AI-Driven Spatial Adaptations Through Emotions

The Case Of Emo-land As A Human-Centric Approach

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The research on controlling and interacting with the environment has been accelerated by developments of artificial intelligence (AI) and the internet of things (IoT). While the quest for intelligence has been widely studied, spatial adaptation and human emotion relation remain ambiguous. This initial research attempts to investigate human-centric spatial adaptations through emotions in architecture. A case study called Emo-Land is designed to unfold the real-time relationship between space and emotion recognition. Emo-Land is an interactive spatial augmented reality installation that responds to the real-time emotions of the viewer via face expressions. A deep learning model developed to detect continuous emotions through cameras. By paying attention to the live interactive level of the detail and quality of the interaction between users and the projection mapping, the research demonstrates how advances in technology and computing can contribute to deeper connection and new layers of interactivity. Emo-Land projection mapping has been examined as a case study. According to the results, a relationship is developed between emotion recognition, form, computation, and human-computer interaction. The project contributes to the well-being of occupants, affective computing theory, and AI's role, such as the interaction between technology using affordable technologies.

Keywords: *Artificial Intelligence, Emotion Recognition, Affective Computing, Spatial Adaptation, Human-Centric Environments, Interactive Design.*

INTRODUCTION

The use of digital technologies, Artificial Intelligence (AI) and the Internet of Things (IoT), has enabled greater control over the environment and customization of living spaces. According to Carpo (2017) the digital turn in architecture has brought significant changes in the design process, enabling architects to create more responsive and adaptable buildings. However, while the state-of-the-art technologies of AI and IoT in relation to designing interactive environments have been extensively investigated through the five senses, the relationship between human emotion and AI remains ambiguous.

Most people's behavior and decision-making are affected by emotional fluctuations, such as stress at work, academic exams, and challenging relationships. While emotions such as fear, anxiety, and depression are happening to everyone, it is never advisable to remain in the same emotional state for a long time without realizing it. Generally, people rely on themselves to regulate their emotions through different approaches; however, in extreme cases, most people find it challenging to maintain a rational and calm mindset due to their overwhelming emotional state (Mengqi et al., 2020). Since Humans spend most of their lives inside buildings, and the built environment has a significant impact on their emotions and wellbeing (Cooper et al., 2011; Evans et al.2003; Fischer, 2011; Eshaghi et al. 2021), researchers in the domain of architecture are trying to explore different ways to support the process of emotion regulation. It has been observed that emotions affect cognition and have a direct impact on attention, motivation, perception, and decision-making (Brosch et al. 2013; Varinlioğlu et al. 2022, Vaez Afshar et al. 2021). Some studies explore the use of neuroscience in architecture, often referred to as "neuroarchitecture" (Eberhard, 2009). This approach involves understanding how the brain processes and responds to architectural spaces and using that knowledge to create emotionally supportive environments. For instance, research has shown that spaces with curvilinear forms are perceived as more pleasant and can evoke positive emotions compared to spaces with sharp, angular forms (Vartanian et al., 2013, Rohani, 2023).

Throughout these researches Affective Computing (AC) field is coming to the forefront regarding the technological developments in AI and its methodological approach to represent/model the human emotions. How the matter of emotion can be modeled in relation to architecture and what kind of ingredients exist and emerge through the computation of these models have been the prior questions in this study regarding the spatial adaptation in interactive design (Kuliga et al., 2015). Spatial adaptation as a means of mental re-construction of the space also can point out a responsive physical change in the environment (Gallagher et al., 2014). Space as the primary element of this adaptation involves tangible and intangible matters regarding its design elements. While tangible matters can be form, shape, color, material, the intangible ones can be sound, movement, smell, etc. Among these matters the form comes to foreground with its multiple definitions based on a set of simple or complex constraint relations. These relations can be constructed on an idea, force of fields (Thompson, 1942), appearance of things, object configuration (Alexander, 1964), or active determining principle of a thing from multiple points of views (Arnheim, 1977). Form complexity is one of the factors that can elicit different emotional responses from occupants, such as curiosity, interest, pleasure, boredom, confusion, frustration, or stress (Bower et al., 2019). However, how these matters engage with spatial adaptations in relation to interactive design still remains ambiguous.

