Form-finding of a Classical Music Learning Center using Sound Wave

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Abstract

This thesis is a Classical Music Learning Center project for people lacking experience in learning music theory can explore and practice. It is designed using the principle of Formation of parametric design. In this particular approach, our concept is to use classical music as an input for a form-finding process. The research question is "How can sound waves be used to design the architectural form of the Classical Music Learning Center through the form-finding process?". The methodology is experimental design, which consists of conducting the form-finding experiment with sound waves from classical music pieces, using parametric design. Then, an evaluation is performed using a 5-scale Likert against criteria of aesthetic, function, access, and structure. The result shows that sound waves from classical music pieces can be converted into architectural forms. This form-finding process can be achieved through parametric tools (Rhino-grasshopper plugins) using the information of frequency, note, and volume from the sound wave. The design becomes the overall roof structure of the Classical Music Learning Center that expresses the curviness of the sound wave.

Keywords: *Learning center, Classical music, Concert hall, Parametric design*

1. Introduction

This paper presents the Classical Music Learning Center Project research. The learning center aims to support a group of musicians and the general public who love classical music. In the Thai context, classical music is not well known yet, especially in today's school children. The basic education system in Thailand does not provide sufficient knowledge and experience related to classical music from the western world. This problem is due to the shortage of classical music teachers, who can generally be found in music schools. For general public and musicians, there is still a lack of space to support musical activities, such as concerts, learning, and workshops. There are not enough public facilities for such usage.

On the other hand, classical music is a subtle form of art with many detailed and expressive elements, such as pitch, scale, tempo, and dynamic. In this sense, the architecture of the Classical Music Learning Center could be expressed musically. This research takes a Computational design approach; the contemporary process is called *Data representation architecture* (Bermudez et al., 2000). In this process, architecture is created using data from external sources, such as music. We propose to use Parametric design for form-finding of the architectural design process. Building forms will be generated using sound waves from 3 famous and widely recognised classic pieces.

2. Objectives and research question

The objective is to create forms and space of the Classical Music Learning Center using sound waves from classical music. The research question is "How can sound waves be used to design the architectural form of the Classical Music Learning Center through the form-finding process?"

We propose that sound waves can be experimented or simulated through computer programs for architectural design. For this project, the sound waves are classical music pieces. They will be input to software and converted into frequencies, notes, and volumes. The software then transforms this numerical information into building forms for the architect to select according to his/her criteria, which is called the form-finding process.

3. Literature review

3.1 Theories and principles related to design

3.1.1 Parametric Design

What can a parametric design do? Walaiporn Nakapan (Nakapan, 2017) suggested that there are six ways to use the parametric design (Figure 1) as follows.

1. Formation: form-finding that responses to environmental factors and efficiency,
2. Materialization: building technique that can create a new effect to the same old material,
3. Iteration: looping in computer science aiming to solve a complex problem,
4. Simulation: a computational technique to simulate building or environmental factors,
5. Optimization: a technique to find the most extreme values as solutions to a problem,
6. Industrialisation: digital fabrication in a large scale following the file to factory concept,

ARCH RSU Parametric Design Studio research applies one or many of these concepts to the project. This research focuses on the use of parametric design for **Formation,** or a specific form-finding process to test and look for forms that can be designed into a Classical Music Learning Center.

