A Biometric Method for Spatial Experience Analysis:
A Case Study of Airport Design and Traveler Stress

Humbi Song[1], Harvard Graduate School of Design, United States
Isa He[2], Harvard Graduate School of Design, United States
Zach Seibold, Harvard Graduate School of Design, United States
Allen Sayegh, Harvard Graduate School of Design, United States

The European Conference on Arts, Design & Education 2022
Official Conference Proceedings

Abstract
Why do certain built environments and events induce stress? How does the design of our spatial environment affect our mental state? What can we do to measure and understand these interactions? Interdisciplinary collaborations between architecture and psychology have given rise to a new frontier of architectural research, and emerging biometric sensor technologies lead to innovative research methods that can provide a unique insight into human spatial experiences. This research uses the passenger experience of air travel as a case study for prototyping methods of quantifying and understanding individual spatial experience. The airport presents a potent case study environment; though significant energy has gone into engineering the passenger experience, the prevailing cultural perception of air travel remains tinged with unease and anxiety. The presented research outlines a methodology for quantitatively measuring the passenger experience of the airport design: equipping passengers with biometric electrodermal activity (EDA) sensors – a biomarker significantly correlated to emotional stress response, analyzing first-person video footage worn by participants to map contextual information, and conducting interviews to assess the participant's perception of the air travel experience. A dashboard was then developed to facilitate visual cross-referencing and analysis of aspects of airport design and social stressors at airports with the biometric data of the passengers and their self-reported perceptions. The overall aim of this research is to identify key elements to help rethink and redesign airport architecture and experience. Future research can utilize this methodology to facilitate speculations on alternative scenarios for designing not only airport architecture but also other analogous public spaces.

Keywords: Biometric Wearables, Spatial Experience, Stress, Built Environment, Airport, Interdisciplinary Research Methods

iafor
The International Academic Forum
www.iafor.org

[1] Co-first authors
[2] Co-first authors

1. Introduction

Occupants experience spaces in ways that are difficult to anticipate. Why do we get frustrated in certain spaces and at certain times? Why do certain built environments and events induce stress? What can we do to measure and understand these interactions? These fundamental questions about the human experience of the built environment have challenged architects, engineers, and experts in human factors alike.

This paper proposes the integration of psychology and neuroscience research tools – specifically emerging biometric wearables technology – into architectural research as an essential toolkit for gaining insight into the human experience of spatial conditions. Using the passenger experience of air travel as a case study, this research presents a methodology and a data analysis dashboard for identifying stress triggers through the airport by tracking physiological changes with biometric sensors. The proposed method of quantifying spatial experiences is intended to be eventually adaptable to a wider variety of built environment settings.

Air travel presents a potent case study environment for observing the effects of designed spaces and systems on the individual experience. Notorious as a stressful experience, airports are tightly controlled, sequential spatial environments with set expectations on the manner of navigating through spaces. To test the validity of the research methodology, preliminary experiments were performed at airports in the United States where passengers were equipped with biometric sensors and cameras. Through a series of trial and error, these studies allowed the development of an appropriate equipment and experiment set-up to quantify the effects of different spatial and contextual elements on passenger stress.

In addition, a prototype dashboard was developed to visualize the collected data for analysis. The dashboard facilitates a visual cross-referencing of video footage, biometric data, spatio-temporal stress map, critical for understanding the context surrounding stressful situations within diverse traveler experiences in airports. From it, a taxonomy of air travel specific stress triggers were determined through examining the antecedents of stress, including event characteristics, people and technology interactions, and location specific qualities.

The overall aim of this research is to invite a rethinking of architecture and systems design by bolstering the dialogue with individual experience data. This research proposes an evidence-based design approach for air travel design professionals as an alternative to conventional precedent-based design approach. Future research can utilize this biometric methodology to gain a detailed interdisciplinary knowledge of how people experience emotions in different spaces. This would empower human-centered individual perspectives during design decision making, and facilitate alternate design speculations by architects, designers, and stakeholders.

2. Measuring the Human Experience at Airports

2.1 Airport as Case Study

Airport presents a compelling case study context for researching the effects of designed spaces and systems on the individual experience, with a particular focus on understanding stress in the built environment. Air travel is commonly regarded as a stressful ordeal, with most passengers able to recount their own previous airport horror stories (Schaberg, 2012). Additionally, airports are tightly controlled spaces that explicitly and implicitly guide people through a sequence of spatial environments (Adey, 2003). These factors make airports a particularly appropriate setting for examining these research topics.

The airport, as a site of governmental border control, is designed to facilitate the controlled flow of large numbers of people. To do so, individuals within the airport are surveilled and tracked, with a limited freedom of movement. Because of this, passengers can feel a lack of autonomy and agency, and at the mercy of the environment, airport processes, and personnel. This contributes to the creation of a new airport culture, consisting of a collection of unspoken norms, etiquette, and social expectations (Schaberg, 2012).

In addition, airport architecture is commonly regarded as sterile and generic spaces that suppress diversity of culture and society, despite the heterogeneity of the travelers and the specific geographic locality of the airport (Augé, 2008; Sharma, 2009). Regardless of the actual location of the airports, airport buildings frequently feel distinctly similar to each other and "function effectively when their occupants need not confront the challenge of otherness—unique places, politics, and personalities" (Wood, 2003).

Though significant energy has gone into improving the passenger experience, the prevailing individual experience of air travel remains tinged with unease and anxiety (Airport Cooperative Research Program et al., 2011). Design discipline commonly looks at existing precedents and tries to improve upon them. However, in the highly regulated air travel sector, driven by needs of safety, efficiency, and logistics, existing designs often deprioritize the human experience. Thus, iterating on previous designs frequently reproduces the same frustrations. The air travel sector may benefit from a more human-centric evidence-based design methodology.

2.2 Biometric Sensing Wearables

While architects have contemplated the human experience of the built environment from arguably the origins of the discipline itself, attempts to methodically research this experience came to the foreground around the 1960s (Karakas & Yildiz, 2020). These foundation studies by Kevin Lynch, Jane Jacobs, and William Whyte relied on observational studies and surveys as their primary research techniques (Lynch, 1960; Jacobs, 1961; Whyte, 1980). Today, advances in biometric sensing tools provide an extraordinary opportunity to build upon this work, allowing novel methods of tracking physiological responses, and adding quantitative understanding of the human experience of the built environment (Sagl et al., 2019). In addition, these methods can offer a measure of systematic repeatability in their studies. Interdisciplinary collaborations among architecture, psychology, and neuroscience have given rise to this new frontier of architectural research, incorporating biometric tools such as eye trackers, proximity sensors, brain electroencephalography scanners, wrist-worn health monitors, body cameras, and others. (ESUM, 2017; Karakas & Yildiz, 2020; Poh et al., 2010; Schlickman et al., 2019).