Departing from these, this study attempts to elaborate potentials of form and complexity matters based on the emotional state of the observer through a real-time responsive computational system. Facial expressions as the most common form of body language have been chosen as the main parameter to detect emotions through camera. To this end, a Facial Emotion Recognition (FER) Convolutional Neural Network (CNN) model is trained via deep-learning methods. An interactive visual art interface called Emo-Land is generated with the trained AI-model through projection mapping. A pattern of wave function based on Joy Division's pattern is used as a visualization material regarding its efficiency with computer power and cost. The pattern's complexity transforms based on the emotional state of the user.

The generated interactive visual projection mapping can be used as a means of emotional and behavioral awareness and it can also be used for designing cyber-physical spaces. With the rise of AI, this topic is gaining significance for understanding the form transformation's effect on human emotions and behaviors.

THEORETICAL BACKGROUND

In ancient times, emotions were considered as a barrier to rational and intellect by many western thinkers, and it has been mentioned that there is a large gap between emotional and rational viewpoints. Computers are normally regarded as rational and logical; they are also considered good at specific cognitive tasks that humans can not. Consequently, any concept related to emotion would need to be dismissed or not taken seriously by the scientific community (Reeves et al.1997).

However, in the past decades, it has been proved that emotional systems affect human cognition. Investigations pointed out that a person's emotions, bright or dark can directly impact their cognition and daily behaviors such as attention, motivation, perception, and decision making (Reeves et al.1997). Antonio Damasio (2000) believes emotions result from chemical and neuronal interactions in the brain which generates behavior and psychological patterns. According to his works, he developed simulations that emulated human behavior used by robotic devices to simulate emotions, feelings, and consciousness.

Rosalind Picard (2000) coined "Affective Computing" to describe how computational systems can recognize and react to human emotions using a computational interface. One of the projects that demonstrates the potential of AC in architecture and design is Mesolite (Farahi, 2018): An Emotive Display. Mesolite is a kinetic installation that consists of 169 shape-changing modules that respond to facial expressions. The modules change their color and orientation according to six basic emotions: anger, disgust, fear, happiness, sadness, and surprise. The installation creates an immersive environment that through ubiquitous computing reflects the user's emotional state and invites them to explore different expressions.

Ubiquitous computing refers to the integration of computing devices and sensors into the environment, enabling seamless and context-aware interactions. It can potentially enhance the quality of life, productivity, creativity, and social connectedness of users by providing personalized and adaptive environments that fit users' needs and preferences (Persada, 2018). However, to achieve this goal, ubiquitous computing systems need to understand not only the physical and cognitive states of users but also their emotional states (Alghamdi et al., 2017). Therefore, using emotional data for developing human-centric environments is essential for creating more engaging, empathic and effective ubiquitous computing applications (Santos et al., 2017).

Although the notion of the smart environment in which digital sensors are integrated with the built environment was introduced years ago, the use of AI allows the environments to become more responsive (Ghandi et al., 2021). As part of spatial design, it is necessary to consider how environments will react to human emotions and identify the proper correspondence between various human emotions and spatial characteristics that best accommodate them. The goal is not to build an emotional architecture but to enable spaces to become more transformable depending on the users' emotional state. A psychological and emotional understanding of space can then be used to understand how people experience the world in their unique way. There are different ways to affect the transformation of space, from a more physical one using an elastic and transformable envelope to a more visual one using optical illusions, as well as light, sound, and temperature, which provide scenic effects. For instance, Jenny Sabin's Ada project adapted responses to occupants' emotional information gathered from facial recognition (Sabin et al. 2020). The project, which can be observed from both indoor units and circulation areas, was positioned in the gallery void of the building, creating real-time responses through the dance of colors and light.

