# Waveshape: Making songs 3D printable by connecting music to shapes

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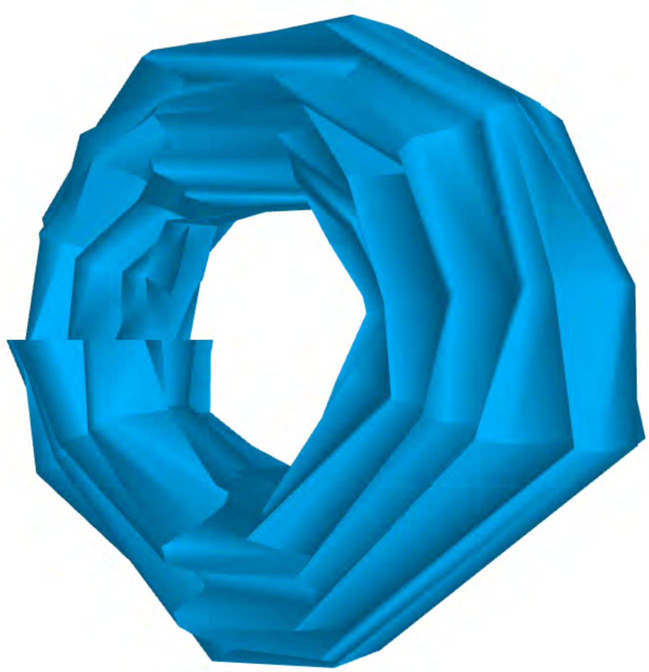


**Abstract**

With most music now being stored and accessed in digital formats, the physical aspect of a connection with a song is less present. Where sometimes a vinyl or a CD can be displayed, this project is aimed at exploring the notion of a physical object representing a song dear to its listener. And whether there is a significant correlation between music and physical form.

To explore this connection, two studies have been conducted, divided in two iterations. The first study found a mapping between song features and physical form. These mappings are implemented in a second iteration, in an effort to validate the concept and mappings, and gain insight into the user experience of the end product, called Waveshape (www.waveshape.nl).

# Contents

# 1 Introduction

Often a song can bring back a lot of memories and personal experiences. In the age of music streaming, these songs and their memories might get lost in the overwhelming amount of music that is available on the internet. This report focuses on ways to make songs tangible and therefore making it easier to store and keep them. The proposed solution to this problem is to create a tool that analyzes music, and according to its features, automatically generates a unique 3d printable model.

During this project, the relations between sounds, emotions and shapes will be explored and applied to the generation of aesthetically pleasing and coherent 3D models.

## 1.1 Motivation

Having a physical object to connect a song that one holds dear can be of great value to that person. Exploring a song through a new set of senses (vision and touch), might transcend ones emotional attachment to that song when compared to the same song when it is only heard. Besides serving as an enhancement to the experience of the song, it can also serve as reminder to the existence of the song or just as an aesthetically pleasing collector's item.

Establishing a connection between physical form and music can learn us more about how different senses are related and learning how to bridge the gap between these senses might serve as a valuable contribution to the field of multi sensory design and research.

## 1.2 Research questions

The first step to creating a tool that transforms songs into a unique and 3D printable shape is to find a link between audio and shapes. To be able to find and overlap between audio and shapes, both sound and shapes will be reduced to their parameters. The goal is to find parameters that describe sound and shapes accurately and discover how these parameters overlap with each other. Therefore, the first question that will be answered is:

- What is the best mapping between audio features and shape parameters?

To already get a sense on how people perceive music and how they would translate this perception into a shape, a pilot study will be conducted. This will be done through a survey. After the pilot study, the project will make use of two iterations. During both iterations a prototype will be developed and evaluated.

The results of the pilot study will be used in the development of the first prototype. This prototype should be able to generate shapes based on certain parameters and will be used to answer the first research question by allowing users to create their own mapping between music and shapes.

Once a sufficient mapping between the two domains has been constructed, a fully rounded application will be created using this information. This application will be used to answer the following two questions:

- What is the current status of the usability of the product?
- How well do the generated shapes match the songs?

After these two iterations are completed, there will hopefully be a foundation for a product that will be useful and usable.

## 1.3 Keywords

Music, 3d printing, Design, Arousal, Valence

# 2 Background and related work

Before designing and conducting any experiment it is a good idea to get an overview on the state of the art and existing literature on the relevant subjects.

## 2.1 Music and emotion

Reducing songs to parameters is a common task when working with music recommendation systems or audio visualizers. In this report we assume that a listener's perception of a song can be split into two categories: Descriptive and emotive parameters. The descriptive parameters of a song have measurable properties. Examples of these are volume, pitch, timbre and tempo. Emotive parameters are not physically measurable and often specific to the listener. Examples of emotive parameters include the emotion a song evokes and the memories it triggers.

Despite the fact that emotion is not physically measurable, due to technological advancements it becomes possible to extract emotional information.There are three main methods of retrieving emotion from music [11]. One method is to create a contextual text analysis of the song, which requires browsing the internet in order to find labels, reviews and other documents that might discuss the mood of the song. Another method is to do an emotional text analysis of the lyrics. The use of NLP methods, using for example Support Vector Machines (SVM's), retrieved interesting results . Extracting emotional information from lyrics has had several applications. [9][17]. However, because of the dis-ambiguity of music lyrics, the retrieved emotion from the lyrics was not always in line with the emotion the music evoked. [3] [16]. The third method of extracting emotion from music is to do a content based audio analysis, which requires analysing the audio and assigning an emotion according to its features. Due to advancements in the field of machine learning, computers are able to more accurately plot the emotion of a song onto the valence/arousal plane [18]. The valence/arousal plane is one of the most common methods used for objectively transcribing emotion.

There is already quite some work being done on content based audio analysis. One of the most extensive applications is one implemented by Spotify. Spotify has created an API that allows users to access any song on their platform and to retrieve a list of audio features they have extracted. Examples of these features include valence, energy, tempo and danceability. Spotify extracts these features by letting professionals assign these values to a small set of songs and then extends this using machine learning [14]. Besides the global features, the Spotify API also automatically divides a song into several segments and assigns features like the loudness or tempo to each of these segments.

## 2.2 Music, emotion, color, and shape

Reducing shapes to parameters is an important task for parametric shape generation. In this report we distinguish between the color of the shape and how the shape is formed. Examples of shape parameters are the symmetry, roughness and edginess. All these aspects have been proven to evoke certain emotions [5]. In figure 1 several shape parameters are grouped by valence and arousal.

While shapes and audio do not share any physical properties they do share an emotive property. Based on the fact that emotion can be retrieved from both audio and shapes, establishing a connection between them by using emotion as a bridge seems like a possible approach. Creating a connection between audio and shapes through emotion has already been done. For example, the system "In a State" takes the audio from a live piano performance, retrieves the emotions from this and generates visuals that are being projected on a stage [12]. A connection audio and visuals does not have to be established using emotion. A popular application of this connection is the audio visualizer. Audio visualizers are mostly lines and colors moving on the beat of the music, with the aim to provide something to look at while listening to music. The most iconic usage of this are the visualisations which were being shown in the old versions of Windows media player (Figure 2). However, most audio visualizers that do not use emotion as a bridge heavily rely on the temporal domain to make the connection make sense.

