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Vuza Rhythmic Canons in Romanian Contemporary Creation

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Abstract: *One of the characteristics of twentieth-century music is the renewal of the tradition of connecting mathematics, both in the creative and analytical processes. In Romania, a notable example is the path from musical thinking (Anatol Vieru's The Book of Modes) to mathematical thinking (Dan Tudor Vuza) and back to musical creation in the form of compositional technique. Vuza starts with the idea that operations from set theory can be applied to periodic rhythms and define classes of rhythms, leading to a mathematical description of polyrhythmia. From here to the musical composition of periodic or infinite canons, there is only one step. We will be analysing two works by Violeta Dinescu—Cronicari (2023) and Vuza Canons (2020)—and one by Mihaela Vosganian—Balinese Interferences on Vuza Canons (2024). Rhythmic canons, defined by the mathematician Dan Tudor Vuza, have great creative potential and can be integrated into a wide variety of musical works.*

Key-words*: Vuza canons, periodic rhythms, musical time, polyrhythms, polyphony*

1. Context. Mathematics and Music in the 20th century

The importance of the relationship between mathematics and music is as indisputable as is little known. It has existed for over two millennia and is self-evident. Still, only a handful of specialists understand its depth, to the point that it is often underestimated, either by musicians who believe that a limited number of arithmetic relationships cannot encompass the ineffable richness of an art of divine origin, or by so-called serious mathematicians who say that the interaction stops at 'elementary' mathematics, such as Diophantine approximation. "Serious mathematicians who believe that the interaction stops at „elementary" mathematics, such as Diophantine

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approximation[2] (Amiot 2024, xiii). This is how Emmanuel Amiot begins his book on the mathematics of music, designed to provide a minimal background for musicians interested in *"the mathematical dimension of their art."*

In the century that has just ended, the role of mathematics in music has become essential, being present both in music theory and musicological analysis, as well as in composition techniques. Starting with Euler's ideas about the numerical harmony of chords, and moving through modern circular representations, mathematics has been organically integrated into contemporary musicology. The advent of computers has led to the development of computational musicology, which investigates the mathematical structures hidden in musical works or uses graphical representations of scores. The examples cited by Richard Ashley – such as the studies of Christopher Hasty and Gerald J. Balzano – show an interest in sophisticated mathematical modelling.

Among the significant events of the 20th century, the dodecaphonism of the Second Viennese School had a decisive impact. Although criticized for its aesthetic shortcomings, it abolished the dominance of tonality and paved the way for composers to create their own language freely. However, this freedom generated extreme diversity, without any common reference points. Computers have enabled complex formal compositions, but the results often reflect theoretical construction rather than artistic intuition, reminiscent of Boethius' speculative ideal, but applied in an individualized way.

Mathematical developments in the second half of the 20th century – fractal geometry and chaos theory – as well as the emergence of computer science, created a new symbiosis between science and music. Composers such as Iannis Xenakis used rigorous calculation, while György Ligeti intuitively integrated mathematical concepts. The pioneers of algorithmic music, Pierre Barbaud and Lejaren Hiller, were trailblazers in this direction. Ligeti advocated a 'generative' way of thinking that would produce organic musical forms. However, he rejected the idea that technology or mathematics could create art itself, emphasizing that only the composer's imagination, stimulated by scientific data, could generate authentic works. In conclusion, the synergy between science and art does not replace creative sensitivity but fertilizes it, opening up new perspectives for music compatible with the spirit of the current era.

[2] *„L'importance de la relation entre mathématiques et musique est à la fois incontestée et très mal connue. Plus de deux fois millénaire, elle va sans dire ; mais seule une poignée de spécialistes connaissent sa profondeur, au point qu'elle est souvent décriée, que ce soit par des musiciens qui estiment que quelques relations arithmétiques ne peuvent pas encapsuler la richesse ineffable d'un art d'origine divine ; ou par les mathématiciens dits sérieux, qui croient que l'interaction s'arrête à des mathématiques élémentaires, comme l'approximation diophantienne."*

2. Vuza rhythmic canons. Mathematical aspects

In Solomon Marcus's vision of interval thinking, the relationship set up by Anatol Vieru between mode and modal structure is similar to that between a set and a function (which can also be defined on that set). Vieru resorted to notions and procedures specific to certain mathematical fields, and Solomon Marcus emphasizes: *„But, each time, the mathematical tools were only components of ad hoc, original and ingenious constructions."*[3] (Vieru 1980, 223)

In conclusions to *The Book of Modes,* Anatol Vieru emphasizes that: *The model created constitutes an abstract system; music is only the reality from which it starts, the reality that incorporates it. As I have described it here, it has an independent existence and can be found or applied in other fields."*[4] (Vieru 1980, 176) The composer's collaboration with mathematician Dan Tudor Vuza led not only to the validation of appropriate solutions to the musical problem under investigation, but also to mathematical generalization, obtaining mathematical constructions correlated with necessary configurations of modern mathematics. Moreover, Vuza returns the transfigured mathematical results to music.

2.1. From modes to periodic rhythms

Dan Tudor Vuza explains that the connection with the mathematical model of modal theory is provided by bijections between specific subsets of rhythms (i.e., rhythmic classes) and the set of modes (i.e., modal classes) in a tempered system with n degrees. However, the author emphasizes that this is only a working tool that allows specific calculations on rhythms or rhythmic classes to be more easily translated into familiar calculations on modes or modal classes. He achieves an isomorphism between the two.

After defining rhythms and rhythmic classes, Vuza sought a convenient way to find rhythmic classes. He studied the correspondence between rhythmic classes and rhythmic structures, the rhythmic analogue of modal structures. He then considered the primary operations across all rhythmic classes —inclusion, complementarity, retrogression, and composition —and, each time, identified the corresponding modal operation by isomorphism. He also paid attention to the phenomenon of polyrhythm and established a procedure for deciding the polyrhythmic character of a given rhythm.

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[3] *„Dar, de fiecare dată, instrumentele matematice au fost numai componente ale unor construcții ad-hoc, originale și ingenioase."*

[4] *„Modelul creat se constituie ca un sistem abstract; muzica este doar realitatea de la care pornește el, realitatea care îl încorporează. Așa cum l-am descris aici, el are o existență independentă și poate fi găsit sau aplicat eventual în alte domenii."*

2.2. Vuza's rhythmic canons

To define periodic rhythms, Vuza starts with two axiomatic statements. He emphasizes that rational numbers are all musical durations used in European music. It follows that the musical time axis is contained within the axis of rational numbers (Q***J***. He also says that periodicity is a frequent characteristic of musical rhythm. Definition is as follows: *„A periodic rhythm is a periodic and locally finite subset of **Q.**”*[5] (Vuza 1985) It gives the following example: **{ 1/2 k, 1/4 + 1/2 k, 3/8 + 1/2 k | k** ∈ ℤ **}** is the mathematical notation for (Figure 1).

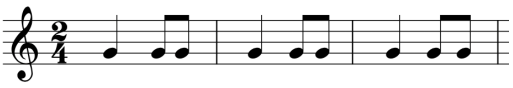

Fig. 1. *Example of periodic rhythm*

Next, Dan Tudor Vuza denotes the set of rhythms with ***Ryt*** and demonstrates that it is a ring.

From this, he deduces that rhythms can be subjected to the following operations:

- union (∪)
- intersection (∩)
- difference (\)
- symmetric difference (Δ)

In fact, the union gives us the "additional" rhythm of the overlapping voices, and the intersection gives us the moments of simultaneity.

The mathematician emphasises the great interest in pairs of rhythms whose intersection is the empty set (there are no moments of simultaneity) because, from a musical perspective, they are complementary rhythms.

