Eliciting and Annotating Emotion in Virtual Spaces

Emmanouil Xylakis[1], Ali Najm[2], Despina Michael-Grigoriou[3], Antonios Liapis[4], Georgios N. Yannakakis[5]
[1,4,5]Institute of Digital Games, University of Malta, Msida, Malta.
[2,3]GET Lab, Department of Multimedia and Graphic Arts, Cyprus University of Technology
[1,4,5]{emmanouil.xylakis|antonios.liapis|georgios.yannakakis}@um.edu.mt
[2,3]{ali.najm|despina.grigoriou}@ cut.ac.cy

We propose an online methodology where moment-to-moment affect annotations are gathered while exploring and visually interacting with virtual environments. For this task we developed an application to support this methodology, targeting both a VR and a desktop experience, and conducted a study to evaluate these two media of display. Results show that in terms of usability, both experiences were perceived equally positive. Presence was rated significantly higher for the VR experience, while participant ratings indicated a tendency for medium distraction during the annotation process. Additionally, effects between the architectural design elements were identified with perceived pleasure. The strengths and limitations of the proposed approach are highlighted to ground further work in gathering affect data in immersive and interactive media within the context of architectural appraisal.

Keywords: *Human computer interaction, Architectural design, Virtual reality, Affective computing, Online annotation, Perceived pleasure.*

INTRODUCTION

An architectural experience is processed by each individual with a multitude of involved senses while being present, exploring, observing, and walking in space. However, what is the emotional impact of this experience remains a pertinent open question.

Gathering knowledge on the affective reactions to our surrounding environment comes with inherent difficulties. An important challenge is creating experiences comparable to real life through stimuli presented in lab settings. These experimental stimuli vary from the use of static images (Vartanian et al., 2013; Vartanian et al., 2019) to stereoscopic views (Chamilothori et al., 2019) attempting to collect data of affect in the context of space. What these methods lack is the recreation of walking and exploring when inside a building.

This study is motivated by the works that consider the temporal dimension in architectural experience (Gregorians et al., 2022, Marín-Morales et al., 2018) and immersive media studies, assessing the importance of situated presence in eliciting emotions (Riva et al., 2007, Kuliga et al., 2015).

Considering the above, we developed an application that allowed the simultaneous exploration and continuous annotation of virtual interior spaces, targeting two media of display: Virtual Reality (VR) and on-screen (desktop). We conducted a series of in-lab participant sessions for both display modes, followed by post session surveys.

Virtual Environments in Empirical Research

Virtual Environments (VEs) provide the means to recreate synthetic situations that alter the experienced perspective of individuals. Researchers exploit user interaction data and responses to these synthetic states. Depending on the nature of the synthetic content, this is either defined as dynamic or static (Marín-Morales et al., 2018). Dynamic content allows the participant to interact with it and explore, while static content present passive stimuli such as photographs or sounds (Kuliga et al., 2015; Gregorians et al., 2022; Marín-Morales et al., 2018).

The importance of taking a first-person perspective within these synthetic experiences accentuates the strength of VR in terms of presence (Slater 1999). The present work sees this first-person interaction with VEs as a platform for empirical research. Furthermore, we envision that these systems can encourage discussions between designers and researchers towards a better understanding of human-oriented design (Sen et al., 2017) by consolidating knowledge in the fields of affective computing and virtual worlds applications.

LITERATURE REVIEW

The following sections present different approaches to eliciting, collecting and processing affect within synthetic environments.

Affect annotation within Virtual Environments

Affective computing (AC), i.e. "computing that relates to, arises from, or deliberately influences emotions" (Picard, 2000) is an interdisciplinary area, bridging computer science with psychology. In AC, the most common practices in capturing affect are self-reports, behavioral measures and physiological signals. Self-reports are addressed with this work. Regarding the representation of human affect, two are the main approaches, dimensions (Russell 1980, Bradley et al., 1994) and labels (Ekman 2004, Desmet et al., 2016). Our scope lies in representing affect in dimensions, allowing a richer treatment by looking at the degree or intensity of affect, rather than using a sole label. Weaknesses of the dimensional models are often attributed to the human inability to assign exact values to that degree of the felt emotion. To solve this, many AC studies treat annotated dimensional data in a relative rather than absolute fashion (Yannakakis et al., 2015, Yannakakis et al., 2018). We follow the same method for processing affect in this paper.