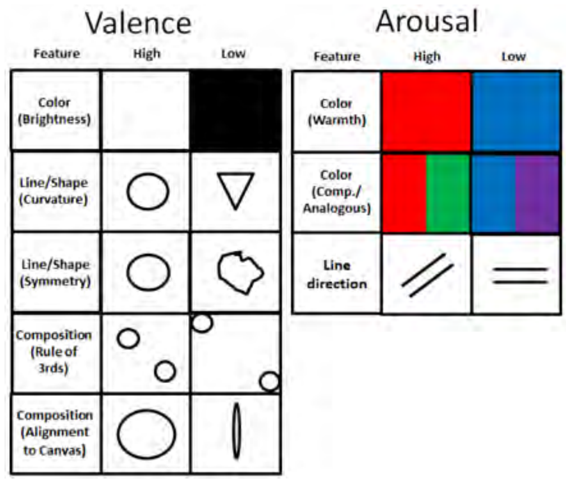



Figure 1: Shape parameters mapped to the valence arousal scale. [5]


Figure 2: audio visualisation within old version of Windows media player

### 2.3 Making music tangible

There is already some work being done on transforming data into 3D prints. Using the physical data like the heartbeat of a person and 3D printing this, made people more conscious about their involvement in physical activity and illustrated different levels of engagement with the artifacts [10]. Figure 3 shows an example of a 3d printed interpretation of spoken word, which was part of an art project by Inmi Lee and Kyle McDonald. There is also a lot of research done on the relationship between 3d shapes and emotions, for example [1], which tries to map this relationship using fuzzy logic, after evaluation this method showed a high correlation between the two domains. Another interesting application of making sound tangible is the Laughter Blossom [19]. Which is an artificial plant whose blossom recognizes and acts upon laughter.

Figure 3: "Mother," from artists Inmi Lee and Kyle McDonald

# 3 Pilot study

This section describes an exploratory pilot study, conducted to get an initial overview of different ways people perceive and remember music, and how they would relate this perception into shapes and colors. To achieve this, a survey is carried out that aims to identify a connection between sound and shape parameters.

## 3.1 Goals

The goal of the first pilot study is to explore whether there actually is a connection between shape and music, and which elements of music people pay the most attention to when listening. To find the most important elements, participants are asked to describe the difference between songs, as to get the most genuine impression of the elements people pay attention to, without explicitly asking, and influencing answers. To research this, two research questions can be formulated:

- Is there a connection between the perception of music, and shape properties?
- Which elements of music do people find distinctive between songs?

## 3.2 Method

According to the literature it is possible to transform both music and shapes onto the valence arousal plane. Therefore during the pilot study this plane will be used as a coupling between the two domains, like illustrated in figure 4.

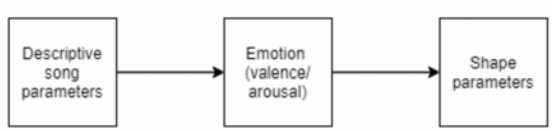



Figure 4: coupling from audio to valence/arousal to shape [5]

### 3.2.1 Measures and procedure

A survey will be created which will be split into two parts. The first part will focus on extracting descriptive parameters that listeners tend to notice, while the second part focuses on how these songs translate into shape parameters.

During the first part of the survey participants will be given two songs with a distinct difference in one of the axes on the valence/arousal plane. They will be asked as an open question to describe all the differences they hear between these two songs. This way it becomes possible to find the parameters that most likely result in a change on this axis of the valence/arousal scale.

Then, during the second part of the study participants are being asked to map shapes and colors to four individual songs. Participants will be given a song and a set of options for shapes and colors to choose from. We have chosen to investigate the effect of three shape parameters, these parameters are based on Figure 1, and the accompanying related work [5]:

- Curvature - Round vs. Angular
- Size/proportions - Small vs. Large
- Symmetry - Symmetrical vs. Unsymmetrical

We have chosen five different colors based on a study that links emotion to shapes [20]. The two questions per song in the second part can be viewed in figure 5. As an optional input we created the possibility for participants to draw and upload their own interpretation of the music. This will provide an overview of different translations from songs into visuals that can serve as an inspiration for the design of the system.

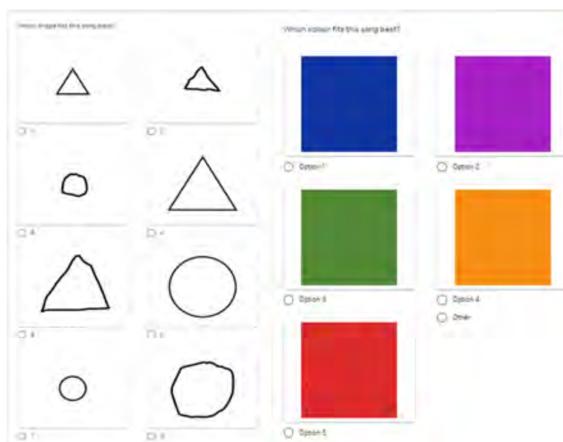


Figure 5: Shape parameter options

#### 3.2.2 Stimuli

We have chosen eight different songs to compare. These were chosen based on the classification of songs to a valence/energy scale visible in 6. These songs are paired based on being opposites on either the energy scale or the valence scale, while the other parameter stays consistent. These pairs are:

- Ace of Spades (Motorhead) - My Immortal (Evanescence). Different energy level, low valence.
- Can't Stop the Feeling (Justin Timberlake) - Dont Worry Be Happy (Bobby McFerrin). Different energy level, high valence.
- Heart Shaped Box (Nirvana) - Happy (Pharell Williams). High energy level, different valence.
- Same mistake (James Blunt) - La Mer (Charles Trenet). Low energy level, different valence.

During the second part, the same eight songs will be shown to the participant but now individually.

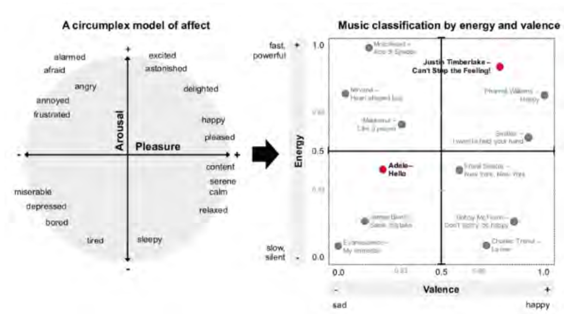



Figure 6: Music classification by energy and valence [8]

#### 3.2.3 Participants

For this study, participants are students from Dutch technical Universities. The aim is to have an equal distribution in gender, and an age range within 18-28. A desired amount of participants would be around 20 persons.

### 3.3 Results

Nine responses were collected during this pilot study. Participants were recruited from fellow students in our direct network. Participants are aged 21-28 and m/f ratio is 4/5. The full responses are visible in Appendix A. We went through the open answers of the first part and retrieved the most occurring descriptive parameters. This was done by manually categorizing results.