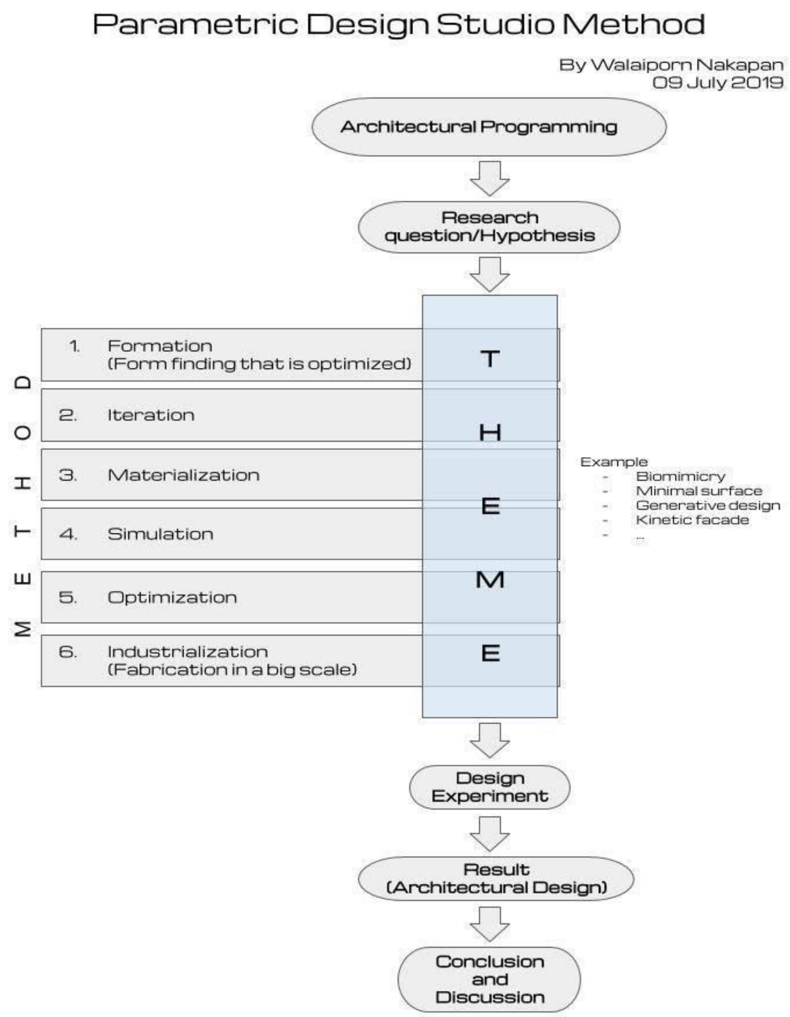


Figure 1 Parametric design studio method is used as a framework of this project

3.1.2 Concert hall design

Concert halls can be designed in many different shapes, depending on the preference of the architect.

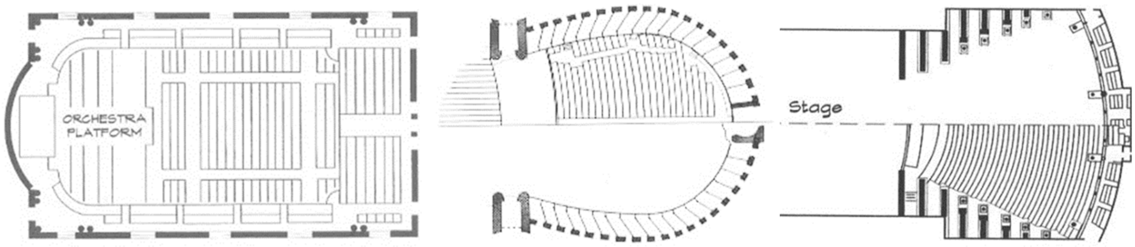


Figure 2 Rectangle shape concert hall (left), horseshoe shape concert hall (middle), and fan shape concert hall (right), from Architectural Acoustics (Long, 1988)

<u>Rectangle shape</u>

A rectangle-shaped concert hall has an advantage in terms of the floor plan, which can fit the typical building floor plan, and is expandable. However, there is a limitation on the size of the stage: if the room is very long, the stage will not be proportional. The size of the stage is usually designed to have a length-width ratio of 2:1, and a height to width of 1.2:1, but should not be more than 32 meters wide, and the ceiling should not be too low. Figure 2 - left shows the rectangle-shaped concert hall, which is suitable for a concert hall with 1,500 seats. Another disadvantage is acoustic; if the room is too narrow, a flutter echo can occur. Flutter Echoes are produced by sound traveling quickly between two parallel reflective surfaces (Flutter echo, 2020).

<u>Horseshoe shape</u>

A horseshoe or an ellipse floor shaped concert hall (Figure 2 - middle) is suitable for opera performances where the sound is directly projected from the stage. Its concave shape allows the spectators to see the performance from all around. However, it is not suitable for music performance with sound equipment because of the sound foci caused by the use of curved walls.