Related to our work, Voigt-Antons et al. (2020), tasked 18 participants to compare two different annotation mechanisms on two different display media, while viewing 360° video content. The first annotation mechanism was retrospective (participants reporting affect after a session). The second method was real-time and continuous, encouraging participants to input their affect levels on a 2D grid overlaid on top of the video content. No significant differences were found between the two annotation mechanisms, but significant differences were found regarding usability and presence. The VREVAL framework and tool developed by Schneider et al. (2018) facilitated the simultaneous collection of wayfinding, spatial experience and qualitative feedback data, while in a VE. Authors evaluated the tool with the participation of 20 design students, and highlighted the tool's ability to assist in identifying problematic scenarios in early design phases.

Similarly, Toet et al. (2019) tasked 40 participants to annotate 360° videos displayed in VR on the arousal-valence dimensions using Emojigrid, a self-annotation reporting tool for immersive media. Results indicated high agreement on valence and moderate agreement on arousal. In the study of Kruger et al. (2020) the development of Morph a Mood (MAM) tool sought to provide a pictorial representation of affect states to be embedded within VEs. MAM aimed to improve the accuracy of discrete models such as PAM (Desmet et al., 2016) by introducing interpolations between emotional states. As with Emojigrid, MAM displayed higher agreements in the valence scale ratings compared to arousal. Lastly, Xue et al. (2021) designed and compared two methods for collecting continuous dimensional input within VR environments, aimed at reducing workload and distraction. For their two proposed methods, HaloLight and Dotsize (opacity and size of filled circle), they considered peripheral visualization techniques to avoid superimposition of the actual stimuli. Results showed both techniques being consistent with discrete labels.

Other works collect user reports on features of generated geometries within VEs. In the work of Gomez-Tone et.al. (2021) VR was employed as means to navigate and interact with a generated set of six rooms, varying in 5 design characteristics from scale, to texture, to architectural style. The study aimed to compare digital twins to their real equivalents in terms of perceived sensations. While experiencing the virtual world and each of the different rooms, participants verbally reported affect from a set of predefined labels, for each of the 5 design categories, with results showing great similarities in induced affect states between real and digital twins. Lastly, Marín-Morales et al. (2018) designed four variations of virtual rooms meant to elicit four different affect states with different valence-arousal combinations according to the circumplex model of affect. A test with 15 participants rating the four rooms confirmed the intended ratio of arousal-valence. The test occurred in VR, presenting rooms with the adjacent dimensions of the Self-assessment manikin (Bradley et al., 1994) embedded within the participant's field of view (FOV).

Assessing Presence and User Experience within VEs

To consider virtual environments a viable platform for empirical research, certain design criteria need to be fulfilled when researchers employ VEs to gather participant data. The assessment of user experience within virtual environments has become a crucial research topic. One of the most common criteria of a virtual experience is in terms of *presence*. Presence refers to the capability of the virtual experience to transfer the individual to the synthetic experience, or else create "the sensation of being surrounded by a VE, with attentional resources allocated toward that environment" (Weber et al., 2021). Presence thus relates to how convincing the synthetic experience was in replicating real life stimuli, and by extension in eliciting experiences comparable to real life, as studied by Gomez-Tone et al. (2021). The most widely adopted tools to assess presence are the Witmer & Singer (W&S) Presence Questionnaire (Witmer et al., 1998) and the Slater, Usoh, Steed (SUS) inventory (Slater, 1999). Both approaches have been compared revealing their suitability across several studies. Nystad et al. (2004) sought to compare these two surveys to measure presence of a VE between desktop monitors and Head-Mounted Displays (HMDs) during the training task of maintenance in a nuclear reactor setting. The comparison between the surveys was made in 3 different categories: (1) system factors, including the system's immersion capability and usability, (2) performance, including errors during retention and (3), personal tendencies towards immersion and environment familiarity.

EXPERIMENT DESIGN

This study seeks to utilize the natural sensorimotor contingencies of Virtual Reality (VR) and enhance the spatial perception of the viewer while they process environment stimuli.

