SPECTROGRAM DATA AS SYSTEM FOR MAKING SCULPTURE

Topic: Art, Music

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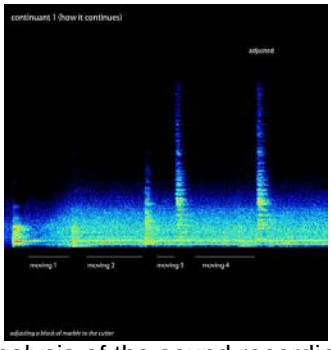
Abstract
This paper proposes a method for making generative art in the form of a system based on an interdisciplinary approach combining sculpture and sound. I will explore the possibility of using data from the spectral analysis of sounds as instructions for making sculpture. Inspired by Sol LeWitt's principles and ideas for the creation of generative art as system and Francis Halsall's definition of a 'system's identity' (Halsall, 2008, p. 27), I am investigating ways for creating a new system that will allow the articulation of the above idea. Furthermore, combining Tom Johnson's (2015) system for composing music after LeWitt's sculpture *Incomplete Open Cubes* and Oscar Wiggli's sculptural and musical work, I will focus on how sequences of sound material could be related to a sculpture. Based on Denis Smalley's *spectromorphology* as 'a descriptive tool based on aural perception' (Smalley, 1997, p. 107), I will analyze sound samples recorded from the workshop during the making and I will focus on their connection to the sculptor's gestures. In this paper, Smalley's 'ideas of onset (how something starts), continuant (how it continues) and termination (how it ends)' (Smalley, 1997, p. 115) will be reconsidered from a sculptural perspective (Figures A and B). Through the realization of a series of practical experiments, I will discuss: a) how actions of making sculpture could be reflected through sound, b) what kind of variations of spectra could inform different actions, c) how different materials could affect the sound samples and d) how the actions of making sculpture could be predefined as sequences through sound material in a systematized way, producing generative outcomes.



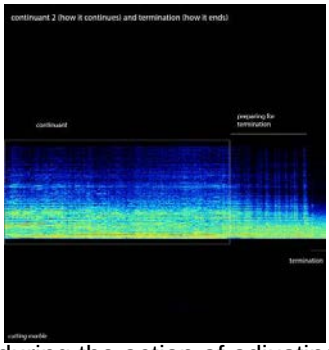


Figure A (left): Spectral analysis of the sound recording during the action of adjusting a block of marble in the cutter by moving it.
Figure B (right): Spectral analysis of the sound recording during the action of cutting.

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Key words: sculpture, sound, spectromorphology, systems, process

Main References:

[1] Denis Smalley, "*Spectromorphology: Explaining sound-shapes*", *Organised Sound, 2*(2), 107-126, 1997
[2] Matthias Frehner and Jochen Hesse (Eds.), "*Oscar Wiggli: Korper, Raum, Klang*", Benteli, Bern, 2007
[3] David Hirst, "*From Sound Shapes to Space-Form: Investigating the relationships between Smalley's writings and works*", *Organised Sound, 16*(1), 42-53, 2011
[4] Francis Halsall, *"Systems of art : Art, history and systems theory"*, Peter Lang, Bern, 2008

Spectrogram Data as System for Making Sculpture

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Abstract
This paper proposes a method for making generative art in the form of a system based on an interdisciplinary approach combining sculpture and sound. I will explore the possibility of using data from the spectral analysis of sounds as instructions for making sculpture. Inspired by Sol LeWitt's principles and ideas for the creation of generative art as system and Francis Halsall's definition of a 'system's identity', I am investigating ways for creating a new system that will allow the articulation of the above idea. Furthermore, combining Tom Johnson's system for composing music after LeWitt's sculpture *Incomplete Open Cubes* and Oscar Wiggli's sculptural and musical work, I will focus on how sequences of sound material could be related to a sculpture. Based on Denis Smalley's *spectromorphology* as 'a descriptive tool based on aural perception', I will analyze sound samples recorded from the workshop during the making and I will focus on their connection to the sculptor's gestures. In this paper, Smalley's 'ideas of onset (how something starts), continuant (how it continues) and termination (how it ends)' will be reconsidered from a sculptural perspective. Through the realization of a series of practical experiments, I will discuss: a) how actions of making sculpture could be reflected through sound, b) what kind of variations of spectra could inform different actions, c) how different materials could affect the sound samples and d) how the actions of making sculpture could be predefined as sequences through sound material in a systematized way, producing generative outcomes.

1. Introduction
The aim of this study is the exploration of a generative method for making sculpture, based on recordings of the sounds generated from the actions of making sculpture and their spectrogram analysis. It also discusses ways to explore and understand sculpting through the sounds generated during making and their 'structure', as defined by the composer Denis Smalley [9]. The energy of the sculptor's gestures, whether these are manually executed or with the use of machines, could be traced through sound recordings during the making process. Exploring the sound material of a sculptor's making process could provide us with information and an understanding of the process itself that we could not otherwise have.
At this point, I will introduce the type of sculpture that my examples will include. Defining the outcome before the making process is an important factor as this will determine the type of actions needed to be realized in order to achieve this. For both examples presented, the intention is to make a three-dimensional minimalist object (*Figures 1 & 2)*. Simplicity of shape will contribute to having clear steps during the making process. In the first example, through cutting marble and in the second through welding steel. Each object represents a series of decisions regarding sequence.

Figure 1. Object in marble.

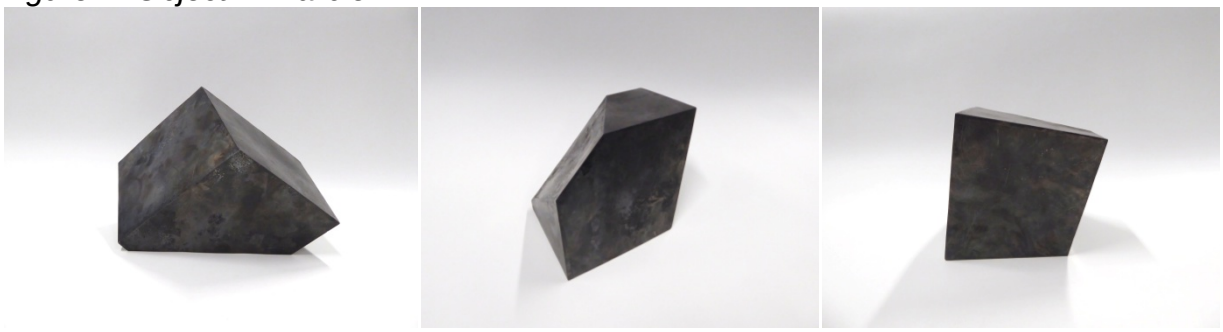

Figure 2. Object in steel.

2. Starting points

2.1 System art and generative processes

The art historian Francis Halsall's definition of the identity of a system includes a focus on its functions [4]. As he mentions, '…through the use of function(s) (rather than structure) as the criteria for identity, the system can retain its recognisable and distinct identity over time even though its structure may have adapted and evolved' [4]. The sculptor Sol LeWitt mentions that the process of making of a work of art is realized either based on decisions made at each stage or through a system that controls these decisions [8]. Following Halsall's approach of functions within a system such as LeWitt's, I investigate ways for creating a new generative system based on functions, which will have analytical and generative purposes within sculptural and sound contexts.

2.2 Composition of sculpture and sound materials

Tom Johnson's system for composing music after Sol LeWitt's sculpture *Incomplete Open Cubes* is a compositional method that uses a system for making sculpture as a starting point [6]. The aim of Johnson's method is to use the function of the initial system by LeWitt in a musical context. He worked with sequences for exploring relationships among chords, which he later formed into a chain. His final outcome was generated through the chain and had the form of a loop [6]. Tom Johnson's approach could be an important example of a system that is functioning across sound material, musical harmonies in his case, and sculpture. The sculptor and composer Oscar Wiggli, has developed methods for composing music based on his sculptures and vice versa [2, 3, 7]. He has invented his own form of musical symbols that are usually comprised of video prints of his sculptures, lithography prints, his drawings called *Sound Lavis*, his *Dessin-Reliefs* and *Sound-Reliefs* as well as verbs that describe stages of the making process. *Figure 3* shows Wiggli's graphic and verbal score for his composition *AVELEK* (1994), a video-print-collage that represents sound material as a sequence [2]. Furthermore, Wiggli has created a system for organizing his sound material in which every sound corresponds to a technique from the making process of his sculptures [3]. Oscar Wiggli's structures originate from his two-dimensional and three-dimensional works and are used as musical symbols based on which he composes his sound material [7]. In this paper, I will attempt the reverse: to make sculpture based on sequences of sound material.

