MINDFUL MANIFESTATION

A method for designing architectural forms using brain activities

DUONG NGUYEN¹, TANE JACOB MOLETA² and
MARC AUREL SCHNABEL³

^{1,2,3}*Victoria University of Wellington*

¹*nguyenduon1@myvuw.ac.nz* ^{2,3}*{Tane.Moleta|
MarcAurel.Schnabel}@vuw.ac.nz*

Abstract. This paper describes the method of establishing a tool, interconnecting a selection of hardware and computational software to design architecture, through the manipulation of forms using brain activities inside a Virtual Reality (VR) environment. This is achieved through the use of electroencephalography (EEG), detecting brain activities and live streaming numerical data inside VR environment. Architectural forms are manipulated and interacted live by this data stream. The paper discusses the methods, findings, technical limitations as well as potential modifications which would otherwise improve the system's performance for the intended purposes.

Keywords. Electroencephalography (EEG); Artificial Neural Network (ANN); Virtual Reality (VR); Interactive Design; Parametric Design.

1. Research Aim, Question & Scope

Designing architecture using one's mental propensities has been an audaciously intriguing idea. In almost certainty, a subject worthy of attracting great amount of interest within both architectural research and practice. This research project initially asks the question of using one's imagination to instantiate digital resemblances similar to what the person can see within their mind, however, the realisation of its enormous difficulty of such undertaking led to a narrower of using "brain activities" instead. The research question, therefore, asks, "Can we use one's brain activities to design architecture?", as a pretext to the other more ambitious question in mind.

Figure 1. Foundational System Diagram (Author's Own).

The diagram from above illustrates the aim of the research project; the aim, being an integrated foundational system acting as a design tool, using their one's brain activities. The *integrated* factor can be found through the cooperation of distinct computational hardware and software, while the *foundational* aspect means the system shall aim to reach minimum operational status – without further considerations such as its durability or accessibility. This system includes the use of a 14-Channel EPOC+ electroencephalography (EEG) headset, collecting electrical brain activities where this data is recorded numerically and live-streamed from the CortexUI cloud database into Grasshopper for geometric design interaction. The manipulated forms are passed into UnityVR as a platform to render the experience inside a Virtual Reality (VR) environment, using the HTC Vive headset. EEG act as the computational input, as for VR is the user's visual feedback. The computational system used was a Chronos Origin PC with Windows 10 Pro operating system, Intel i7-7820X CPU, Nvidia GeForce GTX1080Ti GPU and 2x16GB DDR4 RAM specifications.

2. Literature Review

The key literature reviews within this project include a theoretical study of ANN & EEG in the architectural context.

EEG is often found within biomedical, psychological and neuroscientific applications. As far as this research is aware, the conglomeration of EEG & architectural research had only been prevalent within the recent decade with the

earliest cited source in 2006 (Huang, 2006). The few found recent studies (Mavros et al., 2012; Fraga et al., 2013; Kalogianni & Coyne, 2014; Shemesh et al., 2015; Mavros et al., 2016; Banaei et al., 2017; Coburn et al., 2017) are primarily concerned with EEG in its native biomedical & psychological context, an analytical tool aimed at analysing the human mental state. As a design tool, there had been one present example (Cutellic & Lotte, 2013), where EEG detected P300 signals, are used to recall supposed design interests. Design precedents from both art and architectural discipline, including Cerebral Hut, Furl and Neuroflower (Ozel, 2013; Mangion & Zhang, 2014; Brick, 2015) are found to be highly limited in terms of EEG interactional input, and the design content afflicted by EEG detected inputs are often solely binary; EEG input acting as a toggling switch, while the design has only but two states that correspond to these input devices. Brain2Image (Kavasidis et al., 2017), a key precedent from the neuroscientific field was used with the intention of. Brain2Image utilises two different ANNs, one for EEG data classification, while the other recreates the photograph based on those EEG data classifications from a person viewing that photograph.

ANN, a sub-branch of Machine Learning (ML), is often used for classification purposes within unstructured data (Neef, 2014). ML's great potential for the architectural discipline is acknowledged, yet its prevailing disposition in the architectural field is reflected by Carpo as "[...] "toying" is all that is currently happening" (2017). ML is remarked as "too complex for architects to embed within their workflow" (Meekings, 2017). Whilst acknowledging both the difficulty, and ANN's lack of development in the architectural field, the recent developments of ready-made ANN in Grasshopper components, such as Dodo, Crow and Owl (Greco, 2015; Felbrich, 2016; Zwierzycki, 2018), advocate greater accessibility in its application to the discipline (Khean, 2017). One recent study (Khean, 2017), has proceeded as far as constructing ANN using pre-existing Grasshopper components. Both these examples, demonstrate resolve, in the otherwise, great technical challenge posed in making ANN through traditional means.