The focus of this work is the study of real time continuous affect annotations within VEs. For this, we will be comparing traversals of randomized sequences of different rooms, traveling on predetermined paths at a fixed movement speed.

This ad-hoc fixed navigation ensures consistent duration for all participants within each room and fixed stimuli for the same sequence, allowing the user to only control the field of view (FOV) within the VE. Two media of display (desktop display and a HMD) are compared with the following hypothesis: "*There are significant differences between media of display (desktop or VR) in terms of usability, distraction and presence*". Each of these three aspects of user experience is addressed via a post session survey and tested for significant differences attributed to each display mode.

Design parameters

The generated sequences comprise of 16 rooms varying in three form-affecting parameters: contour curvature, ceiling height and occluding elements. Two extreme settings are considered for each parameter, i.e., *contour*: curved vs. rectilinear; *ceiling height*: low-ceiling vs high-ceiling; *occlusions*: empty room vs room occluded with walls and columns (see Figure 1). Additionally, two *ambient illumination* settings are studied using warm (2500K) and cold (6500K) correlated color temperature (CCT) settings, replicating the conventional light emitting diodes (see Figure 1). The design parameters are chosen from the study of Xylakis et al. (2021) on the impact of interior environments on different affect states.

Pleasure Annotation

The self-annotation protocol used for the present experiment is RankTrace (Lopes et al., 2017). RankTrace enables the recording of user annotations regarding changes in affect across a single affect dimension of arousal, valence, dominance, etc. in a continuous manner. We assess *valence* (or pleasure) in this study, as it is a crucial topic in architectural design (Hildebrand, 1999) regarding how an environment can deliver experiences of comfort and well-being (Hansen et al., 2022). Annotations are always processed relatively, meaning that measured affect is always compared with measurements of previous conditions or states in the same walkthrough. Theories in psychology suggest that affect measurements should be treated relatively by reference assignment, leading to more reliable data with higher inter-annotator agreements (Yannakakis et al., 2015, Yannakakis et al., 2018).

Application Development

We designed an application to fulfill the needs of current and future experiments within the Unity environment (Unity 3D, 2023). A randomized sequence of all 16 rooms described above is generated for each session and remains consistent for both desktop and VR walkthroughs.

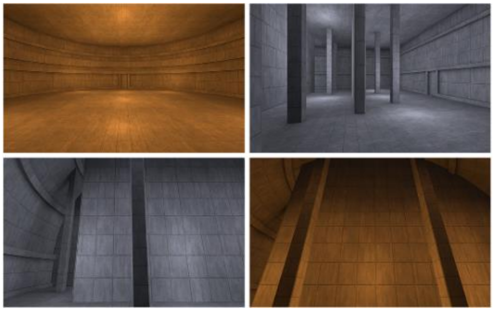

Figure 1
Sample views of 4 of the 16 rooms available, showcasing different design parameters (light color, occlusion, curvature, room height).

Figure 2
Affect annotation during a session.

The RankTrace annotation chart is added at the lower-central part of the view both for VR and desktop views, overlapping the content (See Figure 2). While the participant is annotating, the entire chart history is visible to act as reference of previous ratings. The annotated changes in pleasure are captured via mouse scroll movement (scrolling up: pleasure increase; scrolling down: pleasure decrease) and displayed on the chart.

The avatar's location and FOV are registered every 100 milliseconds. After each session a participant's data file includes the following: timestamp, participant ID, experiment mode, annotated value, room ID, location and viewpoint.

Surveys

All items forming the post session questionnaire have a 5-point Likert scale and anchored at their end points from "strongly agree" to "strongly disagree", with some exceptions where end points were altered to fit the survey item. To eliminate scale bias regarding these endpoints, 3 items have been

Figure 3
Participant tests during VR and desktop sessions.

flipped (i.e. disagreement being a positive response in terms of the measured experience construct).

We assess the usability of the annotation system with 7 items (Q1 to Q7) from the Post-Study System Usability Questionnaire (Lewis, 1995) which were adjusted to fit the content of the system. From the Witmer & Singer presence questionnaire (Witmer et al., 1998), 3 items were taken to address distraction factors related to the medium and interactions with it (Q8 to Q10). Lastly, presence is measured via 5 items (Q11 to Q15) from the SUS questionnaire (Slater, 1999).