#### 3.3.1 Song pair 1: Different energy level, low valence

- Difference in tempo: fast vs slow
- Difference in dynamics: loud vs soft
- Difference in timbre: Loud drums/guitars vs piano/strings
- Vocals: rough vs smooth

#### 3.3.2 Song pair 2: Different energy level, high valence

- Difference in timbre
- Instrumentation: electronic vs old sounding
- Fullness: large band vs intimate
- Difference in tempo
- Difference in dynamics

#### 3.3.3 Song pair 3: High energy level, different valence

- Difference in dynamics: Changing dynamics vs constant
- Instrumentation: raw vs polished
- Voice: rough vs smooth
- Voice pitch: Low vs high

| Colour | LV, HA | HV, HA | LV, LA | HV, LA |
|---|---|---|---|---|
| Black | 11,1 | 0 | 5,6 | 0 |
| Blue | 11,1 | 5,6 | 33,3 | 16,7 |
| Green | 11,1 | 5,6 | 11,1 | 27,8 |
| Orange | 5,6 | 44,4 | 0 | 16,7 |
| Purple | 5,6 | 5,6 | 22,2 | 16,7 |
| White | 0 | 0 | 11,1 | 0 |
| Red | 55,6 | 0 | 0 | 0 |
| Yellow | 0 | 38,9 | 5,6 | 5,6 |
| Brown | 0 | 0 | 5,6 | 0 |
| Grey | 0 | 0 | 5,6 | 5,6 |
| Pink | 0 | 0 | 0 | 5,6 |

Table 1: Distribution of preferred colours compared to valence arousal combination (LV = Low Valence, HA = High Arousal etc.)

| Shape Parameter | LV, HA | HV, HA | LV, LA | HV, LA |
|---|---|---|---|---|
| Small vs Big (%) | 50 — 50 | 78 — 22 | 67 — 33 | 50 — 50 |
| Rough vs Smooth (%) | 67 — 33 | 22 — 78 | 28 — 72 | 44 — 56 |
| Triangle vs Circle (%) | 83 — 17 | 33 — 67 | 22 — 78 | 6 — 94 |

Table 2: Distribution preferred shape parameters compared to valence arousal combination (LV = Low Valence, HA = High Arousal etc.)

#### 3.3.4 Song pair 4: Low energy level, different valence

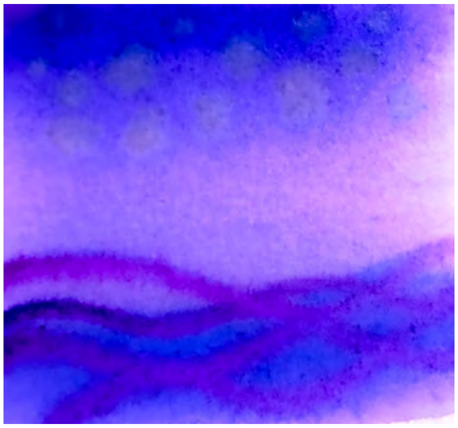
- Difference in lyrics: English vs French
- Production quality: old vs new

While some participants described the difference through descriptive parameters, most participants did this through the describing the emotion they felt while listening to it. Common described differences were happy vs sad and aggressive vs calming. This is not surprising since these contrasts were exactly on which the pairs were selected.

The results to the second part of the survey are summarized in Table 1 and 2, where Table 1 shows the distribution of the preferred colour per VA combination and Table 2 the preferred shape parameters. The full results can be found in Appendix A. Given the low amount of participant it is not possible yet to do reliable statistical analysis on this data. However, the sometimes extreme distributions in the tables seem to indicate that there might be a dependency between emotion and shape or colour. What is interesting to note in Table 1 is that the colour yellow has been chosen by 40 percent of the participants for the combination high valence, high arousal, while the colour yellow was not in the listed options. The fact that 40 percent of the participants were that sure about the colour yellow that they all typed it in, seems to indicate a strong dependency between colour and emotion or music. Due to the fact that it was optional, the amount of participants that submitted a drawing was low, however for the song My Immortal by Evanescence two different drawings were submitted. Which are visible in figure 7a and 7b.

### 3.4 Discussion

Despite the small amount of participants taking part in this study, the survey gained some insights in how people listen to, remember and describe music. It turned out that the descriptions had a large variety of different answers, where only a small part of them were related to descriptive parameters. A large number of answers were either describing how the song made them feel or classifying the songs into genres. It was great to see that people were describing songs based on the perceived emotion.



(a) Submission 1

(b) Submission 2

Figure 7: Submitted drawings

This enforces the idea of reducing music to the valence/arousal scale as a method to map it to shapes. The fact that genres were mostly used to describe the differences between the songs was not surprising. Genres can be seen as a commonly occurring set of various descriptive parameters (instrumentation, tempo, lyrical themes etc.) that is more approachable than listing these individual parameters.

From the responses two often occurring categories of descriptive parameters could be extracted. Where the most common category was the timbre of the sound. Timbre can be seen as the combination of overtones related to a tone. This combination of overtones explains why an acoustic guitar sounds different from a piano for example. In the results two types of timbre differences are apparent. One is a difference in instrumentation and the other a difference in vocals. What was interesting is that most of the responses which are relating to the timbre used terminology that could be applied to shapes as well. An often occurring described contrast was rough versus smooth, which is directly applicable to the texture of shapes as well. Other mentioned contrasts like full and intimate or raw and polished are also applicable to the visual domain. This backs up the assumption that converting a song into a shape is possible, but also indicates that doing this by transforming it into the valence/arousal scale might mean that some information gets lost.

Another descriptive parameter that has been mentioned multiple times was the difference in tempo. However, it was only mentioned in the songs with contrasting arousal. This could indicate that there is a relation between arousal and tempo.

Unfortunately due to the limited number of submissions of this survey, it is hard to draw valid conclusions through statistics. However the results seem to indicate that there is a general consensus between participants on certain colours and parameters. Examples of these are the colour red for Low valence/high arousal songs or the preference for circles for high valence/low arousal songs that has been chosen by 91 percent of the participants. Also the fact that almost 40 percent of the participants had such a strong opinion that they wrote the colour yellow as an additional option, seems to indicate a strong correlation between colour and emotion. However this has to be further investigated in the first iteration to say this for sure.

### 3.5 Conclusion

This survey was a useful method to uncover how people perceive and describe music. The method of transforming musical parameters into the valence/arousal plane seems to work, however it might be the case that some information gets lost in this conversion. Therefore it might be wise to in addition to the valence/arousal mappings, add extra mappings between other features as well.

This pilot study shows potential, but is not conclusive enough to draw strong conclusions. However, the insights into which factors are of importance to participants can be used to select features and make design decisions in order to get a deeper understanding of the relationship between some more important song parameters and a physical shape.

# 4 First prototype

The following chapter describes the development of the first prototype. From the pilot study it became apparent that transforming the musical data towards the valence/arousal plane and using this point on the plane as the data source for creating a shape, showed potential. However chances might be that in this process some relevant information might get lost. Therefore this iteration will focus on finding a mapping between music parameters and shape parameters. The research question that will be investigated is:

- What is the best mapping of music and shape parameters?

This question will be explored through building and testing a working prototype that creates shapes based on a mapping between audio features and shape parameters. This prototype will be tested with human participants, and subsequently evaluated.

## 4.1 Specification

This section will focus on defining some of the important (design) requirements and technical possibilities and limitations before starting the implementation phase.

### 4.1.1 Requirements

In order to answer the research question it is necessary to create a prototype that is able to generate a 3D shape based on a set of parameters. These parameters need to be able to be mapped to a set of audio features which should be automatically extracted from a piece of music. It also needs to be possible to create shapes using different configurations of parameters.

After a shape is created it should be possible to manually adjust it, this way it is possible to track how different people would change the configuration, which allows for precise feedback on the current mapping between parameters.

### 4.1.2 Auditory features

Since the prototype has to map audio features with shape features, it is necessary to look at different parameters that can be extracted from the audio and at the parameters that are required for generating a shape. Assuming that the audio features that can be retrieved using the Spotify API is an almost complete list of the global parameters that are possible to extract from a song, the following features can be used for the prototype. These are our interpretation, for the technical specifications see the Spotify Api website [15].

