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Creating Generative Data-driven Aesthetics Based on Brain Waves

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Abstract. Contemplative environments can significantly impact our mental health, and recent research highlights their importance for well-being. Guided by the principles and aesthetics of Zen Gardens and Zen Buddhism, the medium-term objective is to create an immersive, therapeutic environment with restorative qualities, utilizing a data-driven generative approach. This paper explores the initial phase of translating brain wave data, specifically electroencephalographic recordings of brain waves, into dynamic abstract visual patterns. In this process, the data serves as the pigment, while algorithms shape the visual aesthetics. In this first iteration, a dataset related to the research of brain activity in a resting-state experiment was used, and a Fast Fourier Transform was implemented in the Processing programming language to calculate the average amplitude and frequency. The average amplitude was used as input for the Flow Field algorithm, influencing the velocity visualized through dynamic curves with fading trails. By presenting the current work, this article aims to show the transformative potential of generative art in creating abstract immersive environments.

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Keywords: EEG data-driven Visualization · Computational Aesthetics · Immersive Environments · Zen Gardens

1 Introduction

This paper aims to explore the use of electroencephalography (EEG) data in creating dynamic abstract visual patterns. A medium-term goal is to develop an immersive therapeutic environment with restorative properties based on EEG data-driven dynamic abstract visual patterns. The proposal is to help achieve a balanced life in contemporary society by creating an environment, both physical and mental, for meditation and contemplation amidst the stress and pressures of today's lifestyles.

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There is a growing interest in technologically assisted mindfulness interventions. Recent studies using Virtual Reality (VR) have shown the technology's potential to create immersive environments, making it a valuable tool for promoting mindfulness practices and reducing stress [1]. Research has shown positive outcomes in stress reduction for both clinical and non-clinical populations [2–4]. However, using a VR headset for long periods could lead to motion sickness [3] and, in addition, recent research points to new types of social isolation or other unwanted consequences (e.g., Apple Vision Pro), thus its daily use has been advised against [5–7].

Immersive projection environments (e.g., CAVE) could significantly impact various sectors, particularly mental health care, with recent results showing positive outcomes for therapeutic purposes [8, 9] (forthcoming). Aligned with this, the effectiveness of a low-cost dual-screen projection system designed to reduce stress has been explored. The results showed that a simple two-screen projection method was more effective than a single-screen projection in reducing stress levels among healthy adults and children with medical complexity [6]. Digital technologies can be leveraged to promote physiological and multisensory experiences, helping users to overcome their challenges. The experiment also utilized pre-recorded videos of natural scenes, that is a common approach in VR for therapeutic purposes [5].

Research demonstrates a variety of applications and outcomes that enables the large-scale use of immersive screens in the fields such as art (e.g., Flies on the sky [10], interactive art and experimental psychology as highlighted by [5]. Concurrently, there is also an increasing use of VR in artistic spaces and therapeutic applications [11], based on audiovisual and biofeedback installations (e.g., breath, heart rate, neurofeedback) [12]. For example, the Assembly Lines by Sougwen[1] is a performative installation that includes a personalized multi-robotic system driven by meditation and biofeedback. Moreover, the Eunoia by Lisa Park[2,3] uses brain waves to manipulate water in a performance using NeuroSky (EEG) brain wave headset to manifest the artist's current brain states into ripples of water. Although these projects utilize brain waves as input, they remain beyond the current scope of immersive environments. [13] advocates in their study the use of immersive interactive technologies to promote positive change. The study outcomes that digital technologies can be leveraged to encourage physiological, multisensory experiences for users to work through their challenges [13]. As an intuitive system, the Immersive Interactive Virtual Environment (IIVE) could be used across a range of treatment modalities, enabling users to lead their therapy instead of being led by others.

Importantly, whereas natural scenes are commonly employee in VR scenarios (e.g.. [6]), the use of abstract visual patterns in immersive environments remains underexplored [2, 4, 11, 14, 15] In a recent study, it was found that participants exhibited a preference for abstract imagery when compared to realistic ones. This study offers preliminary insights into audio-visual designs for Optical Head-Mounted Displays (OHMD), and breath-based mindfulness practice in casual walking contexts. The identified reasons for this preference included simplicity, absence of direct associations (e.g., does not promote

[1] https://sougwen.com/project/assembly-lines-2022.

[2] https://www.thelisapark.com/work/eunoia2.

[3] https://www.thelisapark.com/work/eunoia.

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mental wandering), and clear visual guidance [16]. In this context, the geometric shape emerged as the most suitable option, receiving the highest average ratings in all the survey questions. However, and according to the authors, it is essential that the visual elements also have an appealing aesthetic to keep the user engaged. Another finding is that participants perceived 3D figures displayed on the OHMD screen as more obstructive and distracting in comparison to 2D figures. The current research landscape still leaves the question unanswered regarding whether abstract visuals/patterns could have an impact on mental health. Finally, an artistic project worth referencing, although outside the scope of this paper, is The Constant Gardeners[4] installation which combines the aesthetics of Zen gardens with a data-driven approach. This performative installation develops a data-driven visual language, translating the movements of professional athletes into dynamic and expressive abstract patterns. By analyzing video footage from a diverse range of sports, four industrial "gardening" robots, mounted on linear rails, inscribe these patterns on a large gravel canvas.