Vuza defines the rhythmic class as any orbit in relation to the action of ***Q*** on ***Ryt.*** In other words, it is the class of translations of a rhythm ***R*** with regard to the additive group ***Q.*** The musical example proposed by the author clarifies that it refers to temporal translations of rhythm (compared to the measure). Here is the example (Figure 2):

[5] *„Un rythme périodique est un sous-ensemble périodique et localement fini de **Q**.”*

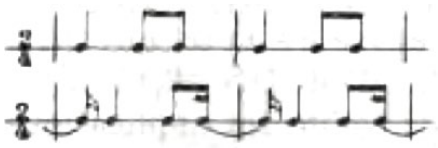

Fig. 2. *Example of translations of a rhythm in rhythmic class*

An interesting fact to note is that rhythm classes are composed according to the model of modal class composition (Figure 3). This composition is commutative, and in both cases, the resulting rhythm (the additional rhythm) is the same. In Vuza's example, the law of composition is written additively (+).

Fig. 3. *Example rhythm composition*

He then elaborates by creating a canon with the rhythmic motif from the first parenthesis distributed according to the rhythm in the second parenthesis, and vice versa: the rhythmic motif is from the second parenthesis, and the distribution is according to the rhythm in the first parenthesis (Figure 4).

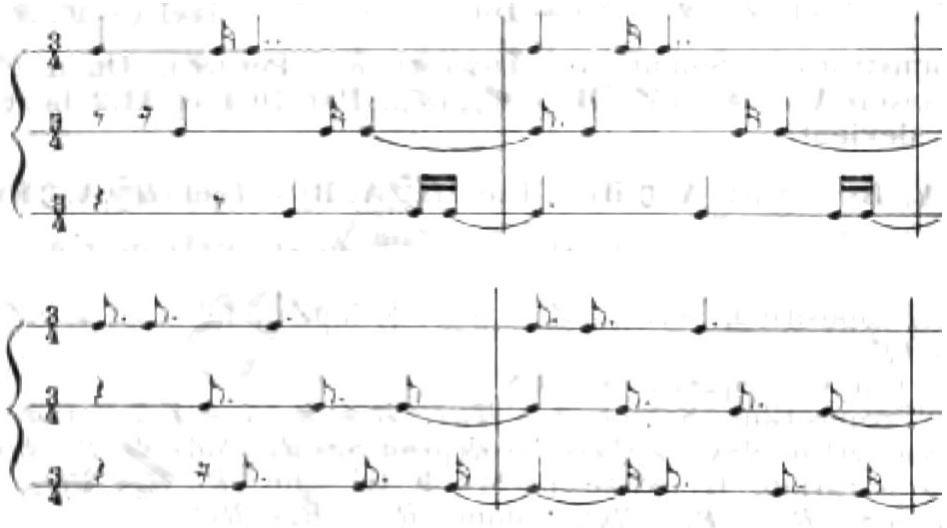

Fig. 4. *Example of commutativity*

In both cases, the result (the additional rhythm) is identical.

Vuza goes further and defines disjoint rhythmic classes and proves (mathematically) that two rhythmic classes are disjoint if and only if the voices of the composition of the two rhythmic classes are complementary in pairs. He also defines polyrhythmic rhythm classes as follows:

„A rhythm is said to be polyrhythmic if R = $R_1 \cup R_2$ *with* $R_i \neq \emptyset$ *and Div(*R_1*) † Div(*R_2*), Div(*R_2*) † Div(*R_1*).”*[6] (Vuza 1985) The author emphasizes that $\mathbf{R_1}$ and $\mathbf{R_2}$ can have arbitrarily large periods in relation to the period of the resulting rhythm class. The following corollary is of interest: Regular rhythm classes are not polyrhythmic.

One of the most important researchers of Vuza canons, in his dual capacity as mathematician and musician, is Moreno Andreatta. He does not limit himself to researching them; he has also developed algorithms for music theory and musical analysis, as well as musical compositions. According to Andreatta, without taking into account all the parameters of a rhythmic canon, it is well defined when the following are known: the number of voices, the “ground class” (the rhythmic class of a voice - R*)*, and the "metric class" (the rhythmic class of voice entries - *S*).

In her article *Mathematics and Music. Several stages in understanding and using the Vuza rhythmic canon structure* presented in 2024 at the *9th Congress on Mathematics and Computation in Music* in Coimbra (Portugal), Violeta Dinescu concisely presents these canons, simplifying the theory to the practical level of its use by composers. *A Vuza rhythmic canon is a musical structure with the following properties: There are several voices, which have the same rhythmic pattern, shifted to avoid silence and overlapping. Let M be the minimum period of the rhythmic pattern. It follows that if V is the number of voices and L is the number of interventions of a voice in a period, then M=V x L. We order the voices according to the moments of their first manifestation"*[7] (Dinescu 2024). The composer defines "internal rhythm" as the numerical sequence of the first voice's interventions. She also describes “external rhythm” as the numerical sequence of the pattern of interventions of each voice by translating the internal rhythm with specific numbers. (The internal rhythm corresponds to the “ground class", and the external rhythm corresponds to the “metric class” above.) The author also mentions a theorem by Vuza, which shows that the number of voices in a Vuza canon has at least two prime factors. It follows that M should also have at least two prime factors. The conclusion is that the shortest Vuza canons have six voices and a period of 72.

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[6] *„On dit d’un rythme qu’il est polyrythmique si* $R = R_1 \cup R_2$ *cu* $R_i \neq \emptyset$ *și Div(*R_1*) † Div(*R_2*), Div(*R_2*) † Div(*R_1*)”*

[7] *„Există mai multe voci, care au același model ritmic, deplasate astfel încât se evită tăcerea și suprapunerea. Fie M perioada minimă a tiparului ritmic. Rezultă că, dacă V este numărul de voci și L este numărul de intervenții ale unei voci într-o perioadă, atunci M=V x L. Ordonăm vocile după momentele primei lor manifestări.”*

2.3. Enumeration of Vuza canons

Franck Jedrzejewski, mathematician and musicologist, has also researched the problem of Vuza canons, generating new results. The most important of these is that he proposes a new enumeration of canons for specific values of *N.* (Table 1.)

In 1962, A.D. Sands gave a classification of all finite abelian groups, which are called *Hajós groups* or *good groups* (as opposed to *bad groups*). The first Vuza canon appears for N = 72, and the next ones appear at N = 108, 120, 144, 168, etc. Jedrzejewski states a theorem of equivalence of the conditions for the existence of Vuza canons.

Theorem: *The following propositions are equivalent:*

(i) *Vuza canons exist for periods N that are not of the form*

$$N = p^{\alpha}, \quad p^{\alpha}q, \quad p^2q^2, \quad p^2qr, \quad pqrs$$

where:

p, q, r, and *s* are different prime numbers.

(ii) *Vuza canons exist only for periods N of the form*

$$N = n_1 n_2 n_3 p_1 p_2$$

where:

p_1 and p_2 are different prime numbers, *pi* $n_i \geq 2$, *for i = 1, 2* and *gcd* $(n_1 p_1, n_2 p_2) = 1$.

In the first sentence, all integers (natural numbers) are eliminated that are: the power of a prime number, the product of a power of a prime number with another prime number, the product of the squares of two distinct prime numbers, the product of two prime numbers with a third prime number or its square, the product of four prime numbers. The second sentence gives us the convenient form of the decomposition of the period values. The author continues with theorems and demonstrations of the construction of large Vuza canons, but these go beyond the scope of musical interest.