To glean potential areas for intervention, this research is particularly interested in understanding changes to emotional stress during an experience. A range of biomarkers were explored for possible correlation to stress, including heart rate, heart rate variability. respiration rate, electrodermal activity, eye gaze, pupil dilation, blood pressure, skin temperature, brain electroencephalography, and more (Gao et al., 2022; Healey & Picard, 2005; Kyriakou et al., 2019; Schmidt et al., 2018). Following a review of the relevant literature, this work focused on electrodermal activity, as a leading candidate for tracking stress and emotional changes (Kyriakou et al., 2019; Picard et al., 2016; Poh et al., 2010; Sagl et al., 2019).

2.3 Antecedents of Stress

An abundance of existing research investigates the cause of stress (Greco & Roger, 2003; Grupe & Nitschke, 2013; Neubauer et al., 2018; Van Hedger et al., 2017), ranging from environmental triggers to personal characteristics, from acute stress to chronic stress. Due to the focus of this paper, the authors are most interested in identifying stress triggers within the air travel experience.

Within the cross-cultural environment of the airport, the passengers' individual cultural differences can have a large impact on their perception of the passenger experience (Pantouvakis & Renzi, 2016) Therefore it is important to separate the situational and environmental influences on stress from individual cultural specificities. Existing research examining the experience of stress concludes that certain settings and environments are prone to triggering particular emotions such as stress (Scherer, 1986; Gatersleben & Griffin, 2017). Thus, understanding the antecedent situation of stress can help reveal situation-specific characteristics that influence the emotional state. Scherer's framework dissects the aspects of emotion clearly into person-specific characteristics and situation-specific ones. The separation of person specific and situation specific characteristics allows for researchers to focus on aspects of emotion independent of individual differences such as personal characteristics, behavioral tendencies, and perceived social and cultural norms.

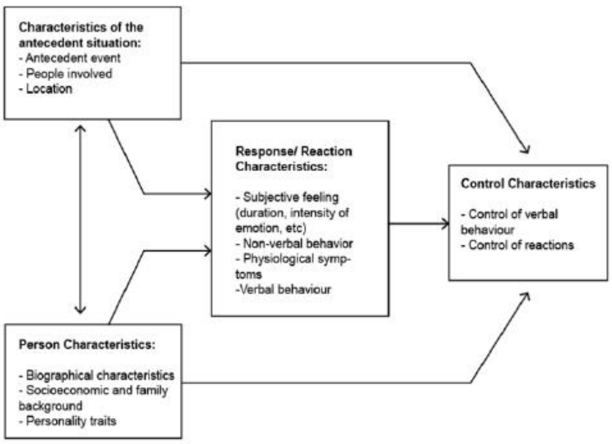

Figure 1. Scherer's diagram of "Relationships between the different aspects of emotion" in Experiencing Emotion: A cross-cultural study (Scherer, 1986).

Within the experience of air-travel stress, this research work is specifically interested in acute stress triggered by an event's nuanced characteristics. Activity qualities such as time sensitivity and uncertainty, while not exclusive to air travel, are significant air travel specific characteristics that affect individual's stress and event perception (Greco & Roger, 2003; Grupe & Nitschke, 2013; Neubauer et al., 2018; Van Hedger et al., 2017). By tackling the characteristics of the antecedent situation of an individual's emotional state, using the lens of Scherer's analysis, this research work strives to clearly determine the exact aspects of air-travel design that trigger passenger stress.

Comprehensively analyzing the context surrounding an activity is critical to understanding passenger experiences and sources of stress. Research by Kirk et al. categorized airport activities into eight taxonomic groups – processing, preparatory, consumptive, social, entertainment, passive queuing, and moving – to better understand passenger experience at airports (Kirk et al., 2012). This activity-centered approach is a useful model for categorizing and analyzing antecedent situations as stress triggers, as a taxonomy of activities can be easily matched to heightened physiological changes.

3. Methodology

3.1. Selection of Biometric Wearable Devices

This case study examines the passenger's physiological responses throughout the air travel experience, focusing on the time of their arrival at the airport to becoming seated at the airplane. In order to better understand one's stress and emotional changes, the researchers focused on electrodermal activity (EDA) in particular.

Electrodermal activity (EDA) is understood to be one of the most useful indicators of stress (Picard et al., 2016). Also known as galvanic skin response (GSR), or skin conductance (SC), this biomarker tracks changes in the skin sweat response on the body's extremities such as fingers, palm, wrist, and feet. Subconscious changes in cognitive and emotional states affect the body's sweat gland production, which can be detected as increased electrical conductance by electrodes placed on the skin. It has been noted to be "one of the most sensitive and valid markers of emotional arousal" (Kyriakou et al., 2019), where emotional arousal refers to the intensity of an emotional state such as anger, excitement, stress, joy, and fear.

Of the variety of wearable types worn at different locations on the body, wrist-worn wearables quickly became a strong preference. Because one of the major stressors at the airport is adhering to numerous anti-terrorism security protocols, researchers chose to explore wearables with a visual similarity to a watch, specifically commercial-grade wearables (Fitbit, Apple Watch, WHOOP), and medical-grade wearable Empatica E4. Not only are security personnel unlikely to mistake these devices as threatening, but also participants often feel more comfortable using these devices in the field. This lessens the potential for the participant's biodata to be contaminated by additional stress response due to the presence of the device itself. In addition, due to their prior familiarity with commercial health trackers, these participants are better equipped to understand and predict how their experience may be altered by agreeing to the study.

Wearable Device	Empatica E4	Shimmer Consensys GSR	Fitbit Charge (and others)	WHOOP	Apple Watch
Location	Wrist	Finger and Wrist	Wrist	Wrist	Wrist
HR	Yes	Yes	Yes	Yes	Yes
HRV	Yes, outputs continuous data	Yes, outputs continuous data	Yes, outputs daily average (Unverified accuracy)	Yes, outputs daily average (Unverified accuracy)	Yes, outputs daily average (Unverified accuracy)
EDA	Yes, med accuracy	Yes, high accuracy	No	No	No
Data Output + Timestamp	Output is .csv file of data points per (<) second	Output is .csv file of data points per (<) second	Cannot export directly. Can screenshot from web interface.	Cannot export directly. Can screenshot from mobile interface.	Cannot export directly. Can screenshot from mobile interface.
Type	Medical grade	Medical grade	Consumer grade	Consumer grade	Consumer grade

Table 1. Comparisons of different biometric sensing hardware available to researchers

3.2. Air Travel Passenger Experiments Set Up

Through numerous trial runs with different participants, the researchers assembled and refined a preferred methodology for measuring the passengers' emotional changes during the airport experience, that allows long term measurement and presents minimal disturbance to their typical behavior. This method collects data through two main devices: (1) an Empatica E4, a wrist-worn wearable which collects HR, HRV, EDA, Accelerometer, Skin Temperature, and Blood Volume Pulse; and (2) a microcamera to be clipped on a shirt pocket which captured a first-person video footage to allow researchers to understand the spatial and situational contexts corresponding to any changes in biodata levels. The experiments consisted of the following steps:

Step 1: Ten Participants who had existing plans to fly out of Boston Logan International Airport were recruited. To ensure the navigation of similar initial spaces,the subject pool was limited to participants flying out of Logan. Many also experienced other airports on layovers.