- **Duration**: The duration of the song in milliseconds
- **Acousticness**: The amount of use of acoustic instruments
- **Instrumentalness**: Whether the song has vocals or is an instrumental
- **Loudness**: The volume of the song
- **Speechiness**: The amount of vocals in a song
- **Time signature**: How many beats are in a time measure
- **Tempo**: The tempo of the song (in bpm)
- **Valence**: Whether the song is considered
- **Danceability**: How inviting the song is to dance to
- **Energy (Arousal)**: The amount of energy in a song
- **Sections**: This splits the song into different sections
- **Loudness**: The loudness per section

### 4.1.3 Shape design

Before building a prototype, it is necessary to define the requirements for the design of the shape that will be generated by the application. In order to make the shape consistent but still adjustable enough to represent a specific shape, a primitive shape will be chosen that can be modified by parameters. Since one of the goals of this project is to make music physical again, the primitive shape is inspired by older forms of physical music, namely the vinyl and CD. In order to increase the adjustability of this shape, this shape will be given a third dimension which results in the shape of a torus (Figure 8).

Given the Torus as a primitive shape there is a more limited set of parameters that can be used to modify the shape, from which the following will be used:

- **Radius**: The width of the tube
- **Latheradius**: The width of the hole within the torus
- **Shape Colour**: The colour of the shape
- **pts**: The amount horizontal segments
- **Noise Factor**: The amount of gaussian noise applied to the shape generation
- **Segments**: The amount of vertical segments

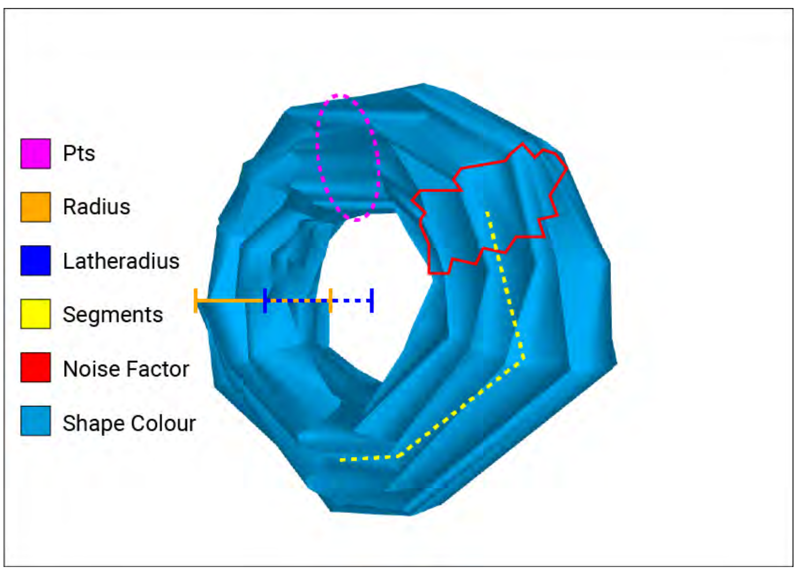



Figure 8: Torus shape and parameters

The first iteration is mainly focused on whether there is a connection between shape and music at all. The first iteration is created with flexibility in mind. It should allow easy adaptation and flexibility in its operation, to be able to be adapted easily to new insights. As a basic starting shape we picked a torus, and applied transformations on it. The torus was picked because it is a geometric prototype which is already seen often in music. Vinyl record, Compact Discs, and many other geometric shapes often associated with storing music are toroidal. In the first iteration, flexibility is key, and the shapes generated in the program are very customisable.

## 4.2 Implementation

The creation of this prototype can be split up into two parts. The extracting of audio features and the creation of a shape using parameters.

### 4.2.1 Audio feature extraction

The audio features will be extracted using the Spotipy API [15]. A program will be made in Python that takes an artist and title and creates a dictionary filled with the corresponding audio features in it. To be able to communicate with the shape generation program, a socket server has been made that continuously runs. When new features are requested, the shape generation program connects to the server and sends a query of an artist and title in order to get the dictionary with features back.

### 4.2.2 Shape generation

The first iteration of the product is created through the use of the open source java graphics library and IDE processing [7]. This program is based on Java and features a simplified environment to create Java or OpenGL graphics. Data on songs is gathered using the Spotify API [15], accessed through the use of a Python back-end and Spotipy [4] . This Python back-end communicates with the Java applet through the use of sockets.

The segments extracted from the Spotify API are used to create the segments of the Toroid shape. The number and length of the segments correspond with the sections of the song. This should help to make the shape more recognisable and provide a coherence between different shapes.

# 5 First evaluation

In order to test the prototype and answer the research questions, a survey is made to test the implementation of the prototype. The goal of this survey is to test several mappings between the music and shape parameters.

## 5.1 Method

**Experiment Design**: The survey will be split into two parts. The first part is aimed at choosing one out of several generated shapes of the same song using different mappings, where different properties are connected to different shape parameters. During the second part the participants can download the prototype and create a unique shape corresponding to a song themselves, which is done by adjusting several sliders. .

**Participants**: Participants between the ages of twenty and forty will be chosen as participants, since they are most likely the target audience of the application. The goal is to get between 20 and 40 individual participants to fill out the survey, in order to be able to draw valid conclusions and perform a statistical analysis.

### 5.1.1 Part 1: Comparing generated shapes

In this part, different mappings between parameters will be compared to each other. Three different mappings have been created based on our expectations of what might be valid mappings. These mappings are visible in Table 3. During the survey the participant will be given a song together with four generated shapes to choose from. Out of these four shapes, three will be created using the parameters retrieved from the Spotify API but using the different mappings as shown in table 3 and one will be created using random integers as shape parameters. When the subsequent API values are larger, the value of the coupled shape parameters increase, and vice versa. In total four different songs will be given to participants, and participants are then asked to consider the four mappings and choose the most fitting one. After each song, the participant has the opportunity to motivate their decision in a text field. The songs will be chosen based on a broad contrast in valence and arousal, based on figure 6. The chosen songs are:

- Nirvana - Heart Shaped Box
- Justin Timberlake - Can't Stop the Feeling
- James Blunt - Same Mistake
- Bobby McFerrin - Don't worry, Be Happy

| | **Mapping 1** | **Mapping 2** | **Mapping 3** |
|---|---|---|---|
| **Radius** | Loudness | Loudness | Loudness |
| **Latheradius** | Length (s) | Length (s) | Length (s) |
| **Shape colour** | Valence | Energy | Valence |
| **pts** | Energy | Valence | Energy |
| **Noise factor** | Energy | Acousticness | Danceability |

Table 3: Mappings between parameters

To analyse the retrieved data, an ANOVA test will be performed to figure out if one mapping is preferred significantly. Additionally, a word cloud of the answers to the optional motivation box will be made to gain insight into what participants were focusing on when trying to map a shape to a song.

### 5.1.2 Part 2: Generating shapes by moving sliders

In this part an embedded version of our application will be provided in which the user can generate their own shape according to how they think it would best match the given song. Four songs will be provided. The songs will be chosen based on a broad contrast of features, based on figure 6. We picked four songs which are placed as far as possible in each quadrant of the table, as to form contrasts in the Arousal Valence plane. The chosen songs are:

- Motorhead - Ace of Spades
- Pharell Williams - Happy
- Evanescence - My Immortal
- Charles Trenet - La mer

The generated shapes will be analysed by performing an ANOVA to see if there is any correlation between the songs and the different parameters. Additionally, the shapes will be recreated and put into a collage to be able to manually analyse the common patterns in the creation of shapes.

## 5.2 Results

### 5.2.1 Part 1

The full responses of the first part can be found in Appendix B. A word cloud using the most common words in the open questions of the survey is created to retrieve get some insights in the way participants link music to visuals, this word cloud is visible in Figure 9.