From a musical perspective, canons can be translated without changing their identity. If (S, R) is a canon from $\boldsymbol{Z_N}$, any translation of the elements in S occurs with the identical R. Therefore, canons are identified by their basic form.

The table below shows the best-known (and most widely used) results.

N	n_1	p_1	n_2	p_2	n_3	$\|S\|$	$\|R\|$	$\#S$	$\#R$
72	2	2	3	3	2	6	12	3	6
108	2	2	3	3	3	6	18	3	252
120	2	2	3	5	2	6	20	8	18
–	2	2	5	3	2	10	12	16	20
144	2	2	3	3	4	6	24	3	8640
–	2	2	3	3	4	6	24	6	36
–	4	2	3	3	2	12	12	6	60
–	4	2	3	3	2	12	12	162	12
–	4	2	3	3	2	12	12	324	6
168	2	2	3	7	2	6	28	16	54
–	2	2	7	3	2	14	12	104	42

Table 1. *Enumeration of canons for first values of "N"*

Jedrzejewski also calculates larger numbers and extends the results as follows. (See the table below.) (Table 2.)

N	n_1	p_1	n_2	p_2	n_3	$\|S\|$	$\|R\|$	$\#S$	$\#R$
180	2	2	3	3	5	6	30	3	77760
–	2	2	3	5	3	6	30	8	2052
–	2	5	3	3	2	6	30	3	84
–	2	2	5	3	3	10	18	16	1800
–	3	3	5	2	2	15	12	9	105
200	2	2	5	5	2	10	20	125	60
216	2	2	9	3	2	18	12	575	72
–	4	2	3	3	2	12	18	6	13680
240	4	2	5	3	2	20	12	32	200
–	4	2	3	5	2	12	20	4100	16
252	2	2	3	7	3	6	42	16	396
–	2	7	3	3	2	6	42	9	366
264	2	2	3	11	2	6	44	40	558
270	5	2	3	3	3	15	18	9	50400
280	2	2	5	7	2	10	28	425	180
–	2	2	7	5	2	14	20	2232	126
300	2	3	5	5	2	10	30	104	240
–	3	2	5	5	2	15	20	104	480
324	2	2	9	3	3	18	18	729	16848
336	4	2	3	7	2	12	28	32	7020
–	4	2	7	3	2	28	12	208	420
392	2	2	7	7	2	14	28	16807	378
400	4	2	5	5	2	20	20	250	2040
450	3	3	5	5	2	15	30	375	1920

Table 2. *Enumeration of canons for more specific values of "N"*

Jedrzejewski's conclusion is as follows: *The aim of this paper was to show how to construct Vuza canons and to compute their numbers for some value of N. We set up new theorems that helped us develop a faster algorithm. But in many cases, the number of solutions is quite large, and some shortcuts must be found."*(Jedrzejewski 2013) He thus allows composers to create a variety of canons.

In the article *OpenMusic et le problème de la construction de canons musicaux rythmiques* (Andreatta 1999) the authors also present decomposition variants for periods with values up to 360. (Table 3.)

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72 : { (2 3 2 3 2) }
108 : { (2 3 2 3 3) }
120 : { (2 3 2 5 2), (2 5 2 3 2) }
144 : { (2 3 2 3 4), (2 3 4 3 2) }
168 : { (2 3 2 7 2), (2 7 2 3 2) }
180 : { (2 3 2 5 3), (2 3 2 3 5), (2 3 5 3 2), (2 5 2 3 3 ) }
200 : { (2 5 2 5 2 }
216 : { (2 3 2 3 6), (2 3 2 3 6), (2 3 4 3 3 ) }
240 : { (2 3 4 5 2), (2 3 2 5 4), (2 5 2 3 4), (2 5 4 3 2 ) }
252 : { (2 3 7 3 2), (2 3 2 3 7), (2 3 2 7 3), (2 7 2 3 3 ) }
264 : { (2 3 2 11 2), (2 11 2 3 2 }
270 : { (2 3 5 3 3) }
280 : { (2 5 2 7 2), (2 7 2 5 2 ) }
288 : { (2 3 4 3 4), (2 3 2 3 8), (2 3 8 3 2 ) }
300 : { (2 3 2 5 5), (2 5 2 5 3), (2 5 2 3 5), (2 5 3 5 2 ) }
312 : { (2 3 2 13 2), (2 13 2 3 2 ) }
324 : { (2 3 2 3 9), (2 3 2 9 3 ) }
336 : { (2 3 2 7 4), (2 3 4 7 2), (2 7 2 3 4), (2 7 4 3 2 ) }
360 : { (2 3 10 3 2), (2 3 4 5 3), (2 3 4 3 5), (2 3 2 5 6), (2 3 2 3 10),
        (2 3 5 3 4), (2 5 2 3 6), (2 5 2 3 6), (2 5 4 3 3) }
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Table 3. *Decomposition variants for periods with values up to 360*

These results help composers to move beyond mathematical calculations and choose the options that best suit their musical ideas.

A team of Italian researchers studied Vuza canons, calling them *regular complementary canons of maximum category (RCMC)*, and developed an algorithmic implementation to generate models for real-time sound spatialisation. (Battista 2017) In addition, they presented VUZALIZER, a tool for the Max/MSP visual programming platform that generates Vuza Canons. They generated both graphically and sonically an 18-voice Vuza canon with a period of 264 (Figure 5).

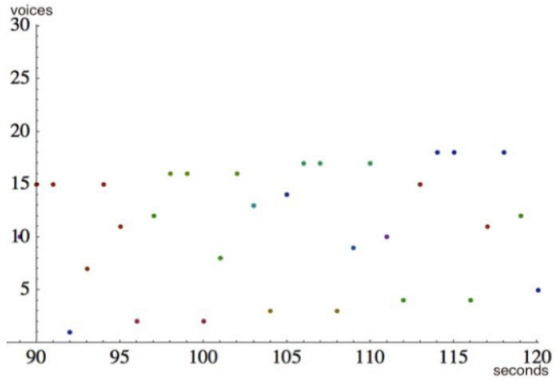

Fig. 5 *Graphic model generated for a Vuza canon with a period of 264*

3. Vuza canons. Musical aspects
3.1. Possibilities of Vuza canons

Mathematical concepts are used in many fields of knowledge, including the arts. Vuza canons return to the music that inspired them. Composer Fabien Lévy (who also has a dual background in mathematics and music) highlights three facets of the concept's use, following his personal aesthetic concerns.

The first perspective is the pedagogical one, applied by the composer in the last piece of the cycle *Pour la classe.* This piece, entitled *Où niche l`hibou,* is a playful application of these canons. The motivic imitations are not superimposed on each other because each voice is assigned its own register. One difficulty in performing this piece is the motif's transposition. Another difficulty is keeping the tempo, as the overlap of two voices detects any error. This approach has great potential both for developing children's creativity and for teaching concentration and discipline in the act of interpretation. From what we know, Violeta Dinescu has experimented with creations of this kind before.

Another perspective is the acousmatic one, through which Lévy asserts that he pushes the limits of the computer. *Soliloque sur [X, X, X et X]* is not a composition in the strict sense of the word, but „*rather, it is a meta-work generated in real-time by a computer using analyses and extracts from other pieces on the concert in which it is featured"* (Lévi 2011). This application of Vuza's canons proves the possibility of algorithmization and paves the way for other creations of this kind.