Experiment Protocol

According to our main hypothesis, we designed the experiment protocol to create a comparable experience of annotating virtual stimuli across the two display modes (see Figure 3).

To explore the potential of medium order having an impact on the gathered data, each participant was randomly assigned to one of two groups: VR session first followed by the desktop session, or the opposite order.

An experiment session starts with each participant welcomed by the researcher at the lab and introduced to the task at hand with a pre-session survey and a consent form. After that, the participant is assigned the order of stimuli and is introduced to the corresponding experience with the following definition for pleasure: *"Pleasure characterizes positive emotions. Pleasure increase is connected with beautiful, exciting, calm and comforting. Pleasure decrease describes dull, uncomfortable, tense and or dissatisfying environments."*

The participant starts with a trial run to familiarize themselves with the actual session. Once confirming that everything is understood the session begins. During the session, participants are also encouraged to comment and think out loud but also to express if they want to leave the session. Once the session is finished, participants are instructed to fill out the post session survey. All these steps are repeated once more for the second display medium.

For each session, the following data was collected: pre- and post-session questionnaire responses, room parameters, Field of View (FOV) pitch and yaw angles and valence annotations via the use of RankTrace.

PARTICIPANTS

The experiments took place at the Institute of Digital Games (University of Malta) and at the Microsoft Computer Games and Emerging Technologies Research Lab (GET Lab) at the Department of Multimedia and Graphic Arts (Cyprus University of Technology) during the period of March and April 2022. Thirty-five (35) participants expressed interest to be involved in the experiment (15 from University of Malta and 20 from Cyprus University of Technology). Out of the 35 participants, two were used as pilot tests and their participation contributed to preparing the study for the remaining subjects. Of the remaining 33, two participants were excluded due to incomplete data and inconsistencies detected during their sessions. Reported results in this paper are from 31 participants (10 female and 21 male). Ages ranged from 18 to 45 years old, with the majority between 18 and 25 years old. Almost all participants were involved with either institution: 21 were students and 7 were lecturers or professors.

The selected sample self-reported high interaction frequency and familiarity with technology and desktop environments (mean 4 out of a 5-point Likert scale). Familiarity with VR displays was ranked low (mean 1.8 out of 5), with only 2 out of 31 rating themselves as high (5 out of 5) in familiarity with VR displays, and 15 out of 31 as low (1 out of 5). Regarding the order of shown media, 14 participants were shown VR first, desktop second, while 17 were shown the opposite order.

RESULTS

Below, we present the survey responses and the two main streams of recorded data within the VE.

Post session Survey responses

The post session survey data are analyzed by categorizing Likert scores of 4 and 5 as positive and scores 1 and 2 as negative. Neutral responses (Likert score of 3) are not included in Table 1. For flipped items, we focus on positive and negative responses in terms of the construct itself, i.e., the reverse of the item's responses and thus Likert scores of 1 or 2 are labeled positive and 4 and 5 as negative.

To assess significant differences between VR and desktop responses, we use all participant responses, including neutral responses, and compare the two media via Wilcoxon signed rank test, with significance at $p<0.05$. Our main hypothesis tests whether there are significant differences in user ratings between VR and desktop.

For the PSSUQ Usability Questionnaire (Q1-Q7) all 7 items display similarly positive tendencies for both setups, with 23 to 29 positive ratings out of 31 total responses. Q7 received the highest Likert score, suggesting that the annotation system was generally perceived as easy to understand and use in both media. There is minor difference between media, with Q1 showing the only significantly higher scores in favor of VR settings on overall user satisfaction.

For the W&S items (Q8-Q10) measuring distraction, 2 of 3 items (Q8, Q9) show significantly higher positive responses for desktop sessions compared to VR, meaning that VR introduces more interference from the medium in the annotation task. These responses could be attributed to participants' lack of familiarity with HMDs or the use of a mouse for the annotations in VR. For Q10, rating the ease of concentrating on the annotation task, VR was rated slightly higher than desktop, but no significant differences were recorded here. This slight favor for VR could be explained by its potential to encourage spatial exploration via the (HMD), suggesting a sensorimotor dependency.

Table 1
Survey responses. Significant differences between VR and desktop are marked with (*).

