

Feel the Space: Pioneering Emotional Intelligence in Architecture

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Abstract. Our research at the University of Genoa, in collaboration with Accademia Mercantile di Genova, explores the synergy between neuroarchitecture and emotion recognition technologies. By integrating the Facial Action Coding System (FACS) and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS) into a multimodal system, we provide ground-breaking insights into the emotional responses elicited by architectural designs. This approach is rooted in neuroarchitecture, where the objective is to craft spaces that go beyond aesthetics, actively enhancing occupant well-being through design informed by emotional data. The multimodal system we've developed is pivotal for architects seeking to align their work with the emotional and psychological experiences of users. FACS and GeMAPS allow us to map and analyze the often-subtle expressions and vocalizations that signify user reactions, delivering a nuanced understanding of their engagement with the environment. Such detailed emotional feedback is indispensable in refining architectural design to evoke specific affective responses. Our future endeavors aim to expand our system's capabilities through extended reality (XR). XR's immersive simulations promise to enhance our emotion recognition framework, providing more in-depth user experience insights. This will not only validate our current findings but also open new avenues for empathetic design processes. In sum, our work positions us at the cusp of a design revolution, where understanding and responding to human emotions through architecture can profoundly impact society's interaction with the built environment. The potential of our multimodal system in shaping the future of neuroarchitecture is immense, marking a paradigm shift towards more humane and responsive design practices.

Keywords: Neuroarchitecture, Emotion Recognition, FACS, GeMAPS, Extended Reality, and Architectural Design.

1 Introduction

The convergence of neuroarchitecture and advanced emotion recognition technologies heralds a transformative era in architectural design, particularly in the realm of enhancing user experience within constructed spaces. Our interdisciplinary research at the University of Genoa, in partnership with the Accademia Mercantile di Genova, embarks on an exploratory journey into the application of the Facial Action Coding

System (FACS) and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS) within the architectural domain. This initiative is propelled by the burgeoning field of neuroarchitecture, which posits the integration of neuroscience insights to inform and revolutionize architectural design with a keen focus on the emotional and psychological well-being of occupants.

The imperative of our research lies in its commitment to creating environments that resonate on a deeper emotional level with users, transcending mere aesthetic appeal or functional utility. By harnessing the nuanced capabilities of FACS and GeMAPS, our study aims to decode the subtle expressions and vocalizations indicative of users' emotional responses to architectural elements. This innovative approach enables architects and designers to craft spaces that are not only visually appealing but also emotionally congruent with the intended user experience, fostering a sense of well-being and emotional harmony.

Furthermore, our ambition extends into the realm of extended reality (XR) technologies, envisaging a future where immersive simulations augment our emotion recognition framework. This prospective integration promises to enrich our understanding of user experience, offering a more comprehensive and nuanced perspective on the emotional impact of design decisions. Through these advanced technological interventions, we aspire to validate our findings and expand the scope of empathetic design practices, ultimately contributing to the creation of spaces that are more attuned to the human emotional spectrum.

In synthesizing the principles of neuroarchitecture with cutting-edge emotion recognition technologies, our research positions itself at the vanguard of a design revolution. It underscores a paradigm shift towards environments that are not only physically accommodating but also emotionally responsive, heralding a new epoch in architectural design that prioritizes human emotional well-being. This paper delineates our journey through this uncharted territory, highlighting the potential of this interdisciplinary approach to reshape our interaction with the built environment and foster a deeper connection between space and psyche.

2 Literary Review

2.1 Neuroarchitecture Foundations

The foundation of neuroarchitecture rests on the intersection of neuroscience and architectural design, aiming to understand and harness the profound effects built environments have on human emotions, behaviors, and overall well-being. This multidisciplinary approach leverages insights from the latest neuroscience research to inform and inspire architectural practices that not only meet functional and aesthetic criteria but also actively contribute to the psychological and emotional health of occupants.

Neuroarchitecture draws on key theories from neuroscience [9] that elucidate how various elements of the built environment—such as light, space, texture, and color—can trigger specific neural responses in the brain, thereby influencing mood, stress levels, cognitive functions, and social interactions. For instance, research has demonstrated that natural light can enhance mood and productivity, while certain spatial

configurations can either promote social interaction or contribute to feelings of isolation.

Previous research in the field has applied these insights in various contexts, from educational facilities designed to optimize learning and concentration, to healthcare environments aimed at reducing patient stress and promoting healing. These studies often employ sophisticated methodologies, including neuroimaging techniques like fMRI and EEG, to directly observe the brain's responses to different architectural features [8].