The most interesting aspect is the aesthetic one. The overlapping of sound planes is characteristic of polyphony, but the internal organisation of each plane excludes overlapping. The musical result is a monody. In other words, the combination of discrete sound planes results in a single continuous sound plane, but the composer's interest is strictly musical. He explains: *Vuza canons may be used as a basis for the discrete temporal organization of a diverse array of musical elements; furthermore, their use responds to a broad range of aesthetic preoccupations. As a composer, not a scientist, and one who composes based upon belief rather than theories, it is the potential for practical musical application, and not purely theoretical significance, which interests me. Of the qualities found in these canons, it is the singular relationship between counterpoint and monody, between the part and the whole, which strikes me as the most interesting; indeed, this notion has long been at the core of my work as a composer. Another characteristic of interest is the rhythmic organization of voices, which, when combined, constitute a Vuza canon. In general, rhythmic motives are expressed over a long period of time (or over multiple timescales when an augmented canon is used; this is perceptually more interesting) and relatively fragmented. Over a long duration, the ear does not perceive the canon*

as such, nor does it recognize exact repetitions; nonetheless, there is, in my opinion, a perceptive sense of structural coherence. Both perceptual paradoxes, at odds with a more analytical belief, were real inspirations for me in using these canons." (Lévi 2011)

Of course, there are other opinions. Mathematician Jeremy Kastine expresses his objections as follows: *Most rhythmic tilings exhibit a high degree of regularity (predictability) in the rhythmic theme and/or in the set of translations of that rhythm. […] Vuza canons, rhythmic tiling's in which neither the rhythmic theme nor the set of translations is periodic, provide an exception to this rule, but they are quite rare."* (Kastine 2020) He continues: *Another objection that we might have to using rhythmic tiling to compose canons is that there is often no sense of interaction among the parts, since the parts are disjoint. Also, the fixed density of musical information (exactly one note per beat, where the beats are evenly spaced) can become rather monotonous."* (Kastine 2020)

The author's statements are either the result of superficial research into the Vuza canons or an exaggerated desire to highlight the "superiority" of L, S, and G canons in musical creation. He reduces Vuza canons to the use of a single musical note per unit of time.

Composers who use these canons have proven that there is more to it than that. The unit of time refers to a brief interval containing a musical motif. Composer Violeta Dinescu states that *"a 3-second time window is enough to convey a musical idea".* Furthermore, there are no restrictions on the use of instruments and human voices; on the contrary, each voice in the canon should have a distinct timbral identity.

3.2. Creations with Vuza canons

Apparently, Vuza's compositional canons can generate works that are like one another. Eventually, an algorithm can be created and (with the help of a computer) compositions can be produced "on an assembly line". The imagination and personality of composers offer us a diversity of creations, proving that these canons can be assimilated into a writing technique like any other. However, this technique is relatively niche and experimental.

We have already mentioned Fabien Lévy and his compositions *Coïncidences* (1999)*, Où niche l`hibou* (2004), and *Soliloque sur [X, X, X et X]* (2001)*.* (***** The X in the title of the last work is replaced by the surname of the composer from whose piece the sound material is taken.) The list of his compositions is more comprehensive and diverse, from chamber music to orchestral music and even electroacoustic music.

Another composer who draws on Vuza's canons is Sébastien Roux. He composed *"Cinq canons de Vuza"* (2016) – an electronic piece. But he doesn't stop there. He composes several dozen Vuza canons. In 2021, he created *"Canons sur écran divisé", a* transdisciplinary piece in which he stages a composition system in which the musical score becomes a split-screen film that is organised in real time. Together with Catarina Miranda, he created *Vuza Canons – Scores for Light and Percussion (*2022), incorporating synaesthetic and scenic elements such as light and colour.

Andranik Tangian is an interesting example of a mathematician who composes and theorises, respectively, analyses his own compositions: *Eine kleine Mathmusik 1* (2002)*, Eine kleine Mathmusik 2* (2003) - *For woodwind sextet.* He is familiar with Vuza's canons but considers them a modest solution. The author also observes that the voices are maximally independent. Tangian argues that these rhythmic canons are harmonically unstable due to anticipations, suspensions, and asynchronous resolutions in different voices, which is highly appreciated in polyphony, where cadences are usually avoided. He chooses another path, suggesting an algorithmic solution to the problem of finding rhythmic canons with augmentations. Instead of theme augmentations, the model can work, the author says, with other arbitrary rhythmic patterns. Thus, in addition to rhythmic canons limited to a single theme, "rhythmic fugues" with multiple themes and counter-themes can be constructed.

4. Vuza Canons in Romanian Musical Creation

In the local compositional landscape, Violeta Dinescu is the one who composed the first works with Vuza canons: Vuza Canons (2020) and *Cronicarii* pe un text de Urmuz (2023). Moreover, the composer has held several masterclasses for students and young composers. But we discover in Laurențiu Beldean's creation - *Stupore II. Hoquetus on a Vuza canon* on a text by Urmuz for seven singers, percussion, two "hesitant performers", a Slavic spectator, and electroacoustic sounds, which premiered in Bucharest on 10 November 2023. Another work is Laura Manolache's *"Perspective"* for 6 percussion instruments and a violin, on a structure of the Vuza Canon, composed in 2024. Mihaela

Vosganian's creations include *Balinese Interferences on Vuza canons* for voices, Gamelan ensemble and electronics (2024) and *Marimbasissima - concert music for marimba and soloist orchestra (*2025). The composition technique based on Vuza canons is recent. There will undoubtedly be more compositions that use it.

4.1. Violeta Dinescu

Violeta Dinescu is a well-known pianist, composer, and teacher. She has had a prosperous career spanning several decades and is an active promoter of Romanian music in Germany. The composer belongs to that distinct category of people who are no strangers to mathematical training and thinking. We find out how she sees this in an interview conducted by Maria-Iulia Rus: *"[...] First of all, I must point out that when we talk about mathematics and music, we are not talking about higher mathematics, research, pure mathematics, anything other than applied mathematics (reine Mathematik – anything other than angewandte Mathematik). I could say that it is a kind of joy of 'play' and*, rather, an understanding of logical thinking, which has major consequences for the focus on musical logic, which, in different contexts, *crystallises ontologically. I do not believe that one can speak of or find a boundary between music and mathematics. Rather, we can say that there are types of music that involve mathematical dimensions, even if the authors did not think of it that way directly. It is possible that music based on precise, mathematical calculations may not 'stand up' to in-depth analysis."*[8] (Rus 2019)

Regarding Violeta Dinescu's compositional style, we read in the Frankfurter Allgemeine Zeitung: *„Folklore (and implicitly history), mathematics (and its principles of order) and musical semantics (sound, linguistic similarities) are the three pillars on which the music of Violeta Dinescu rests, who has developed a unique, personal style, opposed to that which the Western avant-garde considers characteristic of it."*[9] (Büning 2013, 32) The diversity of her sources of inspiration, as well as the variety of genres and compositional techniques she employs, are among the elements that contribute to the presence of her works in the repertoire of leading musicians.

[8] „[…] Mai întâi trebuie sa precizez că atunci când se vorbește despre matematică și muzică nu este vorba de o matematică superioară, de cercetare, de matematică pură, altceva decât matematica aplicată (reine Mathematik – altceva decât angewandte Mathematik). Aș putea spune că este un fel de bucurie a 'jocului' și mai degrabă o înțelegere a gândirii logice, care are consecințe majore asupra concentrării pe o logică muzicală, care în diferite contexte se cristalizează ontologic. Nu cred că se poate vorbi despre sau că se poate identifica o graniță între muzică și matematică. Mai degrabă putem spune că există muzici care implică dimensiuni 'matematice' chiar dacă autorii nu au gândit direct așa și este posibil ca o muzică bazată pe calcule precise, 'matematice', să nu 'reziste' la o analiză aprofundată."

