predicated on the mathematical structure of the attractor curve, as the center of gravity of these patterns diverges from the attractor curve (the curve resultant from the music), the impact of the frequency and intensity of the music upon that pattern diminishes, and vice versa. Consequently, the peak of the pattern proximate to the attractor curve is elevated and descends as its distance augments, thereby ensuring the final shell embodies a subtle deformation (Figure 3).

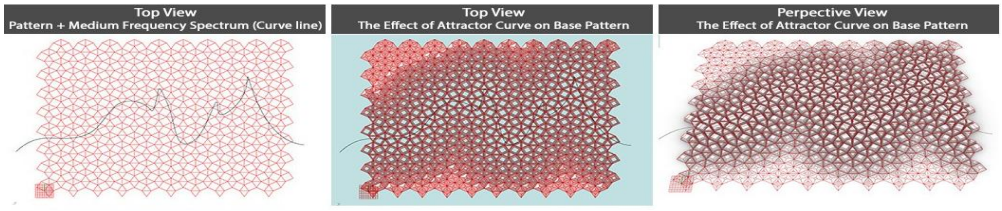

Fig 3. *Attractor curve effect and making geometrical 3D Ornaments (Ronagh et al. 2021, 223)*

4.2. Initial Interaction through QR Code Scanning

In the developed prototype, the QR Code standard is employed to facilitate user interaction, leveraging Pure JavaScript alongside pertinent QR Code libraries to expedite the scanning process within the mobile phone. Subsequently, information pertaining to the selected audio is streamed to the designated device via a web server, architected utilizing ASP.NET 6 and Kestrel, thereby ensuring a seamless auditory experience for the user. This methodology underscores a concerted effort to amalgamate accessible technology with user-friendly interfaces, thereby enhancing the interactive capabilities of the system.

Fig. 4. *Part of scripting QR code scanning and a prototype to identify by mobile device*

Here is a part of scripting QR code scanning and a prototype, inspired by a musical piece, that is 3D printed and features a unique QR code for identification via mobile devices (Figure 4).

4.3. AR Recognition and Tracking

Upon scanning the QR code, the AR application activates its recognition and tracking mechanisms. Utilizing the mobile device's camera, the application identifies and tracks the relief through image recognition or object tracking technologies. Advanced AR SDKs (Software Development Kits) like ARCore (for Android) or ARKit (for iOS) can be employed to facilitate robust and accurate tracking of the physical relief.

4.3.2. Overlaying Visual Maps

The purpose of this section is to illustrate how the augmenting process of reliefs can be visualized and interacted with through an AR application. Upon recognizing a relief, the application retrieves pertinent data like visual maps and music files, which are stored internally or fetched from a cloud database. The visual maps, representing various musical aspects like frequency and rhythm, are overlaid onto the sculpture, ensuring a coherent blend of physical and digital realms. Additionally, the AR overlay incorporates interactive elements, such as buttons or sliders, enabling users to manipulate visualizations and explore different musical segments, thereby enhancing user engagement and interactivity (Figure 5).

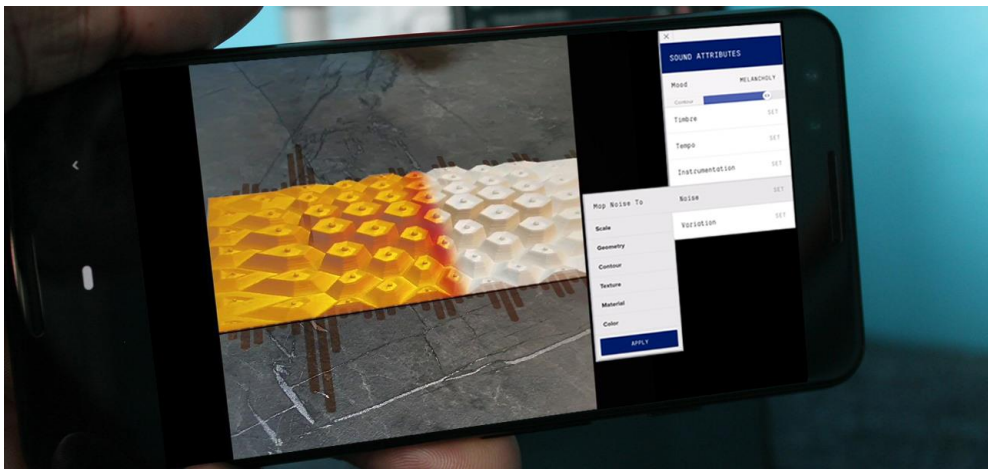

Fig 5. *Rendering visual elements of the relief through augmented reality on a mobile device*

5. Conclusion

The research meticulously investigates a novel methodology that innovatively intertwines music and architecture, creating reliefs with musical identities and introducing a pioneering concept that merges music, architecture, and technology. This provides a platform that goes beyond exploring form and melody, offering a dynamic, interactive, and immersive experience.

The findings from this investigative study have revealed that the language of mathematics and numerals can leverage the numerical attributes of sound, such as its frequency and intensity, to forge an indissoluble connection with geometry and mathematics, which are the predominant languages of architecture. Furthermore, the language of music, as an auditory artistic medium that interfaces with the human soul, can be employed as a visual artistic work, particularly within the realm of architecture.

Through the utilization of contemporary technology, such as QR codes and Augmented Reality (AR), facilitated by mobile devices, it becomes feasible to generate an accurate interpretation of these artistic works, thereby enabling viewers to attain a comprehensive understanding of their significance. This research, therefore, not only contributes a novel perspective to the existing body of knowledge but also propels the field into new, uncharted territories, demonstrating the boundless possibilities that lie at the intersection of music, architecture, and technology.