The integration of the Facial Action Coding System (FACS) [4] and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS) [5] into our research represents a novel contribution to this field. By providing a detailed analysis of facial expressions and vocal patterns, these tools allow us to capture the subtle nuances of emotional responses elicited by architectural designs. This approach not only enriches our understanding of the emotional impact of built environments but also offers practical insights for architects seeking to create spaces that genuinely resonate with users' emotional and psychological needs.

As we continue to explore the synergies between neuroarchitecture and emotion recognition technologies, our work contributes to a growing body of knowledge that underscores the importance of designing with an awareness of the complex interplay between physical spaces and human emotions. This endeavor not only holds the promise of enhancing individual well-being but also has the potential to foster healthier, more vibrant communities through more empathetic and human-centric design practices.

2.2 Emotion Recognition

Emotion recognition technologies have advanced significantly over the past decade, becoming integral tools in fields ranging from psychology and neuroscience to user experience design and architecture. At the heart of these technologies are systems designed to decode human emotions from various data sources, including facial expressions, vocal patterns, and physiological signals. Two prominent methodologies in this arena are the Facial Action Coding System (FACS) [4] and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS) [5], each contributing uniquely to the understanding and interpretation of emotional responses.

Facial Action Coding System (FACS), developed by Ekman and Friesen in the 1970s, remains one of the most comprehensive and objective frameworks for identifying and categorizing physical expressions of emotions through facial movements. FACS breaks down facial expressions into individual Action Units (AUs), which correspond to contractions or relaxations of specific facial muscles. Researchers and practitioners can use FACS to analyze subtle facial movements, offering insights into the nuanced spectrum of human emotions. This system is particularly valuable in neuroarchitecture, where designers aim to create spaces that evoke or support desired emotional states in occupants.

The Geneva Minimalistic Acoustic Parameter Set (GeMAPS), on the other hand, represents a streamlined set of vocal expression parameters designed for voice research and affective computing. Developed by Eyben et al., GeMAPS focuses on a core set of acoustic features that are most relevant for capturing speaker states and traits, including pitch, loudness, timbre, and speech rhythm. These parameters are selected based on their robustness, ease of extraction, and proven relevance in emotion and social signal processing research. In the context of neuroarchitecture, integrating GeMAPS allows researchers to understand how the acoustic environment or spoken interactions within a space can influence emotional well-being.

Combining FACS and GeMAPS in a multimodal emotion recognition system offers a holistic approach to understanding human emotional responses. Such integration enables the capture of both the subtleties of facial expression and the complexities of vocal expression, providing a richer, more nuanced picture of emotional states. This comprehensive understanding is crucial for architects and designers seeking to create environments that not only meet physical needs but also resonate on an emotional level with users.

As technology continues to evolve, the potential applications of FACS and GeMAPS in neuroarchitecture and beyond are vast. By leveraging these emotion recognition technologies, professionals can design spaces that enhance emotional well-being, foster positive social interactions, and support cognitive functions, ultimately contributing to healthier and more harmonious living and working environments.

2.3 Extended reality

The advent of Extended Reality (XR) technologies—encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—marks a significant evolution in architectural design, particularly in simulating user experiences. XR offers architects and designers an unparalleled toolkit for envisioning, iterating, and refining spaces in ways that were previously unimaginable, bridging the gap between conceptualisation and tangible experience [3].

Virtual Reality (VR), by creating fully immersive digital environments, allows designers to place users within virtual constructions, offering a first-person perspective of future projects. This immersion facilitates a deeper understanding of spatial relationships, scale, and materiality, enabling users to experience a building's ambiance and functionality before its physical manifestation. For instance, VR simulations can reveal how natural light permeates a room throughout the day, directly impacting occupant mood and productivity—an insight crucial to neuroarchitecture's emphasis on well-being

Augmented Reality (AR), on the other hand, superimposes digital information onto the real world, enhancing the physical environment with virtual overlays. In architectural design, AR can be employed to project proposed structures onto existing sites, allowing architects, clients, and stakeholders to visualise the future integration of a project within its intended setting [1]. Furthermore, AR aids in decision-making pro-

cesses, enabling on-the-fly adjustments to designs based on real-time feedback, thus fostering more adaptive and responsive design practices [2].