[9] *„Die Folklore (und die darin aufgehobene Geschichte), die Mathematik (und deren Ordnungsprinzipien) sowie die Musikalische Semantik (Klanglichkeit, Sprachähnlichkeit) wurden zu der drei tragenden Pfeiler der Musik von Violeta Dinescu, die einen ganz persönlichen Stil entwickelt hat, jenseits dessen, was die Westliche Avantgarde für richtig befand."*

4.1.1. Vuza Canons (2020)

Vuza Canons is an extensive cycle of nine pieces that share a common compositional technique. Each part is a different type of canon. They are distinguished, on the one hand, by the combination of instruments for each voice and, on the other hand, by the very construction of the canons (number of voices, number of entries, period).

The novelty that Violeta Dinescu brings to the Vuza canon composition is that she extends the "moment" in the canon at 6-8 seconds, which is since "a 3-second window of time is sufficient to convey an idea." *„It is interesting to note that these seemingly limited time windows are, in fact, a miniature universe, a time during which a complex variety of situations can unfold and different imaginary worlds can be created, in which the phenomena that occur define possible contexts of real musical existence."* (Dinescu 2024) The composer considers this to be a first step in her personal understanding and use of the structure generated by the Vuza canons. The example given is the opening piece of the cycle, entitled *Round Table I* for oboe, clarinet, saxophone, violin, viola, and piano. The six instruments correspond to the six voices (soloists) with an internal rhythm {0, 1, 21, 24, 25, 30, 36, 45, 49, 60, 66, 69} and an external rhythm {0, 8, 16, 18, 26, 34}. We remind you that the internal rhythm refers to the active sound moments of a voice (the main voice) and the external rhythm refers to the moments of the other voices' entries (in other words, the distance between voices). The canon period is 72.

The next step was to enrich the colour and texture through instrumentation. Thus, in *Round Table II, Round Table III,* and *Round Table IV,* the voices are groups of instruments as follows: two guitars; clarinet and viola; voice and trombone; trio of recorders; trio of flutes; percussion and piano; horn quartet; wind quintet; and string orchestra. The first canon among these is for 12 voices with an internal rhythm of 6 and an external rhythm of 12. The graph below allows us to visualise the structure of this canon (Figure 6).

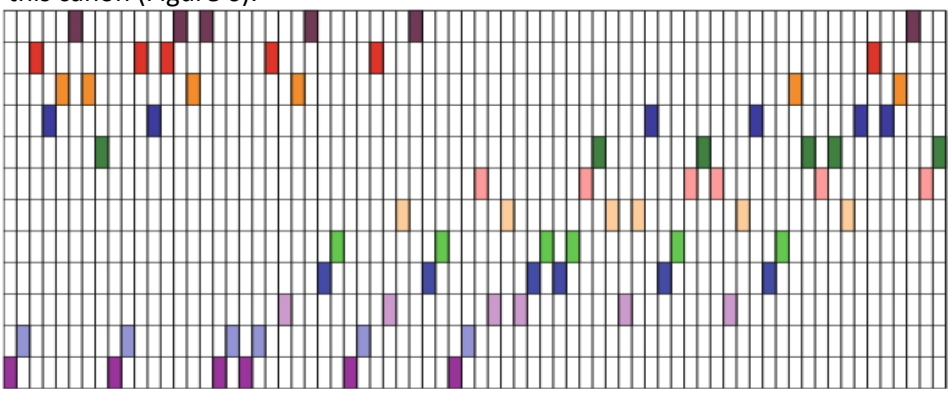

Fig. 6. *Violeta Dinescu - Vuza canon for "Round Table II"*

The next canon is for six voices with an internal rhythm of 17 and an external rhythm of 6. The last canon is for 18 voices with an internal rhythm of 6 and an external rhythm of 17. These two have the same period of 102, so reversing the values of the internal and external rhythms leads us to conclude that one is the dual of the other.

Another level is what the composer calls *"A Brick in a Wall,"* which is a complex polyphony between Vuza canons and an independent melody. In *Transparency I,* there are two canons and an independent melody for solo violin.

The next step is where the composer creates a complex polyphony of strict Vuza canons, with or without other melodies. In *Transparency III,* there are three Vuza canons for 18 voices with a solo mezzo-soprano and a solo clarinet. The piece has a dense texture in which polyphonic moments alternate with heterophonic moments. Thus, the perception is that of a melody with *ison* or, as the author says, the sound image is that of *"the coexistence of a static structure, which we can call timeless, with one that unfolds in time, of a narrative nature"* (Dinescu 2024).

The diversification of Vuza canons continues through the creation of a contrast between rigidity and fluidity. We are seeing the creation of a polyphony of polyphonies. The contrast is between the rigidity of the strict Vuza canons and the flexibility, even spontaneity, of traditional canons. This type of construction is represented by *Transparency II,* which has three Vuza canons and a canon sequence of other voices. Also in this category is *1989-1990*, which features a Vuza canon for 12 voices and three cellos. The cycle ends with *Who Called The Wolf* - a Vuza canon for 18 voices, with a sequence in canon of other voices, among which the violinist Șerban Lupu's voice stands out.

Violeta Dinescu constructs the *Vuza Canons* cycle by alternating strict Vuza canons with asymmetrical periodicity (the four *Round Tables*) with other parts in which she introduces other traditional melodies or canons. Gradually, a voice is represented by an ensemble and achieves what she calls "complexity in transparency" (hence the name *Transparency)*.

These Vuza canons generate musical forms. However, contrary to expectations, rather than simple or more complex polyphony (depending on the composition of a voice), the belief is of monophony. This, in turn, can be simple (if a voice is an instrument) or complex—the constituent elements merge into an aggregate (if a voice is an ensemble). However, we can also perceive and follow the musical discourse polyphonically because the voices are distinguished by timbre, with the sound colours of the ensembles chosen so they cannot be confused.

We can also see a paradox. Even in the simplest Vuza canon, over 72 moments, we have 12 sound presences and 60 pauses, distributed unevenly. That is, we have a discrete sound plan, the overlapping of voices preserves their disjunction, and yet the result is continuous without moments of simultaneity.

4.1.2. Chroniclers (2023)

Laurențiu Beldeanu commissioned the work from Violeta Dinescu for a concert in Bucharest. Whether intentionally or not, it also marks the centenary of the death of the poet Urmuz (Demetru Dem. Demetrescu-Buzău).

The parody-like fable *Cronicari* captures the intellectual and moral superficiality of an era dominated by Eastern influences. The characters – the chroniclers and Rapaport – illustrate the degradation of values: the former are more concerned with fashion than culture; the latter is an ignorant man of power, incapable of understanding the true meaning of culture. The contrast between Aristotle and Rapaport highlights the opposition between the authentic philosophical spirit and its ridiculous imitation. Allusions to figures such as Galileo or Sarafoff amplify the irony, marking the confusion between real and false values. Through symbols such as shalwar pants and frock coats, the fable criticises the chaotic mix of Eastern and Western influences, a sign of a cultural identity in crisis. In essence, *Cronicari* becomes a satire of snobbery and false intellectualism, denouncing the distance between appearance and authenticity.

From the preface to the score, we learn that this is a six-voice canon. As it is a score in which the human voice is dominant, the composer chooses to emphasise the timbral differentiation of the voices and to accentuate the parodic character through the comedy of the discourse. She makes the following distribution:

I. soprano 1
II. soprano 2 and piano
III. soprano 3 and percussion: triangle, vibraphone (which can be replaced with water glasses), and cymbals.
IV. alto 1
V. alto 2 and harpsichord
VI. bass

The author's explanations are indispensable for understanding the score. „*The notation is surprising and invites creative interpretation! The measures have an equal duration of 4 or 5 seconds, which must be fixed and respected as much as possible. Within each measure, the notation is flexible and may suggest a precise interpretation in its context, but the priority is to highlight Urmuz's text. A single voice per measure characterises the structure of the Vuza canon. (N.B.: voice in the sense of colour, in our case, Solo but also Duo as the sum of two different voices, which merge their colours and become one) Therefore, it is necessary to follow the general*

score»[10] (Dinescu 2023).