Considering the critical unanswered question of whether abstract visual immersive environments could have an impact on mental health and our midterm goal of testing those using EEG data-driven aesthetics, the current paper presents the design/creation of a visual abstract pattern based on brainwave data following the visualization framework/pipeline and is organized in three sections. Section one presents a brief description of the context of restorative environments, highlighting the importance of Zen gardens and pointing to a specific type of garden called Tsubo-niwa. A brief analysis related to the aesthetic concepts of Zen gardens is also presented, and the goal is to establish the theoretical concept and clarify the main objective, which is to create an abstract immersive therapeutic atmospheric environment with restorative properties; Section two presents a brief analysis of related work, in which some important clues and approaches are provided. Namely, the works/projects that use a data-driven approach based on brainwave data; Section three describes the implementation process of an abstract visual pattern based on brain wave data that follows the visualization framework/pipeline [17]. The paper is then closed with a final section of discussion and directions for future work (Fig. 1).

1.1 Tsubo-Niwa Gardens as an Immersive Quintessential Environment

The COVID-19 pandemic and associated lockdown measures have resulted in widespread social isolation, with a significant impact on people's mental health worldwide and leading to higher levels of stress, depression and anxiety [18]. This in turn underlines the importance of residential spaces for mental health and well-being [19, 20]. The World Health Organization (WHO) describes the physical environment, along with two other factors, as a determinant of health [21]. In fact, space engages in a salient dialogue with its users and have a profound impact on wellbeing [22, 23], Recent research points out that in North America and Europe, people spend 90% of their time indoors [24–26]. [25] highlights the relationship between the built environment and its effects on physical health. However, its impact on mental health and wellbeing is a more recent issue that still lacks quantitative data for an exhaustive evaluation [25]. Therefore, residential

[4] https://www.jasonbruges.com/art#/the-constant-gardeners/.

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Fig. 1. Tōtekiko is one of the five gardens at the Ryōgen-in sub-temple of the Daitoku-ji Buddhist complex in Kita-ku, Kyoto, Japan[5].

spaces have a major impact on our mental health and general wellbeing. Nevertheless, a key aspect of well-being and public health guidelines for healthy housing is ensuring visible and accessible green elements and spaces [25]. [25] review also highlights that lower stress levels are correlated with the presence of windows providing views of nature, which elicit positive emotions and stimulate recovery. Additionally, access to nature, expansive views, views of natural landscapes, and gardening are all emphasized as beneficial. Therefore, why do certain spaces/environments, promote mindfulness states, while others can be so stressful? Further, how can we create/design such immersive "realities" that can help us live more mindfully by expanding/recreating these mindfulness spaces into our residential indoor spaces? [27]. The design of environments to foster mindfulness continues to exist as a discrete area of knowledge according to [28].

In this sense, [29] highlights the importance of the restorative effects of multisensory open spaces, such as Japanese Zen gardens. Zen gardens are methodically designed to create a harmonious balance in our fast-paced lives, promoting stillness in the viewer's mind [30]. According to the authors traditional Japanese gardens exemplify a multisensory experience, subtly conveying universal principles through a blend of visual and aural elements, along with distinctive scents and textures. This, in turn, led to the study of a specific type of Japanese garden called tsubo-niwa[6] [31, 32]. Tsubo-niwa is a Japanese enclosed garden used in traditional townhouses that functions as a space to enhance mental health, much like the dry landscape gardens where Zen Monks aim for enlightenment [30, 33]. This small residential garden used in traditional houses called Machiya[7], originally designed to illuminate and ventilate, has evolved into spaces that improved people's

[5] https://en.wikipedia.org/wiki/totekiko

[6] https://najga.org/handbook/courtyard-garden/

[7] https://www.nippon.com/en/guide-to-japan/gu900012/

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Fig. 2. Isamu Noguchi, Lessons of Musokokushi, 1962[8]

lives. This means that such gardens are typically not meant to be entered physically but are intended to be viewed from nearby rooms or verandas [32], therefore tsubo-niwa is a garden where the view can be enjoyed from indoors. This quintessential space serves not only as a functional space, but also as a contemplative and mindful space [30], designed to calm the mind. This corresponds with conclusions drawn from a recent study highlighting the importance of contemplative spaces in nurturing mindfulness practices [34]. Recent research also underlines the therapeutic value of Zen gardens, both in medical and psychological contexts [35, 36]. [37] explores the Japanese approach towards nature through the tsubo-niwa as well as historical development and contemporary approaches for both private residences and public buildings. Fifteen characteristics of tsubo-niwa are also mentioned, these being artificiality, distilled nature, enclosing nature in a confined space, miniaturization, simplicity and austerity, tranquility, practicality, unity of interior and exterior, light and shadow, temporal vagueness, abstraction, asymmetrical balance and irregularity, cool and damp shaded areas, finely crafted details, the presence of four seasons, rustic elegance, and the concept of Ma—an interval in time and space representing empty space. This particular concept is linked to the Zen Buddhist concept of Mushin (emptiness) [38], as exemplified in the sculpture created by Noguchi in homage to the Zen Buddhist monk and Zen Garden designer Musō Kokushi (see Fig. 2).

This section aimed to provide the context for the problem with the medium-term goal of developing an immersive and therapeutic environment with restorative properties inspired by the principles of Zen gardens as the main concept. A detailed analysis of the philosophical, principles and aesthetic concepts of Zen Gardens and Zen Buddhism [39, 40], currently exceeds the scope of the current paper.

[8] https://archive.noguchi.org/Detail/artwork/7240.

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2 Related Work

This section aims to briefly reference related work using brain wave data to create immersive environments for aesthetic visualization. Furthermore, it will focus on the transformation of raw EEG data into dynamic visual patterns, without presenting an extended analysis. A few works and projects not published in academic journals are herein due to their relevance to the topic.