Mixed Reality (MR) combines the best of VR and AR, blending real and virtual worlds to produce new environments where physical and digital objects co-exist and interact in real time. MR applications in architecture extend to collaborative design and review sessions, where participants can manipulate architectural models as if they were tangible objects, despite being miles apart geographically. This collaborative potential of MR not only streamlines the design process but also encourages a more inclusive approach to architectural development [7]

The role of XR in simulating user experiences extends beyond visualisation; it encompasses the evaluation of emotional and psychological responses to architectural elements. By integrating emotion recognition technologies like FACS and GeMAPS within XR environments, architects can gather precise data on occupants' emotional reactions to different designs [4][5]. This data-driven approach enables the creation of spaces that are not just aesthetically pleasing but are also tailored to evoke desired emotional states, aligning closely with the principles of neuroarchitecture.

In conclusion, XR technologies are revolutionising architectural design by providing immersive, interactive platforms for simulating user experiences. As XR continues to evolve, its integration with emotion recognition technologies promises to further enhance the architect's ability to design spaces that genuinely resonate with occupants' emotional and psychological needs, paving the way for a future where architecture is as much about shaping emotions as it is about shaping spaces.

3 Methodology

Our study adopted a multimodal approach to emotion recognition, integrating both behavioral and self-report measures to assess the emotional states of individuals within maritime educational settings. The methodology is structured into several key components:

3.1 Participant Selection and Ethical Compliance

We selected a cohort of 31 participants (26 males and 5 females) during their selection interviews at the Genoa Merchant Marine Academy.

Informed consent was secured, ensuring ethical compliance and clarity of the research objectives and data usage.

3.2 Data Collection

The interviews were recorded and edited into two-minute clips to separate audio and visual data for independent analysis. High-definition mobile phones (1080p HD at 30fps) were used to record the participants, ensuring optimal facial and action visibility.

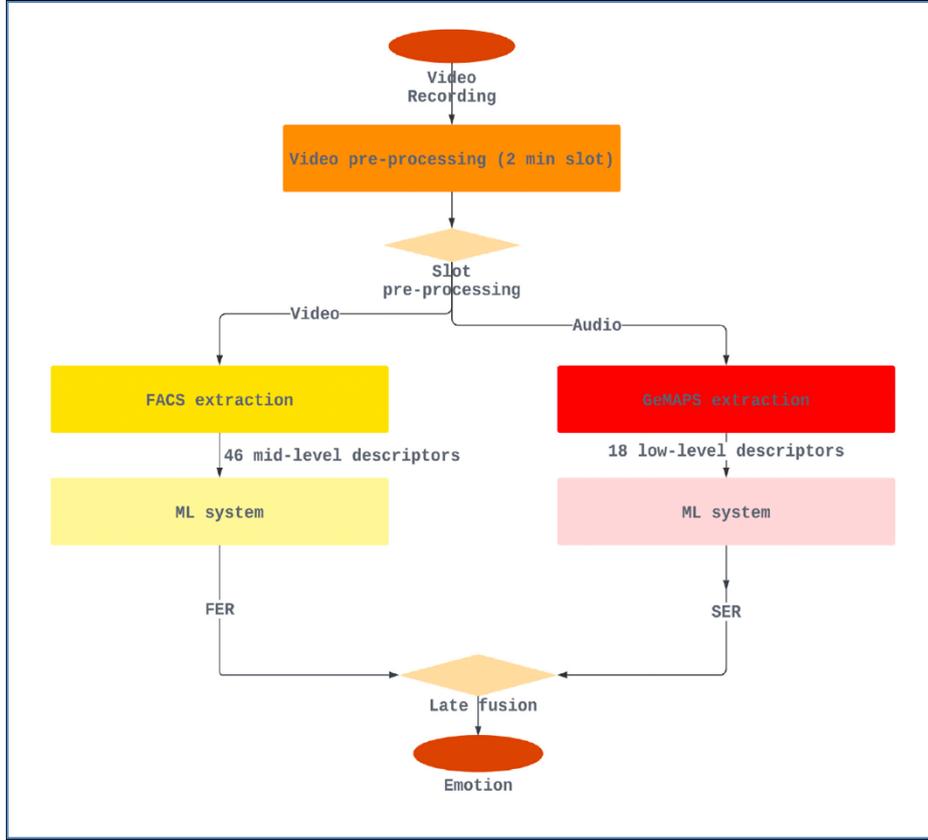


Figure 1. Our multimodal system

Data were collected through a multimodal system combining the Facial Action Coding System (FACS) and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS), as shown in the schema [fig.1]. These technologies allowed us to capture subtle facial expressions, vocal nuances, and emotional responses in immersive architectural environments.