The musical form is given by a Vuza canon modulo 72 followed by a Coda. The inner rhythm has 12 entries (0, 19, 23, 24, 30, 36, 43, 47, 60, 66, 67, 71), and the outer rhythm has 6 entries (0, 22, 38, 40, 54, 56). Voice VI is the first to enter exactly at the moments listed for the inner rhythm. It is followed by voice V, which enters at 0+22, 19+22, ... 71+22. Then voice IV with entries 0+38, 19+38, … 71+38 and in order voices III, II, and I, respectively. The additions are calculated modulo 72. The composer places the text in a theatrical context.

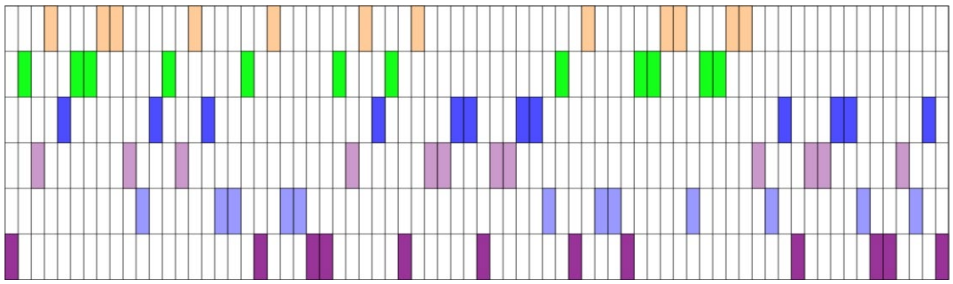

Fig. 7. *Violeta Dinescu - Vuza canon for "Chroniclers"*

If we follow the text, we can imagine the work as a theme with variations. In the Vuza canon, the text is repeated three times. The theme measures 1-27, variation I measures 28-51, and variation II measures 52-71 (Figure 8). The variation occurs on several levels. First, the order of the voices associated with the text is changed, and the sound colour of the text's pronunciation automatically changes as well. The rhythm of each measure is also changed, as is the distribution of the text. This leads to an *accelerando,* with the sections becoming shorter.

[10] *„Notația este surprinzătoare și este o invitație pentru o interpretare creativă! Măsurile au o durată egală de 4 sau 5 secunde, care trebuie fixată și în măsura posibilului respectată. În interiorul fiecărei măsuri notația este flexibilă și poate sugera o interpretare precisă în contextul unei măsuri, dar prioritatea este punerea în lumină a textului lui Urmuz. Structura canonului Vuza este caracterizată prin intervenția unei singure voci pe măsură. (N.B.: voce în sens de culoare, în cazul nostru Solo dar și Duo ca sumă de două voci diferite, care își contopesc culorile și devin una) De aceea este necesar de urmărit partitura generală."*

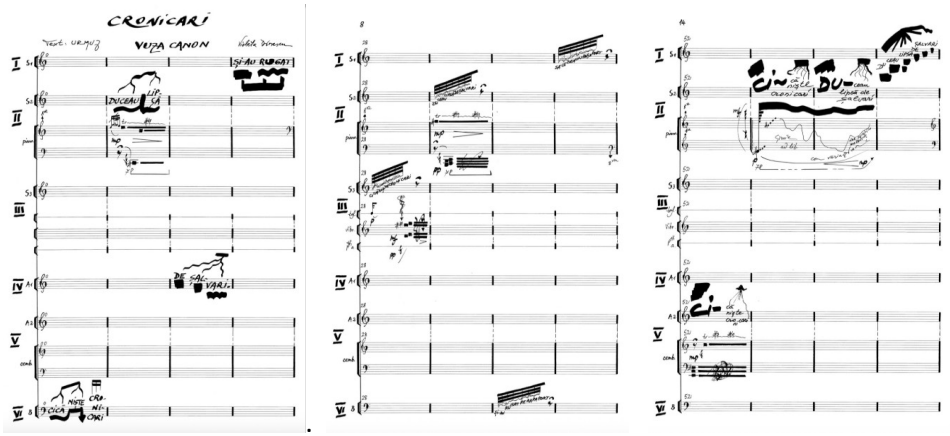

Fig. 8. *Violeta Dinescu* – "*Chroniclers"* m. 1-4, m. 28-31, m. 52-55

The coda is the most extensive section. It is of a completely different nature. Following the text, its form acquires a symmetry that contrasts with the fluidity of the canon (Table 4.)

measures 1 - 8	measures 9–32	measures 33 - 36
Moral	The text of the fable	*Moral*

Table 4. *Violeta Dinescu* – "*Chroniclers". Coda structure*

The complex monophony of the Vuza canon is replaced by heterophony – several voices sing the exact text with different melodies and rhythms. At times, there are moments reminiscent of the canon, as if an echo were being produced. The effect is achieved by delaying the entry of the secondary voices by varying pauses relative to the leading voice, which starts the attack in a measure (Figure 9). Below, we can see the organisation of the voices.

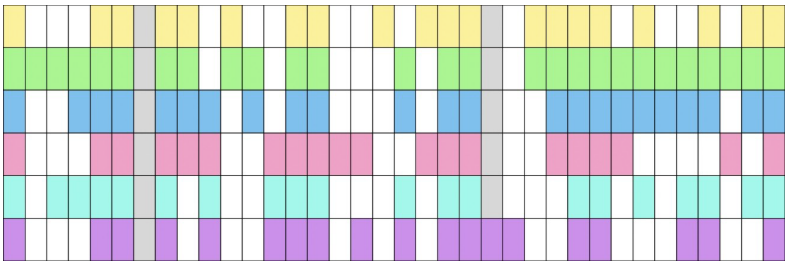

Fig. 9. *Violeta Dinescu* – "*Chroniclers". The organisation of the voices in Coda*

But the author reveals that "*I added two other parts in which I allowed some voices to sing/play supplementary. This way, the moments of intervention of the voices are no longer disjoint, but the structure of Vuza canon remains at the level of attacks, as a subset of the set of all attacks. The "new attacks" are not synchronous with the "old" ones."* (Dinescu 2024)

In the score we have access to, the coda has 36 measures (moments), which is insufficient for a minimum period (remember that this is 72 measures). In most measures, we can associate the main attack with the voice heard first, but in some measures, we cannot set up a priority attack for a voice. This approach represents the seventh level of using Vuza canons. In the previously analysed work (*Vuza Canons),* the composer has already gone through six stages, increasing the complexity of the sound material and the use of structure.

We can observe the most significant complexity achieved so far in *Meandering.* The work has five parts and is constructed in an arc form. The third part is a strict Vuza canon. The first two parts prepare the canon musically, and in the last two parts, the fluidity continues, leading to the finale, which is also a dramatic climax.