A millstone project that should be referenced is the Interactive Brain-wave Drawing: EEG Telemetry Environment (1975)[9], which consisted of translating EEG data "shared" between two participants into line drawings, [41]. Another important project is the project Mutual Wave Machine[10] that is an experiment with interactive neurofeedback decoding in real-time EEG correlations dyads into light patterns [42]. It is an installation that explores and incorporates the notion of "being on the same wavelength" with another individual through the synchronization of brain waves. In the experiment carried out, the most prominent waves were in low alpha (~7–10 Hz) and low beta (~20–22 Hz) oscillations. The project aimed to identify a neural correlate through face-to-face social interaction in a context outside the laboratory. Users were placed in a capsule and immersed in a Brain Computer Interface (BCI) that generated audiovisual neurofeedback in a dome. Therefore, the dome illumination and sounds were generated corresponding and reflecting the correlation between two users' brain activity. In the "images" generated, the higher correlation values correspond to more light projected onto each of the surfaces. According to the authors, four scores based on a correlation coefficient were used to create four separated circular moiré patterns. The correlation for each frequency band is based on the average of the r values in all sensor pairs and considers the highest r value among all sensor pairs, with an equal contribution from each one (50/50). It is also important to note that the movements of the circular patterns that emerge from the center of each sphere are determined by the synchronization value in each frequency band, which varies from 0 to 1. A value of 1 corresponds to the surface being filled, while a value of 0 means no visual elements are projected. However, there is no detailed description of the visualization framework/pipeline (e.g. how the data was visually encoded, namely the graphic variable types and the used algorithms [17].

VALENCE is an interactive visualization based on real-time brain wave visualization. It was used a wireless EEG headset to record the user's alpha oscillations (indicating relaxation) and valence (indicating emotion or arousal). NodeBox for OpenGL was used to generate the graphical elements. When the user wearing the headset relaxes, the graphic elements react by generating an aesthetic composition driven by Artificial Life self-organization algorithms. The authors stress that the graphic elements were controlled by "Boids" that mimic the flocking behavior of birds [43]. The attractor differs from other agents in that it has an invisible radius, which increases when the user's EEG alpha wave reading increases, indicating a relaxed state, however, the visualization framework/pipeline is not explained in detail. It's crucial to highlight that most users (> 90%) successfully relaxed and controlled the visual output within one or two attempts.

[9] https://www.ninasobell.com/ninasobell/parkbench_docs/portfolio/3/frame.html.
[10] https://neon.org.gr/en/exhibition/mutual-wave-machine/.

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However, the results for arousal (valence) consistently showed poor outcomes, indicating that users often struggle to achieve a relaxed state [44].

In the project EEG KISS[11] (2014), [45] users use their senses and share an intimate kiss as an aesthetic and a sensory experience. Users' brain activity is measured and visualized with EEG, and the data is translated into an immersive projection on the floor, enveloping them with a stream of EEG data in real time. According to the authors, combining spatial BCI data visualization and audification enhances focus, concentration, immersion, and feelings of safety.

The digital artwork Narcissus [46, 47], provides information on the variable mental states experienced during meditation and includes user studies, namely users with and without meditation experience. A dynamic visualization was designed to represent meditative states. The aim was to establish a link between the meditators' interpretation of their own experience. It also explores which properties of visualization patterns can serve as additional informational parameters. The study revealed some challenges on creating an aesthetic visualization using the EEG Neurosky MindWave headset. A dynamic visualization was created to represent the meditative state and resonate with meditators' interpretations of their inner meditation experience. The brain waves of meditation, namely low alpha (red) and high alpha (green)) have been translated into a visual aesthetic based on the visual metaphor of the Buddhist mandala. Three levels were defined, namely normal, meditation and deep meditation status. In the normal state, brain wave activity was illustrated by circles spiraling toward the center, with each brain wave type's amplitude indicated by its distance from the center. This visualization appears when the EEG sensor detects theta oscillation amplitudes exceeding the threshold. Each color represents a specific brain wave, namely blue, green, red, purple, dark purple and yellow to represent theta, low alpha, high alpha, low beta, high beta waves, and gamma.

In the state of meditation, visual forms appear in orbital patterns and gradually transform, at a slower pace, into a mandala pattern. The calm state of mind during meditation is translated through the slower rotation speed of the visual elements. It is also essential to note that the size of the pattern is influenced by the ratio between the alpha and theta amplitudes. During deep meditation, the authors introduce a sustainability parameter. If the meditative state is maintained without distractions, the sustainability value increases, eventually revealing a lotus shape that symbolizes a state of deep meditation. The project provides valuable knowledge and methodologies, including the definition of a meditation model with different phases. It also attempts to link the meditators' meditation experience with their interpretations of the visualizations. Another observation was the interpretation of color, and although the colors used were linked to Eastern conventions, some users established a Western interpretation of the colors. The user study also reveals that most participants could discern differences in the data patterns between meditators and non-meditators. Users indicated scale, color and rate of change as the most important variables for differentiating the visualized patterns, which in turn represent the defined meditation model. Another aspect worth mentioning is the differentiation between the two phases of meditation, meditation and deep meditation, which is indicated by the size of the pattern. However, there is no detailed description of

[11] https://www.lancelmaat.nl/work/e.e.g.kiss-print/.

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the visualization framework/pipeline (e.g., data abstraction and transformation process), however the Processing code can be found in [46].

The art of Feelings[12] (2017) allows users to turn their emotional memories into visual patterns. Muse EEG headset collected data from each participant to be translated in a visualization. Each color and movement were controlled by the fluctuating brain waves of the participants. Another point is that it was used the flow field generative algorithm, that will be discussed in the next section. Two features worth highlighting are the use of light projection mapping, and that the colors are based on the Geneva Emotional Wheel (GEW)[13] [48]. However, there is no detailed information regarding the visualization framework/pipeline, namely how the brain wave data was translated into a visual pattern, namely a detailed description of the used parameters.