Step 2: Participants were outfitted with two wearable devices. 1) the wrist-wearable Empatica E4 device, and 2) a microcamera, a small pen-like video camera wearable that can be clipped onto a person's shirt pocket.

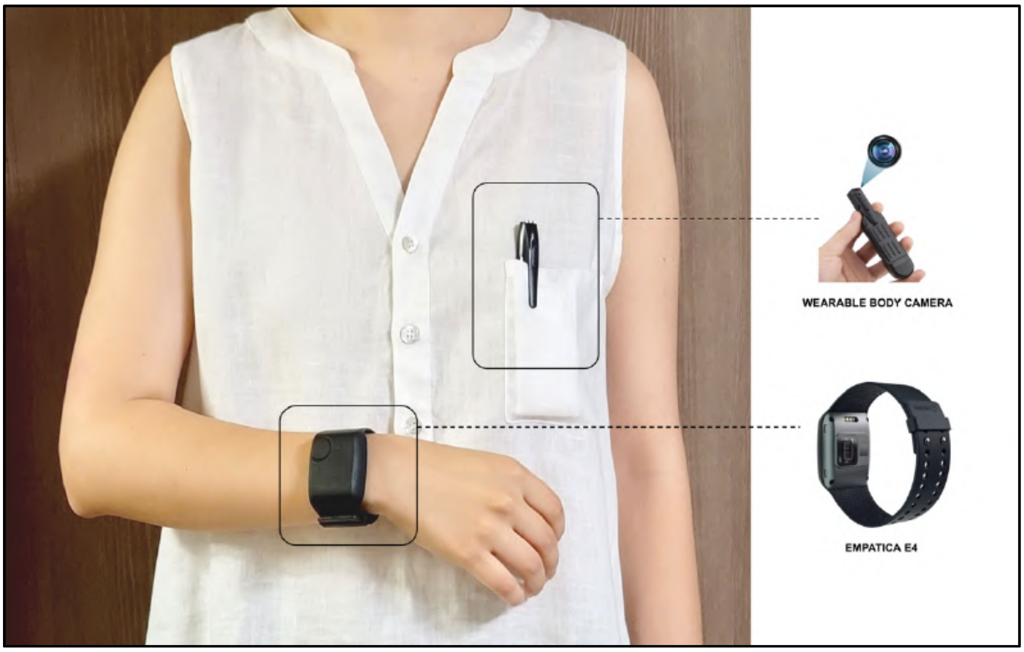

Figure 2: Participant outfitted with Empatica E4 and microcamera.

Step 3: Participants were instructed to turn on both devices as they leave home. Both devices should be left on during their transportation to the airport, and throughout the airport, except for the moment of going through the security scanner. As a privacy measure, the microcamera has a sliding cover over the lens which participants may use whenever desired.

Step 4: Participants were instructed when to turn off the devices. Due to privacy reasons and battery longevity, the microcamera is to be turned off once seated in the flight, and the Empatica is to be turned off after exiting their destination airport.

Step 5: Participants were interviewed after the flight. Because EDA biodata correlates to the intensity of emotional arousal response, rather than the valence – interviews were conducted to record whether a recorded spike in EDA corresponded to a positive (i.e. excitement) or negative emotion (i.e. stress).

The data output from these two devices were then compiled by the researchers (Figure 3). The Empatica software provides an initial visualization interface and allows the exporting of data as a .csv file. The microcamera provides video footage which is then stabilized through a video editing software.

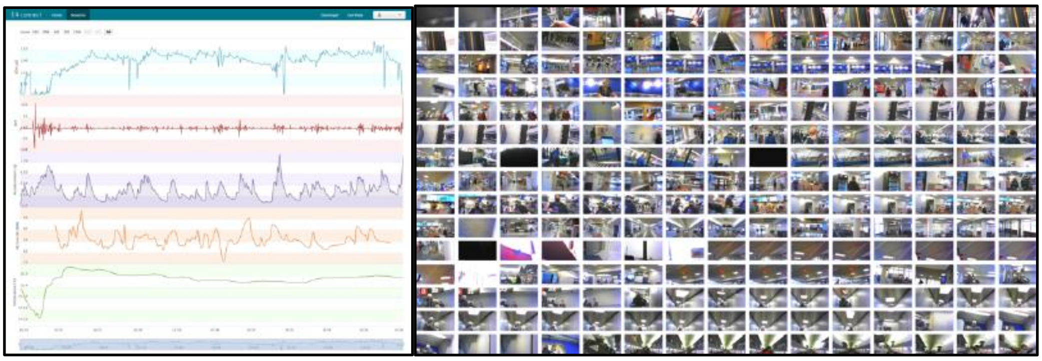
Figure 3: Empatica visualization interface (left), and video footage from microcamera (right).

4. Data Analysis Methods and Dashboard

To understand the effects of air travel activities on passenger stress, the initial analysis method involved manually analyzing the video footage frame-by-frame (Figure 5), rigorously documenting activity events by timestamp (Figure 6), and corresponding the events to the EDA levels collected from Empatica (Figure 7). With this method, researchers were able to identify the specific antecedent events that caused an increased EDA, such as interactions with human or technology, or location specific characteristics.