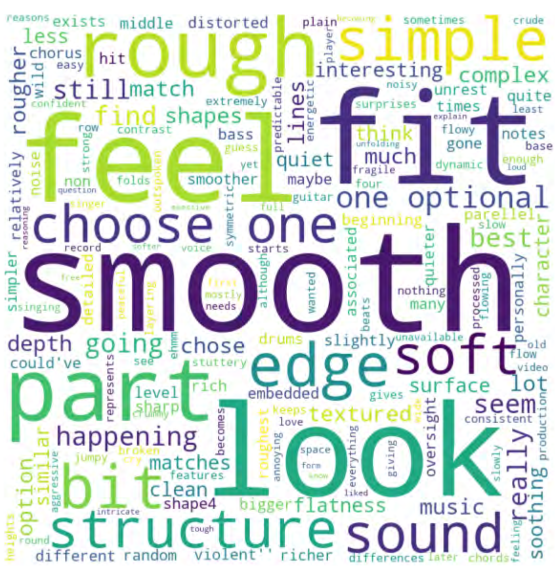



Figure 9: Wordcloud of answers

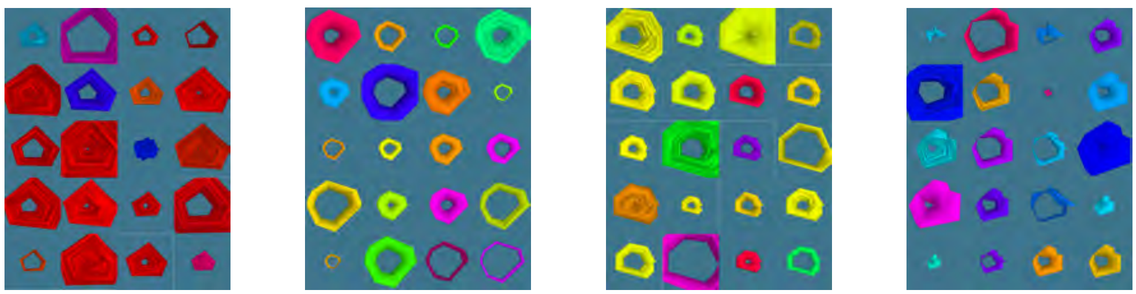
The frequency of each chosen mapping is shown in Table 4.

### 5.2.2 Part 2

The generated images created by the participants for each song have been put in different collages to get an idea of the most occurring patterns within each song, These collages are visible in Figure 10. Additionally an ANOVA has been performed to get some insights in which parameters are significantly correlated with a difference in Valence and Arousal. The results of this ANOVA can be found in Figure

| Mapping | Frequency | Percent |
|---|---|---|
| 1 | 15 | 17,9 |
| 2 | 24 | 28,6 |
| 3 | 25 | 29,8 |
| 4 | 20 | 23,8 |
| **Total** | 84 | 100 |

Table 4: Frequency of chosen mappings



(a) Motorhead - Ace of Spades 1

(b) Charles Trenet - La Mer 2

(c) Pharell Williams - Happy

(d) Evanesence - My Immortal

Figure 10: Generated shapes per song

?? and Figure 11. From these ANOVA results can be derived every parameter except the latheradius was significant.

| Parameter | Significance |
|---|---|
| Colour | 0,006 |
| Latheradius | 0,456 |
| Radius | 0,004 |
| Noise factor | 0,000 |
| Pts | 0,007 |

Table 5: ANOVA results

### 5.3 Discussion

This study gave some interesting insights into the people's perception of how music can be linked to shape parameters. This section will discuss some insights that can be gained from the retrieved data. Allowing participants to generate their own interpretation of how a song would relate to the given shape parameters, turned out to be a very useful method for defining the user's perception of how these parameters would relate to songs with differences in valence and arousal levels.

However, from Figure 4 it becomes clear that the first part of the survey was not really successful, since the chosen mappings are very equally distributed. This is most likely due to the similarity between the shapes the participants could choose from. Only small variations had been chosen between the different mappings in order to get a better insight into the effects on the individual parameters. Unfortunately, this resulted into a set of images that looked too much alike. But given the fact that option 4 (the random option) is only chosen 23 percent of the time, it indicates that the assigned mappings perform better than a random initialisation.

The word cloud made out of the answers of the open questions in the first part of the survey indicates that the most common reasoning for matching songs to shapes is to find words that apply

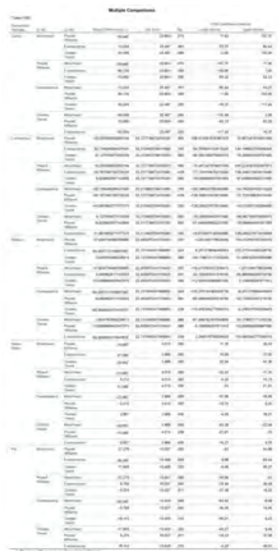



Figure 11: Multiple comparisons Anova results part 2

to both music as shapes. The use of these words already became apparent when analysing the results from the pilot study.

When analysing the generated images one of the first things that stands out is the difference in colours between the different songs. Especially the difference between the songs Ace of Spades (Figure 10a) and Happy (Figure 10c) is quite prominent. When looking at the ANOVA results (Figure ??), it becomes clear that the colour parameter is significant, but only between these two songs (Figure 11). However when analysing the generated images, one could argue that the song My Immortal (Figure 10d) has more cool tones and the song La Mer (Figure 10b) more happy/warm ones. It is interesting to see that these colours correlate to the standard ideas of which colours match to which emotion. This is also backed up by other research. A study investigating the correlation between colours and music also came to the conclusion that colour association was influenced by emotion [13]. The results from the interviews conducted during this research also resulted in some of the same colours as during this research.

When looking at the ANOVA results in figure ?? it appears that every parameter is significant, except the latheradius. This means that there is no significance between this parameter and the valence or arousal of a song. The latheradius parameter was originally coupled to the loudness of the song per segment. This is now justified by the fact that it would not make sense to couple this parameter to either the valence or arousal.

Looking at the ANOVA results there appears to be a strong significance for the noise factor. However when looking at Figure 11, it becomes clear that this significance is mostly due to the fact that the song Ace of Spades by Motorhead has a way higher noise factor than any of the other songs. Given the fact that the second highest noise factor is the song Happy by Pharell Williams, the noise factor is most likely related to the arousal of the song. One of the often used words to describe this song by Motorhead was the word rough, interesting enough the texture of the shape becomes more rough when the noise factor is increased. This could also indicate that the noise factor is correlated with the feature of a song that makes it "rough". Besides Motorhead another song that was often described as rough was the song Heart Shaped Box by Nirvana, which also scored low on valence and high on arousal. This could indicate that this combination of a low valence and high arousal leads to the feeling of roughness in a song and therefore would positively correlate to the noise factor of the shape.

The results indicate that the radius of the shape also was significant between songs of different valence and arousal. However from Figure 11 it becomes clear that the two songs with the biggest radius were contrasting to each other on both the valence as the arousal scale. This could indicate

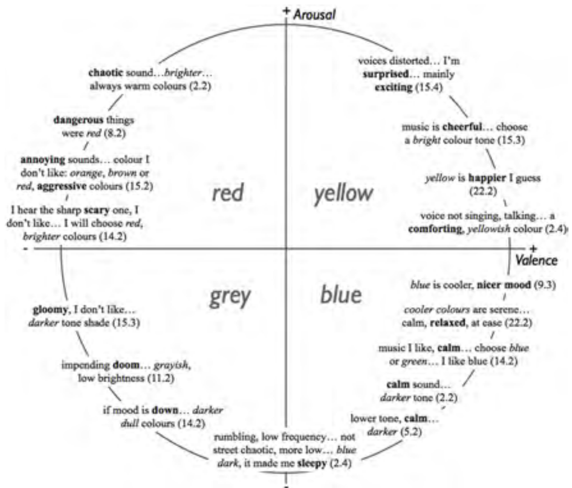



Figure 12: Colours based on position on valence arousal scale [13]

that there might be an underlying parameter that varies between the different songs that is explaining the difference in radius per song.