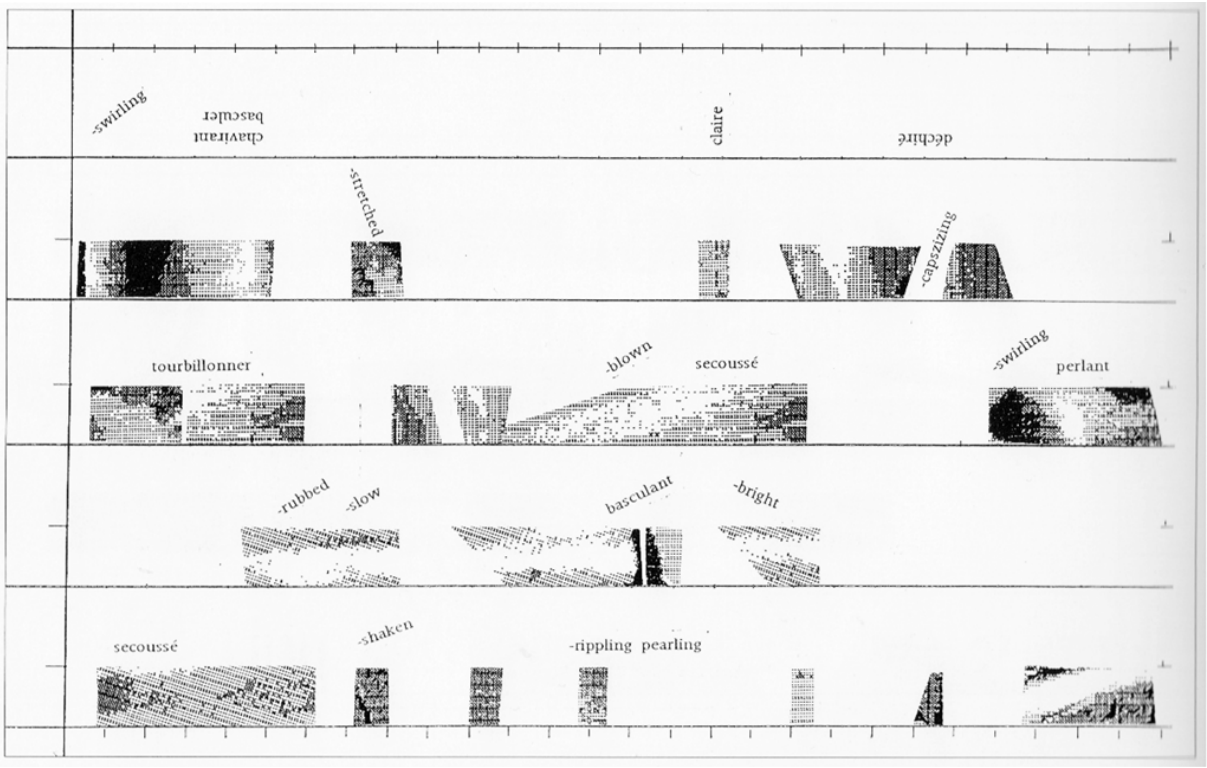

Figure 3. Oscar Wiggli, 'Partition graphique-verbale pour la composition AVELEK', 1994

2.3 Spectromorphology: an analytical tool

Spectromorphology was first introduced by the composer Denis Smalley who defines it as '…an approach to sound materials and musical structures which concentrates on the spectrum of available pitches and their shaping in time' [9]. The composer David Hirst analyzing Smalley's work, underlines that spectromorphological approach concerns sound material of spectral kind, whose source cannot be easily identified [5]. One of Denis Smalley's 'fundamental strategies', concerning 'multi-level focus and the experience of the temporal unfolding of structure, is *gesture*' [9]. It is 'concerned with action directed away from a previous goal or towards a new goal; it is concerned with the application of energy and its consequences; it is synonymous with intervention, growth and progress, and can rise from its energetic profile that could have been caused, and its spectro-morphology will provide evidence of the nature of such a cause' [9]. Following this, I will explore the idea of the connection of the making process of a sculptural object and its sounds through the concept of gesture.

Smalley speaks of 'three morphological archetypes at the source of instrumental sounds: the attack-impulse, the attack-decay, and the graduated continuant' [9]. He mentions specific notation symbols for each of them that represent 'three linked temporal phases: onset, continuant, and termination' [9]. In this paper, I will focus on the three temporal phases in relation to the actions of making sculpture. Smalley refers to them 'as models for structural functions' that allow to insert morphological ideas within structure (*Figure 4*) [9]. Smalley further discusses that the onset group (how a sound starts) concerns the initiation of sound material and could vary from the downbeat, to 'anacrusis' and to 'the less specific emergence' [9]. The continuant group (how a sound continues) has a wider range of possibilities such as the 'maintenance', 'prolongation', 'statement' and 'transition' [9]. These terms are showing that the 'continuant function is not neutral: time cannot stand still, and real stasis is not possible', as Smalley mentions. As for the termination group (how a sound

ends), it includes concepts such as this of 'plane' as 'arrival', 'a goal of what has come before' [9].

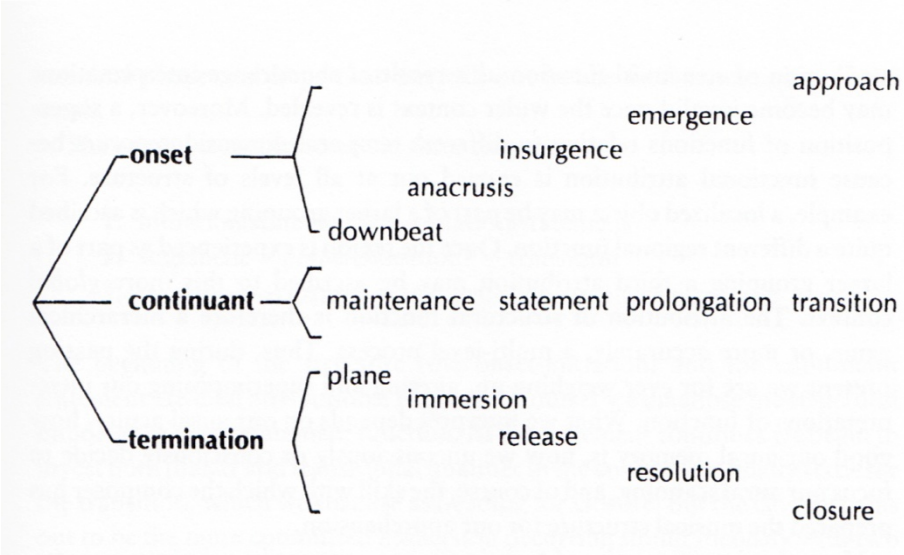

Figure 4. Smalley's structural functions.

3. Methodology

3.1 The process of making

As mentioned in the introduction, examples will be derived from two different making processes each using different material: marble and steel. The point of departure of this exploration will be these two processes of making sculpture: cutting marble in an electrically operated marble cutter and welding sheets of steel. Working with two different materials and techniques could contribute to showing how different materials could affect the sound samples, the making process and finally, the generative outcome of this study. Recording audio and filming the above two processes will allow to realize an analysis of the sound recordings based on concepts of spectromorphology, while having video material as a visual reference concerning gestures. For the visual analysis and editing of spectra, two software programs are used: Ircam Audiosculpt and Sonic Visualiser [1].

3.2 Concepts of spectromorphology

Samples from each action of making will be used to identify the three temporal phases: onset, continuant and termination as discussed by Denis Smalley [9, 10]. This analysis is intended to show how actions of making sculpture in each material differ. It will explore how gestures are happening and highlight how actions of making sculpture can be reflected through sound: what kind of structures of spectra could inform different actions. Actions will be studied as they are happening in time and how they contribute to the transformation of materials.

3.3 Generative processes

Using the structures identified based on the concepts of spectromorphology as mentioned above, I will explore the possibility of ordering them into sequences. Based on Smalley's examples of 'hypothetical *function chains*' [9] (*Figure 5*) I will create potential sequences of sounds for predefining actions of making sculpture. Smalley's function chains concern the interpretation of functions and as we can see in *Figure 5*, they can happen in multiple stages. For instance, Smalley's second example is happening in three stages (*Figure 5b)*. Based on Wiggli's graphic scores such as this in *Figure 3* and Smalley's 'hypothetical *function chains*' [9], I will explore how my example of sound sequence could generate from new, sculptural objects through actions.

anacrusis→statement?/prolongation?/transition?/plane? =
plane = closure

(a)

1. initiation/statement? = initiation/statement
2. statement = plane/transition? = transition
3. transition→closure? = immersion/insurgence/emergence

(b)

Figure 5. Denis Smalley's examples of 'hypothetical function chains'

4. Experimentation

4.1 Materials, techniques and actions

Both objects have a similar shape (*Figures 1 & 2*). Their difference lies in the material and in the fact that the marble object is solid, whereas the metallic hollow. This is not only related to materiality but also to the method according to which they are made. The process of cutting a block of marble uses three types of actions: placing the marble on the cutter (*Figure 6*), adjusting the marble in relation to the blade (*Figure 7*) and finally, cutting (*Figure 8*). Placing the marble involves lifting, landing and pushing the marble on the track slider of the machine. Adjusting includes moving and pushing the marble until it is on the right position for cutting in relation to the blade. Cutting happens by pushing the block of marble towards the blade. This sequence of actions is happening for each cut. The object is formed by a sequence of cuts.

Figure 6. Placing marble.

Figure 7. Adjusting marble.

Figure 8. Cutting marble.

To create the metallic object, I need to initially cut the sheets in the guillotine (*Figure 9*) in the shape of each side of the object, weld them together (*Figure 10*) and then grind the edges (*Figure 11*). Cutting the sheets in the electrically operated guillotine requires rotating and adjusting them before each cut. Welding includes holding the pieces together and rotating the object as it is being built. This action is happening in a repetitive manner across the edges of the object. Grinding is executed with an electrically operated grinder being moved back and forth for removing extra material from welding, rotating the object for completing

this process in all its edges (*Figure 12*). In this process, actions are happening in a single sequence: cutting all sides, welding all sides, grinding all sides. Conversely, in marble's making process, the sequence of actions (placing, adjusting, cutting) happens multiple times.