<u>Fan shape</u>

A fan shape (Figure 2 - right) is a form that has many advantages. It can provide many seats while the cost of investment is not too high. However, in terms of acoustic, it is still not very good, since each wall is separated, resulting in the dispersion of sound. The bad spot usually occurs in the middle of the concert hall. A solution to this is to make walls with angles as small as possible. The wall angles should be greater than 90 but not more than 115 degrees. The rear wall tends to be concave in order to help with the acoustic.

<u>Hexagon shape</u>

A hexagon shape concert hall (Figure 3) is a style that has been invented to solve the problem of the number of seats in a rectangle and fan shape. Hexagon shape provides flexible seating with an adaptable stage. However, sound control is quite difficult. It is a multipurpose space for school activities, meetings, sports events, music performances.

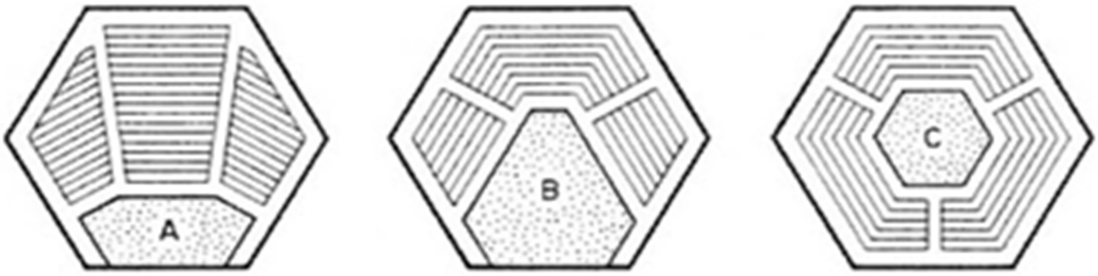


Figure 3 Hexagon shape concert hall with adaptable stage
From: Auditorium Acoustics and Architectural Design, (Barron, 1933)

3.2 Theory of music related to the sound wave

3.2.1 Related terms in music theory

- the ***pitch*** of a note means how high or low the note is. In physics, it is measured in a unit called Hertz. A note that is vibrating at 261Hz will be caused by sound waves that vibrate at 261 times per second, which will be Middle C note on the piano.

- a ***scale*** is a set of notes in order of their pitch. Major scale (sounds lively and more common) and minor scale (sounds serious or melancholic).

- ***tempo*** is the speed or pace of a given piece (for example *Largo* meaning "broadly," *Adagio* meaning "slowly with the great expression," *Andante* meaning "at a walking pace," *Moderato* meaning "at a moderate speed," *Allegro* meaning "fast, quick, and bright," *Vivace* meaning "lively and fast," and *Presto* meaning "very, very fast."

- ***dynamic*** refers to the volume of a sound or note: *pianissimo* meaning "very soft," *piano* meaning "soft," *mezzo-piano* meaning "moderately soft," *mezzo-forte* meaning "moderately loud," *forte* meaning "loud," and *fortissimo* meaning "very loud."

3.2.2 Sound wave

Technical terms related to sound wave are:

- *Frequency* of the sound wave is the rate of vibration that results in the pitch of the sound.
- *Note* is a specific group of frequencies that results in different musical notes (see Table 1).
- *Volume* is the loudness of the sound.

Table 1 Notes and frequencies (Interactive Mathematics, 2020)

Note	Frequency	Note	Frequency	Note	Frequency
C(Do)	262	C(Do)	523	C(Do)	1047
C#	277	C#	554	C#	1109
D(Re)	294	D(Re)	587	D(Re)	1175
D#	311	D#	622	D#	1245
E(Mi)	330	E(Mi)	569	E(Mi)	1319
F(Fa)	349	F(Fa)	698	F(Fa)	1397
F#	370	F#	740	F#	1480
G(Sol)	392	G(Sol)	748	G(Sol)	1568
G#	415	G#	831	G#	1661
A(La)	440	A(La)	880	A(La)	1760
A#	466	A#	932	A#	1865
B(Ti)	494	B(Ti)	988	B(Ti)	1975

3.3 Previous works and case studies

3.3.1 Previous works

There are some previous works related to form-finding from music. Christensen and Schnabel (2008) have studied the music of J.S. Bach, a famous German composer. Their research is called Spatial polyphony, which consists of transforming Bach's preludes and fugues of Book I of The Well-Tempered Clavier (BWV 846-869) into architecture using data from the MIDI file. Another work done by Jeremy Ham (2018) explores the creative process of digital representation of spatial form using improvisation on the digital drum kit.