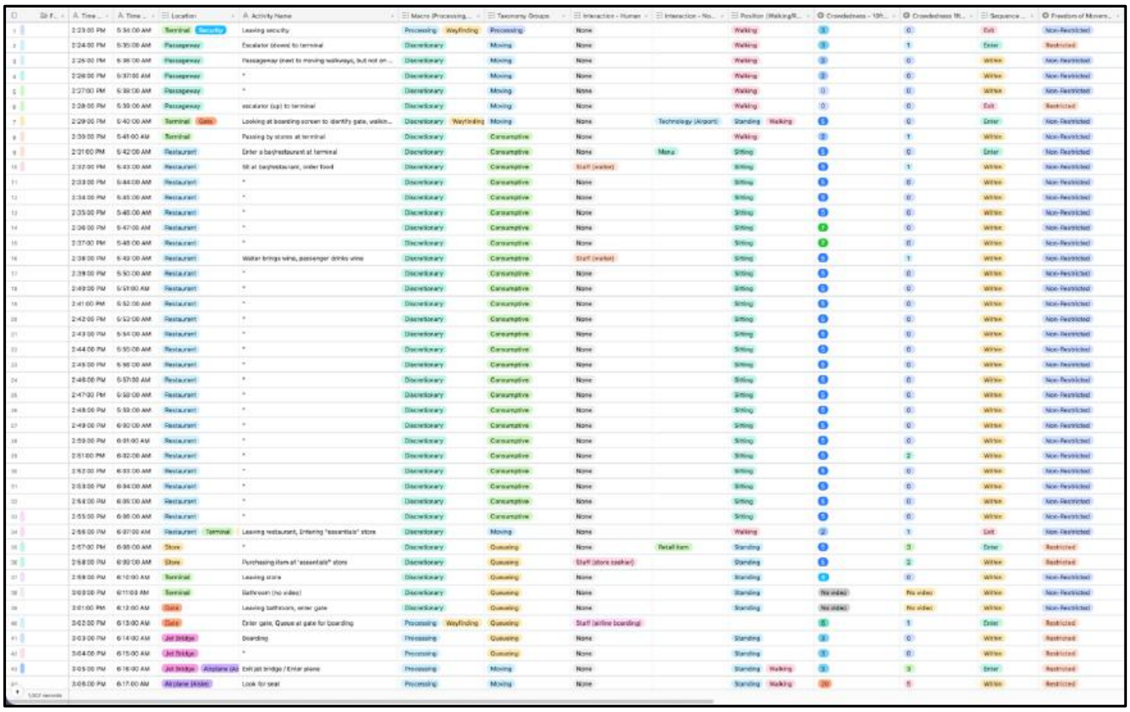

Figure 4. Documentation of the sequence of events from video footage.

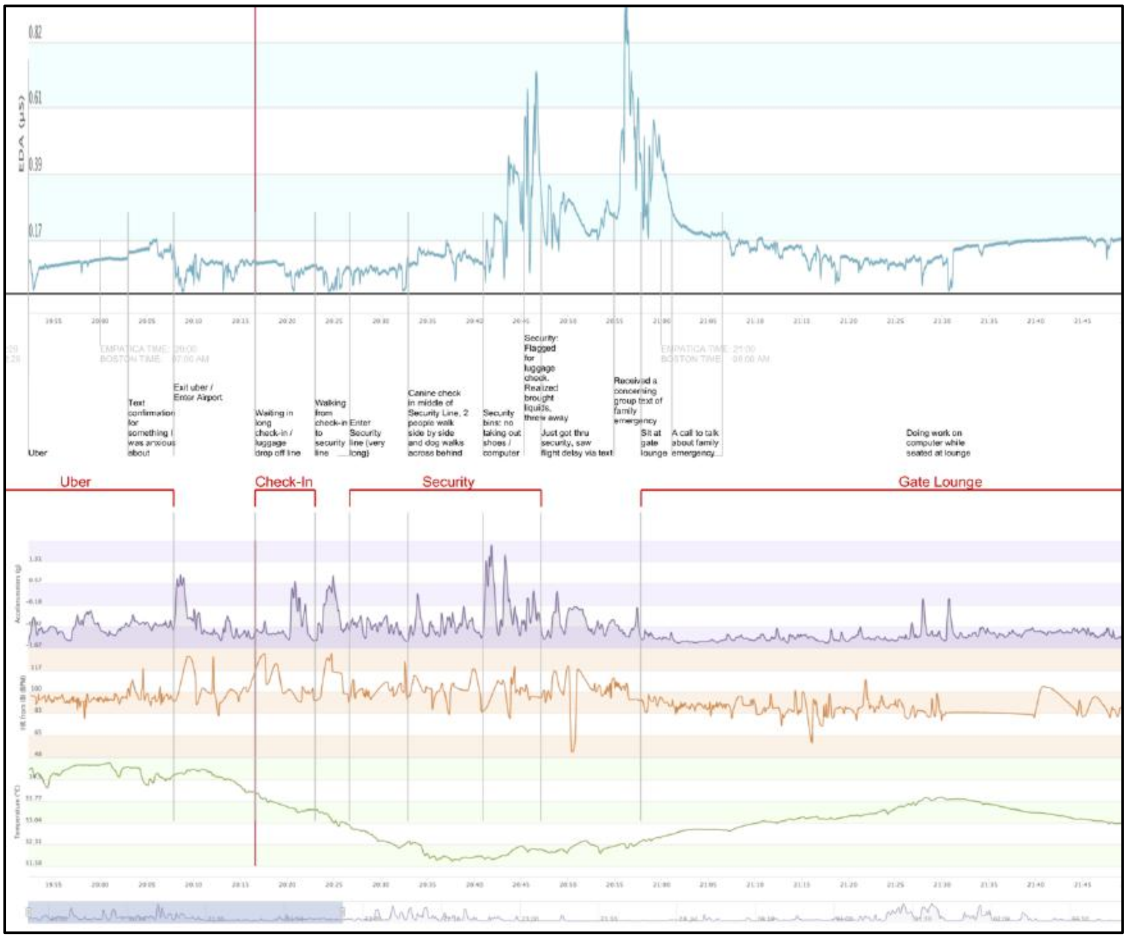

Figure 5. Documentation of macro and micro events corresponding to biometric data collected from the Empatica E4.

4.1 Development of the Dashboard

Researchers found that this initial method, while extremely detailed and informative, was not conducive to easily cross-referencing the different aspects of the air-travel experience. To streamline the analysis process, a draft dashboard was developed to simultaneously view all biometric data, video, stress trigger activities, and location within the airport (Figure 8). After initial testing of the draft dashboard, areas of improvement were identified and a finalized dashboard was developed (Figure 9). The resulting dashboard facilitates concurrent analysis of the spatial and social stressors at airports with the quantitative biometric data of the passengers and their qualitative self-reported perceptual experiences. This allows the identification of the antecedent situations affecting stress level changes in airports.