Figure 9. Cutting steel in the guillotine.

Figure 10. Welding steel.

Figure 11. Grinding steel.

Figure 12. Rotating the object.

4.2 Sound recordings and spectrogram analysis

Images from the spectrogram analysis of the sound recordings from both making processes are presented below (*Figures 13-19*). They were analyzed with Sonic Visualiser [1]. They include a time ruler and a sound frequency column on the left part of the image. A description follows based not only on the spectrograms but also on the recordings and the video documentation:

Concerning the making process in marble, *Figure 6* shows the action of placing the marble on the track slider of the marble cutter. As we can see from the spectrogram (*Figure 13*), there is a sound lasting for almost 0.5s before 1s, which is then repeated more intensely before 2s. It is the sound of placing the marble on the metal track slider. *Figure 14* shows the spectrogram of adjusting the marble by moving and pushing it and each time it is on a potential position for cutting, it is being tested by bringing it closer to the operating blade until they are in contact (*Figure 7*). Before 1s we can see the initiation of the operation of the blade, followed by moving the piece of marble that produces sound before 3s and before 6s

and testing its position with the blade in 7s and again after 10s. *Figure 8*, illustrates the action of cutting marble in the machine. As we can observe in the spectrogram (*Figure 15*), there are no obvious changes, the sound continues in the same way throughout the sample until before 20s when it gradually moves towards termination. Concerning the intensity of the sound during the action of cutting (*Figure 15*), the energy at this stage is much greater than at the other two (*Figures 13 & 14*).

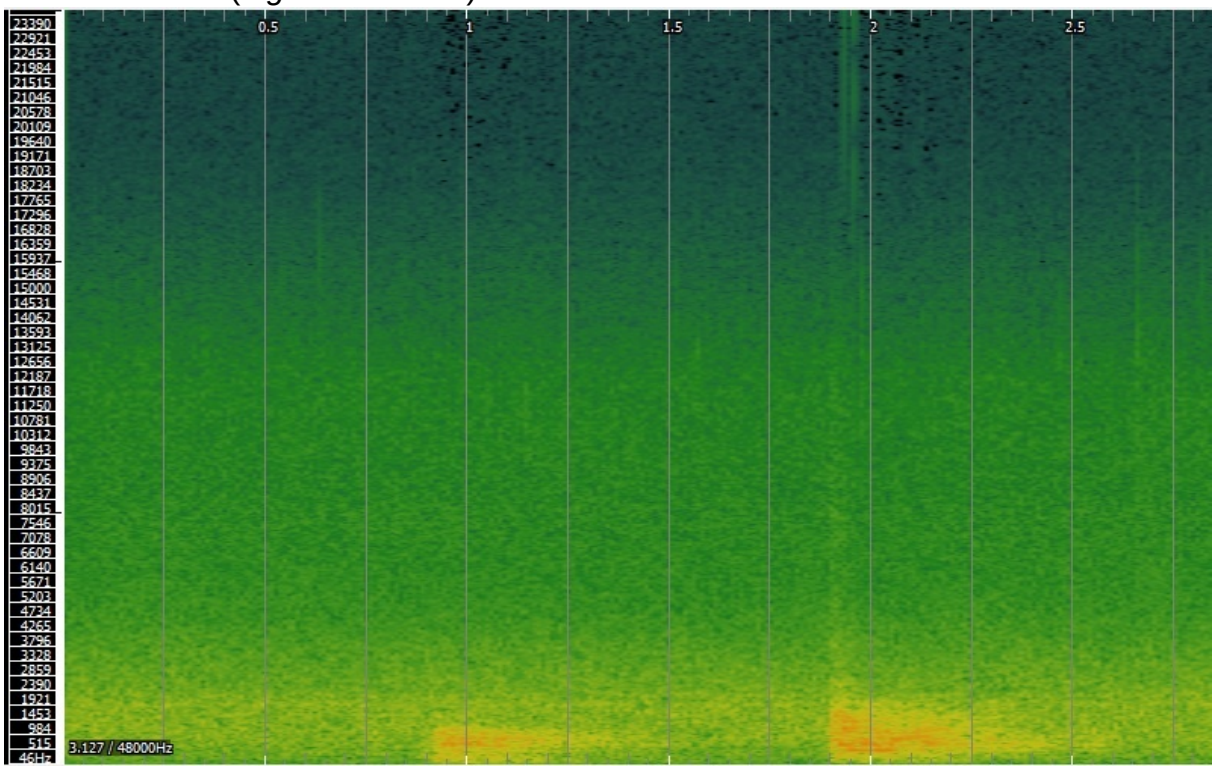

Figure 13. Spectrogram of 'placing marble on the machine'.

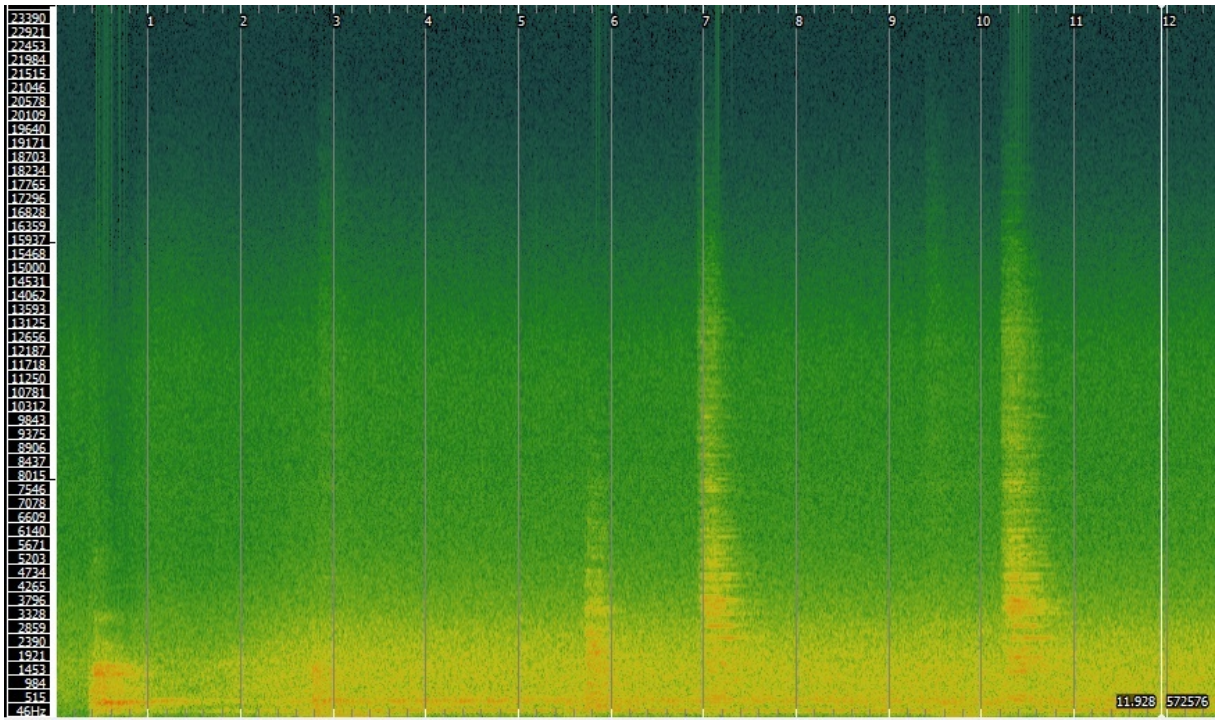

Figure 14. Spectrogram of 'adjusting marble in relation to the blade'.

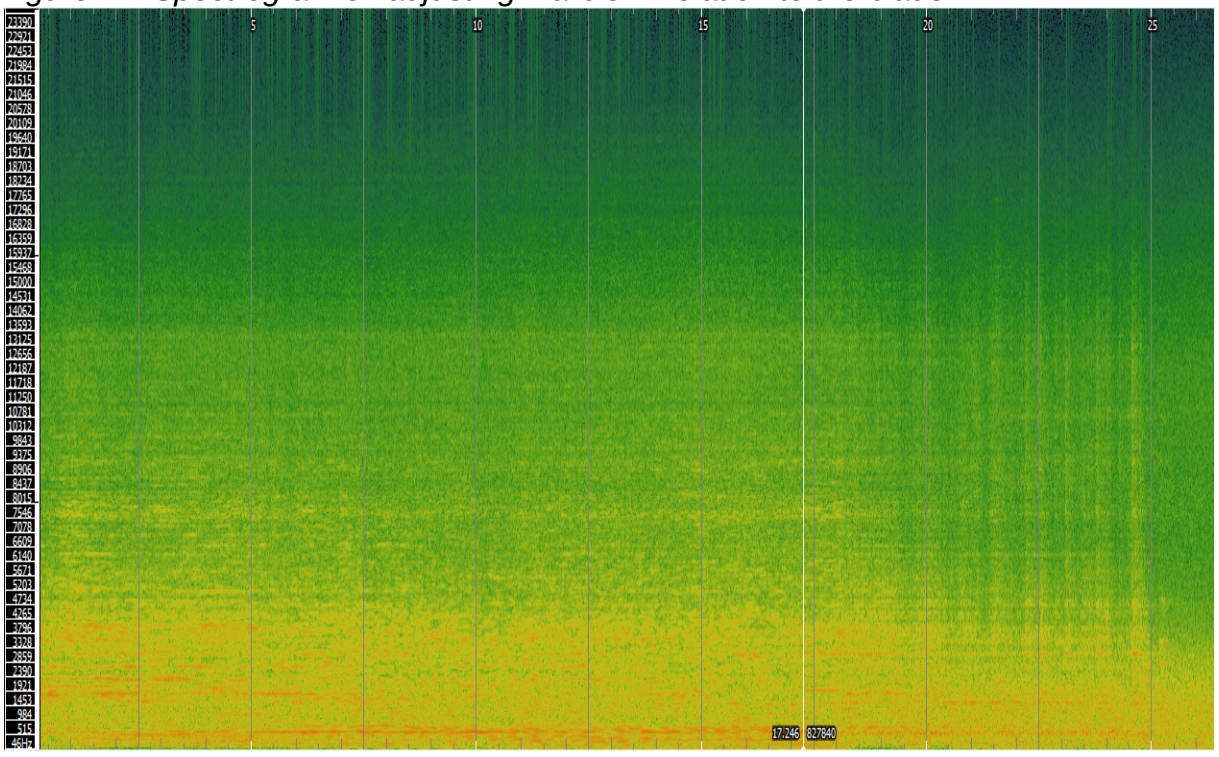

Figure 15. Spectrogram of 'cutting marble'.