3.3.2 Case studies

Following cases related to concert halls and music schools have been studied:

- **Prince Mahidol Hall** (Prince Mahidol Hall, 2020) is a multi-purpose building of Mahidol University, Salaya campus for a conference, concert, stage play, cultural performance. The building is a great example of the study of building components, the layout of the area, and the music rehearsal rooms.
- **Suryadhep Music Sala**, Rangsit University, Pathumthani, Thailand (Suryadhep Music Sala, 2020) is an example of concert hall functions and how to accommodate a large number of spectators.
- **KPN Music School** is an example of a single rehearsal room system (KPN Music Academy, 2020).
- **Yamaha Music School** is an example of a medium-sized rehearsal room. Its exhibition area is not very large (Yamaha school, 2020).

4. Methodology

The methodology used in this research is experimental design. It proceeds as follows:

1. Study of related theories and principles, as shown in paragraph 3 (literature review),
2. Study a Rhino-Grasshopper plug-in component that allows conversion of sound waves to parametric forms,
3. Conduct the form-finding experiment with sound waves from classical pieces, using parametric design,
4. Evaluation of the form,
5. Conclusion and discussion.

4.1 Experimental framework

Three classical pieces by famous composers are chosen. The reason for choosing these three pieces is because they are classic pieces that most people recognise. All three songs have different expressions:

1. ***Canon in D*** by Johann Pachelbel: a light and soothing piece of music, but the dynamics are not very different,
2. ***Four Seasons*** by Antonio Vivaldi: the tone changes throughout the set according to each season. However, the selected piece is ***Spring***, which is lively and most well-known. It has got merry melodies, and there are different dynamics in each section;
3. ***1812 Overture*** by Pyotr Ilyich Tchaikovsky: starting softly and sadly, then becoming upbeat, fierce and dramatic, full of Russian nationalism. It emphasises on the dynamic of the notes, resulting in a different feeling in each part.

For each classical piece, three types of sound wave conversion are used in the experiment: *frequency*, *notes*, and *volume*. A Rhino-Grasshopper plugin called "Firefly" is used; its component allows conversion of sound waves to parametric forms. It is to be coupled with another component called "Kangaroo physics" for mesh manipulation. The process is called "Spring from mesh," which allows force vectors to act on each point of the mesh, thus creating different forms from bouncing movements.

4.2 Form-finding experiment with sound waves from classical pieces

The experiment takes the following steps:

1. Import the classical piece into the Firefly's *Sound Capture* component via the computer's internal audio (Figure 4 - left). This component will convert the music into sound waves.

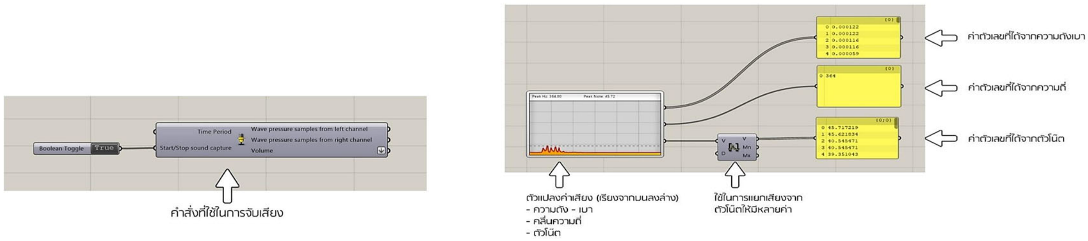


Figure 4 Firefly's Sound Capture component (left), and converted sound waves (right)

2. The converted sound waves are shown in a series of numbers, representing frequency, notes, and volume (Figure 4 - right)

3. The sound waves conversion definition will be input into the Kangaroo physics' spring from mesh definition (Figure 5). At this point, three classical pieces have experimented (*Canon in D*, *Four Seasons*, and *1812 Overture*).