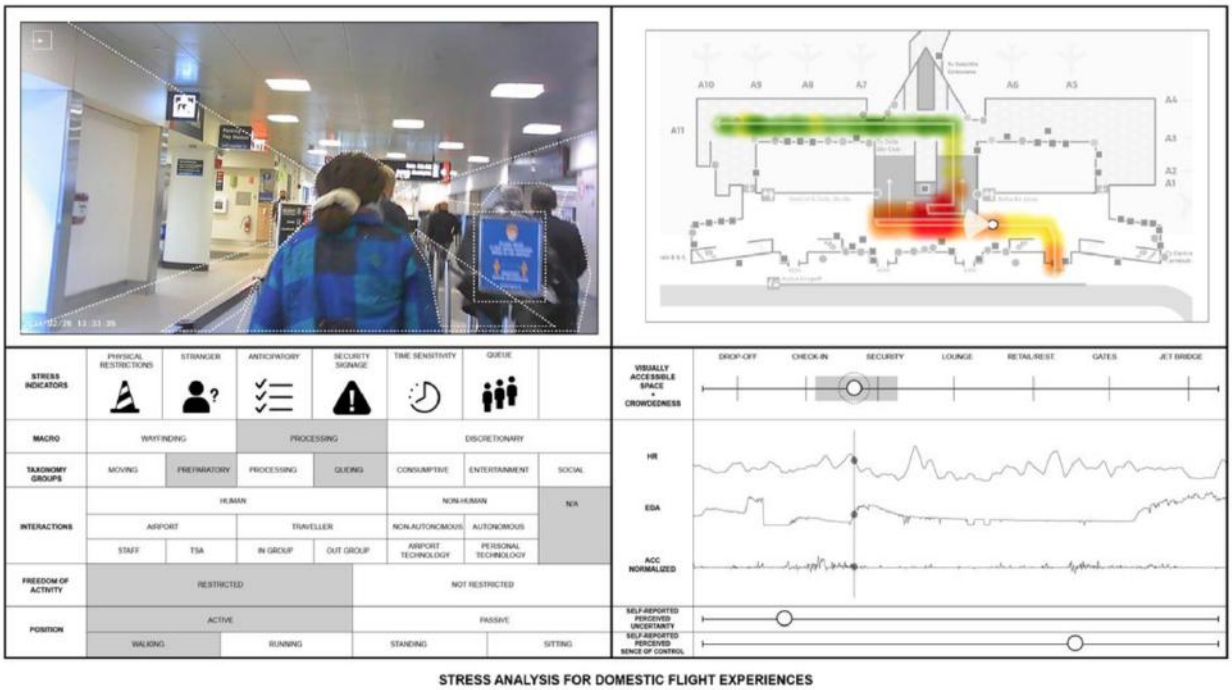

Figure 6. Draft dashboard visualizes biometric data, video, stress trigger activities and location within the airport.

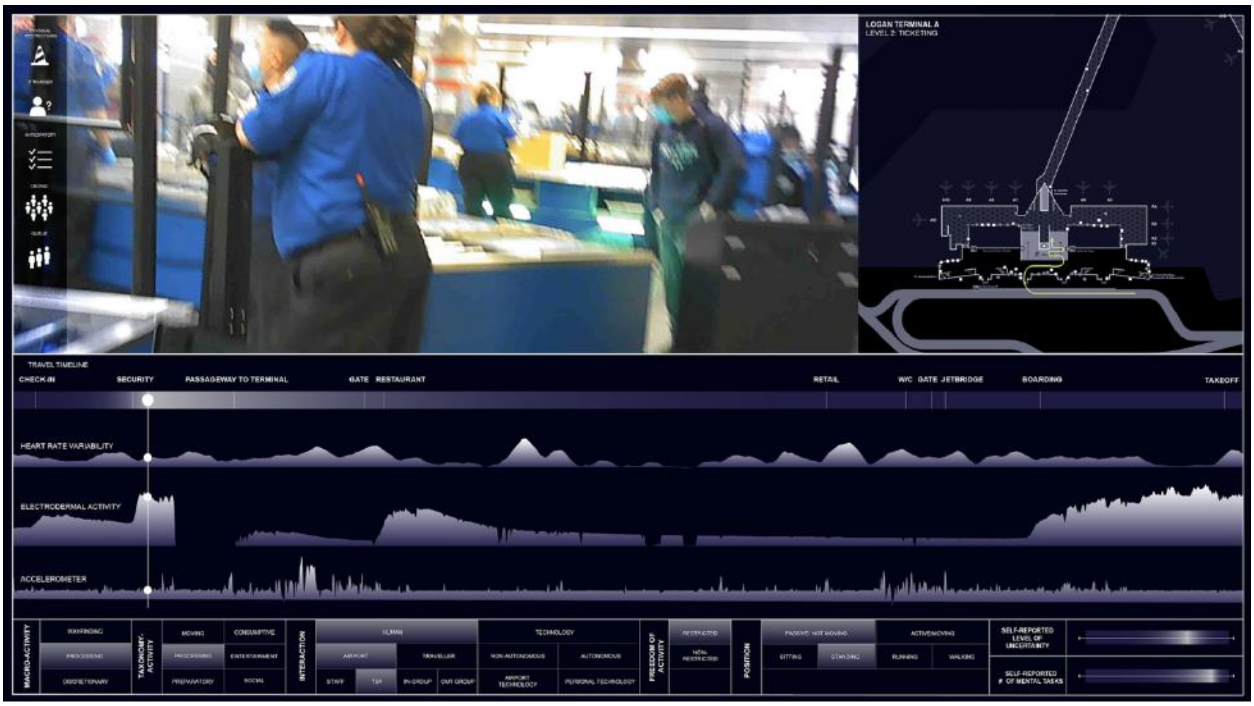

Figure 7. Finalized dashboard allows for cross-referencing of raw biometric data, video footage, spatial representation of stress, and stress trigger analysis.

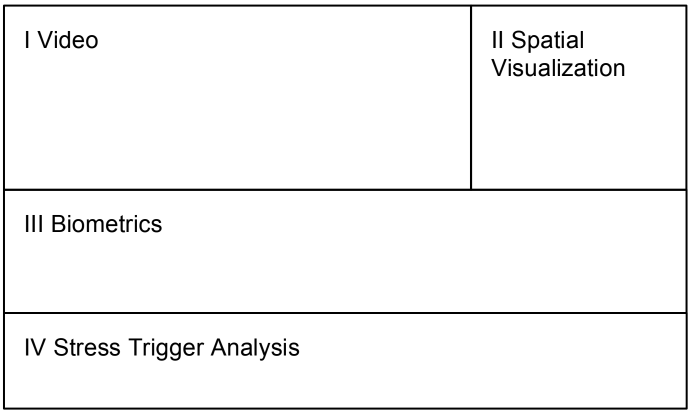

Figure 8. Finalized dashboard organization.

The proposed dashboard consists of four major sections (Figure 10). Section I contains video footage collected from passengers via traveler's microcamera. The footage is processed to identify spatial and physical elements, traveler activity and surrounding context. Section II indicates the traveler's geographic movements mapped onto the airport terminal plan. Section III contains a modified visualization of the biometric data collected from Empatica E4, which allows for easier identification of the heightened physiological change. Section IV provides analysis of the type of stress trigger causing the change in biometric markers. Stress indicators are identified using the macro activity, taxonomy groups, interaction types, and additional environmental contingencies.

A cross comparison of data can help indicate build up, climax, and dissipation of stress as it relates to different stress triggers. Through this dashboard, analysis can expand beyond the identification of moments of stress, to understanding the longer-term experience surrounding various stress triggers.

4.2. Identification of Stress Triggers

To pinpoint the exact cause of stress for passengers in airport settings, researchers used Scherer's method of analyzing emotion which separates situation-specific characteristics from person-specific characteristics (Scherer, 1986). This helps identify specific qualities of the airport experience as possible stress triggers, without the interference of idiosyncratic personal characteristics, behavioral tendencies, and cultural norms.

Researchers used the aforementioned method, using biometric markers as indication of physiological stress and video footage to identify aspects of the antecedent situation of stress. Borrowing and modifying the activity centered approach taken by Kirk et al, air travel activities were cataloged according to Scherer's definition of the antecedent situation. The taxonomy of spatial-social conditions were drawn from video analysis, interviews, and prior research (Calvo & Gutiérrez-García, 2016; Fink, 2016; Kirk et al., 2012; Scherer, 1986) to identify a collection of possible stressors during air travel. Stress triggers were categorized into three types: airport specific events, interaction types, and the location characteristics.