Regarding the making process in steel, *Figure 9* illustrates the action of cutting the sheets in the electric guillotine. In the spectrogram (*Figure 16*) after 6s, sound is produced from the action of adjusting the sheet prior to cutting. This action is evolving in steps, followed by cutting and pieces falling on the ground after cutting. *Figure 17* shows the spectrogram of the action of welding (*Figure 10)* that is happening in a rhythmic manner. *Figure 18*, depicts the

spectrogram of grinding (*Figure 11*). Starting at around 10.500Hz and 16.000Hz respectively, we can see two lines that represent the sound of the disc of the grinder. The fluctuation of the lines indicates their changing of frequency as for example, between 5s and 8s. This depends on the contact of the grinder to the material. In 8s-12s there is a repetitive activity due to the back and forth movement that is happening during grinding. *Figure 12* concerns the action of grinding and rotating the object. The difference with the previous action lies in the line that occurs in the spectrogram (*Figure 19*) from the sound of the disc of the grinder. Its fluctuation is now more intense. Additionally, parts such in 3s-5s, 8s-9s, 12s-13s and 15s-18s show the sound from the rotation of the object. The most intense action of this process is grinding (*Figures 18 & 19*), in which energy is greater than cutting in the guillotine or welding. Comparing the spectra of the two materials can be used to explain material characteristic. For marble, the first two actions are not as intense and their sound spectra are not continuous (*Figures 13 & 14*). The action of cutting (*Figure 15*) involved continuous sound. Regarding steel, the first two actions (*Figures 16 & 17*) are not continuous either but more intense than the first ones in marble (*Figures 13 & 14*). Grinding steel has similar spectrograph (*Figure 18*) to cutting marble (*Figure 15*) but it is again more intense and involves repetitive parts due to the back and forth movement of the grinder. Following this, selecting a material is also selecting sound spectra.

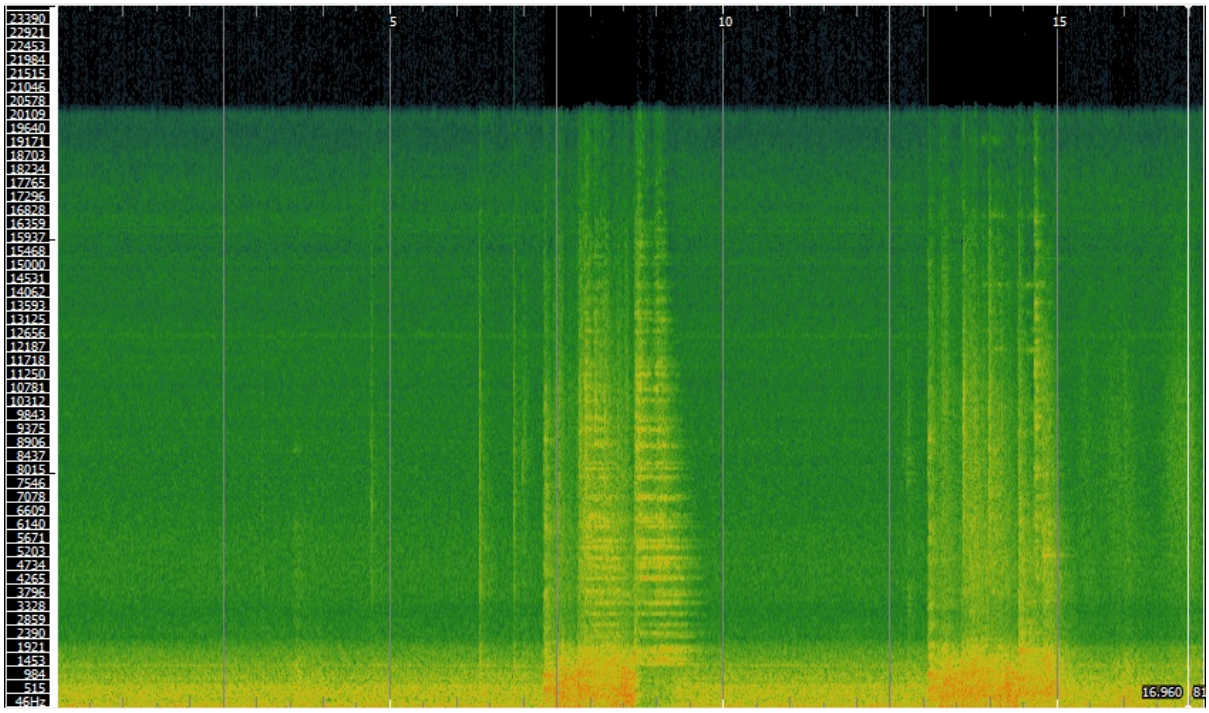

Figure 16. Spectrogram of 'cutting steel sheets in the guillotine'.

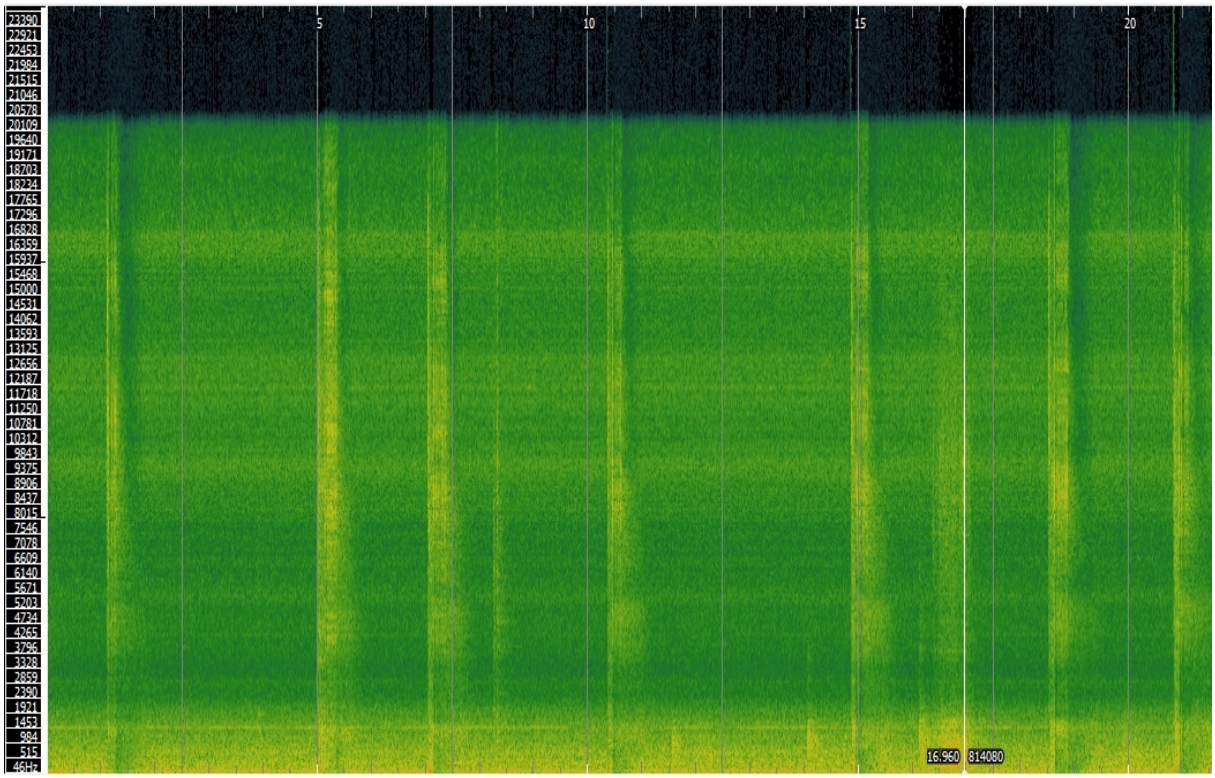

Figure 17. Spectrogram of 'welding'.