Humans spend more than 87% of their lives inside buildings, and the built environment significantly impacts behavior, decision-making, emotions, and wellbeing (Cooper et al., 2011; Evans et al., 2003; Fischer, 2011). In this regard, the importance of designing human-centric environments appears when considering emotion's importance on motivation, reasoning, decision making, and Picard's emphasis on emotional needs. One of the factors that affects human emotions in relation to the built environment is visual complexity. Visual complexity refers to the amount of information or detail present in a visual scene. It can be measured objectively by using metrics such as entropy or edge density (Rosenholtz et al., 2007). Visual complexity can have both positive and negative effects on human emotions depending on the context and individual preferences. For example, high visual complexity can induce negative emotions such as confusion, frustration, and stress (Leder et al., 2004). Similarly, low visual complexity can induce positive emotions such as calmness, relaxation, and boredom relief (Berto et al., 2014; Kaplan,1989).

Facial Expression Recognition (FER)

This study uses facial emotion recognition (FER) to develop a responsive and reconfigurable projection mapping that can undertake different configurations through form and complexity helping respond to the occupants' emotional state and emotional needs, including self-awareness. Mehrabian (1968) found that 55% of emotions are primarily conveyed through facial expressions in daily human communication. With the open expression of ideas and thoughts on social media platforms and websites, a vast amount of physical affective data, including textual, audio, and visual signals, can be easily gathered. Consequently, numerous researchers are focusing on detecting subtle emotions expressed either explicitly or implicitly (Alm, Roth & Sproat, 2005; Sajjad et al., 2019). Wegrzyn et al. (2017) selected FER as the method of choice due to its precise numerical variations and considerably high accuracy compared to other methods such as heart rhythm, skin conductance, or body temperature. Facial expression is regarded as the most prevalent form of body language and is produced by human emotions. Machine learning models make FER possible by identifying landmarks on the human face to create a facial representation of an emotional state.

FER is possible by the machine learning models that try to detect landmarks on the human face to form a facial emotion. Many studies in architecture, fashion, and industrial design, such as Coutrix et al. (2011), Sabin et al. (2020) and Farahi (2020), used facial expressions as input data. According to Farahi, computational systems should engage not only with quantitative aspects of the human experience but also with emotional aspects of our lives. For instance, FER has been implemented in some scenarios to create experiences in the media and entertainment industry. This type of camera based sensor enables dynamic, flexible, and responsive spaces, structures, and objects. As a result of the sensory data, Microsoft's machine learning algorithms were used to convert facial expressions, noises, and voices (Plass J et al., 2016). Alternatively, the Opale project is a clothing sense aggression based on emotional interaction through facial emotions that try to create an empathic experience by establishing an affective loop with the user (Farahi, 2020).

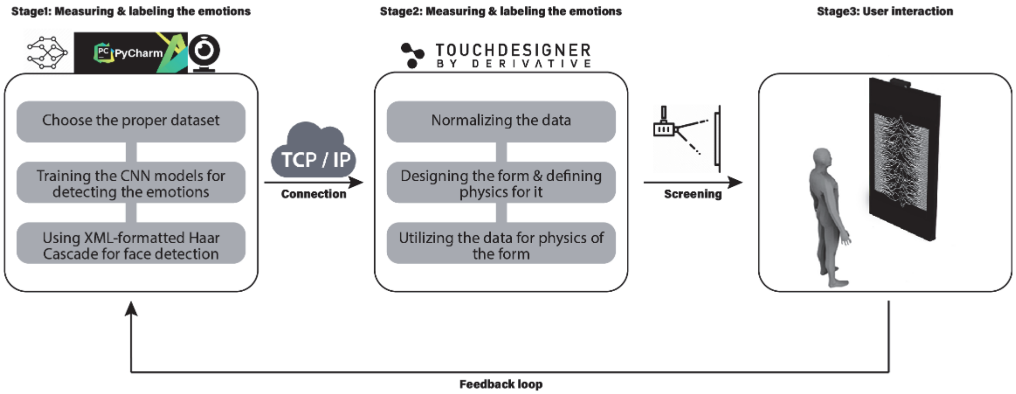
METHODOLOGY

The Emo-Land project consists of six phases: (1) Recognizing and labeling facial expressions, (2) Training the AI model through a CNN algorithm, (3) Mapping the real time data with the trained AI model (4) Designing the FER-based interactive projection mapping, (5) User experience, and (6) Analyzing user feedback to refine the system. The general process of the methodology used is depicted in (Figure 1). The project development relies on PyCharm, which is a comprehensive integrated development environment for the Python programming language, and Derivative TouchDesigner, which is a platform for real-time rendering and visual programming. The two systems are able to connect via the use of TCP/IP sockets that are sent over the network. This study concentrates on the initial four phases. The user experience stage will be elaborated in a further examination. The sixth phase, analyzing user feedback, is crucial for refining and improving the Emo-Land experience by addressing any issues and enhancing the emotional connection between the user and the installation.