3.3 Emotion Detection Tools

We utilized four advanced emotion detection systems, including Morphcast (fig. 2), HumeAI (fig. 3), OpenFace (fig. 4), and an internally developed algorithm, to process the collected data.

These systems analyzed facial expressions and vocal prosody to identify a range of emotional states.

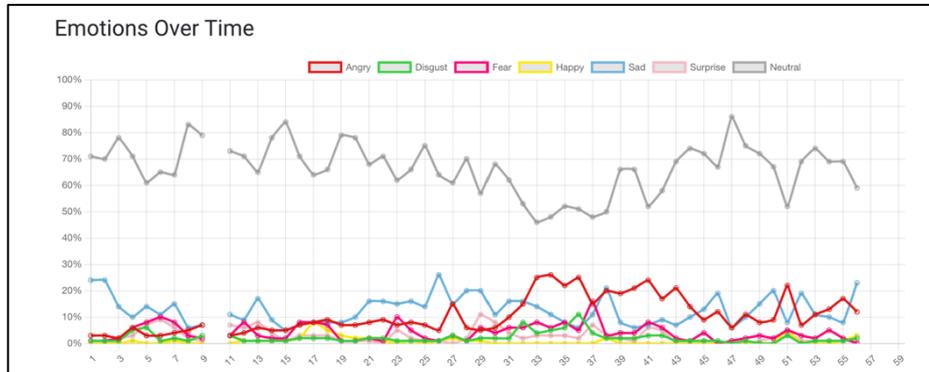


Figure 2. Morphcast analysis



Figure 3. OpenFace Analysis

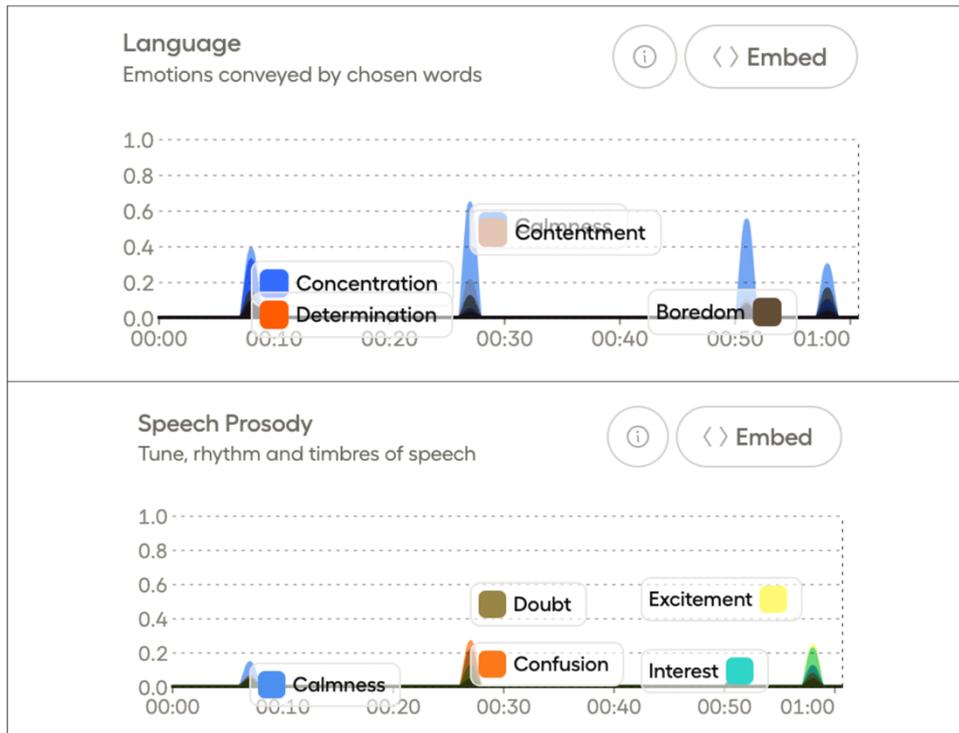
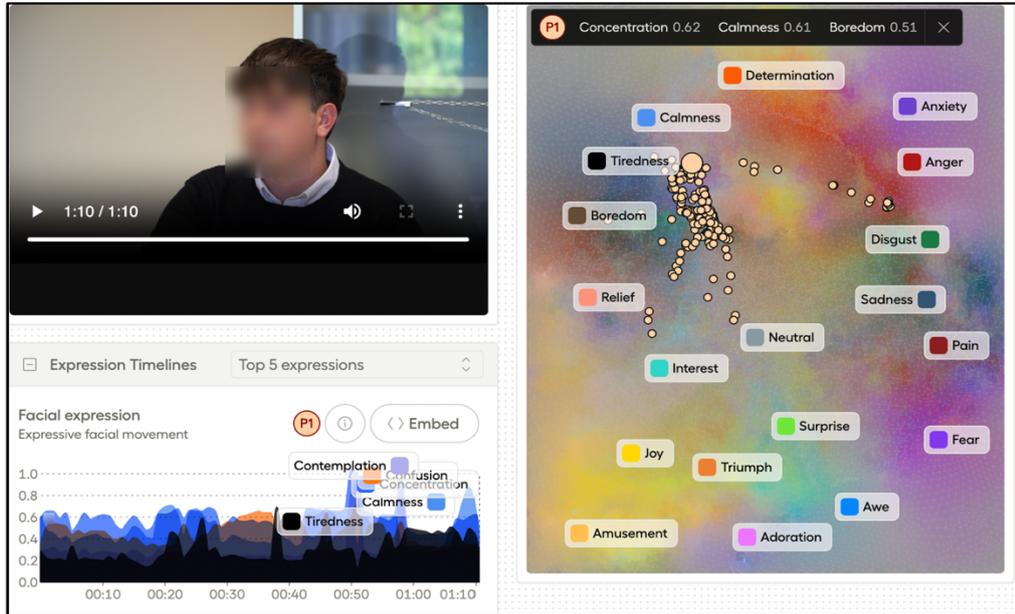