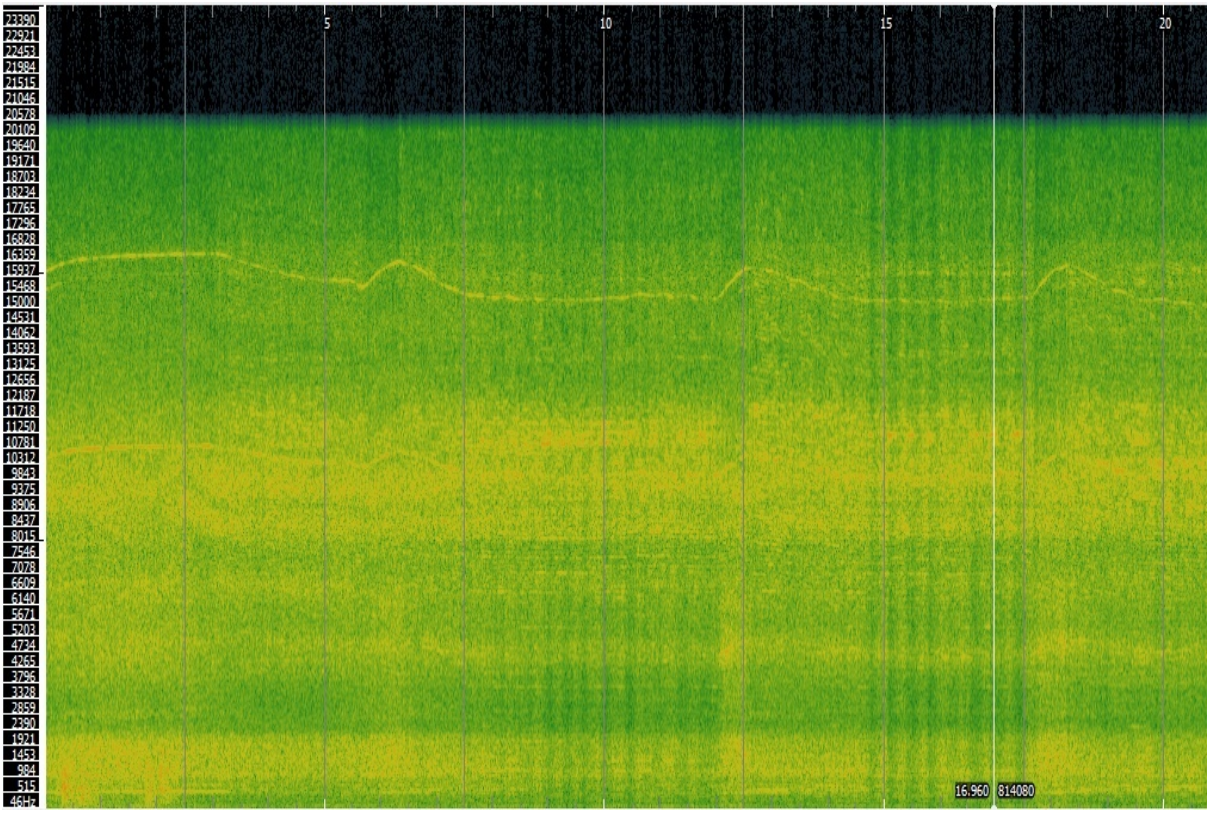

Figure 18. Spectrogram of 'grinding steel'.

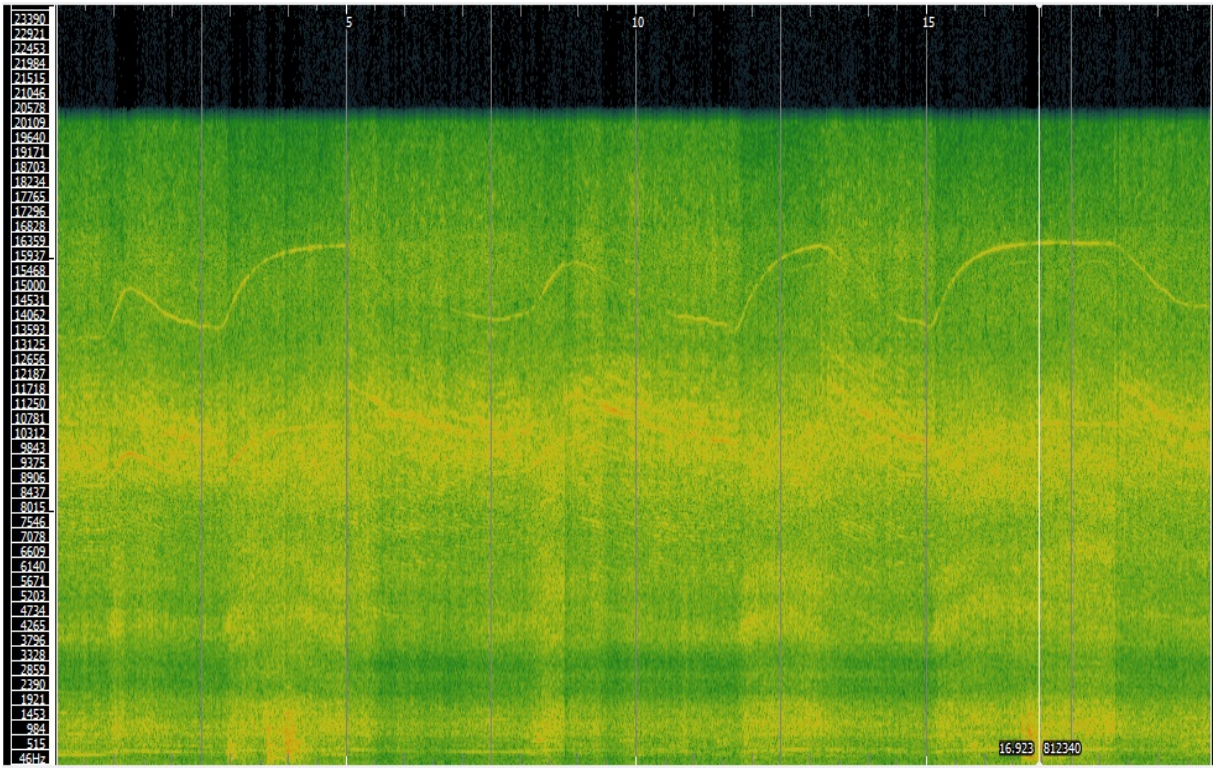

Figure 19. Spectrogram of 'grinding and rotating'.

4.3 Structures

Analyzing more profoundly the above spectrograms, I aim to identify and interpret sound structures as well as their relation with concepts of spectromorphology. Initially, there is the issue of the type of structures, the way they could function within sequences and their impact to the outcome. At this point, it is worth mentioning that multiple levels of analysis seem to exist: firstly, there is a sequence that is comprised of actions, then in a lower level I am identifying structures within actions [10]. The reason for this type of analysis is that it could create links among materials, actions and sounds.

Figure 20 relates the action of placing marble (*Figure 6*) to Smalley's 'onset (how it starts)' [9, 10] and shows how it is structured. The two main sound events of this action are enclosed in the rectangles. The onset is being considered as the start of the sequence 'placing, adjusting and cutting'. It concerns an action that is happening in stages: lifting, placing, moving. *Figure 21* illustrates an action that includes three stages: 'moving, placing and testing' until the object is adjusted, which is related to the continuant phase [9, 10]. We can see that between the above mentioned stages there is always the action of moving. The spectrogram (*Figure 22*) of cutting marble in the machine does not include any remarkable patterns as it continues in the same way it started. What is obvious on its spectrogram analysis is the gradual termination as the blade crosses the material, cutting off the piece. If we consider all three actions together then placing marble could be the onset as 'downbeat', adjusting could be a continuant such as 'transition' along with part of cutting as 'prolongation', followed by a gradual termination, a 'closure' [9] (*Figure 4*).

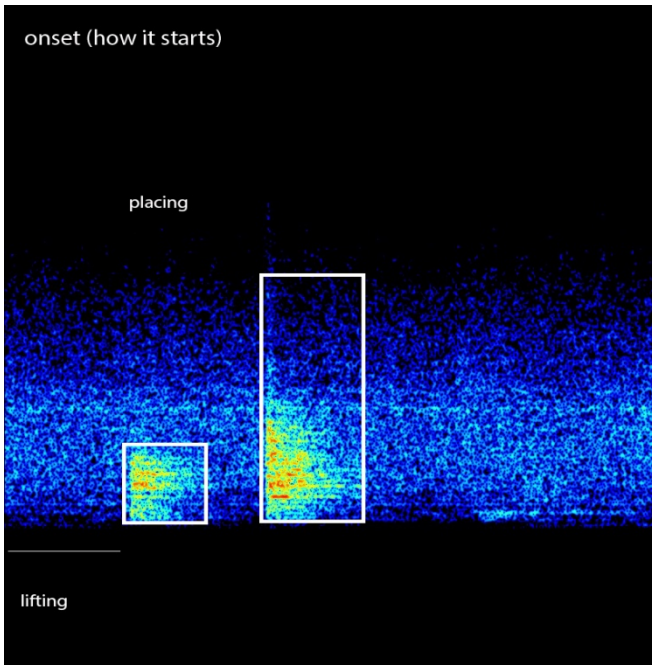

Figure 20. Placing marble: structure.