Airport specific events: The majority of airport specific events are preparatory and processing activities (Kirk et al., 2012) and are assumed to induce stress more readily in individuals (Dohrenwend & Martin, 1979; Grupe & Nitschke, 2013; Neubauer et al., 2018). These events and activities have characteristics, such as uncertainty and time sensitivity.

1. **Unfamiliarity of events** occurs when a traveler is uncertain about the acceptable conduct associated with an event, or is unfamiliar with the context surrounding an event. Traveling during the Covid-19 pandemic is a good example of a recent external event that was unfamiliar to both beginner and seasoned travelers.

2. **Decision-making events** require the passenger to perform an action without perfect information and frequently under time constraint. The uncertainty of the subsequent result, and the consequences in a highly regulated and controlled environment with a clear hierarchy of authority makes even small decisions in an air travel experience seem high stakes.

3. **Anticipatory events** occur before a known event. In air travel it happens before *processing activities,* such as security checks, passport control, and boarding. Anticipation is associated with the event prediction and the effects of an individual's actions and responses (Canaveral et al., 2020).

Interaction Types: Stress triggers associated with interactions are often accompanied by a clear delineation of authority, whether it is through security personnel or physical signage, and are heavily influenced by external forces beyond their control such as the involvement of powerful others (Steptoe & Poole, 2016).

1. **Interaction with strangers** is an active form of engagement that involves traveler interaction with a stranger. Aspects of the interactions, such as social anxiety, differences in cultural norms that may affect individuals' understanding of personal space and acceptable social behavior, may induce stress.

2. **Interaction with authority** involves travelers' interaction with airport staff or security personnel. Majority of these interactions happen within three areas - check-in, security and the boarding gate. Stress that is triggered by interaction with authority involves lack of agency, sense of surveillance, and restriction on personal freedom.

3. **Interaction with airport technology** involves travelers interacting with technology used for processing activities, before or during security, at the airline check-in counter and security checkpoints. These interactions can include the use of Automated Screening Lanes (ASLs), Biometrics Technology, and Credential Authentication Technology (CAT).

Location Characteristics: The location of the air travel related activity is crucial in determining if an event is stressful for the passenger. Spatial and social qualities of a location provide situational context that can change the passenger's perception of the situation. For example, a tense confrontation within a confined space would be perceived differently than if the same interaction took place within a more spacious environment.

1. **Presence of security signage** reminds passengers of security measures before and during processing events. These include signs such as preparatory requirement signs, prohibited item signs, stop signs and warning signs.

2. **Spatial restriction** occurs in areas with more security and mainly were found within security checkpoints and jet bridges. They often occur as a transition between a less

controlled environment and a more controlled environment. Queuing, for example, occurs before processing events and interacting with authority or airport technology.

5. Discussions

5.1. Discussion on Case Study Methods and Findings

As air travel trends change, the identification of airport stress triggers can provide valuable insights to designing better air travel experiences. A major advantage of the proposed dashboard is the ability to discern the build up, climax, and dissipation of extended stress, as well as identifying the emotional spikes corresponding to momentary stress. For example, a stressful encounter from an interaction with a human, may cause a longer residual stress as compared to momentary stress caused from an interaction with an airport technology. This is critical because the majority of people have difficulty recognizing the exact cause for stress, often misidentifying and generalizing the stress trigger (Censuswide, 2019).

Through using the research methodology detailed in this paper, researchers were able to go beyond subjective generalizations and assumptions long taken for granted. For example, while there is widespread understanding that security processing is among the most stressful events within the passenger experience, this methodology allows researchers to gain a more nuanced understanding and pinpoint the specific moments within the process that triggered notable spikes in EDA (Figure 11, 12). In this participant example, heightened physiological response was not present during the majority of security processing activities, including queuing, canine checks, security bins, and only began dramatically increased during one-on-one conversations with TSA agents. Residual stress following the conversation contributed a newly increased baseline for all subsequent stress triggers. Through similar analysis, airports and airlines can better understand the root cause of the stress and make more informed design decisions to improve the air-travel experience.

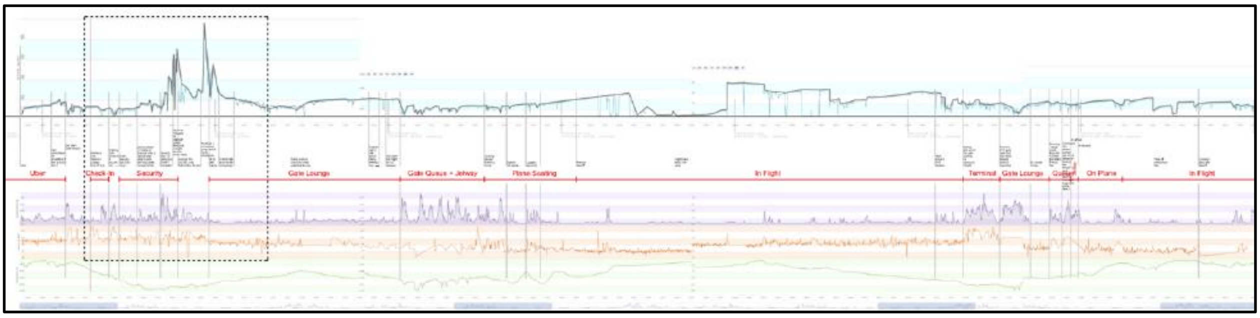

Figure 9. Macro-view of participant EDA levels throughout the experience, and subjective memory of stress during security. Figure 12 extends are outlined in a dashed line box.