	Pos. VR	Neg. VR	Pos. DES	Neg. DES
1. Overall, I am satisfied with how easy it was to annotate while in the environment. **(*)**	27	1	23	2
2. It was simple to use the annotation system.	28	0	29	1
3. I could effectively complete the tasks and scenarios quickly using the present environment.	26	1	24	1
4. I was able to complete the tasks and scenarios using the environment.	27	0	26	0
5. I was able to efficiently complete the tasks and scenarios using the environment.	28	1	28	0
6. I felt comfortable using this environment	23	3	25	3
7. It was easy to learn to use the annotation system	29	0	27	0
8. To what extent did the visual display quality interfere or distract you from performing assigned tasks or required activities? (flipped) **(*)**	13	14	4	22
9. To what extent did the control devices interfere with the performance of assigned tasks or with other activities? (flipped) **(*)**	9	19	3	21
10. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	23	3	19	5
11. I had a sense of being there during the experience **(*)**	27	0	15	11
12. There were times during the experience when the virtual world was the reality for me **(*)**	18	6	10	17
13. Thinking back at the experience you just had, do you think that the buildings were images you just saw or more somewhere that you visited? **(*)**	16	3	8	16
14. During the time of the experience, which was strongest overall, your sense of being in the virtual environment, or of being in the real world of the laboratory? (flipped) **(*)**	6	20	16	10
15. During the time of the experience, did you often think to yourself that you were just sitting in a laboratory or did the experience overwhelm you? **(*)**	29	5	9	15

For the SUS presence questionnaire (Q11-Q15), VR sessions were rated significantly higher than the desktop on all items. As expected, VR offers a better experience of presence, with 27 of 31 participants agreeing that they had a sense of being there during the experience (Q11).

A subsequent test was carried out to determine if there is an impact on responses based on the order of presentation of each medium. We implemented a Mann-Whitney U test with the hypothesis that there is a significant difference between the two groups. Tests revealed that a few items were significantly different between the VR first and the desktop first group ($p<0.05$): for VR 3 out of 15 items (Q1, Q7 and Q9), and 2 for desktop (Q1 and Q7). Since only a few items showed significant differences, we reject that order played a major effect in the users' feedback.

Impact of design parameters

Based on the user's interaction data (i.e., pleasure annotations and viewing behavior), we explore how these map to the design parameters of the individual rooms that the user is in. We split the data into rooms (see Figure 4) based on the timestamp when the user enters and exits a room, and measure the *mean pleasure* annotated in each room (all traces are normalized between 0 and 1 before processing them) and the total *angular distance* (pitch and yaw angles) of the FOV per room.

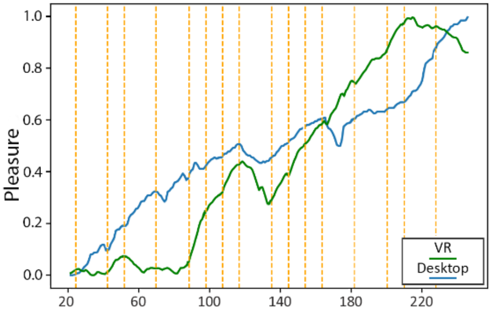

Figure 4
Pleasure annotations over time (sec) for a participant for both displays. Dashed lines represent room time-windows.

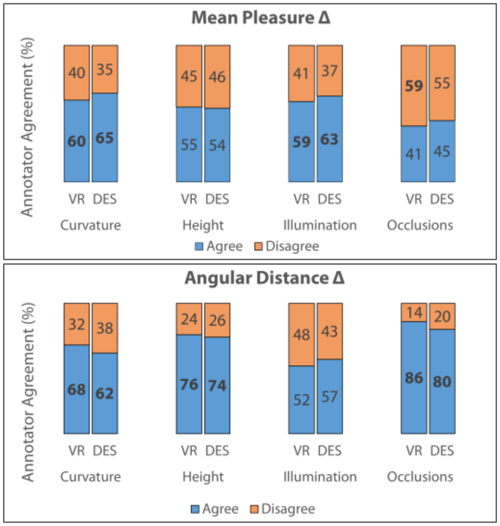

Figure 5
Mean pleasure and angular distance agreements with design parameters for VR & desktop. Bold values denote statistical significance.