3. Research Methodology

The research methodology can be broken down into seven steps. These steps are explained with brief explanations and significance detailed within each section.

1. Preliminary Design Geometries were first designed without the consideration of EEG data and what it has to offer. The various preliminary design iterations were developed inside Grasshopper, to which can be summarised into four differing types. Of the four, three are implemented into the system at later stages. The first stage was executed with the intention to bring architectural content without the consideration of EEG data, in the hope of achieving an exciting design outcome through such a combination.

2. The following stage, the EEG interaction exploration investigated various EEG data extraction methods. EEG data were extracted through static, then live methods. Static methods are imported raw EEG data from a .csv spreadsheet export, gathered through Emotiv, the current EEG's developer's EmotivPRO

software, recording at 128Hz. The research had found the static was found to be slow and not fitting within the desired aim of the research, which was an interactive live design tool feedback. The live method, live streamed raw EEG data from the CortexUI database into Grasshopper via a User Datagram Protocol (UDP) connection. This particular method resulted in data loss, where an average of 5Hz was transferred instead of 128Hz. The live method, however, is more suitable in achieving what this research has intended.

3. EEG & Preliminary Design Incorporation involves the merging of Stage 1 & 2 together. The sizeable constant update of information means that certain preliminary designs were discarded due to their high complexity causing the workflow to lag. It was discovered that movement would create large spikes in terms of detected information through the EEG, the raw EEG data after being received in Grasshopper were, therefore, filtered and processed to interact with the geometries as how one would desire it to be. The level of interaction could be seen simplified to types of geometries, scale, position, colour and orientation.

4. Preliminary Design & VR Incorporation stage attempted in transferring geometries from stage 1 into the VR environment. The first method is the UDP method. The method uses a UDP connection to transfer information of geometries from Grasshopper to Unity. Its drawbacks are the requirement for the geometries to be available in both Grasshopper and Unity. The position, colour, scale & orientation of these geometries are processed, sent and parsed inside UnityVR. The other method, which would otherwise allow for transference of geometries of greater complexity would be the MeshStreaming method (Horikawa, 2017) via a WebSocket connection. The UDP method is, nonetheless, implemented as it requires lesser computational processing, and thus appropriated a live connection without latencies.

Figure 2. User Datagram Protocol (UDP) from Grasshopper to Unity Data Transference Methods (Author's Own).

Figure 3. MeshStreaming Method, meshes transference from Grasshopper to Unity (Author's Own).

5. Fully Connected Design System is established through the amalgamation of both stage 3 and 4. The system is tested and found to have achieved the research aim, which was the establishment of an integrated foundational system as previously mentioned. What was found is the tendency for the system to break down. The cause, as an example, would be the CortexUI EEG stream cloud database disconnecting its data stream. As a result of interlinking so many software & hardware to work with one another, as well as the high influx of information, which would rapidly change and update information. The order of operation, a sequence of hardware and software initialisation is necessary in order to function without immediate system failure; the sequence is as follows: UnityVR, followed by Grasshopper, VR headset activation in Unity, EEG headset and finally, the CortexUI data stream. The amount of geometric had to be reduced even further to maintain the system's stability. The system's durability span from approximately 30 seconds to 300 seconds.

6. From this stage forth, any further additions are extraneous to the research aim. The system was further enhanced with two additions, the ability to toggle three developed design interactions and the ability to bake geometries from Grasshopper into Rhino.

1. The first design interaction, the Rapid Self Organising Maps (SOM) Experiment, implemented the use of an SOM ANN architecture, via the Crow plugin (Felbrich, 2016). A three-dimensional grid with boxes at their vertices, where the grid that iterates towards a set seed of coordinates. Raw EEG data were used to directly randomise the seed numbers, altering the seed co-ordinates to which the array iterate towards to continually alter the coordinates to which the SOM iterates, forming a 3D regression grid to fit through these coordinates.
2. The second design interaction is a result the Glitch Box Experiment was a result

through the construction of a convolutional neural network (CNN), where an edge detection algorithm was applied with the intention of highlighting an imported image edges in Grasshopper. The algorithm is under development and would require further editing. Nonetheless, given how sluggish the algorithm took to compute, the incorporation of such ANN may not be realistic within a live workflow, along with its use in Grasshopper. This example reflects the original intention of an ANN used to indicate features within an image, and the values shall be manipulated to formulate space from the image. Instead, EEG data are now only used to translate the boxes in the Z-direction.