We conclude with the words of Violeta Dinescu: *"Through these stages, I've pursued freedom within Vuza's precise structure, using mathematical rigor as a foundation for musical innovation and expression. Each stage reflects a new depth of possibility, weaving complexity and nuance into the elegant framework Vuza envisioned".* (Dinescu 2024)

4.2. Mihaela Vosganian

Mihaela Vosganian belongs to a different generation of composers. She is known in her triple capacity as composer, performer, and theorist. She is the promoter *of archetypal trans-realism* in the performing arts, an orientation she has also described theoretically in her 2020 book. The author aims to reiterate the archetypal functions of art (ritual, cathartic, thaumaturgical, and ecstatic) and, at the same time, to express a new form of *the surreal,* which she calls *trans-real.* In numerous compositions, she also bridges musical traditions (archetypes) with the latest technologies, creating syncretic works. The unity of her creation is ensured by her fundamentally polyphonic thinking, which she explains as follows: "*It is an interesting theory about polyphonic typologies in which I raise the issue of understanding polyphony as a syntactic category, to paraphrase Niculescu, as the most complex syntax that can subsume them and the others, provided you define their plans. If you have succeeded in such an approach to the polyphonic plan, not necessarily as a melody (as in classical polyphony), but as a possible structure, which can be a mass,*

or even another syntax, then suddenly everything that is multi-planar enters the realm of polyphony in this type of vision."[11] (Apostu 2018)

4.2.1. Balinese Interferences on Vuza canons (2024)

The work's world premiere took place in the year of its composition at the *Meridian* Festival held between 3 and 10 November 2024. From the preface to the score, we read: "*The piece is written on 2 Vuza Canons, given to 6 Gamelan groups, together with 2 Extra Vuza soloists and electronic medium. As well, besides the Vuza structures (notated with numbers), there is an Introduction, some extensions, and a Coda. Traditional Vedic texts and rituals inspire the piece, and this is the reason why it is conceived to be performed in a sycretic form, including dance, video, and scenography."* (Vosganian 2024)

The two Vuza canons form the scaffolding on which the extra-Vuza soloist group is placed, consisting of a coloratura soprano with instruments (Forks, Ceng-Ceng, Kajar, and Large Gong) and spoken voices with instruments (Ocean drum, Kajar, Large Gong, Kendang Beleganjur, Gentorag). There is a sound layer—voice and a group of extra-canon instruments —but there are also spoken interventions by the gamelan musicians. Then there is another complex layer consisting of pre-recorded voices processed electronically. The last layer is syncretic (extramusical) and includes movement—dance —and video projection, combining real footage and AI effects. The scenography and editing by Armine Vosganian unify all these layers.

The structure of the work is as follows (Table 5):

A (00'.00'')	**B-G** (01'.11'')	**H** (06'.18'')	**I-O** (06'.42'')	**P-R** (10'.39 ''- 14'.19'')
m. 1-5	m. 6-77	78-80	m. 81-152	m. 153-163
Introduction	**Vuza Canon I**	**Transition**	**Vuza Canon II**	**Coda**

Table 5. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". The structure*

[11] *„Este vorba despre o teorie interesantă despre tipologiile polifonice în care pun problema înțelegerii polifoniei ca și categorie sintactică, ca să îl parafrazez pe Niculescu, drept cea mai complexă sintaxă care le poate subsuma și pe celelalte, cu condiția să îi definești planurile. Dacă ai reușit o astfel de abordare a planului polifonic, nu neapărat ca o melodie (ca în polifonia clasică), dar ca o posibilă structură, care poate fi o masă, sau chiar o altă sintaxă, atunci dintr-o dată tot ce este pluriplanic intră în domeniul polifoniei în acest tip de viziune."*

The two Vuza canons are each 72 measures long and are performed by six voices as follows:

I. 2 Kantil
II. 2 Pemade/Spoken Voice/Fix Ceng-Ceng, 1 Pemade changes to Suling
III. Ugal/ Spoken Voice/Ceng-Ceng
IV. Trompong (10 Gongs)/Spoken Voice
V. Kendang Legong/Ocean drum
VI. 2 Jegog/Spoken Voice/Gentorag

In both canons, the distribution is identical. The leading voice is **VI,** it has an inner rhythm of 12 (= 0, 19, 23, 24, 30, 36, 43, 47, 60, 66, 67, 71) and an outer rhythm of 6 (=0, 22, 38, 40, 54, 56) (Figure 10).

The order of entry of the voices is: VI - V - IV - III - II - I. Its image can be seen below.

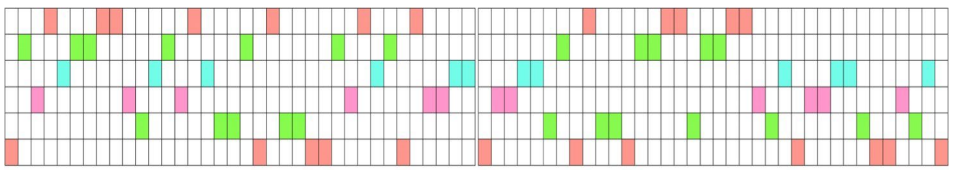

Fig. 10. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". Canon structure*

The orchestra is subject to a creative division that affects several levels of sound construction. The instruments used in the Vuza canon (Vuza Gamelan) strictly adhere to the measure. In the first canon, this is $^{4}_{4.}$ In the second canon, the measure changes along the way: $^{3}_{4}$ from measure 117, ^{58} from measure 129, and $^{2}_{4}$ from measure 141 to measure 152. The introduction has a measure of 84. The coda is free, without rigorous metrical indication, only temporal landmarks accompanied by approximate pulse indications. In fact, the entire score has temporal landmarks and metronomic indications. All the other instruments—those going with the melody—play freely, using other temporalities.

If Vuza provides a constant pulse of dialogue between voices, within a moment (measure), the composer's freedom is devoid of any constraint. The presence of other sound planes contributes to the creation of a polyrhythm. On the one hand, in the extra-Vuza percussion, the Kajar brings a quasi-ostinato quarter note pulse over large surfaces, providing important support for rhythmic stability in measures 6-91. Starting with measure 92, it takes part in the acceleration of the composition by halving the durations (to eighth notes). The transition to the second

canon heralds an acceleration of the movement. Kendang Beleganjur intervenes in the second canon with an alert counterpoint rhythm in sixteenth note durations or sixteenth note triplets. Within the canon, the similarity between the musical motifs (from a modal, melodic perspective) is counterbalanced by numerous rhythmic variations.

Polyrhythm appears in two forms. The first is intrinsic to the Gamelan (the Vuza canon). An interesting example is in measure 78, where each voice has its own rhythm, not necessarily proportional to the others (Figure 11).

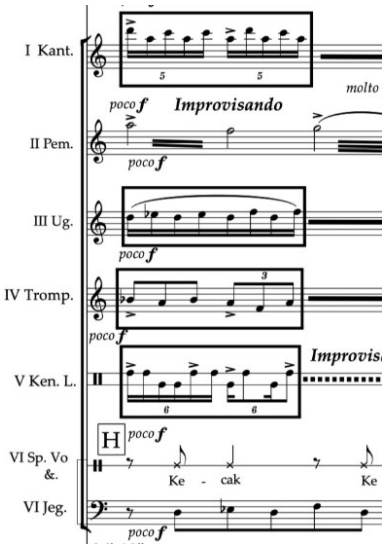

Fig. 11. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". m. 78*

Another variety of polyrhythms manifest itself between the sound plane of the Gamelan and that of the extra-Vuza group. Within the limits of a measure, sometimes we have two variants of the same musical motif simultaneously, as in a heterophony. For example, in measure 20 or measure 26 (Figure 12).