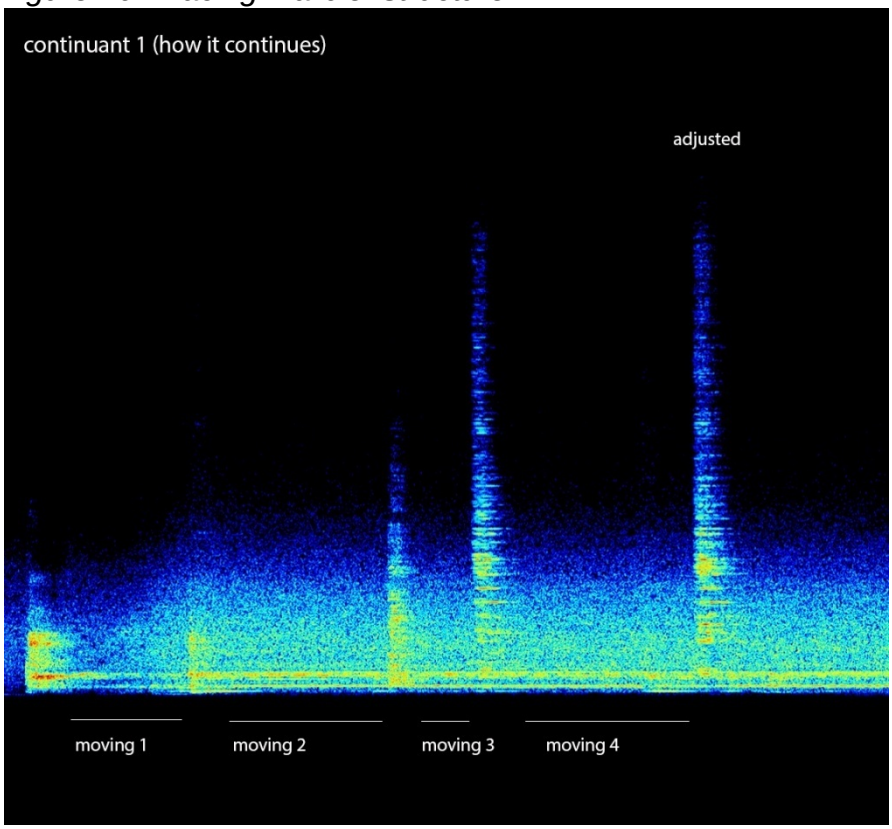

Figure 21. Adjusting marble: structure.

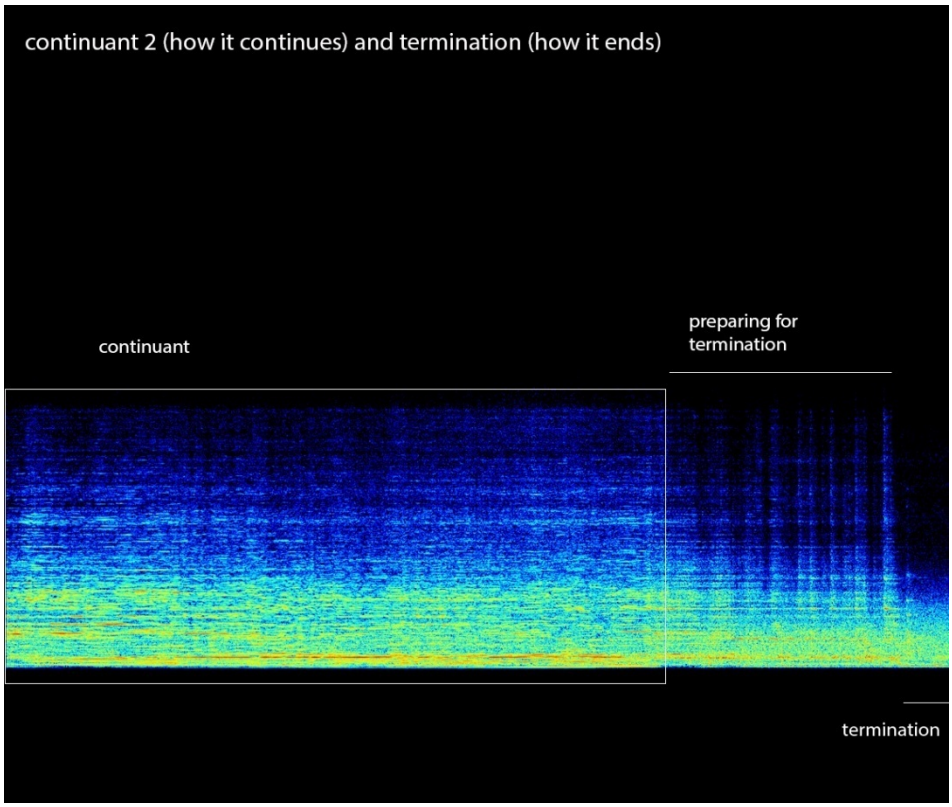

Figure 22. Cutting marble: structure.

Figure 23 illustrates part of the spectrogram of cutting steel sheets in the guillotine. The three rectangles show three different parts, actions within the action of cutting: adjusting, pressing the pedal and cutting/pieces falling. This could act both as an 'initiation' onset with the action of adjusting the sheets and as a 'transition' continuant with the actions of pressing the pedal and cutting/pieces falling. *Figure 24* relates the action of welding to a continuant that is happening in a repetitive manner. Based on Smalley's terms, it could be a 'prolongation' [9, 10]. As in the action of adjusting the marble in *Figure 21*, between each sound of welding there is a pause while rotating, which creates a specific rhythmic pattern. *Figure 25* shows the action of grinding that is happening through a back and forth movement with pauses in between. The pauses of the main action concern observing the process for adjusting the grinder appropriately. Distancing the grinding disc from the object has as consequence the loss of contact with the material and the change of its sound. This can be observed in the spectrogram (see the two rectangles) (*Figure 25*). It could also be characterised as a 'prolongation'. *Figure 26* concerns another continuant: grinding and rotating the object. The difference to the previous sample is the action of rotating that creates another type of sound in the recording. Its structure is very similar to this of grinding (*Figure 25*) but the additional action of rotating/moving produces an extra sound.

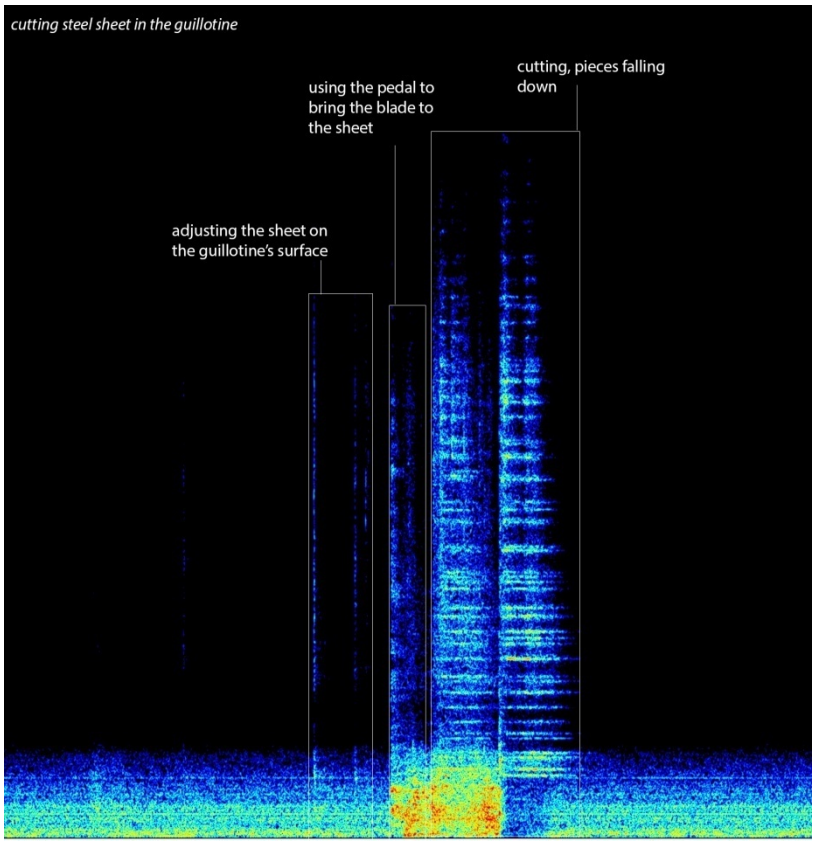

Figure 23. Cutting steel sheets in the guillotine: structure.