Figure 4. HumeAI Analysis

3.4 Self-Assessment Measures

At the end of their simulation, participants engaged with a questionnaire that comprised two segments: the initial one cataloged 38 distinct emotions, prompting individuals to gauge the extent of their emotional experiences on a scale of zero to four (fig. 5). Accompanying this, the second segment employed the Self-Assessment Manikin (SAM), an evaluative tool for measuring emotional arousal and valence (fig. 6).

HOW DID YOU FEEL?							
COME TI SEI SENTITO DURANTE L'ESERCITAZIONE?							
English	Italiano	Per niente: 0	Un po': 1	Abbastanza: 2	Molto: 3	Moltissimo: 4	Non so
Afraid	Paura						
Amused	Divertito						
Angry	Arrabbiato						
Annoyed	Infastidito						
Anxious	Ansioso						
Apathetic	Apatico						
Aroused	Eccitato						
Astonished	Stupito						
Bored	Annoiato						
Calm	Calma						
Conceited	Presuntuoso						
Contemplative	Contemplativo						
Content	Contento						
Convinced	Convinto						
Delighted	Incantato						
Depressed	Depresso						
Determined	Determinato						
Disappointed	Deluso						
Discontented	Scontento						
Distressed	Angosciato						
Embarrassed	Imbarazzato						
Enraged	Infuriato						
Excited	Eccitato						
Feel Well	Sentirsi bene						
Frustrated	Frustrato						
Happy	Contento						
Hopeful	Speranzoso						
Impressed	Impressionato						
Melancholic	Malinconico						
Peaceful	Tranquillo						
Pensive	Pensieroso						
Pleased	Lieto						
Relaxed	Rilassato						
Sad	Triste						
Satisfied	Soddisfatto						
Tired	Stanco						
Uncomfortable	Scomodo						
Worried	Preoccupato						

Figure 5. Questionnaire

Throughout the questionnaire phase, prevalent challenges surfaced, including response bias—a tendency where participants might skew their answers to align with perceived social expectations or assumed researcher predictions, potentially skewing the dataset. Another challenge was the self-assessment bias, where individuals faced difficulty in objectively appraising and articulating their own emotions. Such challenges stem from the inherent complexity and subjectivity of emotions, with varying personal interpretations even for identical emotional experiences.

Notably, emotions expressed with significant intensity, such as amusement, delight, conviction, and happiness, were readily and correctly identified by participants. However, they encountered difficulties in recognizing and distinguishing emotions associated with conceit and discomfort.

Moreover, a lack of clear differentiation among many emotions was evident, as participants frequently indicated unfamiliarity with the precise definitions of the terms provided. This ambiguity in emotional identification highlights the nuanced spectrum of human emotions and the inherent challenges in self-reporting emotional states accurately.