Recognizing and labeling facial expression

The study uses the FER method for detecting emotions due to the precise numerical variations and considerably high accuracy among other methods, such as heart rhythm, skin conductance, or body temperature (Wegrzyn et al., 2017). FER is

Figure 1
Design process

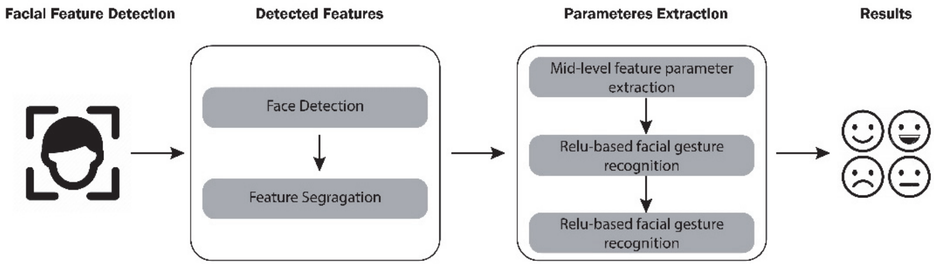


considered the most common form of body language and is generated by human emotions. FER is possible by the deep learning models that try to detect landmarks on the human face to form a facial emotion of an emotional state. The vision processing part of the system is done in two steps. First, the Open Computer Vision (OpenCV) library, a typical computer vision approach for face tracking, is applied to the webcam to process the video. Viola-algorithm Jones's algorithm uses Attentional Cascades of Haar Like features to estimate whether or not a given sub-window in a video contains human faces. At this point, the real-time video is processed using the OpenCV library in Python, specifically the XML-formatted Haar Cascade files and used for frontal face detection.

Training the AI model

Keras and TensorFlow frameworks are used to construct a Deep Learning model based on a Convolutional Neural Network (CNN) for the second stage of facial expression recognition. A CNN model is a type of deep learning algorithm that is particularly well-suited for image recognition and processing tasks. The generated CNN model employs five layers that have been proven successful in the Kaggle facial expression recognition competition in 2013. The model has been trained using the FER 2013 dataset, which included 28,000 training and 3,000 test images of faces recorded as 48-by-48-pixel grayscale images. This CNN model classifies the emotions by numbers from 0-6, where 0=Angry, 1=Disgust, 2=Fear, 3=Happy, 4=Sad, 5=Surprise, 6=Neutral (Figure 2).

Figure 2
FER architecture



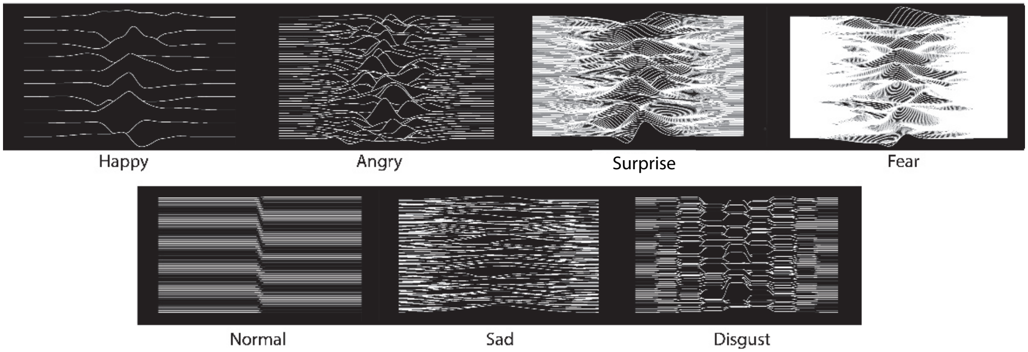


Figure 3
Form’s reconfiguration based on different emotions.