The work Melting Memories[14] (2018), is an intersection between art and neuroscience. A 32-channel Enobio headset was used to record the EEG and collect data on the neural mechanisms of cognitive control. Beta and theta oscillations were used to identify the short- and long-term memories. For scaling, the Higuchi Fractal Dimension (HFD) algorithm was used [49], along with a Fast Fourier transform (FFT) applied to a moving average to refine the data. EEGLearn [50] supported the recurrent neural networks employed during the recording sessions to produce spectral results, which were used as height maps in the visual representation pipeline. FieldTrip, an open-source GPU library for HLSL/VVVV, was used to transform EEG data into visual aesthetics.

Another project is Sense of Healing: AI Data Sculpture[15] (2023), a multisensory immersive installation created to improve mental health through artistic expression. This work interprets brain activity datasets collected with EEG sensors, fMRI, and Diffusion tensor imaging (DTI) imaging techniques to develop an immersive artwork that promotes mental well-being.

In sum, previous projects on generating visual patterns based on EEG activity provide important clues, techniques and approaches to achieve our goals. However, most of the reviewed works lack a detailed explanation of the framework and visualization pipeline, as well as empirical validation of the neurological effects for some projects.

The next section will explore our creation of a dynamic abstract pattern based on brain wave data.

3 Data-Driven Aesthetics Based on Brain Wave Data

This section aims to explain the process behind a data-driven approach using brain wave data. The medium-term goal is to develop an immersive therapeutic environment with restorative properties based on dynamic abstract visual patterns using Zazen monks brain data and then measure the psychological effects. This project aims in a future iteration to establish connections between the neurobiological mechanisms underlying the mental states of Zazen monk's trough a synchronization between the user's mental states and the visual aesthetics (Fig. 3).

[12] https://www.randomquark.com/work/the-art-of-feeling.

[13] https://www.unige.ch/cisa/gew/.

[14] https://refikanadol.com/works/melting-memories/.

[15] https://refikanadol.com/works/sense-of-healing-ai-data-sculpture/.

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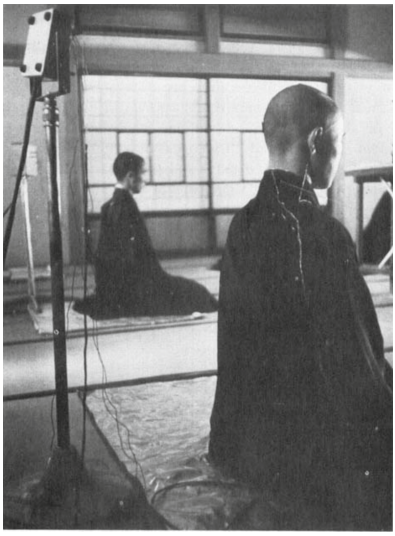


Fig. 3. Kasamastu et al., An Electroencephalographic Study on The Zen Meditation, 1966

During meditation monks sit quietly and clear their minds, and in this process, the brain constantly generates waves of electrical activity (e.g. theta, alpha, gamma) [51]. Research shows that on Zazen meditation there is an increase in alpha and theta brain waves during relaxation and meditation, involving both a decrease in frequency rate, indicating a slowdown on brain processing and thus a calming effect, and an increase in the amplitude of the referred frequencies [51, 52]. Also, long-term meditators, such Tibetan Buddhist monks, self-induce high-amplitude gamma synchrony during mental practice suggesting that attention is a flexible skill, which can be trained [53]. However, it is important to note that this paper presents the first iteration of the project. Given the context and usage scenario described, the dataset used does not reflect the main aim, specifically the use of Zazen monk´s brain waves. Since it has not yet been possible to collect data from the described source, a dataset of brain waves available in a data repository[16] was used instead.

For the first iteration, a dataset related to the research of brain activity in a resting-state experiment based on electroencephalographic (EEG) analysis is used. The data concerns sixteen electrodes recording the wave activity of twenty (20) individuals who took part in a resting state experiment in 2017. The recordings were taken using an EEG during the experiment protocol. Each row represents one electrode recording, and the columns are indexed numerically, providing data points that can be used to interpret neurological phenomena. The data in each file is stored in comma-separated value format (CSV) and includes 42 columns. These columns represent the subject ID, 16 different electrode recordings from the left or right side of each brain lobe (frontal, temporal, parietal, occipital) or junctional area (frontal-central), as well as 20 additional alpha wave readings. The occipital dominant rhythm, commonly known as occipital Alpha, is most

[16] https://zenodo.org/records/2605110.

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pronounced in the occipital and parietal regions. Therefore, to design, implement and test our first iteration, we randomly selected subject 12, and the Oz (Midline Occipital) column as shown in Fig. 4.

To find out the sample rate of the dataset, namely the time between each sample it was used the following formula:

$$\text{Time between sample} = \frac{1}{Samplingfrequency}$$

Given a sampling frequency of 512 Hz, the time between samples is:
Time between sample $= \frac{1}{512Hz} \approx 0.001953 seconds (or 1.953 milliseconds)$
Therefore, for a 512 Hz sampling rate, the time interval between consecutive samples is approximately 0.001953 s.