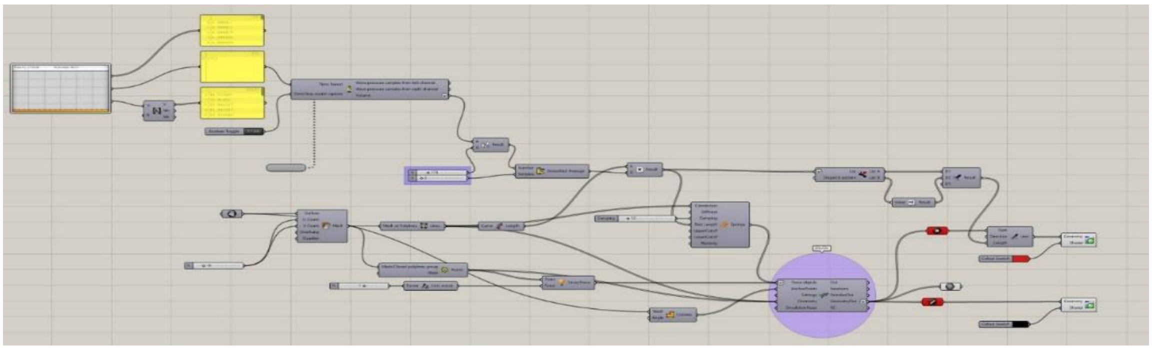


Figure 5 Sound wave conversion definition connecting with Kangaroo Physics' spring from mesh definition

The original mesh for an initial test is square. It will be input into the spring from mesh definition. Figure 6 shows the resulting mesh in Rhinoceros window. The form continues to change with the music. Only some key instances are captured randomly.

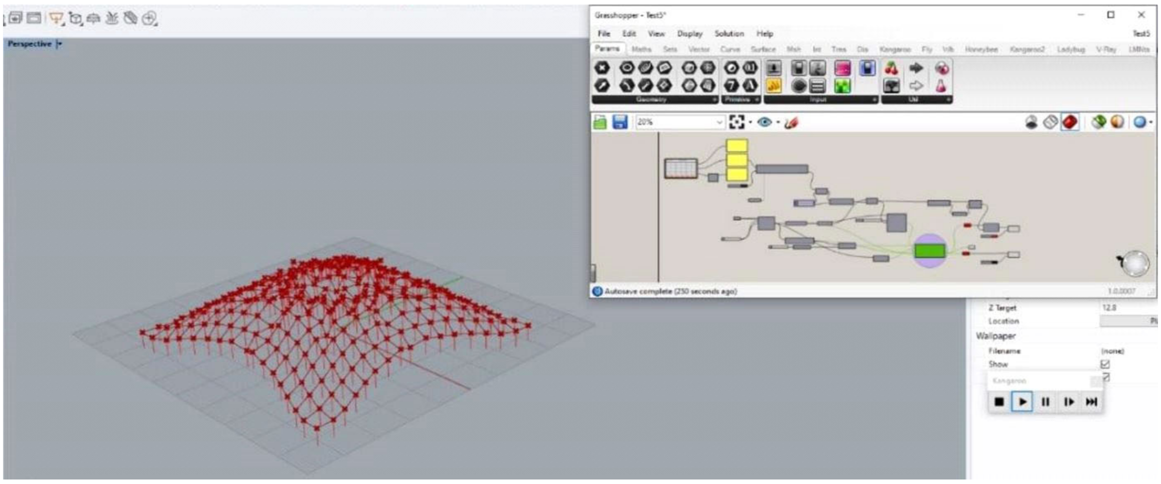


Figure 6 Spring from mesh result in Rhinoceros

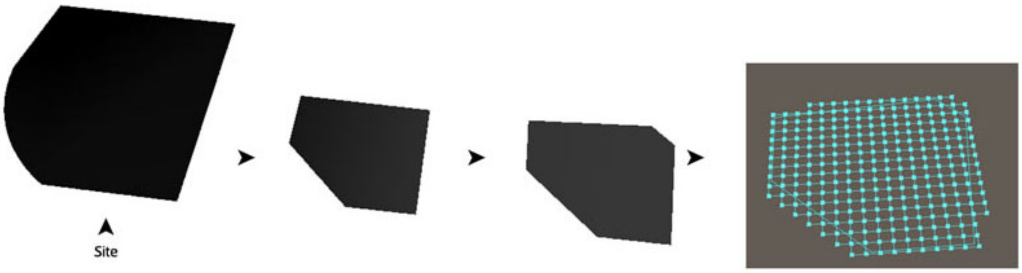


Figure 7 Site analysis as a way to find original mesh for form-finding process

However, for the experiment, the original mesh before applying the spring from mesh definition will be derived from the site analysis process (Figure 7). The project site is situated in the Bangna area, near Udom Suk BTS station. The site is found on the corner between Sukhumvit Road and Bang Na-Trad Frontage Road. The site corner is rounded and its opposite corner is a right angle. By cutting the rounded corner of the site into three straight sides, the process results in an original mesh for the form-finding process (Figure 7).