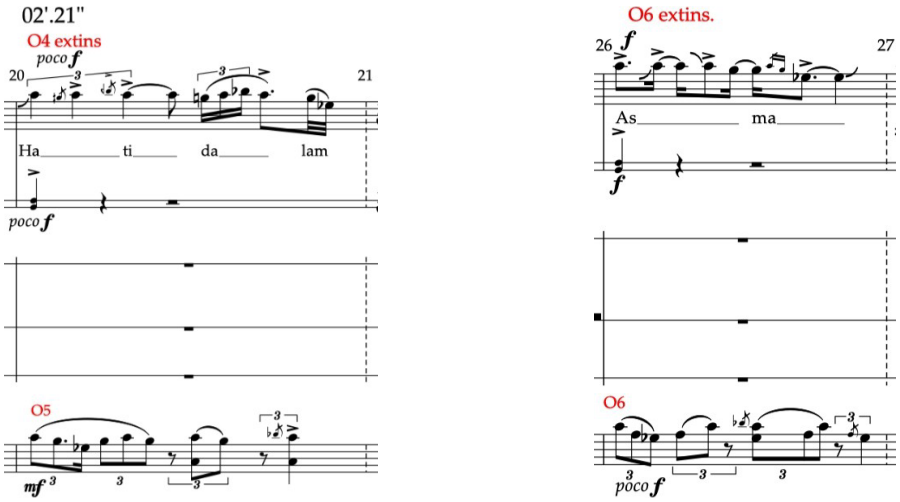

Fig. 12. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". m. 20, m. 26*

In the second canon, the overall acceleration is achieved by reducing the durations to the level of thirty-two notes.

The organisation of the extra-Vuza solo soundscape contributes to the composition's originality.

The text (Table 6), which appears mainly in the first part of the work, is as follows:

Kekak (original text)	**Kekak** (EN translation)	**Kekak** (RO translation)
Hati dalam lara Cinta mistik abadi Asmaradana Menikam sanubari Kekal selamanya Kemuncak destinasi murniii Bermimpi ... berlari, Dudu bondho dudu rupo, Amung ati pawiitaaaaneee..... **Asmaradana**	Heart in pain, Eternal mystical love. Eternal forever Asmaradana Born from the soul Stabbing the threads of the heart, Dreaming... running towards the true destination. **Asmaradana**	Inimă în durere, Iubire mistică eternă. Eternă pentru totdeauna Asmaradana Născută din suflet Înjunghiind firele inimii, Visând ... alergând spre adevărata destinație**.** **Asmaradana**

Table 6. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". Text*

In the second canon, the rhythmic acceleration is accompanied by an inverse proportionality to the extension of the text, which appears more sporadically.

Kekak (or Kecak), also known as *the Song of the Monkeys from Ramayana*, is actually a Balinese ritual dance. The poetic dimension of the dance is given by the repetitive voices that create a rhythmic trance. The above text is an incantation. *Asmaradana* is also the title of a poem and a *tembang* (classical Javanese song) about mystical love. This poem describes spiritual, eternal love in which pain becomes a path to purification. The repetition of "Asmaradana" acts as a sacred refrain.

The score is written in contemporary Western musical notation – predominantly musical notes with a specific pitch, but also graphic symbols specific to contemporary music. However, gamelan instruments use other tuning systems. In this case, the tuning system is *pelog—a* heptatonic musical scale that differs from *the* well-known *slendro (a* division of the octave into five approximately equal intervals). There are several peculiarities of pelog. On the one hand, the tuning varies from island to island and even from locality to locality. On the other hand, even though the musical scale is heptatonic, a pentatonic scale derived from it is often used. In addition, the transcription into Western notation is an approximation because the heptatonic scale (*pelog)* is part of the musical scale that divides the octave into nine equal tones (Figure 13).

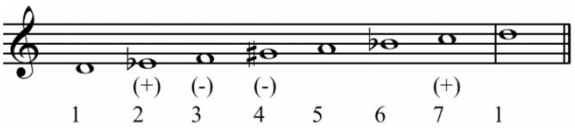

Fig. 13. *Pelog in Western notation*

In this work, the composer uses (in Western notation) the following musical scale (Figure 14):

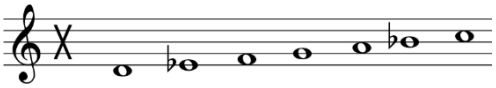

Fig. 14. *Mihaela Vosganian – "Balinese Interferences on Vuza canons". Scale*

It can be assimilated with a transposed Phrygian mode. However, this scale does not appear in its entirety throughout the work; we encounter tetrachordal, pentachordal, and even hexachordal formulas extracted from the primary mode. This is consistent with the character of the Balinese pelog.

Beyond the melodic connection between the soprano and the gamelan (the first Vuza canon), Mihaela Vosganian makes another connection between them. In

the extra Vuza voice part, starting with measure 20, there is an extension, a sequence O4 - O11 of the canon.

The composition is vibrant musically. Mihaela Vosganian's propensity for polyphony is very well exploited. In fact, it is a polyphony of polyphonies, some rigorous, others very free rhythmically. The author calls the composition technique used "*controlled randomness"*. She juggles all the sound parameters, and the result is impressive. *"Thus, the combination of tempo, meter, and rhythmic cells often leads to characteristic and recognizable themes that can be incorporated into a stylistic, expressive, or even narrative project," [12]* as Claude Abromont would say. (Abromont 2019)

The composition also has a poetic, spiritual dimension that escapes analysis. This dimension opens the door to a territory known to people of all times, fulfilling a thaumaturgical function.

The work *Balinese Interferences on a Vuza canon* is perfectly integrated into the composer's creation, continuing her predominantly polyphonic creative thinking, but also bringing new and original elements. Several other compositions explore the area of interference between different types of music: Romanian-Balinese Interferences (2018), Japanese Interferences for flute, percussion, harp, violin, cello, and tape (2002), and *Armenian Interferences for mezzo-soprano, clarinet, and string quartet (1994-1995).*

Continuity with the Vuza canon composition technique is provided by Marimbasissima – concert music for marimba and soloists orchestra, a work premiered in May 2025 at the Oltenia Philharmonic in Craiova. In this work, Mihaela Vosganian uses three different Vuza canons, thus delimiting the three sections of the composition and "generating so-called ontological forms". Part I is a Vuza canon for 12 voices, modulo 72; Part II is another Vuza canon for six voices, also modulo 72; and the last part is a Vuza canon for 10 voices, modulo 120. "*There are permanent extra Vuza voices, namely the piano and harp, and other extra Vuza voices specific to different parts, which have other types of temporalities that deviate from the canonical mathematical patterns of the Vuza type. At the same time, the canonical Vuza-type voices can change into percussion instruments in the pauses between the canonical entries"* (Vosganian2025, 4). However, the marimba's placement in the leading role is also a novelty. The concertante work combines mathematical rigour with freedom of artistic expression, both placed under the sign of its original aesthetics, inviting us into an unusual world of sound with spiritual depths.

[12] *„Ainsi, la combinaison d'un tempo, d'une métrique, et de cellules rythmiques, aboutit fréquemment à des topiques caractérisés et reconnaissables qui peuvent s'inscrire de façon large dans un projet stylistique, expressif, voire narratif."*

5. Conclusions

The Vuza canons highlight a fascinating interdependence between mathematics and music, proving that mathematical rigor in the generation of musical forms can coexist with artistic expressiveness. Theoretical analysis has highlighted the fundamental principles of constructing these canons and their importance for exploring new ways of organizing time and rhythm in contemporary music.

The examination of the compositions of Violeta Dinescu and Mihaela Vosganian demonstrated the practical applicability of these principles, highlighting how each composer integrates Vuza's canons into their own musical language while maintaining structural coherence. The results of the analysis suggest that these approaches not only preserve the mathematical integrity of the canons but also offer expressive opportunities and freedom of imagination in musical creation.

In conclusion, Vuza's canons are not just a theoretical exercise, but a living tool capable of inspiring new forms and perspectives in contemporary music.

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