Acknowledgements

The authors extend their gratitude to Espandar Total Solution Company and Mr. Rambod Ghasemi, who played a pivotal role as a software developer, for their invaluable support and significant contributions to this research.

References

Arbab, Mojgan, Mohammadjavad Mahdavinejad, and Mohammadreza Bemanian. 2022. “A Mathematical Framework for Evaluation of Stagnation and Movement in Architectural Spaces, Case Studies: Iranian Traditional Houses.” *Iran University of Science & Technology* 32(4): 1-15.

Antoniades, Anthony.C. 1992. *Poetics of Architecture (Theory of Design)*. Wiley.

Bool, Flip, J.R. Kist, F. Wiedra, and J.L. Locher. 1992. *M.C. Escher: His Life and Complete Graphic Work.* Harry N. Abrams, Inc.

Capanna, Alessandra. 2009. “Music and Architecture: A Cross between Inspiration and Method.” *Nexus Network Journal* 11: 257-272.

Ching, Francis D.K. 2007. *Architecture: Form, Space, and Order*. Wiley.

Chladni, Ernst Florens. 2015. *Treatise on Acoustics*. Springer.

Christensen, Peter and Marc Aurel Schnabel. 2008. “Spatial Polyphony: Virtual Architecture Generated from the Music of J.S. Bach.” *CAADRIA 2008*.

Eslamirad, Nasim, Soheil Malekpour Kolbadinejad, Mohammadjavad Mahdavinejad, and Mohammad Mehranrad. 2020. “Thermal comfort prediction by applying supervised machine learning in green sidewalks of Tehran.” *Smart and Sustainable Built Environment* 9 (4): 361-374.

Fallahtafti, Reza, and Mohammadjavad Mahdavinejad. 2021. “Window geometry impact on aroom's wind comfort.” *Engineering, Construction and Architectural Management* 28 (9): 2381-2410.

Goodarzi, Parichehr, Mojtaba Ansari, Mohammadjavad Mahdavinejad, Alessio Russo, Mahdi Haghighatbin, and Farzad Pour Rahimian. 2023. “Morphological analysis of historical landscapes based on cultural DNA approach.” *Digital Applications in Archaeology and Cultural Heritage* 30: e00277.

Jormakka, Kari. 2009. *Basics Design Methods*. Berlin: Birkhauser Press.

Jenny, Hans. 2001. *Cymatics: A Study of Wave Phenomena & Vibration*. MACROmedia Publishing.

Kasraei, Mohammad Hossein, Yahya Nourian, and Mohammadjavad Mahdavinejad. 2016. “Girih for domes: analysis of three Iranian domes.” *Nexus Network Journal* 18: 311-321. https://doi.org/10.1007/s00004-015-0282-4

Mansourimajoumerd, Parinaz, and Mandavinejad Mohammadjavad. 2018. “Kinetic Architecture Reinterpreting Persian Mathematics and Astronomy.” In *36th International Conference on Education and Research in Computer Aided Architectural Design in Europe*, pp. 605-612. *eCAADe*-36th Annual Conference, September 17–21, Lodz, Poland, Volume 1.

Mahdavinejad Mohammadjavad, Raha Bahtooei, Seyyed Mohammadmahdi Hosseinikia, Mahsa Bagheri, Ayoob Aliniaye Motlagh, and Fatemeh Farhat. 2014. “Aesthetics and architectural education and learning process.” *Procedia-Social and Behavioral Sciences* 116: 4443-4448.

Ranjazmay Azari, Mohammadreza, Mohammadreza Bemanian, Mohammadjavad Mahdavinejad, Axel Körner, and Jan Knippers. 2023. “Application-based principles of islamic geometric patterns; state-of-the-art, and future trends in computer science/technologies: a review.” *Heritage Science* 11(1): 22.

Ronagh, Ehsa, Mahdavinejad Mohammadjavad, and Kia Anoosha. 2021. “A New Paradigm in Generative Design Linking Parametric Architecture and Music to

Form Finding.*" 9th ASCAAD Conference Proceedings ISBN 978-1-907349-20-1] Cairo (Egypt) [Virtual Conference]* 2-4 March 2021, pp. 227-240.

Rahbar Morteza, Mahdavinejad Mohammadjavad, Bemanian Mohammadreza, Amir Davaie Markazi, Ludger Hovestadt. 2019. "Generating Synthetic Space Allocation Probability Layouts Based on Trained Conditional-GANs." *Applied Artificial Intelligence*. Jul 3;33(8):689-705. https://doi.org/10.1080/08839514.2019.1592919

Rahbar, Morteza, Mahdavinejad Mohammadjavad, Bemanian Mohammadreza, Davaie-Markazi Amir. 2020. "Artificial neural network for outlining and predicting environmental sustainable parameters." *Journal of Sustainable Architecture and Urban Design* 7(2):169-182. https://doi.org/10.22061/jsaud.2019.4501.1333

Wattenberg, Martin. 2002. "Arc Diagrams: Visualizing Structure in Strings." *Proceedings of the IEEE Symposium on Information Visualization 2002* (InfoVis'02).

Werner, Liss C. 2019. "Form and Data - From Linear Calculus to Cybernetic Computation and Interaction." *eCAADe + SIGraDi* 7(1): 675-682.

Xenakis, Iannis. 2008. *Music and Architecture*. Pendragon Press; annotated edition.