Mapping the real-time data with the trained AI model

During this phase, a method was devised to represent the user's emotional states by modifying a projection mapping installation. The
latest emotion prediction is read by a PC running TouchDesigner every five seconds through communication with the server using the TCP/IP method, allowing PyCharm and TouchDesigner to communicate with each other.

The installation then completed a transformation before reconfiguring to align with the user's new emotion. By utilizing this state-space approach along with machine learning techniques, changes were detected through communication with the server, and the relationship between the user's emotions and alterations in the installation's speed and form are mapped out.

Designing the emotion-based interaction and projection mapping

The study chose Joy Division's form concept due to the emotional connection it forms with the user. Scholars such as Flanagan (2009) and Gosling (2019) have highlighted the emotional impact of abstract forms, which can trigger a sense of mystery and intrigue in the viewer, leading to a deeper connection with the artwork.

Joy Division's form concept also has the advantage of being computationally efficient, requiring minimal computation power to render its distinctive lines and waves. As a result, even low-cost PCs can execute the necessary computations to create an interactive installation. Therefore, the Joy Division form concept was deemed suitable for this study's purposes, as it is both emotionally engaging and computationally efficient (Figure 3).

The study involves the use of Derivative TouchDesigner as a real-time rendering and visual programming platform. It provides a powerful set of tools for creating interactive installations, media performances, and real-time visual effects. TouchDesigner has been utilized to generate various visual patterns and speeds that can affect human behavior in different ways. To investigate the impact of these visual stimuli on human emotions, the study draws on Tan's (2016) research, which demonstrates that different shape-change behaviors can influence users' emotional states. By combining TouchDesigner's visual programming capabilities with Tan's findings, this project explores the real-time visual stimuli and human behavior.

Humans tend to prefer forms that are more complex but not overly complicated. Research has shown that moderate levels of complexity in visual art can evoke positive emotions such as curiosity and interest (Berlyne, 1971). Thus, the speed and density of lines in the Joy Division experience could be mapped to the user's emotional state in a way that reflects the level of complexity in the visual design. For example, the lines become denser and transform faster in response to positive emotions such as happiness and surprise, while becoming less dense and slower in response to negative emotions such as sadness and anger.

CASE STUDY ANALYSIS: "EMO-LAND—AN INTERACTIVE INSTALLATION"

Emo-Land is an interactive installation capable of creating an emotional bond by actively responding to the physiological conditions of the user through a reconfiguration of its qualities. The design tries to create an emotional landscape of the user through the interaction of real time data and projection. Emo-Land can communicate with seven emotions of the user, which are anger, disgust, fear, happiness, sadness, surprise, and neutral (Figure 4). Emo-Land's creation mechanism is presented in this study, as a living structure that became a representation of the user's facial expressions. The project results include:

1. Analyzing, interpreting, and detecting facial emotion data, including a deep learning algorithm that continuously predicts the user's emotional state.
2. A projection mapping design that responds to the emotions of the user by the real-time transformation of form, speed of transformation, order, and complexity; enhances the ability to bond a relationship between machine and user.

The visual features of the Emo-Land experience can be classified based on the user's emotional state as follows:

1. Happy and Surprise: An abstract form of landscape appears, and lines become denser and move faster, which causes more complexity in the design.
2. Sad and Angry: Lines become less dense and slower, and less complexity in the design decreases.
3. Normal: Maintain the same level of complexity and order.
4. Disgust and Fear: Lines become distorted and disordered.