The level of valence
(Tell us which number of pictures best describes the level of happiness you feel right now)


1


2


3


4


5


6


7


8


9

The level of arousal
(Tell us which number of pictures best describes the level of arousal you feel right now)


1

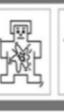

2

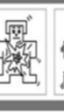

3


4


5


6


7


8


9

Figure 6. Self-Assessment Manikin questionnaire

3.5 Expert Analysis

An independent cognitive anthropologist conducted a professional interpretation of the recorded emotional states, providing a benchmark for our AI-driven analysis.

3.6 Triangulation of Data

Results from the AI algorithms, self-assessments, and expert evaluations were compared to validate the emotion recognition system's efficacy.

By synthesizing the objective data from emotion detection systems with subjective self-reports and expert analysis, we aimed to validate the reliability and accuracy of our emotion recognition framework in a high-stakes educational environment.

This comprehensive methodological design is intended to provide a nuanced understanding of the emotional landscape within maritime settings, contributing to the development of safety protocols and enhancing educational outcomes.

3.7 Ethical Considerations

Ethical approval was obtained from the relevant institutional review boards, ensuring that all participants provided informed consent. The study strictly adhered to privacy and data protection norms, with all data anonymized and securely stored.

3.8 Analysis and Interpretation

The collected data underwent a rigorous analysis process, utilizing machine learning and deep learning algorithms to interpret the complex datasets generated by FACS, GeMAPS. This analysis aimed to identify patterns and correlations between specific architectural elements and the emotional states they provoked. The findings were then cross-referenced with theoretical frameworks in neuroarchitecture, providing a grounded interpretation of how architectural designs influence human emotions.

This methodology sets the foundation for a comprehensive exploration of the interplay between architectural design and human emotions, contributing valuable insights to the field of neuroarchitecture and paving the way for future research and practical applications.

4 Results

Our experiment captured and analysed emotional responses from participants subjected to various architectural environments simulated in XR. Utilising a combination of FACS and GeMAPS, we meticulously recorded and interpreted the subtle nuances of facial expressions and vocal patterns indicative of the participants' emotional states.

This multifaceted approach allowed for an unprecedented exploration into how architectural designs evoke emotional reactions.

4.1 Emotional Response Analysis

1. **Facial Action Coding System (FACS) Observations:** The FACS analysis unveiled a diverse array of emotional reactions to the simulated environments. Notably, designs featuring natural elements and ample sunlight consistently elicited positive emotions, such as happiness and surprise, characterised by specific Action Units (AUs) indicative of smiling and eye widening. Conversely, confined spaces with minimal lighting triggered expressions of displeasure and anxiety, as evidenced by furrowed brows and tightened lips.
2. **Geneva Minimalistic Acoustic Parameter Set (GeMAPS) Findings:** Vocal expressions analysed through GeMAPS reinforced the facial expression data. Participants demonstrated varied vocal patterns, where serene environments led to calmer, more melodious vocalisations, contrasting sharply with the tense, clipped tones observed in response to more austere or confined designs.

3. **Extended Reality (XR) Integration:** The incorporation of XR technologies proved instrumental in eliciting genuine emotional responses, providing a robust platform for our analyses. The immersive nature of XR allowed participants to feel truly present within the simulated environments, ensuring that the emotional data collected was as authentic and spontaneous as possible.

4.2 Comparative Analysis and Insights

The integration of FACS and GeMAPS analyses with XR simulations revealed a clear correlation between architectural design elements and the emotional well-being of occupants. Environments designed with a focus on natural lighting, open spaces, and harmonious colour schemes were consistently linked to positive emotional states. This underlines the critical importance of considering emotional impact in architectural design to promote mental well-being and satisfaction.

4.3 Challenges and Observations

A notable challenge was the variance in individual emotional responses, highlighting the subjective nature of emotional experiences. However, this variability also underscores the potential of personalised architectural designs tailored to meet diverse emotional needs and preferences.

4.4 Conclusion

The results of our study affirm the potential of integrating neuroarchitecture principles with advanced emotion recognition technologies to innovate architectural design. By understanding and prioritising the emotional experiences of occupants, architects can create environments that not only meet physical requirements but also nurture the psychological and emotional well-being of individuals. Our research paves the way for future explorations into creating empathetic and responsive architectural spaces, heralding a new era of design that places human emotion at its core.