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Time	Fp1	Fp2	Fc5	Fz	Fc6	T7	Cz	T8	P7	P3	Pz	P4	P8	O1	Oz	O2	EyesClosed	EyesOpened
0	-1858.2	6924.8	5374.8	14941	22055	14292	13505	19882	15273	5082.2	6766	13840	16398	3939.3	5401.2	4494.5	0	0
0.0019531	-1858.5	6923.4	5372.9	14936	22052	14286	13496	19881	15272	5081.8	6762.8	13838	16394	3939.4	5401.2	4493.9	0	0
0.0039063	-1856.3	6926.5	5372.8	14936	22051	14287	13494	19882	15273	5079.9	6760.5	13837	16397	3940.9	5402.3	4498	0	0
0.0058594	-1863.2	6921.2	5367.6	14933	22048	14284	13487	19876	15260	5071.7	6753.7	13830	16390	3925.5	5391	4488.4	0	0
0.0078125	-1862.8	6922.7	5368.7	14935	22049	14284	13488	19862	15268	5074.9	6753.1	13830	16394	3930.8	5395.5	4494.3	0	0
0.0097656	-1860.8	6921.5	5371.7	14938	22049	14289	13492	19856	15271	5077.4	6755.8	13833	16401	3933.7	5401.2	4498.1	0	0
0.011719	-1861.8	6923.9	5370.1	14936	22053	14287	13489	19853	15265	5072.7	6750.1	13824	16394	3923.2	5390.1	4483	0	0
0.013672	-1854.2	6929.2	5373.8	14942	22056	14287	13492	19861	15268	5074.6	6750.6	13823	16395	3925.6	5389.7	4477.2	0	0
0.015625	-1854.7	6928.2	5377	14944	22054	14290	13493	19874	15276	5080.4	6753	13823	16395	3932.7	5397.6	4478.8	0	0
0.017578	-1856.4	6924.7	5376.2	14942	22048	14287	13490	19877	15275	5079.3	6753.6	13825	16393	3934.9	5396.2	4484.1	0	0
0.019531	-1852.7	6930.4	5374.8	14945	22052	14287	13493	19881	15269	5076.3	6752.3	13825	16392	3928	5388.3	4483.8	0	0
0.021484	-1850.6	6931.7	5377.5	14947	22055	14289	13493	19882	15269	5078.2	6754.7	13830	16400	3934.6	5397.8	4493.9	0	0
0.023438	-1849.3	6932.7	5379.4	14947	22054	14292	13494	19878	15266	5079.8	6754.9	13831	16402	3941.3	5401.8	4497.9	0	0
0.025391	-1854	6929.6	5376	14943	22050	14289	13493	19872	15267	5077.3	6751.6	13824	16387	3934	5390.7	4482.3	0	0
0.027344	-1859.1	6920.7	5375.4	14939	22047	14289	13489	19875	15260	5074.1	6747.7	13815	16383	3927.3	5387.5	4479.7	0	0
0.029297	-1853.9	6920.8	5375.1	14941	22047	14290	13490	19879	15260	5076.8	6752.9	13819	16387	3929.1	5391.4	4480.3	0	0
0.03125	-1846.6	6927.9	5378.7	14946	22054	14292	13495	19875	15269	5083.1	6757.9	13821	16390	3934.4	5396.8	4482.2	0	0
0.033203	-1840.4	6935.7	5385.9	14955	22062	14301	13505	19865	15278	5091.5	6766.2	13829	16397	3935.6	5402.8	4489.1	0	0
0.035156	-1849.8	6927.3	5388.7	14950	22055	14298	13505	19861	15277	5090.5	6766	13829	16394	3930.3	5397.3	4484.2	0	0
0.037109	-1855.5	6924.1	5387.6	14943	22050	14290	13503	19861	15265	5082.8	6763.5	13829	16390	3925.3	5388.7	4481.1	0	0
0.039063	-1846.1	6931	5390.4	14949	22056	14297	13506	19875	15268	5089.5	6768.1	13831	16398	3930.3	5390.7	4485	0	0
0.041016	-1849.2	6930.9	5385.6	14949	22057	14294	13506	19885	15269	5089	6768.5	13836	16400	3940	5395.9	4490.4	0	0
0.042969	-1849.3	6932.9	5385.5	14948	22056	14297	13508	19884	15274	5091.2	6768	13836	16407	3944.7	5399.7	4494.2	0	0
0.044922	-1845.6	6937.4	5390.1	14953	22061	14301	13510	19882	15285	5097.3	6776.4	13844	16410	3956.6	5410.6	4504.5	0	0
0.046875	-1846.9	6935.5	5387.2	14952	22063	14296	13510	19881	15279	5096.1	6773.6	13842	16398	3955	5407.8	4500	0	0
0.048828	-1850.2	6933.5	5386.4	14950	22065	14297	13509	19877	15270	5090.3	6771.8	13836	16393	3938.8	5396.7	4491.8	0	0
0.050781	-1848.9	6934.9	5386.9	14952	22066	14300	13512	19871	15275	5092.2	6771.5	13836	16397	3938.3	5400.4	4490	0	0
0.052734	-1851.2	6932.6	5386.3	14951	22065	14299	13511	19874	15270	5088.7	6771.7	13836	16399	3933.2	5396.6	4491.4	0	0
0.054688	-1845.2	6935.9	5391.6	14956	22071	14300	13519	19889	15275	5095.9	6779	13843	16411	3939	5406.2	4500.3	0	0
0.056641	-1850.4	6934.5	5387.2	14950	22067	14297	13512	19888	15279	5094.6	6777.1	13840	16402	3939.3	5397.8	4486.7	0	0
0.058594	-1847.6	6934.2	5387	14953	22069	14297	13514	19895	15275	5093.5	6777.2	13845	16410	3943.6	5403.9	4494.5	0	0
0.060547	-1844.9	6936	5386	14949	22072	14293	13511	19899	15269	5088.5	6774.3	13848	16408	3944.6	5405	4498.7	0	0
0.0625	-1842.4	6940.8	5386.3	14954	22071	14295	13511	19889	15274	5092	6775	13849	16403	3947.1	5406.7	4497.9	0	0
0.064453	-1839.3	6945.1	5388.4	14956	22073	14300	13514	19879	15273	5091.1	6772	13846	16404	3949.6	5405.9	4496.8	0	0
0.066406	-1840	6942.8	5391.6	14957	22073	14298	13513	19881	15279	5093.1	6775.6	13848	16410	3948.7	5410.1	4501.1	0	0
0.068359	-1843	6934	5389.1	14953	22065	14299	13506	19881	15275	5089.4	6770	13837	16395	3942.3	5405.8	4491.6	0	0