Since the starting point of the parameters for the shapes were already based on the songs, the results might be a bit skewed towards the initialisation of the shapes. This might be because the participants might not have touched certain sliders which would leave them in their initialised position. However, given the fact that the standard deviation of every parameter is sufficiently large, we can assume that most participants have been adjusting every parameter.

### 5.3.1 Deployment

Initially, the application was first implemented in a fully functioning Java application, with the goal of running the application in a browser window. However, unbeknownst to us Java web apps had been phased out completely as of a few years ago [2]. This presented us with the challenge of how to deploy and test the application. Especially because physical testing was made impractical due to the COVID-19 pandemic and accompanying "intelligent" lockdown. For the research on the second application, an adapted applet was shipped which used preconfigured JSON files instead of the actual Spotify API.

## 5.4 Conclusion

The goal of this iteration was to find a logical mapping between audio features and shape parameters. For four out of five shape parameters there appeared to be a significant difference between the answers per song (see figure 11), which indicates that the valence and arousal might have an effect on these parameters. Based on the previously discussed results the mapping as shown in Table 6 can be seen as a logical conclusion. There are still some uncertainties like the radius that are not yet explained and that combined with the fact that some of the parameters discussed were not completely leaning into one direction it is still a wise idea to test the accuracy of this mapping.

| | **Mapping** |
|---|---|
| **Radius** | Loudness |
| **Latheradius** | Length (s) |
| **Shape colour** | Valence + Energy |
| **pts** | Energy |
| **Noise factor** | Energy (+ valence) |
| **Segments** | Segments from API |

Table 6: Final mapping between parameters

# 6 Second prototype

Thanks to the previous iteration there now exists an idea on how to create a mapping between sound features and shape parameters. During the second iteration, the mapping between parameters will be applied to a fully working prototype. While the first iteration was more focused on the fundamentals, the second iteration is aimed at refinement of the concept, and increasing the span of the picture painted in this project. In the previous iteration some insight was gained on how certain aspects of a shape are perceived in conjunction with different valence and arousal levels. In the second iteration, we take a look at what a full product and user experience might look like. The goal of this iteration is to test the usability of the product and how well the generated shapes actually represent the music. Therefore the research questions that will be explored during this iteration will be:

- What is the current status of the usability of the product?
- How well do the generated shapes match the songs?

These questions will be explored by creating and testing a fully functional web-based prototype.

## 6.1 Specification

To get a solid idea of how this product would be perceived by its users, a website will be made that can be publicly accessed and will have all the necessary functionality for a fully rounded user experience. Before starting to build this website it is sensible to first establish some requirements for the system. This section will go over some of the most important requirements,

### 6.1.1 Technical requirements

This version of the system should allow us to test and experience the entire concept. A user should be able to input a title and artist of any song, and the application should be able to generate a shape accordingly.

The generation of this shape should be done using the mapping that was derived from the first evaluation. According to these results the shape color and size were quite personal and defining to people, therefore the shape color and size have to be customizable after the shape has been generated. The valence will be used to initialize the radius, which then afterwards can be adjusted.

When a user is content with a shape, the user should be able to download the object file (.OBJ) which a user can print or use themselves, or potentially order it to be printed elsewhere and be delivered by mail.

### 6.1.2 Design requirements

The application has two main screens. The Entry screen, where the user can make a query and will be informed about the project. The second main screen is the page where the shape can be viewed and customised. A background gradient is used to draw users to the actionable buttons on the right, and provide aesthetic value.

Some reference geometry can be toggled on and off. The reference geometry in question is a compact disk case. We believe that this allows people to get a clear idea of the size of the object using a thematically appropriate, well known object with set dimensions.

## 6.2 Implementation

The frontend client uses p5.js to serve pre generated shapes (OBJ), and the user can change the parameters mentioned above. The system uses a flask[source] backend to serve web pages and call backend applications. When a request is made using a title and artist, a SQL database is queried to see if the shape has been generated before. If so, the shape is served directly. If the song has not been queried before, the Spotify/Spotipy API is called via the backend. Subsequently, the data is transferred to a Java application, and the app is called from the command line. The generated shape is added to the asset collection and served to the client.

The shape now lives client side in the user's browser. The user can make personalised modifications to the shape, pick the size and color, and subsequently download or order it. The ordering and printing of such a shape would most likely be conducted by a 3rd party fulfillment company. There are a number of companies offering mail order 3d prints, and fulfillment. Some examples are larger companies like shapeways [a], 3d hubs [b], or local partners. For now, this commercial aspect is not implemented, as this piece is still ongoing research. However, the amount of clicks on both buttons is tracked, along with the number of views to have an indication on how many people would want to buy or download a shape.

(a) https://www.shapeways.com/

(b) https://www.3dhubs.com/

### 6.2.1 Deployment

The application now known as Waveshape (www.waveshape.nl) is a Flask based application running on a Virtual Private Server (VPS). Using a combination of uWSGI and NGINX, the website is served efficiently. When a title and artist are given to the application, the application first checks whether a shape has previously been generated in a SQL table. If the shape already exists, the shape file is sent directly to the front-end. Otherwise, the flask back-end executes a processing sketch adapted from the first iteration, and sends the newly generated file to the front-end.

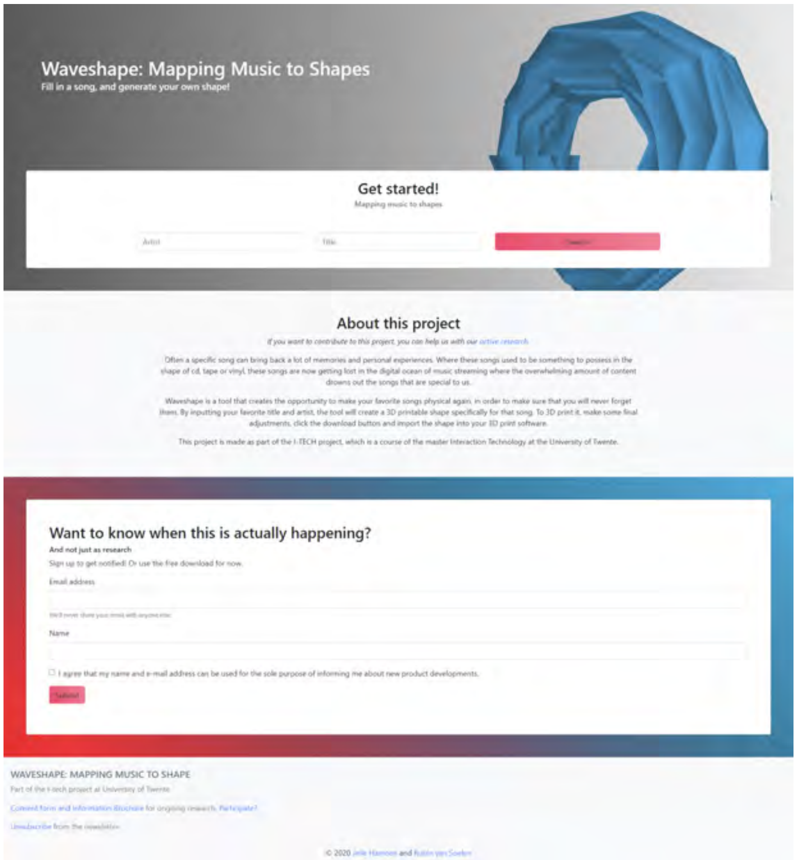



Figure 13: The home screen and entry point of the application

### 6.2.2 Screenshots

This section contains some screenshot of the application, which can also be found on www.waveshape.nl.