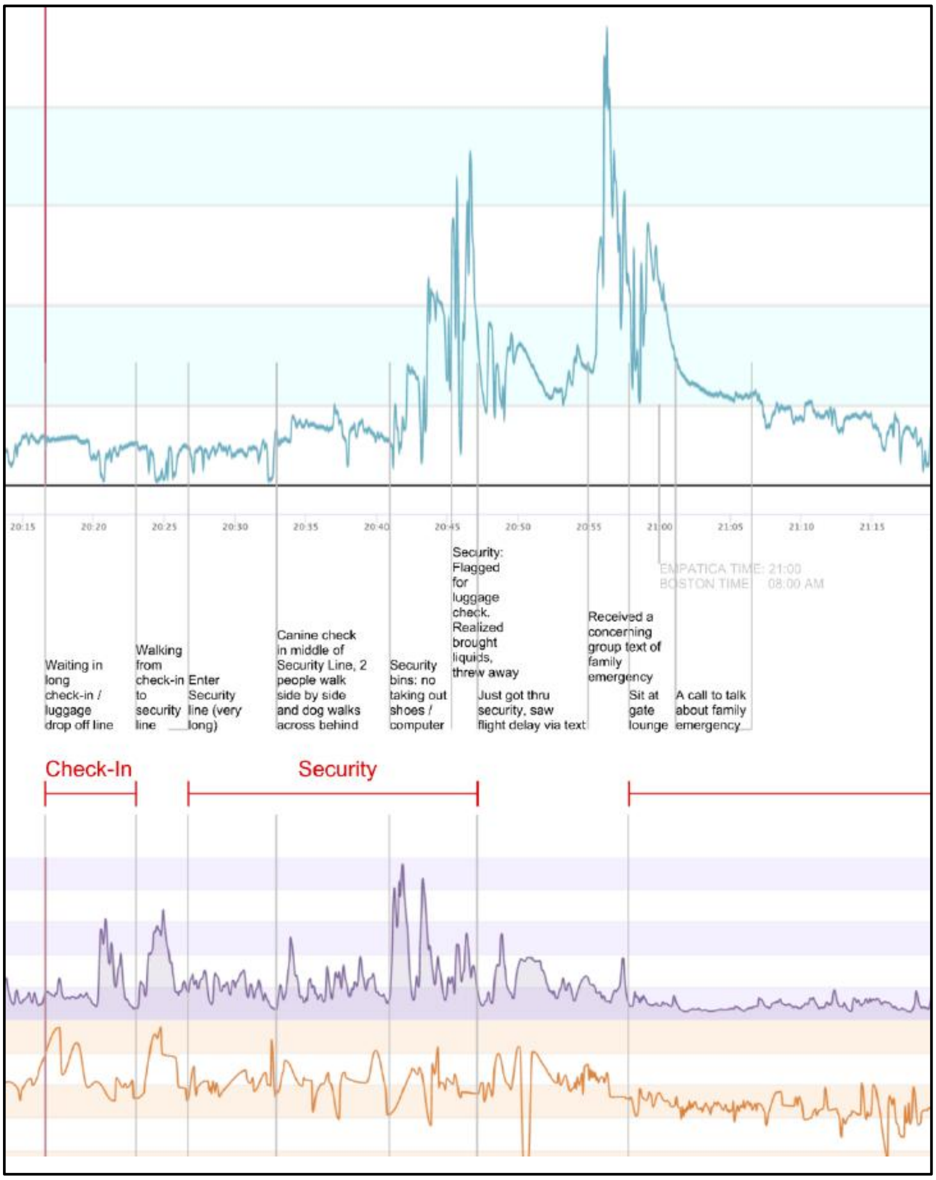

Figure 10. Micro-view of participant's activity and biometric data during security.

Understanding the antecedent situation draws a clearer picture of the context surrounding stress triggers, such as the activity performed, the types of human interaction encountered, and unique spatial characteristics of the airport. The study found that there were certain characteristics of the antecedent situation that were more likely to trigger stress in individuals. Participants' elevated EDA levels were correlated with situational characteristics such as time sensitivity, uncertainty, interacting with people in confined spaces, and interaction with a person of authority. For example, interaction with strangers and authority tended to result in more prominent stress responses within confined spatial configurations than open spaces.

By mapping stress levels within the air-travel experience and understanding airport specific stress triggers, designers and planners can design airports to anticipate and alleviate expected high stress situations.

5.2 Discussion on Limitations

The researchers' final combination of wearable technologies relies on Empatica E4's ability to accurately collect EDA data. However, verification studies of the E4 report mixed results, because sensors worn on the wrist were document to be accurate than sensors worn on the fingertips, palm, or soles of the feet (Kleckner et al., 2020; Milstein & Gordon, 2020; Sagl et al., 2019) as there are more sweat glands on the latter areas. However, due to this paper's less stringent requirements, wrist wearable is enough to collect data on changes to the EDA value. Wrist wearables also dampened participant's initial anxiety and concerns about gathering data in the highly controlled airport environment.

In addition, further refinement should be done to allow better differentiation between positive and negative emotions when analyzing EDA data. Interviews conducted after the experience allowed for some insight, but other modes could be explored. Examples of contemporary efforts to better understand valence include a mood-logging app and a PHQ-9 Depression Test Questionnaire by FitBit, and Amazon Halo's "emotion tracking via voice detection" facilitated by Amazon's Alexa devices (Charara, 2020). The existence of these research efforts indicate the rising interest in quantitatively tracking emotions, providing a fertile research field.

While there are limitations to the method described above, this case study demonstrates that the above methodology is useful in concurrently analyzing various types of data including biometric data, video footage, spatial data and activity data to understand the reason behind changes in the emotional state. The aggregation of results can then help identify not only stress points within the travel experience, but entire stress areas, leading to a more comprehensive understanding of air travel stress. In subsequent research, the dashboard should be used to test the effects individual stress triggers identified through this research.

6. Conclusions

This research proposes a biometric methodology for measuring and quantifying the psychological and physiological impact of designed spaces on occupant experience. Using the airport as a compelling case study location, the authors conducted preliminary tests of quantifying the emotional experiences of spatial environments, putting the human experience at the forefront to rethink how to design spaces, experiences, and systems. A dashboard was prototyped to allow analysis of both the resulting biometric data from a wrist-worn wearable Empatica, and the visuospatial data from a microcamera video footage. The resulting findings allows airport designers and management to rethink ways to identify nuanced stress triggers within respective airports, and ultimately create less stressful air-travel experiences.

The authors hope that the biometric methodology can easily be adaptable to other similar and dissimilar contexts. Similar indoor contexts include other public buildings, such as retail, transportation hubs, hospitals, and government facilities such as DMVs. Conducting experiments using this methodology in dissimilar contexts may bring forth greater improvements to the method. For example, outdoor contexts such as urban neighborhoods and parks may be intriguing case study environments to understand how people phenomenologically and physiologically respond to the different visual and other sensory stimuli.

The research work hopes that further interdisciplinary research on individual experiences can enable better designs of spaces, systems and processes. The authors and other interested researchers may benefit from further exploring the following questions: How can we predict behavior and emotional responses in different spatial and material environments? How can this knowledge empower and enable better design the experience of various spaces?

References

Adey, P. (2003). Secured and Sorted Mobilities: Examples from the Airport. *Surveillance & Society*, *1*(4). https://doi.org/10.24908/ss.v1i4.3333

Airport Cooperative Research Program, Transportation Research Board, & National Academies of Sciences, Engineering, and Medicine. (2011). *Passenger Level of Service and Spatial Planning for Airport Terminals* (p. 14589). Transportation Research Board. https://doi.org/10.17226/14589

Augé, M. (2008). *Non-places: Introduction to an Anthropology of Supermodernity* (2nd English language ed.). Verso.