We process annotation values following a relative approach, whereby we compare the changes in mean valence (or the total viewing angular distance) between consecutive rooms with the respective design feature change in these rooms. For instance, if the user moves from an empty room to an occluded room, we note that the occlusion parameter increases. If the annotated mean pleasure of the second room is also higher than the mean annotated pleasure of the first room, we treat this as an agreement between design parameter and valence (design parameter increase leads to increased pleasure value). If the mean pleasure of the second room is lower than the mean pleasure of the first room, we note this as disagreement (design parameter increase leads to decreased pleasure value). By observing all participants' room sequences, we collect pleasure annotation and viewing behavior agreements and disagreements with their corresponding design parameter changes. Results are summarized in Figure 5 for both media, across all four design parameter categories.

We calculate significance based on the binomial distribution of all affect and FOV changes, when the spatial feature changes, assuming a 50% probability that the changes may be in agreement. Significance is established at 95% confidence.

In Figure 5 (top), the mean pleasure difference results show significant agreements both for VR and desktop in contour curvature and ambient illumination. This recorded agreement tendency for this selected sample indicates a mild preference towards curved contours, aligning with results from previous studies (Gómez-Puerto et al., 2018) and colder illumination scenarios. On the other hand, and only in the VR sessions, increased occlusion led to a decrease in valence, which could be explained by discomfort of enclosed spaces, particularly noticeable in VR settings due to the higher presence it offers.

Results regarding participants' viewing behavior (see Figure 5, bottom) show consistent agreements for both media. Especially for occlusion and height, participants move their heads more in high-ceiling rooms or in rooms with occlusion (higher angular distance). Thus, users tend to explore visually more in such rooms compared to empty rooms or rooms with lower ceilings. This viewing behavior is understandable for both features considering a transition from a lower ceiling room to a high ceiling (Meyers-Levy et al. 2007) or from an empty room to one that has occluding elements.

DISCUSSION

The present work introduced an approach for exploring a sequence of interior spaces and integrated an online annotation approach. This is in line with our previous work (Xylakis et al., 2021) which emphasized the temporal dimension of environment appraisal. The task of spatial exploration occurred by controlling only the FOV, while moving on a fixed predetermined path. The moment-to-moment annotation of pleasure was carried out by 31 participants using two means of display, one via desktop display and one via HMD.

The scope of this work was to study the effect of display medium (desktop versus HMD) on the task of experiencing synthetic interior forms while continuously reporting affect changes. A post session survey containing items on usability, distraction and presence revealed the following: (1) significant indications of presence for VR sessions, (2) higher distraction tendencies for VR sessions and (3) positive feedback with no significant differences between the two media in terms of usability. Higher interference by the VR medium could be explained by participants' limited experience with VR technology. Another factor that could have affected the participants' ratings is that the VR experience used a computer mouse as the annotation device rather than a VR-ready controller (such as the HTC Vive controller). The computer mouse was chosen as the input controller for VR to limit the varying parameters with the desktop experience.

Beyond usability and ease of annotation, we carried out a subsequent analysis on the data collected from within the VE, aimed at comparing viewing behavior and affect annotations in relation to the design parameters, considering either of the two media displays. Trends between presence or absence of design features and viewing behavior or affect annotation were similar in both media, with users moving their field of view more in high ceiling rooms and rooms with occlusions, while reporting higher valence when moving from a rectilinear to a curved room and from warm illumination to cold illumination.

Limitations & Future work

A limitation of our current study is the use of randomly generated sequences of rooms per participant. This allowed us to more robustly check how users perceive the annotation task in many scenarios, but could not allow us to perform inter-annotator agreement tests in terms of their reported valence or their FOV behavior on the same stimuli shown in the same order. Future directions will focus on gathering more affect annotations for VR with the aim of providing more robust results, including other dimensions of affect (such as arousal, tension, etc.). Secondly, the traversal of the rooms was done on a fixed path (on "rails") at a fixed move speed. This ensured consistent task durations and easier data analysis regarding the varying design parameters and their order of appearance. However, it does not capture how users move around the space and explore it. Future directions could consider greater freedom of exploration, but would need to invest in stimuli alignment methodologies as explored by Xue et al. (2021). Lastly, immersive media such as VR call for domain-specific self-assessment mechanisms. Our current methodology leveraged a successful affect annotation tool for desktop and implemented it in VR while occluding part of the user's view. It is important to define ad-hoc goals and criteria as in (Xue et al., 2021, Toet et al., 2019) and design real-time continuous affect annotation interfaces explicitly for immersive media or mixed realities.