Fig. 4. Subject 12 EEG Data sample, 2017

A Fast Fourier Transform (FFT) [54] implemented on java[17] was used in the Processing programming language to calculate the average of frequency and amplitude. Amplitude is the height of a wave, namely the maximum and minimum of the wave, and frequency is the amount of time it takes for the wave to repeat itself, namely how long

[17] https://introcs.cs.princeton.edu/java/97data/InplaceFFT.java.html.

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is one cycle that repeats. In signal processing, an FFT is used to analyze the frequency content of signals, and essentially, is an algorithm that computes the Discrete Fourier Transform (DFT)[18] of a time series (discrete data samples), and its inverse. The DFT is utilized in signal processing and various other fields to analyze the frequencies in a sampled signal, perform spectral analysis, and transform signals between time and frequency domains. It is a reversible mapping operation for time series. Therefore, the data was buffered and the FFT was applied to the OZ data (OZ column). It is important to underline that in this approach it was not calculated its inverse. The next step involved calculating the average amplitude and frequency over a range of frequencies of interest (spectrum window). In this case, the frequencies analyzed range from 2 Hz to 40 Hz (Delta, Theta, Alpha, Beta), the logic is to analyze the frequency every x time, based on a small sampling window, where 256 is the number of EEG samples that are read from the file into memory at each time, and 16 is the number of samples it is advancing with each iteration, as shown in the following line of code:

```
double[] data = eeg.meanfrequencyamp(eeg.readEEG(256,
"Oz", 16), 512, 2, 40);
```

The data from the OZ electrode column was used as input for the Flow Field algorithm. The following section describes the implementation process in the Processing programming language and the algorithms used to generate an abstract and dynamic visual pattern based on curves with fading trails.

3.1 Generative and Dynamic Data-Driven Flow Field

The previous section described the data abstraction and transformation process of brain wave data. This section describes the implementation of a generative, dynamic and recursive visualization, namely a data-driven Flow Field[19] (see Fig. 6). Since the data is stored in rows and columns, it was used the`Table class` (java) to parse the EEG data.CSV file.

The brain wave amplitude (average) influences velocity, as shown in the following line of code (see Fig. 7):

```
v.maxspeed = (float)data[1]/100;
```

Fig. 7.Mean Frequency and Amplitude

An important algorithm for implementing a Flow Field is Perlin Noise, designed to generate procedural textures for computer-generated effects (Perlin, 1985). [55] provide a review of the state of the art on procedural noise functions, emphasizing that noise is a widely used technique for various purposes in procedural texturing and highlighting its potential advantages. Procedural signifies an algorithmic approach where entities are defined by program code rather than by data structures (e.g. digital photography) [55]. It generates patterns composed of characteristics, namely regions of similar value of

[18] https://paulbourke.net/miscellaneous/dft/.

[19] https://github.com/nature-of-code/noc-examples-processing/tree/master/chp06_agents/NOC_6_04_Flowfield.

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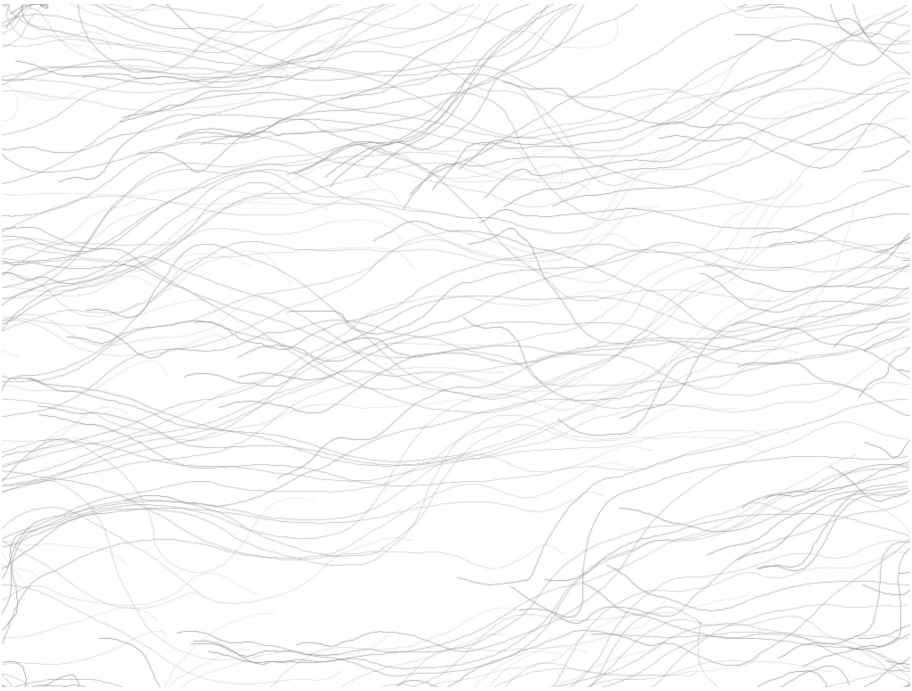