3. The third design interaction, Scale Box Experiment, are similar to the second. However, the boxes scaled, instead translating, by the EEG data. The emotional affect data are also added to change the colour of the boxes. This iteration therefore contains two types of interaction, through the fluctuation of EEG data and affect data provided by Emotiv to alter the geometries.

The baking functionality, which enables interacted geometries to be baked into Rhino. This allows the user to conscious capture sections within the design interaction of the user's choosing. The user, therefore, has agency in keeping certain geometric forms and use these for further design developments. These could metaphorically be seen as a screenshot of the brain activities at that given moment.

Figure 4. System Enhancements (Author's Own).

Figure 5. Grasshopper Script Anatomy (Author's Own).

Figure 6. VR Design Experience, interaction with design scenario 1, the SOM ANN architecture (Author's Own).

4. Research Findings

The research discovered a correlation between the person's restfulness and the magnitude of the EEG data when using the Glitch Box Experiment design scenario. This is to say, when the system's user is in a restful state, the boxes translated a great deal less in the Z-axis. The user's brain electrical activities must emit lesser brain electrical activities in comparison with when the mind it is thinking more perturbing thoughts. This would otherwise affect how EEG state of mind in correspondence to the geometrical manipulations to which occur within the environment. "restful mental state & restless thoughts". Such a connection supports the authenticity of the system in its aim of creating a system to interact

with architectural forms using brain activities, rather than a system facilitating changes through EEG as merely random number generator within this system – a concern to which originally shared by many who came to know of the system.

Figure 7. Design Outcome Example from using the System (Author's Own).

In addition, further findings is related to the issues of physical movements tampering EEG data, this is recognised through both EEG literature and the practical use of the established system. However, it is reasonable to suggest, that enabling one's capabilities in moving through a virtually constructed environment inside VR, without real physical movements would ultimately mitigate this issue. The effect of moving through virtual spaces can, therefore, be investigated without the need for motion filters.

5. Discussion

Extensive modifications would influence various possible design outcome. Such improvements can be focused in the system's design interaction, where despite its ability to bake and toggle between design scenarios, each of the scenarios themselves appears to be very mono-directional, similar to the design precedents (Ozel, 2013; Mangion & Zhang, 2014; Brick, 2015). The improvement of this aspect can be understood between two aspects: EEG data processing and how architectural form's response to these data.

In terms of EEG data processing, the CortexUI EEG cloud database offers five different types of data stream, raw EEG data, emotion data, motion data, mental commands & facial commands. The research identifies only raw EEG data, emotion data and mental commands are appropriate for the research with its alignment in interacting with architecture using *brain activities*, not movement. Should the system incorporate the Mental Commands, the user can record a segment of their brain activities to the system to recognise whenever the user intentionally enter the same mental state to give the same patterns of electrical

brain activities. A numerical from zero to one is given to see how strong these signals can be used to trigger a design interaction.

Other EEG data processing would require the manual constructions of filters, feature extraction & analytical methods. Frequency bands (Mahler, 2018), a commonly discussed features, found within the Emotiv's static data extraction method. Other EEG features, such are the EEG P300 signals utilised by a study (Cutellic & Lotte, 2013). An ANN would be needed to extract these features, which would prove computationally heavy given the process needs to be live. Upgrading the computational system may also improve the geometric variational capabilities as more geometries could be transferred from Grasshopper to Unity, as well as fast transferring of meshes via the previously mentioned MeshStreaming (Horikawa, 2017) method.

6. Conclusion

To conclude, what the research has achieved is a process where brain activities can be used as inputs to manipulate pre-existing architectural forms. The research project, consequently, has been successful in accomplishing its aim. The system has great potential for further future developments. With increasing efficient workflows, computational powers and a better understanding of the mental imagery, a design tool with capabilities from the Mental Imagery (Farah, 2000) is perhaps not one day far from reach.