CONCLUSION

In this work we introduced a methodology for capturing online continuous assessment of affect during interaction with an immersive environment. We developed an application to support this methodology, targeting both a VR and a desktop experience and conducted a study evaluating the user experience in both media. The current approach served as an initial step to combine the moment-to-moment experience of spatial stimuli and their simultaneous assessment in a one-dimensional manner. More research is needed regarding the expressivity of one-dimensional annotation protocols in the context of spatial appraisal. Moving forward, future studies should assess the cognitive load and obstructiveness of the proposed method. Advancements in this area would directly benefit the study of architecture and emotion and can potentially be targeted at pre-evaluation stages of the architectural design process.

ACKNOWLEDGEMENTS

We would like to thank Domna Banakou for her feedback and suggestions for the manuscript and Christos Kyrlitsias for recruiting the participants at the Cyprus University of Technology. Ali Najm has been supported by the special scientists budget (3/319) of the Department of Multimedia and Graphic Arts of the Cyprus University of Technology. Emmanouil Xylakis, Antonios Liapis and Georgios N. Yannakakis have been supported by the European Union's H2020 research and innovation programme (Grant Agreement No. 951911).

REFERENCES

Bradley, M.M. and Lang, P.J. (1994). 'Measuring Emotion: The Self-Assessment Manikin and the Semantic Differential', *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1), pp. 49–59.

Chamilothori, K., Wienold, J. and Andersen, M. (2019). 'Adequacy of Immersive Virtual Reality for the Perception of Daylit Spaces: Comparison of Real and Virtual Environments', *Leukos*, 15(2-3), pp.203-226.

Desmet, P.M.A., Romero, N. and Vastenburg, M.H. (2016). 'Mood Measurement With Pick-A-Mood: Review of Current Methods and Design of a Pictorial Self-Report Scale', *Journal of Design Research*, 14(3).

Gómez-Puerto, G., Rosselló, J., Corradi, G., Acedo-Carmona, C., Munar, E. and Nadal, M. (2018). 'Preference for Curved Contours across Cultures', *Psychology of Aesthetics, Creativity, and the Arts*, 12(4).

Gregorians, L., Velasco, P.F., Zisch, F. and Spiers, H.J. (2022). 'Architectural Experience: Clarifying its Central Components and their Relation to Core Affect with a Set of First-Person-View Videos', *Journal of Environmental Psychology*, 82.

Hansen, E.K., Bjørner, T., Xylakis, E. and Pajuste, M. (2022). 'An Experiment of Double Dynamic Lighting in an Office Responding to Sky and Daylight', *Indoor and Built Environment*, 31(2).

Hildebrand, G. (1999). *Origins of architectural pleasure*. University of California Press.

Hugo, C. (2021). 'Perceived Sensations in Architectural Spaces through Immersive Virtual Reality', *VITRUVIO - International Journal of Architectural Technology and Sustainability*, 6(2), pp. 70–81.

Krüger, C., Kojić, T., Meier, L., Möller, S. and Voigt-Antons, J.N. (2020). 'Development and Validation of Pictographic Scales for Rapid Assessment of Affective states in Virtual Reality', in *Proceedings of the International Conference on Quality of Multimedia Experience*, pp. 363–375.

Lewis, J.R. (1995). 'IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use', *International Journal of Human-Computer Interaction*, 7(1), pp.57–78.

Lopes, P., Yannakakis, G.N. and Liapis, A. (2017). 'Ranktrace: Relative and Unbounded Affect Annotation', in *Proceedings of the International Conference on Affective Computing and Intelligent Interaction*, pp. 158-163.

Marín-Morales, J., Higuera-Trujillo, J.L., Greco, A., Guixeres, J., Llinares, C., Scilingo, E.P., Alcañiz, M. and Valenza, G. (2018). 'Affective Computing in Virtual Reality: Emotion Recognition from Brain and Heartbeat Dynamics Using Wearable Sensors', *Scientific Reports*, 8(1).