5. Results

5.1 Concert hall design

From the study of concert hall design (paragraph 3.1.2) and case studies (paragraph 3.3), it is found that the most appropriate shapes for concert halls are rectangle shape and fan shape. Nevertheless, from the site analysis, it is found that the fan shape is similar to the site curve (Figure 7); it has got more possibility to fit into the site. Therefore, the fan shape concert hall will be used to analyse the forms converted from music for the following form-finding experiment.

5.2 The form-finding experiment

The form-finding experiment uses Firefly and Kangaroo physics, which are parametric design plugins. It consists of converting sound waves from 3 classical pieces (*Canon in D*, *Four Seasons*, and *1812 Overture*), each using three types of output (frequency, note, and volume). For each piece, the form dances according to the changing frequency, note, and volume of the piece. In order to find a particular form, we choose to stop the spring from the meshing process at the same moment of every piece. The experiment results in 9 three-dimensional forms; each piece of music gives three forms (Figure 8, Figure 9, and Figure 10).

5.2.1 Building forms captured from *Canon in D* (Figure 8)

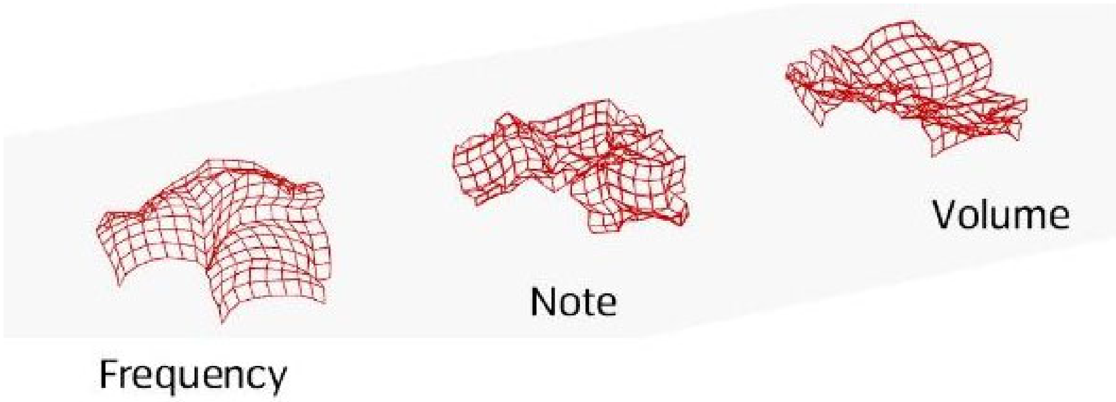


Figure 8 Building forms captured from *Canon in D*

5.2.2 Building forms captured from *Four Seasons* (Figure 9)

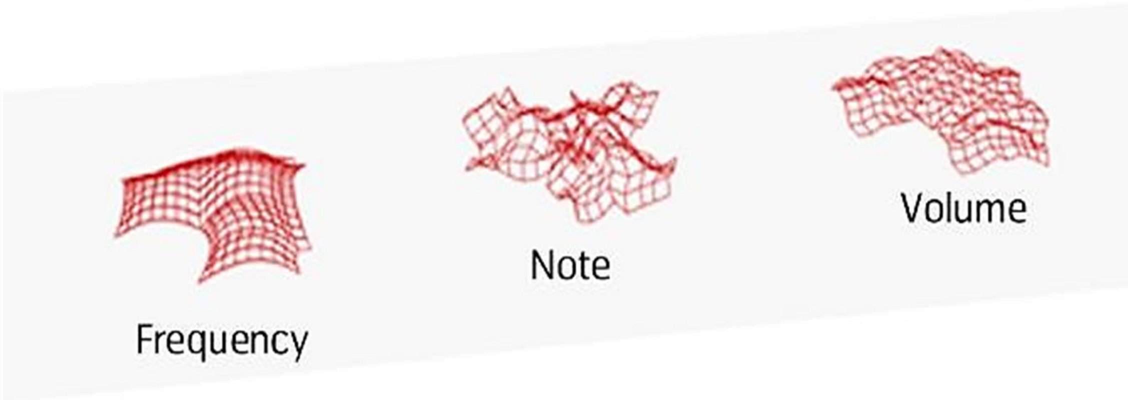


Figure 9 Building forms captured from *Four Seasons*

5.2.3 Building forms captured from *1812 Overture* (Figure 10)

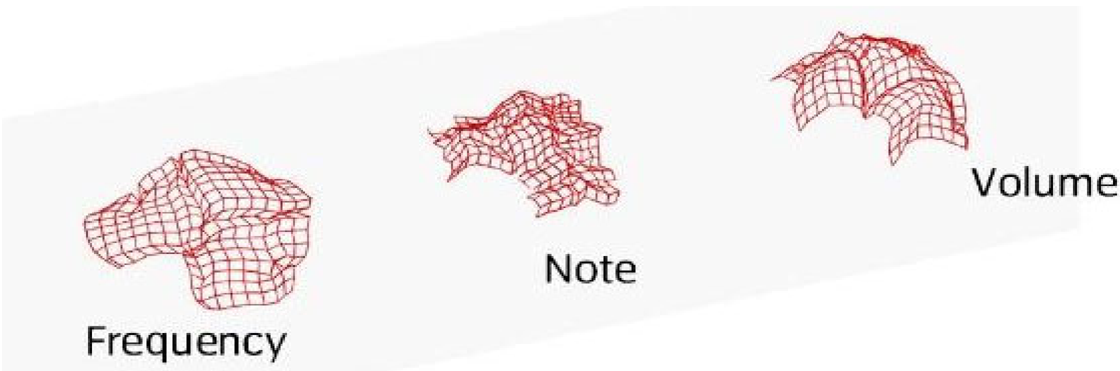


Figure 10 Building forms captured from *1812 Overture*

It is found that the forms converted from classical pieces varied greatly:

- The forms derived from frequency is more balanced (Figures 8, 9, and 10 on the left). The reason is that the form dances according to a range of frequencies of that particular piece of music. Usually, the range is not very large.

- The form derived from notes is quite messy and angular (Figures 8, 9, and 10 in the middle). The reason is that the form dances according to a range of notes. A piece of music uses many notes in order to create a flowing melody. Since notes are expressed by a range of frequencies, they give more angular forms.

- The forms derived from volume is more balanced, but some creases can be found (Figures 8, 9, and 10 on the right). The reason is that the form dances according to a range of volume – whether it is soft or loud. *Canon in D* (Figure 8 – right) and *Four Seasons* (Figure 9 – right) has a small range of volume, so the form is quite flat. On the contrary, *1812 Overture* is more expressive and has a larger range of volume, so the form bounces highly.

5.3 Evaluation of the forms converted from sound waves

From the form-finding experiment, the results come in different spring from mesh forms. These forms can be adapted into architecture such as building components, overall shape, or space. Therefore, it is necessary to have criteria that help to choose them. The criteria are aesthetic, function, access, and structure. The forms are evaluated against these criteria using a 5-scale Likert (Surveyking.com, 2020): 1 = 'not appropriate,' 2 = 'unlikely to be appropriate,' 3 = 'neutral,' 4 = 'likely to be appropriate,' and 5 = 'appropriate.' Table 2 shows the criteria for building form selection. Note that the forms are evaluated by one of the authors, except for the structural criteria that is evaluated by a structural engineer.