References

- Algeciras-Rodriguez, J.: 2016, Trained Architectonics: Parametricism Vs. Materialism: Evolution of Digital Technologies for Development, *8th ASCAAD Conference Proceedings*, London, UK, 461-468.
- Andreani, S. and Sayegh, A.: 2017, Augmented Urban Experiences: Technologically Enhanced Design Research Methods for Revealing Hidden Qualities of the Built Environment, *Proceedings of ACADIA 2017*, Cambridge, Massachusetts, 82-91.
- Brick, J.: 2015, "Mind-Controlled Flowers Respond to Strength of Your Mental Muscles" . Available from <<https://www.psfk.com/2015/05/mind-controlled-flowers-neuroflowers-sustainable-magic-eeeg-headset.html>> (accessed 2nd February 2019).
- Carmo, M.: 2017, *The Second Digital Turn: Design Beyond Intelligence*, MIT Press, Cambridge, Massachusetts.
- Coburn, A., Vartanian, O. and Chatterjee, A.: 2017, Buildings, Beauty, and the Brain: A Neuroscience of Architectural Experience, *Journal of Cognitive Neuroscience*, **29**(9), 1521-1531.
- Cutellic, P. and Lotte, F.: 2013, Augmented Iterations: Integrating neural activity in evolutionary computation for design, *Proceedings of the 31st International Conference on eCAADe 2013*, Delft, The Netherlands, 393-402.
- Farah, F.: 2000, *Cognitive Neuroscience Vision*, John Wiley & Sons, Malden, Mass., USA.
- Felbrich, B.: 2016, "Crow - Artificial Neural Networks" . Available from <<https://www.food4rhino.com/app/crow-artificial-neural-networks>> (accessed 24th October 2018).
- Fraga, T., Pichiliani, M.C. and Louro, D.: 2013, Experimental Art with Brain Controlled Interface, *Proceedings of the 7th International Conference on Universal Access in Human-Computer Interaction, UAHCI 2013, Held as Part of HCI International 2013*, Las Vegas, NV, USA, 642-651.
- Greco, L.: 2015, "Dodo" . Available from <<https://www.food4rhino.com/app/dodo>> (accessed 23rd June 2018).

- Huang, Y.C.: 2014, A Space Make You Lively: A Brain-Computer Interface Approach to Smart Space, *Proceedings of the 11th International Conference on Computer Aided Architectural Design Research in Asia*, Kunamoto, Japan, 303-312.
- Kalogianni, D. and Coyne, R.: 2014, Thinking about sound and space: Recording people's emotional responses to spaces, *Proceedings of the 32nd eCAADe Conference*, Department of Architecture and Built Environment, Faculty of Engineering and Environment, Newcastle upon Tyne, England, UK, 185-194.
- Karandinou, A. and Turner, L.: 2018, Architecture and neuroscience: what can the EEG recording of brain activity reveal about a walk through everyday spaces?, *International Journal of Parallel, Emergent and Distributed Systems*, **32**, 54-65.
- Kavasidis, I., Palazzo, S., Spampinato, C., Giordano, D. and Shah, M.: 2017, Brain2Image: Converting Brain Signals into Images, *In Proceedings of MM '17*, Mountain View, CA, USA,, 1809-1817.
- Khean, N., Lucas, K., Martinez, J., Doherty, B., Fabbri, A., Gardner, N. and Haeusler, H.H.: 2018, The Introspection of Deep Neural Networks: Towards Illuminating the Black Box, *Conference: Learning, Adapting and Prototyping - 23rd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA)*, **2**, 237-246.
- Mahler, P.: 2018, "The Complete Pocket Guide to EEG" . Available from <<https://imotions.com/eeg-guide-ebook/>>.
- Mangion, F. and Zhang, B.: 2014, "Furl: Soft Pneumatic Pavilion" . Available from <<http://www.interactivearchitecture.org/lab-projects/furl-soft-pneumatic-pavilion>> (accessed 1st September 2018).
- Mavros, P., Austwick, M.Z. and Smith, A.H.: 2016, Geo-EEG: Towards the Use of EEG in the Study of Urban Behaviour, *Applied Spatial Analysis and Policy*, **9**(2), 191-212.
- Mavros, P., Coyne, R., Roe, J. and Aspinall, P.: 2011, Engaging the Brain: Implications of Mobile EEG for Spatial Representation, *User Participation in Design*, 647-656.
- Meekings, S.: 2017, *Dataecture: Creating a real home for a virtual identity*, Master's Thesis, Victoria University of Wellington.
- Neef, D.: 2014, *Digital Exhaust: What Everyone Should Know About Big Data, Digitization and Digitally Driven Innovation*, Pearson FT Press, Upper Saddle River, New Jersey.
- Shemesh, A., Bar, M. and Grobman, Y.J.: 2015, Space and Human Perception: Exploring Our Reaction to Different Geometries of Spaces, *Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia*, Daegu, 541-550.
- Zwierzycki, M.: 2018, "Owl" . Available from <<https://www.food4rhino.com/app/owl>> (accessed 17th June 2018).