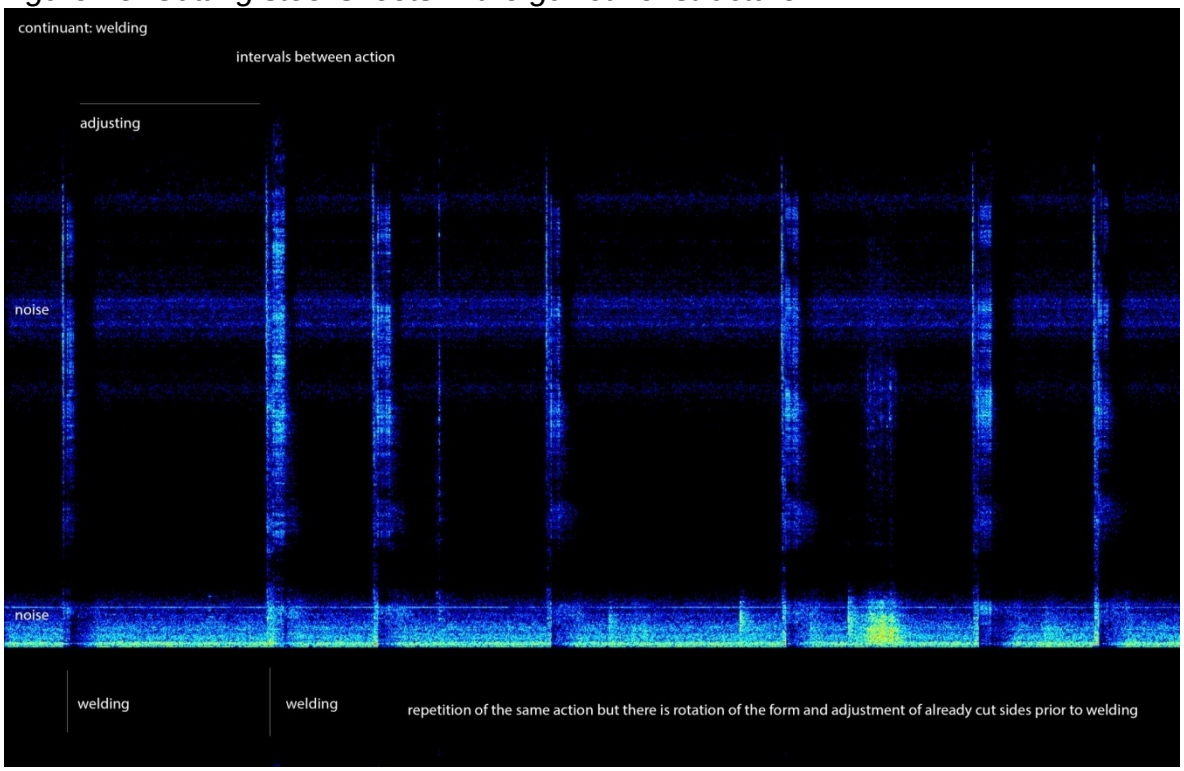

Figure 24. Welding: structure.

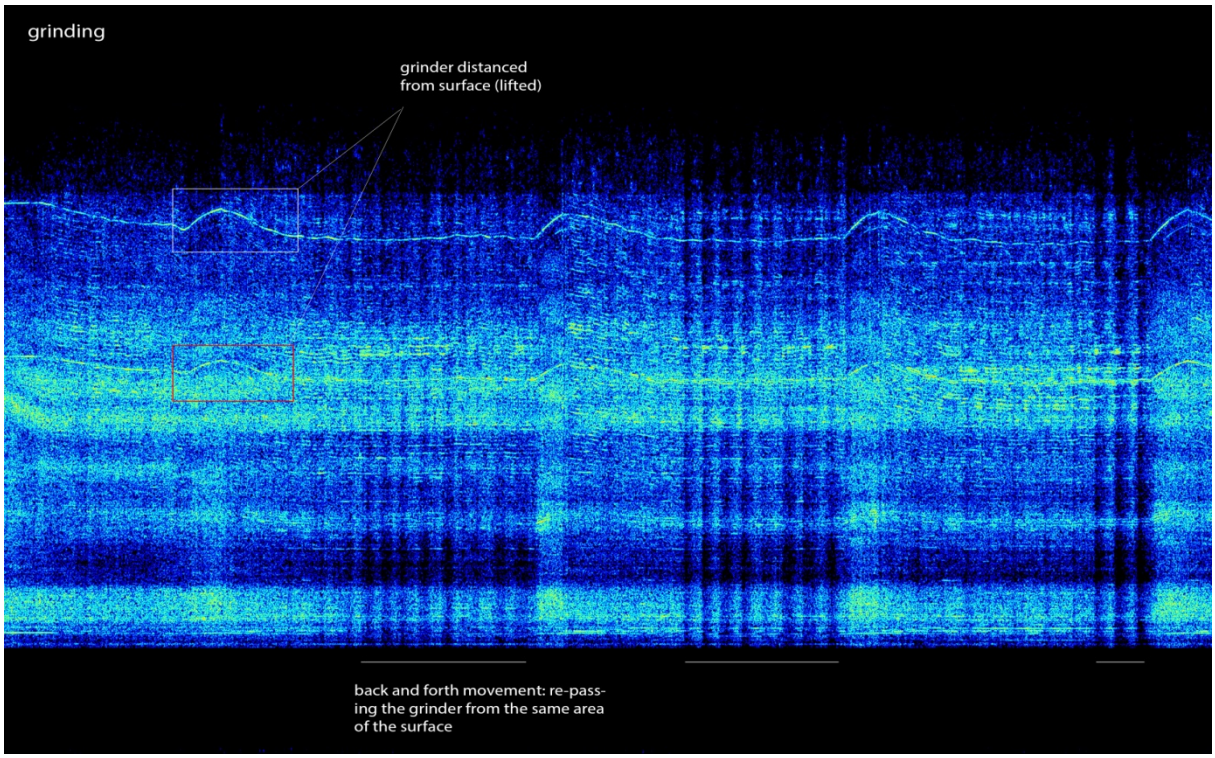

Figure 25. Grinding steel: structure.

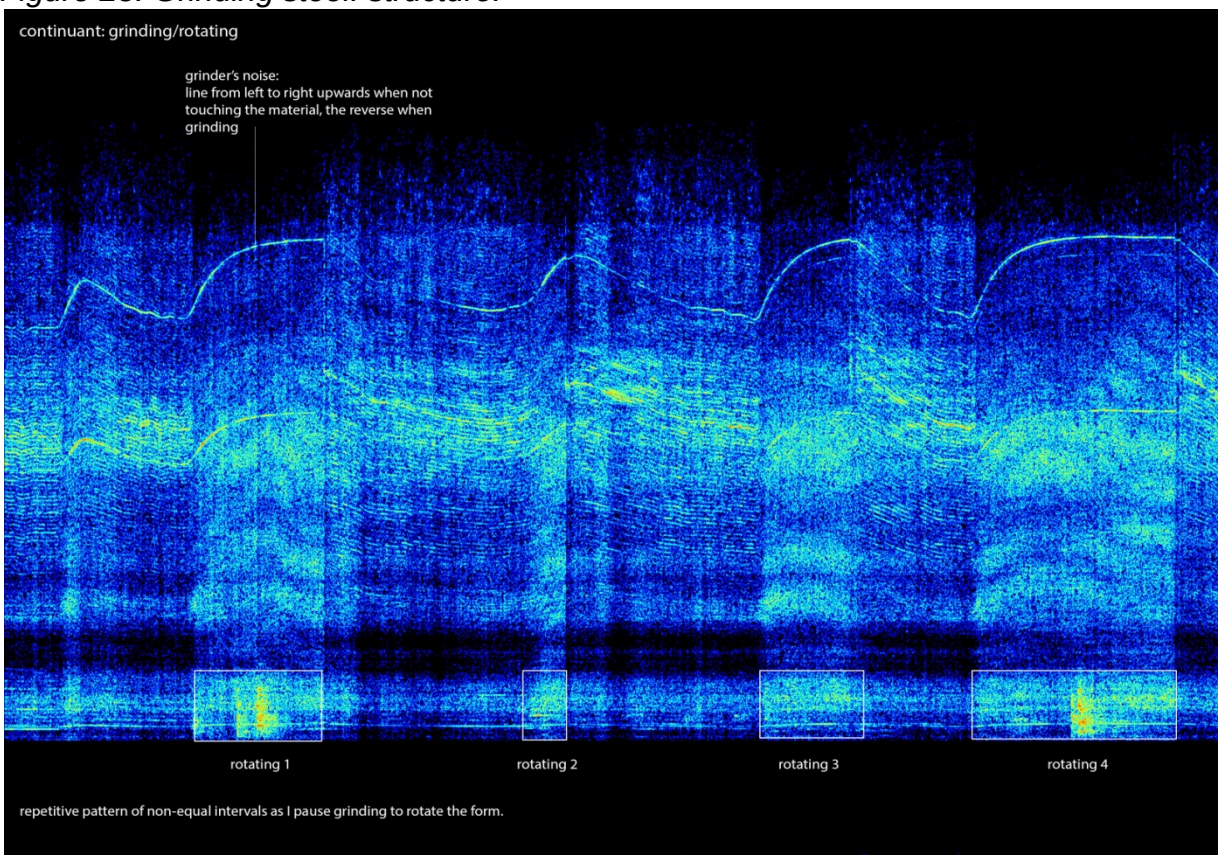

Figure 26. Grinding steel and rotating the object: structure.

Overall, categorizing the sound samples according to their 'structural function' [9, 10] contributes to understanding the connection of sculptural gestures and sound material (*Figures 27 & 28*). So far, we have encountered three types of sounds occurring from:

repetitive actions somehow regular such as welding, continuous such as cutting, and fragmented such as adjusting. The intensity of sounds can be traced through the spectrograms. For instance, cutting the marble or welding and grinding steel are much more intense than loading and setting the piece.

placing (onset) < lifting, placing, moving

adjusting (continuant) < moving, placing, pushing/testing

cutting (continuant/termination) < pushing/cutting

Figure 27. Smalley's structural functions - marble making process

cutting < adjusting/moving (onset) pedal/cutting (continuant)

welding (continuant) < adjusting/moving, welding

grinding (continuant) < moving/rotating, grinding

Figure 28. Smalley's structural functions - steel making process

4.4 Sequences: a generative process

In this part I will discuss how the structures analyzed in paragraph 4.3 could be used as new sequences in an order that would inform the making process of a sculptural object. Could sound material from actions be used for different materials and making processes? Wiggli's sequences of verbs that represent actions are used for the generation of sound material [3] (*Figure 29*). Making potential sequences with the samples of actions from the analysis above could be a first approach to a generative process. Following Tom Johnson's method concerning LeWitt's work [6], I will use the function of the initial sequences in a sound context.