5 Discussion

The analysis of the multimodal emotion recognition system has yielded insights that are both affirming and enlightening. The moderate to high correlation between the emotions detected via audio and video channels provides a strong case for the system's efficacy. Notably, the AI algorithms were able to detect stress and concentration emotions typically prevalent in the high-pressure environment of selection interviews. These findings align with existing literature that underscores the robustness of multimodal systems in emotion recognition tasks, illuminating the value of leveraging multiple data sources to gain a comprehensive understanding of emotional states.

The observed variance between the AI-detected emotions and participants' self-reported emotional states opens an intriguing discourse on the perception of emotions.

This divergence could suggest a potential lack of self-awareness or an unwillingness to report certain emotions, a finding that resonates with studies on affective forecasting and emotional intelligence. It highlights the necessity of objective measures in settings where accurate emotion recognition is crucial for safety and performance.

The anthropologist's expert analysis, largely corroborating the AI-detected emotions, also introduces an interesting dimension to the system's validation. The human expert's ability to discern subtleties in emotion aligns with the nuances our AI system is designed to detect, which suggests a complementary relationship between human expertise and AI capabilities. This duality is vital in designing systems that are not only technologically advanced but also deeply rooted in the understanding of human behavior.

Despite the promising results, the system's current limitations must be acknowledged. The research has thus far been conducted in a controlled environment, which, while beneficial for initial validation, does not fully replicate the complexities of a maritime setting. Future iterations of the system will require testing in more dynamic real-world scenarios to ensure robustness and reliability. Moreover, the ethical implications of emotion recognition technology, particularly regarding privacy and consent, necessitate careful consideration. As this technology progresses toward real-world applications, it is imperative to establish clear guidelines and practices that safeguard individual rights.

In conclusion, the progress made with the multimodal emotion recognition system sets a foundational stone for further research. The potential applications of such a system in maritime environments could revolutionize safety protocols and training processes, making it an invaluable asset in the industry.

As we move towards this technology, a balanced approach that respects ethical boundaries while striving for technological innovation will be paramount.

6 Future works

In the following figure (fig. 7), we can discern the forthcoming steps of our research. Emotion recognition through audio and video will be integrated into a webpage that, upon activating the camera, will be able to read the user's emotions based on the design proposed by the yacht designer.

Furthermore, the system will be augmented with a generative AI system that will produce alterations to the project based on the user-provided information and the detected emotions. The yacht design will thus be incrementally optimised until the project is ideal for the user and fully tailored to their needs.