Fig. 5. Generative & Dynamic Data-driven Flow Field using Amplitude Average

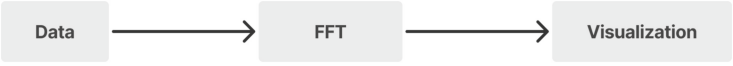


Fig. 6. Simplified Visualization Framework/Pipeline

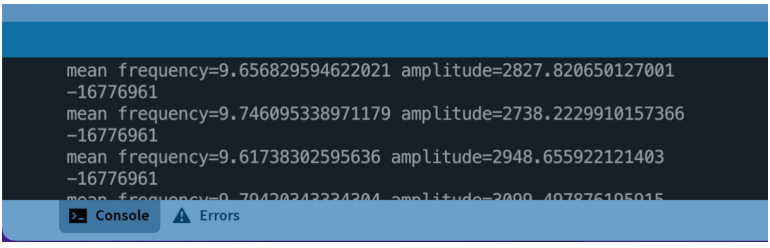


Fig. 7. Mean Frequency and Amplitude

controllable size, thus serving for creating a wide variety of patterns and textures (e.g. water, clouds, wood among others) [56, 57]. More recently, it has been used to generate realistic cardiac fibrosis, as can be seen in the work of [56]. According to [55] random patterns are defined in the frequency, where a signal is defined by denoting the amplitude and phase for each frequency. In contrast, in the spatial domain, a signal is defined by

Author Proof

specifying the value at every location in space. For unstructured patterns, the phase is random and does not provide useful information. According to the author there are three noise functions categories, lattice gradient noises, explicit noises and sparse convolution noises. Perlin noise is a lattice gradient noise, and it as an organic appearance due to the generation of a naturally ordered sequence of pseudo-random/smooth numbers [55, 58]. In two-dimensional noise, the value is the same for all neighbors, unlike one-dimensional noise where neighboring values are similar along one dimension. Therefore, the noise field is generated by placing randomly oriented vectors on the vertices of a spaced grid, and instead of having a grayscale value for each pixel as in Perlin Noise, it uses a vector pointing in a direction. The value of the noise at any given point is determined by how much the surrounding vectors point towards or away from that point [56].

Flow fields are used to create complex, dynamic visual patterns by guiding Vehicles, also known as "Boids", along a field of vectors, by using Perlin Noise to generate smooth, natural-looking motion, resulting in visually appealing and intricate pattern that evolve over time, in this case according to the input data. To implement a Flow Field, a built-in two-dimensional `noise()`[20] function is used. One key point is to decide the scale of the cells, and it is fundamental to set a scale based on the number of rows and columns. Therefore, it is used the `class FlowField` to store the number of columns and rows, namely a two-dimensional array.

The next step consisted in the use of Vehicles (vectors), which were then converted into "lines". A vector is usually represented as an arrow, with its direction indicated by the arrow's point and its magnitude by the arrow's length [58]. To store these two values, namely location and velocity a `Pvector`[21] class is used. In Processing, the `PVector` class is a part of the core library and provides a way to represent and manipulate 2D (x,y) or 3D vectors (x,y,z). The concept of Vehicles typically refers to objects that move and interact within a simulation, often based on steering behaviors [43]. These Vehicles are implemented using vectors to control their position, velocity, and acceleration. Therefore, a two-dimension array, namely `PVector` is essential to store the x and y location of the Flow Field and Vehicles. Vehicles are then placed in the field and their movement is influenced by the `noise()` function. However, it is fundamental to establish a Vehicle capable of calculating a steering force based on the desired direction obtained from the Flow Field. The function `PVector desired= flow.lookup(position)` receive a location on the screen and return the corresponding vector.

Another point is that vectors were replaced by "lines", where `the curve()`[22] function is used to draw a "line" (visual variable: shape) and served as the visual output (see Fig. 5). The vehicle's position is computed at each iteration, and the last n positions are stored. The fading curves are controlled using the alpha property by using the `stroke()`[23] function.

The use of white and gray colors aligns with Zen aesthetics, particularly with the concepts of negative space and emptiness/whiteness. However, an analysis of this topic falls outside the scope of this article.

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[20] https://processing.org/reference/noise_.html.
[21] https://processing.org/reference/pvector.html.
[22] https://processing.org/reference/curve_.html.
[23] https://processing.org/reference/stroke_.html.

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4 Discussion and Future Work

Considering the contemporary constraints to relaxation, and the pressing need to address the mental health problematic there is a crucial demand for innovative and creative interventions [15, 30, 59]. The presented work explores the design of a data-driven visualization approach based on abstract visuals. The aim is to create a future immersive environment for mindfulness and contemplation. This paper represents a proof of principle, and the current results are still at a preliminary stage, but they prepare the ground for the main objective, that is to validate the positive effects of abstract visuals on mental wellbeing. In future work, we intend to use other types of noise, such as simplex noise, which is a Perlin-type noise based on a simplex grid, among other approaches such as Artificial Intelligence, and conduct user studies based on performance metrics and satisfaction metrics. Another future goal is to establish a synchronization between the neurobiological mechanisms underlying the mental states of the Zazen monks and the mental states of the subjects through a generative visual aesthetic based on data.

Sonification, as highlighted on Extended Digital Musical Instruments for therapeutic purposes, plays an important role [8, 60]. One of the purposes of this interdisciplinary project is, therefore, to create a relationship between sonification and the visual part that is connected to the subject's gestures through virtual affordances [60]. In this case, certain virtual affordances will represent audiovisual stimuli - as if they were objects, in accordance with Gibson's theory of visual perception [61] - that can be used to modify the audiovisual feedback.