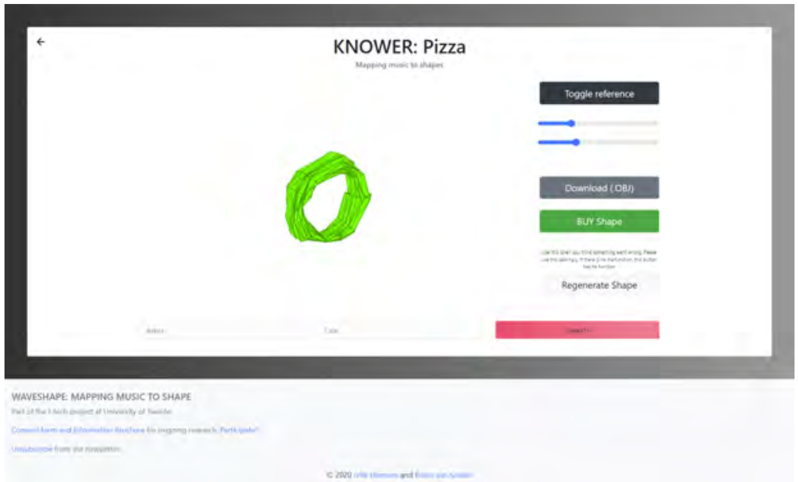



Figure 14: The shape screen, here users interact with the generated shape

# 7 Second evaluation

In order to test the renewed prototype and answer the research questions a set of user tests will be conducted to evaluate the current status of the application.

## 7.1 Method

**Participants**: For this study people between the ages of twenty and forty were asked to participate, since this is most likely the target group of the application. It is widely assumed that five participants is sufficient for a user testing, although some studies prove that it is not enough to uncover most problems [6]. But since the prototype is fairly simple in its amount of features, five to ten participants will most likely be sufficient.

**Experiment design**: Due to the current situation regarding the COVID-19 developments, the user tests will be done virtually. There will be two separate evaluations in order to answer the two different research questions. To uncover more about the usability and user experience of the application, a user test will be conducted to find out more about the flaws, shortcomings and positive aspects. Additionally to the user test, a small quiz will be made where the generated shapes have to be mapped to the correct song. This will be done to get an overview of how recognisable the generated shapes are.

### 7.1.1 Part 1: User experience

The user test will be held virtually using Skype. During the test, participants will be asked to visit our website and try to perform a view tasks. These tasks will be:

- Create a shape of a song you like
- Download the 3D object file

After the participants have performed these action, which we not expect to be a challenge, we will ask them if they want to continue to try out the application with different songs. We will observe those actions as well. When the participants are done, a survey/interview will be used where we will ask them a number questions to get an insight into their reasoning for performing certain actions. These questions are:

- Do you think the shapes represent the song?

| Question | Song | Arousal | Valence |
|---|---|---|---|
| PART 1 | | | |
| 1 | Hegedü, Bor, Pálinka - Bohemian Betyars | 95 | 94 |
| | In Love and War - XamVolo | 9 | 70 |
| | Raining Blood - Slayer | 100 | 4 |
| | Sometimes It Snows in April - Prince | 6 | 6 |
| 2 | Give the Drummer Some - Nickodemus | 90 | 92 |
| | Formula - Aphex Twin | 88 | 12 |
| | Sweet Jane - Cowboy Junkies | 20 | 81 |
| | To Build A Home - Cinematic Orchestra | 12 | 7 |
| 3 | We Didn't Start the Fire - Billy Joel | 90 | 92 |
| | Hide and Seek - Imogen Heap | 17 | 9 |
| | I Like It - The Marias | 18 | 76 |
| | Maps - The Yeah Yeah Yeahs | 94 | 16 |
| PART 2 | | | |
| 1 | I Walk the Line - Johnny Cash | 35 | 71 |
| | Barreleye - Mark Lettieri | 78 | 65 |
| | Into You - Ariane Grande | 73 | 37 |
| | Time To Send Someone Away | 31 | 35 |
| 2 | I'll Follow The Sun - The Beatles | 31 | 63 |
| | We Found Love - Rihanna | 77 | 60 |
| | Around - KNOWER | 79 | 17 |
| | Madness - Muse | 42 | 22 |
| 3 | Fields of Gold - Sting | 34 | 32 |
| | Feel Good Inc. - Gorillaz | 71 | 77 |
| | If I Had A Gun - Noel Gallaghers High Flying Birds | 74 | 21 |
| | Send It On - D'Angelo | 26 | 34 |

Table 7: Songs chosen for survey based on valence/arousal

- What do you think about the concept?
- What do you think about the quality of the application?
- What do you think about the intuitiveness of the application?

The user test and interview will be manually documented by writing down the actions and answers of the participants.

### 7.1.2 Part 2: Song matching

To evaluate the final mapping between the parameters that resulted from the previous iteration, a small survey will be created that will ask the participants to choose the song that they think is used to generate the shape. Since the results of iteration 1 indicate that the valence and arousal values make a big difference in the shape generation, the songs will be chosen based on their differences in valence and arousal. The valence and arousal (energy) values will be retrieved using the API from Spotify. There will be a total of four songs per question and two sets of three questions in total. In the first set, the values of valence and arousal are chosen to be very extreme, while at the second set these differences will be milder. The areas on the valence/arousal plane that will be considered for both sections are visible in Figure 15. Expected is that the first set will be easier to answer. The chosen songs per question are visible in Table 7.

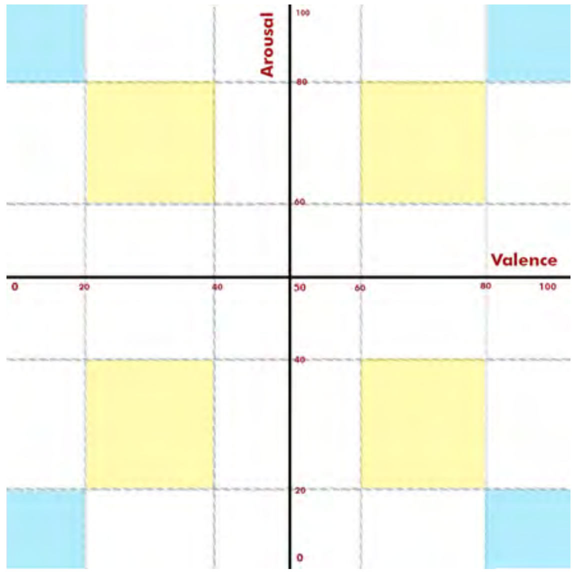



Figure 15: Areas of valence and arousal that will be considered for each set of questions. Blue: First set, Yellow: Second set

## 7.2 Results

In total 9 responses were recorded for the online quiz (part 2), recruited from our network. The average score participants achieved was 7.67 out of 24 points, with a range between 6 and 10 points. Additionally, seven user tests were conducted (part 1). The notes from these user tests can be found in Appendix C. A summary with some observations is given in this chapter.

### 7.2.1 Do you think the shapes represent the song?

For this question, results were mixed, 2 thought the shape represented the song well, 1 response was ambivalent, and 4 persons thought the shape did not represent the song.