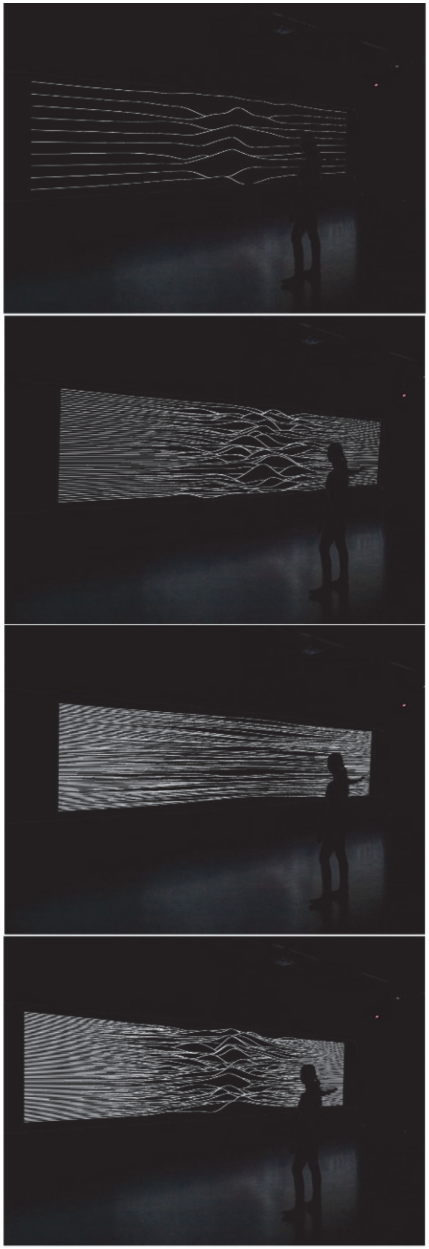


Figure 4
Emo-Land's real-time mechanism

Complexity and order of the design let the users develop an emotional landscape that transforms in real time. This is achieved by adjusting the complexity and order of the design based on the above emotional state classification formulas.

A human-centric environment should provide a comfortable and pleasant atmosphere that makes the user feel welcomed, safe, and relaxed. By regulating the emotional state of the user through customization, the user can experience a more human-centric environment that matches their needs and emotions.

By utilizing projection mapping techniques in Emo-Land, the study aims to create a more engaging and human-centric environment that responds to the emotional needs of its visitors. Projection mapping also called spatial augmented reality generates an environment for creating immersive and visually stunning experiences. One of the key advantages of projection mapping is its ability to transform any surface into a dynamic canvas. This technique allows designers to create interactive and engaging displays that can change the look and feel of any environment. Projection mapping also offers the advantage of energy efficiency since it requires minimal equipment and does not generate heat or consume significant amounts of energy. Additionally, projection mapping is versatile and can be used in a variety of settings, including indoor and outdoor environments, making it a popular choice for art installations, live performances, and marketing events.

With the rise of using augmented reality and its equipment, projection mapping opens new gates for spatial adaptation via the ability of transforming the surfaces of real-world objects into a dynamic display using projection technology (Vallance, 2015). By projecting images, videos, or animations onto physical objects or spaces, projection mapping creates immersive experiences that can interact with the surrounding environment. Projection mapping is being used in various applications such as advertising, art installations, and architectural designs. In architectural designs, projection mapping can create dynamic and adaptable spaces that can change according to user needs and emotions. Research has shown that projection mapping can positively impact user experience, behavior, and emotions (Seichter & Tscherteu, 2014).

CONCLUSION

The core concept of this research is to create a human-centric design that explores and uses scientific and technological disciplines with broader relevance to many media settings. Interactive art has been investigated for many years, by artists experimenting on different human-computer interaction scenarios using various sensors and controllers. New types of "AI aesthetics" have been proposed by artists, and real-time rendering engines can efficiently develop programmable shaders, high-resolution, and high-quality real-time data-driven media. This research demonstrated how emotions can be communicated through spaces, and the mechanism of emotive projection mapping becomes a live part of the environment. The development of technologies that promote emotional awareness and self-regulation can have significant benefits for individuals and society as a whole, and future work will involve the use of low-cost technologies to enhance the accuracy of the emotion prediction model. Integrating emerging technologies into the built environment has the potential to significantly improve human affective experiences and general wellbeing. The effects of different configurations on emotion regulation will be considered in future studies. User experience tests is needed to classify the visual features like form and complexity matters with the interactive experience based on the user's emotional state through facial expressions. By building upon the current findings and incorporating new technologies, it is possible to develop more advanced systems that can better support the emotional wellbeing of users in a variety of built environments.

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