To the best of our knowledge and based on the literature review, light projection environments with restorative properties are a topic that requires further development. This includes both aesthetic creation and the evaluation of physiological and neurobiological processes.

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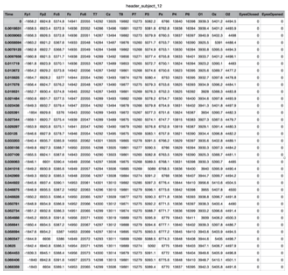
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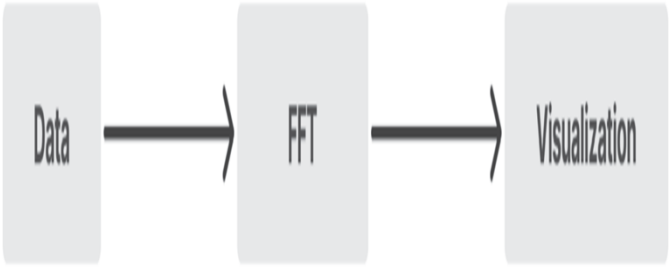
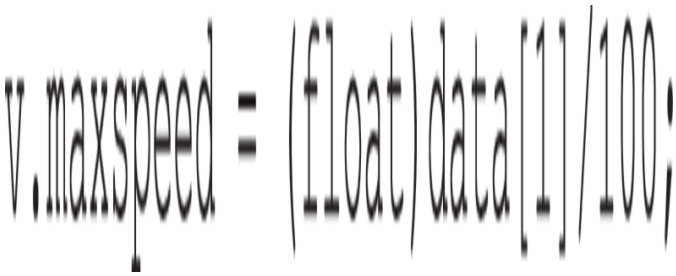
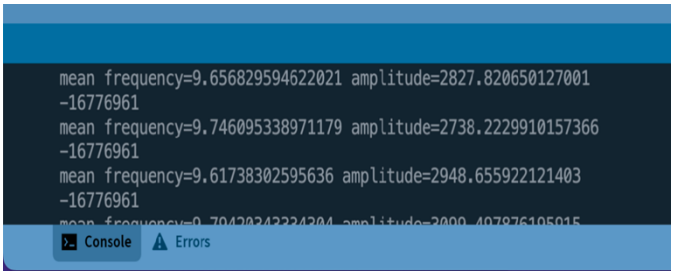
Chapter 7

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Page no	Fig/Photo	Thumbnail	Alt-text Description
4	Fig1		A traditional Japanese rock garden inside a wooden room. The garden features carefully arranged stones and raked gravel, creating a serene and minimalist design. Wooden benches line the walls, and a sign with text is visible on the right side. The scene conveys a sense of tranquility and simplicity.
5	Fig2		A minimalist room with a concrete floor and plain walls, featuring five irregularly shaped gray rocks placed on the floor. The rocks vary in size and are scattered across the space, creating a simple and serene atmosphere. The room is well-lit, with a soft light coming from an unseen source, highlighting the textures of the rocks and the floor.
9	Fig3		A black and white photograph showing two individuals seated in a meditative posture in a traditional room. The person in the foreground has a shaved head and is facing away from the camera, with wires attached to their head, possibly for monitoring purposes. The second person is visible in the background, sitting cross-legged and facing forward. The room features sliding doors and a tatami mat floor. A stand with equipment is positioned to the left, suggesting a scientific or observational setting.

Page no	Fig/Photo	Thumbnail	Alt-text Description
10	Fig4		A table titled "header_subject_12" displaying numerical data across multiple columns. The columns are labeled: Time, Fp1, Fp2, Fc5, Fc6, Fz, Cz, T7, C3, T8, P7, P3, Pz, P4, P8, O1, Oz, O2, EyesClosed, and EyesOpened. The table includes time-stamped data points with values for each column, indicating measurements or readings. The "EyesClosed" and "EyesOpened" columns contain binary values, likely representing states of eye activity. The table is structured to show changes over time, with precise numerical values for each parameter.
11	Figa	`double[] data = eeg.meanfrequencyamp(eeg.readEEG(256, "Oz", 16), 512, 2, 40);`	Code snippet showing a function call in a programming language. The line reads: `double[] data = eeg.meanfrequencyamp(eeg.readEEG(256), "02", 16, 512, 2, 40);`. This line appears to be related to processing EEG data, involving a method `meanfrequencyamp` that takes parameters including EEG data, a string "02", and several numerical values.
12	Fig5		A sketch featuring numerous overlapping, curved lines of varying thicknesses and styles, creating an abstract pattern. The lines are predominantly black on a white background, forming a complex, wave-like texture. The image conveys a sense of movement and fluidity.

Page no	Fig/Photo	Thumbnail	Alt-text Description
12	Fig6		Flow chart illustrating a process with three steps. The first step is labeled "Data," followed by an arrow pointing to the second step labeled "FFT" (Fast Fourier Transform). Another arrow points to the final step labeled "Visualization." The chart represents the transformation of data through FFT to achieve visualization.
11	Figb		The image contains a mathematical expression in code format: `v.maxspeed = (float)data[1]/100.0;`. The expression assigns a value to `v.maxspeed` by converting `data[1]` to a float and dividing it by 100.0.
12	Fig7		A screenshot of a console window displaying a list of data entries. Each entry includes a "mean frequency" value followed by an "amplitude" value. The numbers are precise, with multiple decimal places. The console interface includes a "Console" tab and an "Errors" tab at the bottom. The background is dark, with light text.