Table 2 Criteria for building form selection (F = Frequency, N = Note, V = Volume; A1 = Average for each form; A2 = Average for each piece of music)

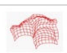
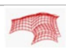
	Canon in D			**Four Seasons**			**1812 Overture**		
	F	N	V	F	N	V	F	N	V
									
Aesthetic	4	3	3	5	3	3	2	3	3
Function	4	3	3	4	5	3	2	4	5
Access	4	2	3	4	2	3	2	4	5
Structure	4	2	2	4	3	2	2	3	3
A1	**4**	**2.5**	**2.75**	**4.25**	**3.25**	**2.75**	**2**	**3.5**	**4**
A2	**3.08**			**3.42**			**3.17**		

Table 2 shows that the forms from *Four Seasons* (Spring) have got the highest average marks (3.42, which is between 'neutral' and 'likely to be appropriate'). From this piece of music, the form converted from frequency is selected because it has got the highest mark (4.25, which is between 'likely to be appropriate' and 'appropriate').

Therefore, the form from *Four Seasons* is chosen to be developed into the roof structure of the Classical Music Learning Center (Figure 11). It has wavy flowing curves, resulting from sound waves of the music. The interior space is grandiose and can receive a large number of audience. It is also suitable to fit a fan shape concert hall inside.

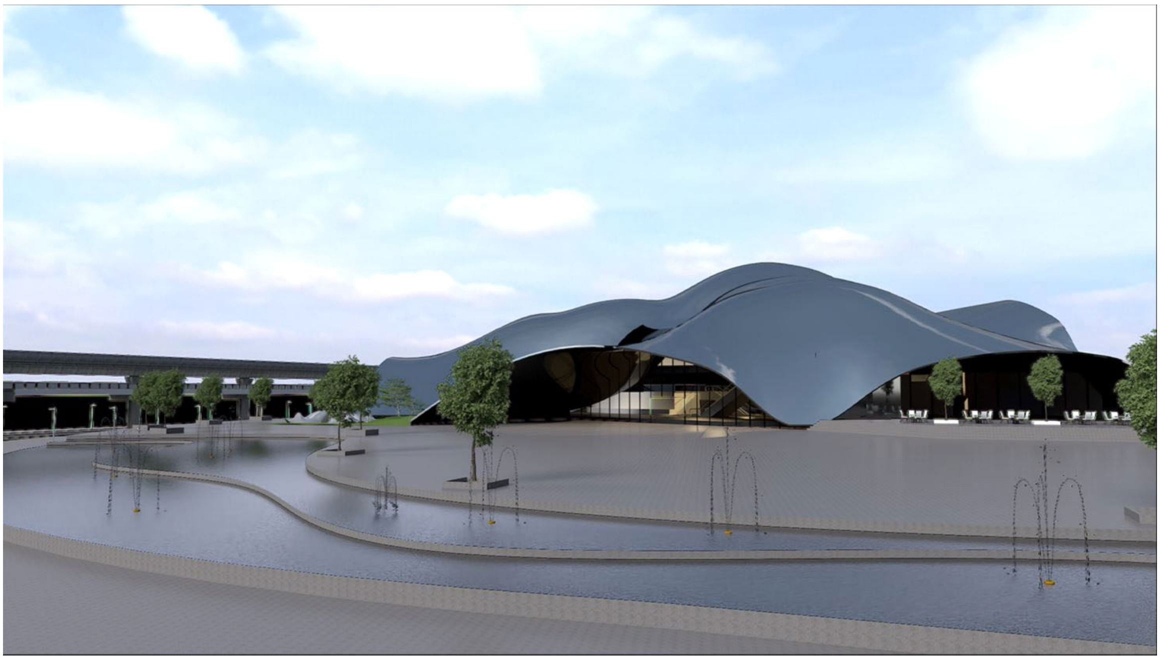


Figure 11 Perspective rendering of the Classical Music Learning Center

6. Conclusion and Discussion

From the research question mentioned above ("How can sound waves be used to design the architectural form of the Classical Music Learning Center through the form-finding process?"), it can be concluded that sound waves from classical pieces of music can be converted into architectural forms. This form-finding process can be achieved through parametric tools (Rhino-grasshopper plugins) using the information of frequency, note, and volume. The experiment demonstrates this specific form-finding process, which results in the overall roof structure of the Classical Music Learning Center. The structural solution of the roof is subject to further study. Also, there are many other architectural components of the project to be considered, such as an indoor concert hall, outdoor concert hall, and retail shops. The landscape design also plays an important part in spatial arrangement of the project. Besides, it is important to take into account the principle of concert hall design in order to achieve a good result. This discovery contributes as an alternative form-finding process, which can be adapted to other projects as well.

7. Acknowledgements

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