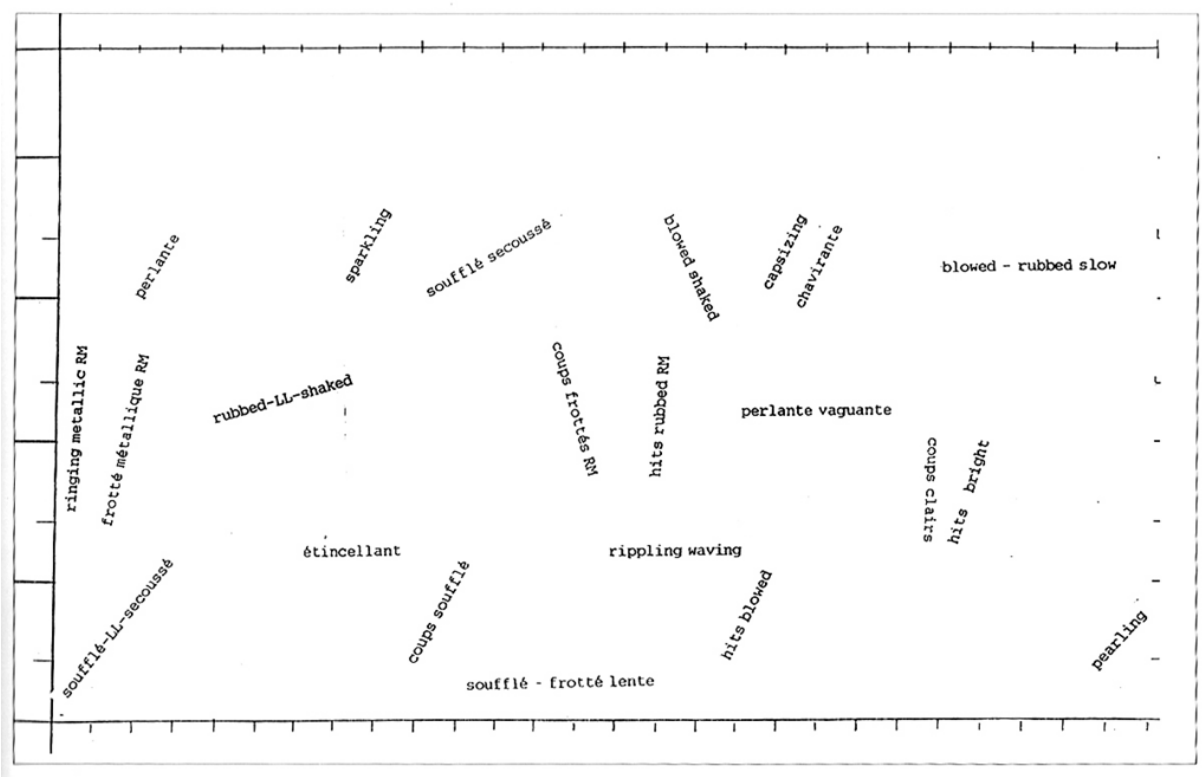

Figure 29. Oscar Wiggli, 'Partition verbale pour la composition "RESEMBLANCES ET MIROITEMENTS", 1994

The potential verbal/sound sequences will explore relationships among actions. Spectrograms and their analysis in paragraphs 4.2 and 4.3 reveal the already existing sequences and structures of sound material during the making of a sculpture in marble and steel. The aim of the potential sequences is to be able to generate a sculptural outcome. This will be the main function of my system, which according to Halsall's definition [4] will be recognizable at all times. For achieving this, the order of each action within the sequence needs to be taken into consideration. A potential sequence could be: lifting/placing, welding, adjusting and grinding. Due to the action of welding, this process will have to concern metal. The spectrogram of this potential sequence is presented in *Figure 30* with material from the initial processes. Onsets, continuants and terminations could determine the progress of each potential sequence. In this sequence, I have used placing as an onset, welding as a 'prolongation' continuant, adjusting as a 'transition' continuant and grinding as another 'prolongation'.

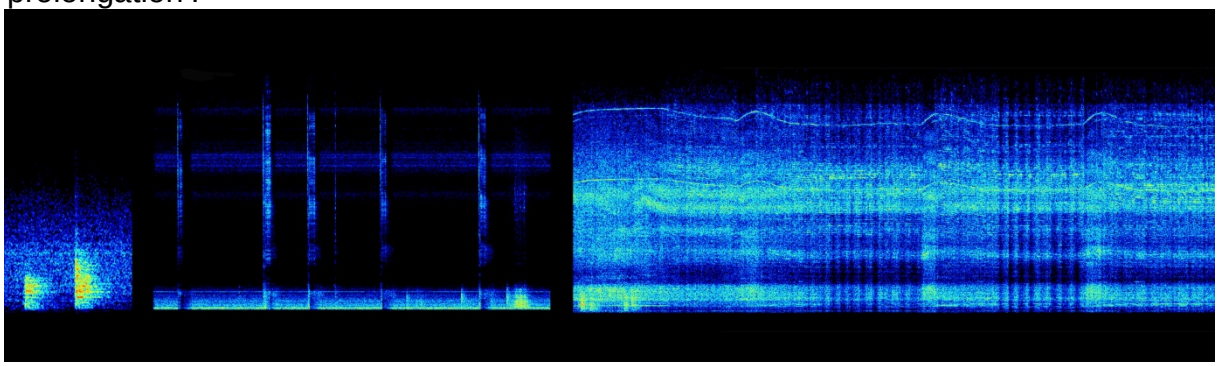

Figure 30. Potential sequence: placing, welding, adjusting, grinding.

5. Discussion and Conclusion

The observation of the spectrograms of the sound recordings, contributed to identifying how a sound starts, continues and ends. Concerning different actions, these three phases were visualized in a different manner, creating different structures. They are either repeated as they initially appear, changing during repetition or happening only once during the action. This analysis offered a deeper understanding of the process of making, providing an alternative method for combining sculpture making and sound material through sequences. The sound is a memory of the process that may not always be evident on the object itself. The process of grinding for example, eliminated the evidence of welding, which in itself adds to the final expression of the object on a not material manner. The object then represents a sequence of sound spectra. The representation of sound sequences through spectrograms is not to be mistaken for notation. My intention is to use them as means for analyzing and understanding sound structures visually.

A first issue that arises from the potential sequence is duration. I have used the duration of the spectrograms from the initial processes analyzed in this study. Different duration of actions could have different sculptural outcomes. There are actions that could last longer depending for example, on the size of the object. Using Smalley's concepts, I am able to classify the various actions through sound but this needs to be further studied also concerning the energy and the intensity of actions. Furthermore, material creates other issues in the process as for example, welding is not possible when working with marble. Each material has its own sound sequence depending on actions and their intensity. In this study the consequence of material choice in sculpture is reflected through sound.

This paper is part of my continuous study and a first approach of using spectromorphological thinking in relation to the context of sculpture in a systematized way. Further exploration of other concepts introduced by Smalley and analyzed by Hirst needs to be undertaken for reaching a more profound analysis of the samples from the making processes. Additionally, it is necessary to address the issues mentioned above and to test potential sequences practically, by making sculptural objects according to them. This might lead to new questions regarding this generative process as well as the sculptural outcome and materials used.

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Figures

Figure 1. Object in marble. Panourgia, E., 2016.
Figure 2. Object in steel. Panourgia, E., 2016.
Figure 3. Oscar Wiggli, 'Partition graphique-verbale pour la composition AVELEK'. From *Oscar Wiggli: Corps, Espace, Son,* p.250, by Frehner, M. & Hesse, J. (eds.), 2007, Bern: Benteli.
Figure 4. Smalley's structural functions. From "Spectro-morphology and Structuring Processes" in S. Emmerson (ed.) *The language of electroacoustic music* (pp.61-93), p.85, by Smalley, D., 1986, Basingstoke: Macmillan.

Figure 5. Denis Smalley's examples of 'hypothetical function chains'. From "Spectro-morphology and Structuring Processes" in S. Emmerson (ed.) *The language of electroacoustic music* (pp.61-93), pp.86-87, by Smalley, D., 1986, Basingstoke: Macmillan.

Figure 6. Placing marble. Panourgia, E., 2016.

Figure 7. Adjusting marble. Panourgia, E., 2016.

Figure 8. Cutting marble. Panourgia, E., 2016.

Figure 9. Cutting steel in the guillotine. Panourgia, E., 2016.

Figure 10. Welding steel. Panourgia, E., 2016.

Figure 11. Grinding steel. Panourgia, E., 2016.

Figure 12. Rotating the object. Panourgia, E., 2016.

Figure 13. Spectrogram of 'placing marble on the machine'. Panourgia, E., 2016.

Figure 14. Spectrogram of 'adjusting marble in relation to the blade'. Panourgia, E., 2016.

Figure 15. Spectrogram of 'cutting marble'. Panourgia, E., 2016.

Figure 16. Spectrogram of 'cutting steel sheets in the guillotine'. Panourgia, E., 2016.

Figure 17. Spectrogram of 'welding'. Panourgia, E., 2016.

Figure 18. Spectrogram of 'grinding steel'. Panourgia, E., 2016.