Calvo, M. G., & Gutiérrez-García, A. (2016). Cognition and Stress. In *Stress: Concepts, Cognition, Emotion, and Behavior* (pp. 139–144). Elsevier. https://doi.org/10.1016/B978-0-12-800951-2.00016-9

Canaveral, C. A., Savoie, F.-A., Danion, F. R., & Bernier, P.-M. (2020). Dissociation between Temporal and Spatial Anticipation in the Neural Dynamics of Goal-directed Movement Preparation. *Journal of Cognitive Neuroscience*, *32*(7), 1301–1315. https://doi.org/10.1162/jocn_a_01547

Censuswide. (2019). *Airport Stress Survey*. https://www.prioritypass.com/en/blog/2019/airport-stress-survey

Charara, S. (2020, August 28). A new Fitbit claims to track your stress levels. Can it really do it? *Wired*. https://www.wired.co.uk/article/fitbit-stress-tracking-eda

Dohrenwend, B. S., & Martin, J. L. (1979). Personal versus situational determination of anticipation and control of the occurrence of stressful life events. *American Journal of Community Psychology*, *7*(4), 453–468. https://doi.org/10.1007/BF00894386

ESUM. (2017). *Human perception of urban environment*. https://www.esum.arch.ethz.ch/

Fink, G. (2016). Stress, Definitions, Mechanisms, and Effects Outlined: Lessons from Anxiety. In *Stress: Concepts, Cognition, Emotion, and Behavior* (Vol. 1, pp. 3–11). Academic Press. https://doi.org/10.1016/B978-0-12-800951-2.09992-1

Gao, N., Marschall, M., Burry, J., Watkins, S., & Salim, F. D. (2022). Understanding occupants' behaviour, engagement, emotion, and comfort indoors with heterogeneous sensors and wearables. *Scientific Data*, *9*(1), 261–261. https://doi.org/10.1038/s41597-022-01347-w

Gatersleben, B., & Griffin, I. (2017). Environmental stress. In *Handbook of environmental psychology and quality of life research* (pp. 469–485). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-31416-7_25

Greco, V., & Roger, D. (2003). Uncertainty, stress, and health. *Personality and Individual Differences*, *34*(6), 1057–1068. https://doi.org/10.1016/S0191-8869(02)00091-0

Grupe, D. W., & Nitschke, J. B. (2013). Uncertainty and Anticipation in Anxiety. *Nature Reviews. Neuroscience*, *14*(7), 488–501. https://doi.org/10.1038/nrn3524

Healey, J. A., & Picard, R. W. (2005). Detecting stress during real-world driving tasks using physiological sensors. *IEEE Transactions on Intelligent Transportation Systems*, *6*(2), 156–166. https://doi.org/10.1109/TITS.2005.848368

Jacobs, J. (1961). *The Death and Life of Great American Cities*. Random House.

Karakas, T., & Yildiz, D. (2020). Exploring the influence of the built environment on human experience through a neuroscience approach: A systematic review. *Frontiers of Architectural Research*, *9*(1), 236–247. https://doi.org/10.1016/j.foar.2019.10.005

Kirk, P. J., Popovic, V., & Kraal, B. (2012). *Towards a Taxonomy of Airport Passenger Activities*. 13.

Kleckner, I., Feldman, M., Goodwin, M., & Quigley, K. (2020). Framework for selecting and benchmarking mobile devices in psychophysiological research. *Behavior Research Methods*. https://doi.org/10.3758/s13428-020-01438-9

Kyriakou, K., Resch, B., Sagl, G., Petutschnig, A., Werner, C., Niederseer, D., Liedlgruber, M., Wilhelm, F., Osborne, T., & Pykett, J. (2019). Detecting Moments of Stress from Measurements of Wearable Physiological Sensors. *Sensors (Basel, Switzerland)*, *19*(17), 3805-. https://doi.org/10.3390/s19173805

Lynch, K. (1960). *The Image of the City*. MIT Press.

Milstein, N., & Gordon, I. (2020). Validating Measures of Electrodermal Activity and Heart Rate Variability Derived From the Empatica E4 Utilized in Research Settings That Involve Interactive Dyadic States. *Frontiers in Behavioral Neuroscience*, *14*, 148. https://doi.org/10.3389/fnbeh.2020.00148

Neubauer, A. B., Smyth, J. M., & Sliwinski, M. J. (2018). When you see it coming: Stressor anticipation modulates stress effects on negative affect. *Emotion (Washington, D.C.)*, *18*(3), 342–354. https://doi.org/10.1037/emo0000381

Pantouvakis, A., & Renzi, M. F. (2016). Exploring different nationality perceptions of airport service quality. *Journal of Air Transport Management*, *52*, 90–98. https://doi.org/10.1016/j.jairtraman.2015.12.005

Picard, R. W., Fedor, S., & Ayzenberg, Y. (2016). Multiple Arousal Theory and Daily-Life Electrodermal Activity Asymmetry. *Emotion Review*, *8*(1), 62–75. https://doi.org/10.1177/1754073914565517

Poh, M.-Z., Swenson, N., & Picard, R. (2010). A Wearable Sensor for Unobstrusive, Long-Term Assessment of Electrodermal Activity. *IEEE Transactions on Biomedical Engineering*, *57*(No. 5), 1243–1252.

Sagl, G., Resch, B., Petutschnig, A., Kyriakou, K., Liedlgruber, M., & Wilhelm, F. (2019). Wearables and the Quantified Self: Systematic Benchmarking of Physiological Sensors. *Sensors (Basel)*, *19*(20), 4448-. https://doi.org/10.3390/s19204448

Schaberg, C. (2012). *The Textual Life of Airports: Reading the Culture of Flight*. Continuum.

Scherer, K. R. (1986). Studying emotion empirically: Issues and a paradigm for research. In K. R. Scherer, A. B. Summerfield, & H. G. Wallbott (Eds.), *Experiencing emotion: A cross-cultural study*. Cambridge University Press ; Maison des Sciences de l'Homme.

Schlickman, E., Domlesky, A., & SWA. (2019). *Field Guide to Live in Urban Plazas: A study in New York City*. SWA. https://live-swa-2019.pantheonsite.io/wp-content/uploads/2019/08/Field-Guide-to-Life-in-Urban-Plazas_digital1.pdf

Schmidt, P., Reiss, A., Duerichen, R., Marberger, C., & Van Laerhoven, K. (2018). *Introducing WESAD, a Multimodal Dataset for Wearable Stress and Affect Detection*. 400–408. https://doi.org/10.1145/3242969.3242985

Sharma, S. (2009). BARING LIFE AND LIFESTYLE IN THE NON-PLACE. *Cultural Studies*, *23*(1), 129–148. https://doi.org/10.1080/09502380802016246

Steptoe, A., & Poole, L. (2016). Control and Stress. In *Stress: Concepts, Cognition, Emotion, and Behavior* (pp. 73–80). Elsevier. https://doi.org/10.1016/B978-0-12-800951-2.00008-X

Van Hedger, K., Necka, E., Barakzai, A., & Norman, G. (2017). The influence of social stress on time perception and psychophysiological reactivity. *Psychophysiology*, *54*(5), 706–712. https://doi.org/10.1111/psyp.12836

Whyte, W. (1980). *The social life of small urban spaces*. Conservation Foundation. http://id.lib.harvard.edu/alma/990008811700203941/catalog

Wood, A. (2003). A Rhetoric of Ubiquity: Terminal Space as Omnitopia. *Communication Theory*, *13*(3), 324–344. https://doi.org/10.1111/j.1468-2885.2003.tb00295.x