Meyers-Levy, J. and Zhu, R. (2007). 'The Influence of Ceiling Height: The Effect of Priming on the Type of Processing that People Use', *The Journal of Consumer Research*, 34, pp. 174–186.

Nystad, E. and Sebok, A. (2004). 'A Comparison of Two Presence Measures Based on Experimental Results', in *Proceedings of the Seventh International Workshop on Presence*, pp. 266–273.

Picard, R.W. (2000). *Affective computing*. MIT press.

Pinilla, A., Garcia, J., Raffe, W., Voigt-Antons, J.N., Spang, R.P. and Möller, S. (2021). 'Affective Visualization in Virtual Reality: An Integrative Review.' *Frontiers in Virtual Reality*, 2.

Riva, G. (2007). 'Affective Interactions Using Virtual Reality: The Link between Presence and Emotions', *Cyberpsychology & Behavior*, 10(1), pp. 45–56.

Sen, S., Flyvholm, A., Xylakis, E., Nielsen, S.M.L., Hansen, E.K., Mullins, M.F. and Triantafyllidis, G. (2017). 'Towards Assessing the Impact of Circadian Lighting in Elderly Housing from a Holistic Perspective', In *Proceedings of ARCH17*, pp.227-240.

Slater, M. (1999). 'Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire', *Presence: Teleoperators and Virtual Environments*, 8(5), pp.560-565.

Schneider, S., Kuliga, S., Weiser, R., Kammler, O. and Fuchkina, E. (2018). 'VREVAL-A BIM-based Framework for User-Centered Evaluation of Complex Buildings in Virtual Environments', in *Proceedings of the 36th eCAADe Conference*.

Toet, A., Heijn, F., Brouwer, A.M., Mioch, T. and van Erp, J.B. (2019). 'The EmojiGrid as an Immersive Self-Report Tool for the Affective Assessment of 360 VR Videos', in *Proceedings of the 16th EuroVR International Conference*, pp. 330-335

Unity 3D, https://unity.com/, (Accessed 8 February 2023)

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L.B., Leder, H., Modroño., C, Nadal., M, Rostrup., N and Skov., M. (2013). 'Impact of Contour on Aesthetic Judgments and Approach-Avoidance Decisions in Architecture', in *Proceedings of the National Academy of Sciences*, pp.10446-10453.

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L.B., Leder, H., Modroño, C., Rostrup, N., Skov, M., Corradi, G. and Nadal, M. (2019). 'Preference for Curvilinear Contour in Interior Architectural Spaces: Evidence from Experts and Nonexperts', *Psychology of Aesthetics, Creativity, and the Arts*, 13(1).

Voigt-Antons, J.N., Lehtonen, E., Palacios, A.P., Ali, D., Kojic, T. and Möller, S. (2020). 'Comparing Emotional States Induced by 360 Videos via Head-Mounted Display and Computer Screen', in *Proceedings of the International Conference on Quality of Multimedia Experience*.

Weber, S., Weibel, D. and Mast, F.W. (2021). 'How to Get There when You Are There Already? Defining Presence in Virtual Reality and the Importance of Perceived Realism', *Frontiers in Psychology*, 12.

Xue, T., El Ali, A., Zhang, T., Ding, G. and Cesar, P. (2021). 'RCEA-360VR: Real-Time, Continuous Emotion Annotation in 360 VR Videos for Collecting Precise Viewport-Dependent Ground Truth Labels', in *Proceedings of the Conference on Human Factors in Computing Systems*.

Xylakis, E., Liapis, A. and Yannakakis, G.N. (2021). 'Architectural Form and Affect: A Spatiotemporal Study of Arousal', in *Proceedings of the International Conference on Affective Computing and Intelligent Interaction*.

Yannakakis, G.N. and Martinez, H.P. (2015). 'Grounding Truth via Ordinal Annotation', in *Proceedings of the International Conference on Affective Computing and Intelligent Interaction*.

Yannakakis, G.N., Cowie, R. and Busso, C. (2021). 'The Ordinal Nature of Emotions: An Emerging Approach', *IEEE Transactions on Affective Computing*, 12(1), pp. 16–35.