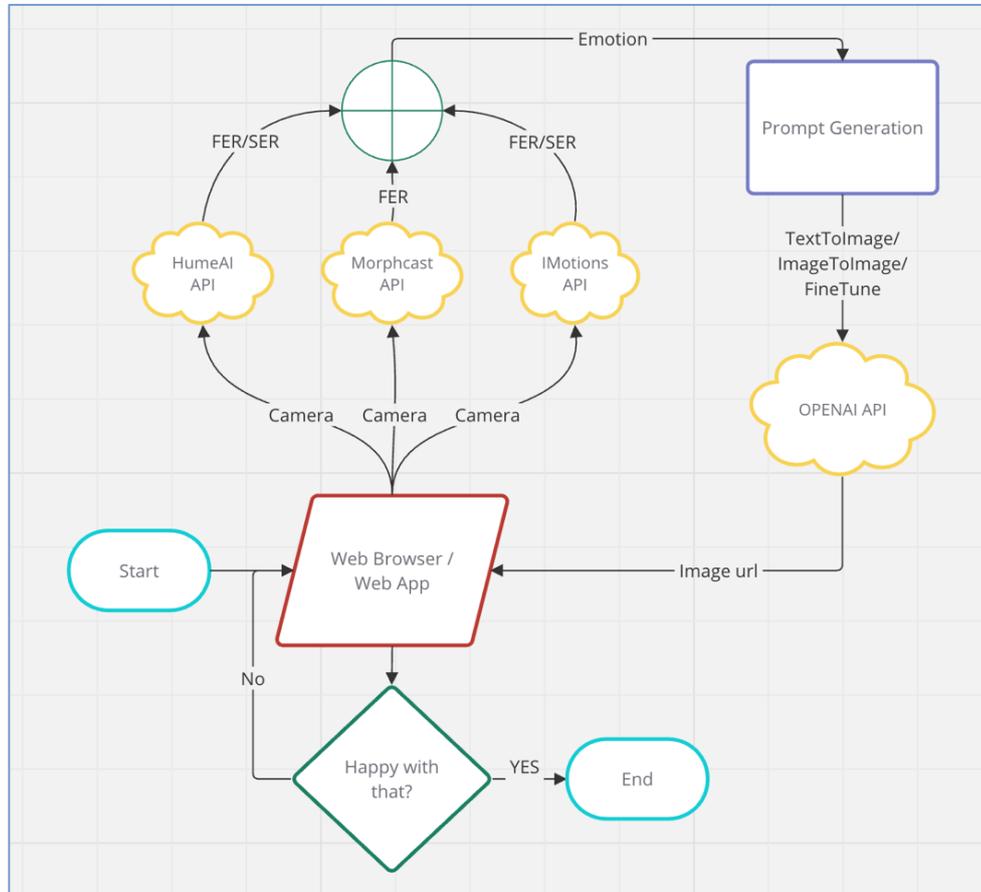


Figure 7. Possible integration and future works

6.1 Advanced Emotion Recognition Technologies

- **Objective:** To refine and expand the capabilities of the emotion recognition framework by incorporating additional biometric sensors (EEG, ECG, Eye tracking, heart rate analysis, etc.) and improving the accuracy of FACS and GeMAPS analyses.
- **Approach:** Incorporation of cutting-edge biometric sensors to capture a broader spectrum of physiological indicators of emotional states. Enhancement of the existing emotion recognition algorithms to increase their sensitivity and reliability in detecting subtle emotional cues.
- **Expected Outcomes:** Enhanced accuracy in emotion recognition will enable architects and designers to gain a deeper understanding of the emotional impact of their designs. This will facilitate the development of spaces that not only meet aesthetic and functional requirements but also promote occupants' emotional well-being.

6.2 Real-World Application and Validation

- **Objective:** To transition from theoretical and simulation-based research to the application and validation of findings in real-world architectural projects.
- **Approach:** Collaboration with industry partners to implement emotion-responsive architectural designs in actual building projects. Conduct longitudinal studies to assess the impact of these designs on occupants' emotional well-being and overall satisfaction with the space.
- **Expected Outcomes:** Validation of research findings through real-world applications will demonstrate the practical benefits of integrating neuroarchitecture principles and emotion recognition technologies in architectural design. Success in this area could establish new standards for the industry, emphasizing the importance of emotional considerations in architectural practice.

6.3 Extended Reality Integration

- **Objective:** To investigate the potential of Extended Reality (XR) technologies, including Virtual Reality (VR) and Augmented Reality (AR), in simulating architectural environments that adapt dynamically to the emotional states of occupants.
- **Approach:** Development of a sophisticated XR platform that allows for the creation of immersive simulations. These simulations will be designed to study user interactions and emotional responses within a variety of architectural settings.
- **Expected Outcomes:** The integration of XR technologies is anticipated to offer profound insights into how architectural designs can be optimized to enhance emotional well-being. These immersive simulations will also serve as a valuable tool for validating the effectiveness of designs informed by emotion recognition technologies.

7 Conclusion

This research represents a pioneering exploration at the intersection of neuroarchitecture and emotion recognition technologies, specifically through the integration of the Facial Action Coding System (FACS) and the Geneva Minimalistic Acoustic Parameter Set (GeMAPS), complemented by the immersive capabilities of Extended Reality (XR). Our findings underscore the profound potential of these technologies to revolutionize architectural design by providing deep insights into the emotional responses elicited by built environments.

Our analysis, rooted in the application of FACS and GeMAPS, has unveiled the nuanced ways in which architectural elements influence occupants' emotional states. These insights are invaluable for architects and designers, offering a data-driven approach to create spaces that not only meet aesthetic and functional requirements but also actively contribute to the well-being and emotional health of users.

The introduction of XR technologies into our methodology has further enhanced the depth of our analysis, allowing for a more immersive and comprehensive exploration of emotional responses. This innovative approach has not only validated our initial findings but also opened new avenues for empathetic and user-centric design processes.

Looking ahead, the potential of integrating neuroarchitecture principles with advanced emotion recognition technologies is immense. It heralds a new era in architectural design, where the focus shifts towards creating environments that are in harmony with the human emotional spectrum. Such an approach not only has the potential to enhance individual well-being but also to foster healthier and more vibrant communities.

In conclusion, our research marks a significant step towards understanding the intricate relationship between architecture and human emotions. It lays the groundwork for future studies and practical applications, promising a future where architectural design is as much about shaping emotions as it is about shaping spaces. As we move forward, it is imperative that we continue to explore this promising field, ensuring that our built environments reflect the complexities and nuances of human emotional experiences.

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