### 7.2.2 What do you think about the concept?

People were positive about the concept, but were unsure of what to do with the product.

### 7.2.3 What do you think about the quality of the application?

Overall participants thought the application was of good quality. Some improvements were suggested:

- Elaborate on the website content
- Sometimes the page had to be reloaded to make the shape work properly
- Add a loading bar
- Label sliders better
- Show where spelling errors are in the search bar
- Make the application only have one search bar, not separate artist and title boxes

### 7.2.4 What do you think about the intuitiveness of the application?

Participants were positive about the usability of the website. They could find the needed buttons easily, and could use the application. Users also commented on the points raised in the previous question.

## 7.3 Discussion

The results of this evaluation gave some great insights into the current status of the application from a user perspective and into how recognisable the shapes generated by the mapping used in this iteration are.

The results from the survey indicate that the recognisability of the shapes is far lower than was expected. The amount of correct answers is just slightly higher than a random guess. However, some shapes were answered very accurate, an example of this is the shape corresponding to Raining Blood by Slayer which got a hundred percent accuracy. This song is very similar in its features and feel compared to the song Ace of Spades by Motorhead which was used in the previous iteration in order to define the correct mapping. It could be the case that the mapping that was created out of the first iteration is not universal enough and only works accurately with songs similar to the ones that were discussed during the first iteration.

The results of the user test were far more positive towards the application. What was specifically interesting was, that when the participants were asked whether they thought the shapes resembled the song, most of them saw a relationship between the song and the shape, which is in contrast with the results of the survey. The fact that the relationship between a song and its corresponding shape is only acknowledged when both components are revealed, seems to indicate that there is no inherent relation between a song and a shape but that one attaches meaning to the shape when it is placed next to a song. Or in some cases putting the two together will amplify an inherent relationship between song and shape. This means that the actual shape might not be as important as previously thought, since apparently a large part of the relationship between sound and shapes comes from the meaning derived from the context the two components are placed in.

However, some people did not really see a correlation between the shape and the song. It was interesting to see that some people who at first did not see any correlation started seeing a connection when they tried it out with multiple songs. This is most likely due to the limitation of sticking to the torus shape, every shape that is generated is essentially the same shape, it is only the details that make this shape unique. There was some critique on these details as well. A large part of visualizing the arousal in a song is done through the amount of noise. Some participants thought this noise was to spiky to represent certain styles of music. They thought this noise represented a more electronic music style while they used a classic rock song as input.

This is one of the downsides of using the valence and arousal scale as a mapping between the music and the shape. The interpretation of the shape becomes very abstract. A lot of participants started to over-analyze how the shape was constructed, which resulted in some confusion for the participants. For future work it might be a good idea to look into a way to combine the use of the valence/arousal with some more descriptive features, which would make it easier to confirm that a shape indeed corresponds to a certain song.

The usability of the website turned out to be decent, which was expected given the limited amount of screens and functions of the application. What was not that clear to the users was the fact that the sliders that change the color and size were not labeled. However, after adjusting these sliders their functions became clear immediately. Nevertheless, adding labels would increase the clarity of the website. Additionally, since the loading time of generating a shape was sufficiently large, a participant suggested the addition of a loading bar when the shape is generating.

Participants were impressed with the quality of the website and liked the idea of 3D printing one of the shapes. It was clear for the participants how to download the shape, however it was not so clear what to do once the obj. file was downloaded. With the exception of one participant with a background in 3D modelling who imported the object in a 3D modelling software and made a beautiful render out of it, which can be seen in Figure 16. Nevertheless, for a final application it would be a good idea to either make a tutorial on how to 3D print the downloaded file with a 3D printer or print the shapes ourselves and ship and sell them.

In general the participants liked the concept of the application and really enjoyed looking at the different results for different songs. However, they did not have the need to use it to 3D print their own shapes, since they would not know what to do with it. This could mean it might be a good idea to look into either adding a functionality or purpose to the 3D printable object to make the incentive

Figure 16: Render made by participant during user tests (Credit: Pepijn Peeters)

of printing it better or into re-branding the application into an exploratory tool.

# 8 Conclusion

Overall, this project has been an interesting journey into investigating the relationship between songs and shapes. According to the user tests the current website is fairly easy to use and the songs match the shapes despite the poor results from the quiz, since most likely the connection is only established once both the song and the shape are given. To increase the usability the labels have to be added to the sliders and more clarity should be given on how to 3D print the actual shapes.

During the course of this project we have used the valence/arousal plane as a general guideline to classify songs and map them towards the parameters of the shape. This approach gave quite a good insight into the general feel of the song. However, reducing musical data like this, might have caused some important data and associations to get lost which the evaluation of iteration 2 seemed to indicate. For future work it might be interesting to investigate a mapping between songs and shapes using for example the lyrics or the instrumentation.

Since the participants liked exploring the results of different songs using the website, but the desire to actually print the shape was quite low, creating an incentive to 3D print the shape would be interesting to research. An example of such an incentive could be the addition of an NFC chip to the shape, which has a link to the song on Spotify. This would make the product resemble the original physicalisations of music, like cds and vinyls, on which it was based on even more. A more low-technology solution to creating an incentive for 3D printing would be to create accessories to store the 3D prints in. This could nudge the users into starting a collection. Also, during the evaluation sessions a participant suggested the idea of incorporating the musical artists into the development of the shapes. When the artist has a say into how the shape is generated it would correlate more with his intentions and the public would have more incentive to buy/download it.

We found that using the website as a medium to distribute the application works well. According to our evaluation and the user testing the website is of sufficient quality to be kept online. We are curious to see if and how the program will be used be used in the future.

# 9 Reflection

This project has been a very broad experience, covering many aspects of the Interaction Technology space. We covered almost all areas, from the economical side to going deep into configuring web servers and applications, to doing user studies and distilling principles. It also gave a great taster on how research is conducted within the faculty, including things like ethics procedures. However, this project also posed a number of unanticipated challenges.

Firstly, during the project, the Covid-19 pandemic hit. This made many of the planned activities impractical or impossible. We believe that this has caused most of the delays. Usually, we would have conducted user test in person, which would have been more efficient than conducting a survey through an online platform. This has most likely caused a delay of a number of weeks. However, we could adapt to the situation, and manage as good as possible. Additionally, it was harder to reach participants than expected. Usually, many participants could be recruited face to face, for example in DesignLab. Physical recruitment was off the table, so we had to rely on recruitment via social media within our network, who were also all dealing with the lockdown in their own ways. However, many came through and participated enthusiastically, for which we remain ever grateful.

Secondly, during the implementation of the second iteration, some unexpected issues came up with the server running the application. The last bit of delay was filled with staring at and negotiating with a bash prompt and ever evolving error messages and disfunction. Eventually, however, we managed to get the website up and working to a deployable standard. It did teach us that there are still many particularities in deploying a web application to an actual server environment in comparison to a development environment. Many things that worked fine in the development version failed in production. Including, but not limited to many particularities in running OpenGL and Java.

Finally, the course this project is a part of was aimed at projects executed by teams of four. We did the project with the two of us. While it still was manageable, some more finesse could potentially be applied if more collaborators would have been part of this project. However, cooperation went smoothly with the two of us, also throughout the lockdown. Decisions were made in conjunction, and work was done mostly separately due to the working conditions. This method, while maybe not as efficient as face to face cooperation, was more than satisfactory to get work done on the project.

All in all, this project has been a very educational experience, and we believe to have achieved good results, despite some challenges and setbacks. This project has been a great opportunity to dig in deep into a subject and create something close to our hearts, alongside being of great educational, and developmental value.

## 9.1 Acknowledgements

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