Measuring atmosphere: relationships between room ambience, activity, and human emotional responses in virtual reality

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Measuring atmosphere: relationships between room ambience, activity, and human emotional responses in virtual reality

By

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Abstract

This exploratory study aims to create a framework for measuring the strength of atmosphere in interior spaces, as defined by the architectural elements within them. A survey questionnaire based on PANAS was created, along with 10 3D modeled rooms that were simulated in virtual reality. The rooms were designed using parameters derived from studies in environmental psychology that informed the creation of a room activity level scale (RALS). Each of the rooms was given a score on this scale. 24 participants were asked to report their feelings while in the VR spaces using the questionnaire. The rooms were first shown to them in color and afterwards in grayscale. It was hypothesized that 1) the participants would report stronger emotional responses in the rooms that were lower on the RALS, 2) that participants would report stronger emotional responses in colored rooms compared to their grayscale counterparts, and 3) that participants with a background in spatial design fields would report weaker emotional responses than participants without such a background. The data was analyzed using a mixed methods approach, where quantitative and qualitative data was gathered during the surveys. The quantitative data was analyzed with a linear regression model that informed the qualitative analysis. The results showed that hypotheses #1 and #3 were not supported, while hypothesis #2 was partially supported. It was determined that the opposite of hypothesis #1 was true, and that spaces higher on the RALS featured stronger emotional responses, alluding to the greater strength of atmosphere within them. Common architectural knowledge would claim that more mindful, less active spaces would feature a stronger atmosphere, as atmosphere is thought to be easier to perceive in such spaces. Opposing this notion, I suggest that the strength and perceivability of atmosphere are two different constructs.

Keywords: atmosphere, ambience, mood, emotion, activity, color, form, architecture, interior design, virtual reality
Thesis motivation

The following work is a continuation of the past two thesis projects I have completed. The projects in question are “Fusing Intuited Atmosphere and Empathy into the Architectural Design Process”, completed at Aalto University in 2019, and “A Garden for Atmosphere”, completed at Harvard University in 2020. Together these three projects constitute a triptych of works investigating the phenomenon of atmosphere.

The first of my thesis projects looked at the way intuited atmosphere and empathy blend together in the architectural design process by interviewing several high-profile architects who, in their own words, had considered the phenomenon of atmosphere important to their design process during their careers. The second thesis was an attempt at designing an outdoor museum with different, atmospherically unique pavilions, and grappled with controlling atmosphere — whether it was possible and to what degree. As a quasi-objective phenomenon (Böhme and Thibaud 2016, p. 13-14), the atmosphere of a space could be shaped according to some of the distinguished interviewees in the first thesis project, yet how one went about doing this was contentious. The results of the second thesis project were mixed when it came to how successfully control over atmosphere had been established, yet what was evident, was that the pavilions that had been designed did all have distinct features that most likely did — depending on the imagination of the beholder — vary in terms of their ambience. Naming any of these atmospheres was, however, a futile attempt due to the elusive nature of the phenomenon.

With the mood and ambience of any given space being arguably an important aspect to architectural design. I was further intrigued by the objective aspects of atmosphere, and moreover, the importance of imagination in this process. The second thesis had utilized a fairly sparse style of representation in order to make room for the imagination of whomever viewed the work; this approach was determined as the best solution to the dilemma of representing an embodied phenomenon in 2D drawings, according to the guidance of Professor Toshiko Mori of Harvard Graduate School of Design. While it was assumed that a truly rigorous study on atmosphere would require the erection of actual, physical spaces, where people could experience the multi-sensorial phenomenon in its entirety (Pallasmaa 2014), the previous thesis had alluded to the phenomenon being stronger than it first seemed. If imagination — and personal associations — could be brought into any given experience, it was possible to elicit feelings akin to those created by spatial atmospheres.

This study attempts to investigate the quasi-objective aspects of atmosphere from a visual standpoint, bridging the multi-sensorial requirements of the embodied phenomenon with the imagination of the sample group (Pallasmaa 2011, p. 67, 74-76). The study is exploratory in nature, and aims to create a framework for a more scientifically rigorous methodology, that is still manageable in terms of its need for physical building resources. As atmosphere is
inherent to all human experience, its broader understanding could be key to giving architects new tools in their design endeavors. It is my hope that this study can help move this process forward, together with raising interest in the phenomenon within architectural discourse, and perhaps arguing for its depiction in a more universal light. It is my opinion that atmosphere is too often viewed as obtuse, too subjective, to warrant serious discussion due to fear of such action proving pointless. With the last few years resulting in renewed philosophical interest in the phenomenon, as seen in the works of Tonino Griffiero and Gernot Böhme, it is my belief that an attempt should be made to create experiments for researching atmosphere. This study hopes to prove that that is possible, and consequently serves as a fitting conclusion to my thesis endeavors.

**Introduction**

A healthy relationship between people and their surroundings is important for wellbeing. For example, people who like their local environment, such as their neighborhood, tend to have better social ties in these areas (Mesch and Manor 1998). Such attachment to a local community effectively predicts individual wellbeing (Theodori 2001). Also, when individuals enjoy their surrounding areas, they are more likely to engage in beneficial behaviors, such as taking care of the natural environment (Scannell and Gifford 2010). Further, the relationships between people and their surroundings are important to understand as people move from one place to another, be it voluntarily to leverage globalized opportunities or involuntarily due to conflicts and natural disasters, experiencing a wide variety of emotions and adaptation processes (Billig 2006; Sanders, Bowie, and Bowie 2003).

The atmosphere of physical environments has a significant impact on how people feel in them. While one’s attachment to a place is a socially constructed phenomenon, it is also true that various physical characteristics of places both influence and enable this attachment, as argued in length by Böhme and Thibaud (2016). In their seminal work, Böhme and Thibaud (2016) define atmosphere as a holistic characteristic of space that is experienced by individuals in similar ways. These arguments have found support in empirical studies. For example, Stedman (2003) showed through a questionnaire-based study on lakeside property owners in Northern Wisconsin that the influence that physical characteristics had on the owners’ attachment to and satisfaction with their properties were best explained through the associated meanings of individual physical properties. Specifically, low levels of shoreline development were associated with properties as *places of escape*, while high levels of development were associated with properties as *social places*. Hence, in individuals, the physical features and atmospheres of places elicit meanings, which in turn elicit experiences of attachment.

Despite these proposed connections between human wellbeing and atmosphere, there exists little scientific research on the topic. In fact, much architectural knowledge is based on the personal experiences and philosophical writings of renowned architects; for example Peter Zumthor’s book *Atmospheres* (Zumthor 2010) and Juhani Pallasmaa’s *Eyes of the Skin* (Pallasmaa 2012). While these works, along with Böhme’s writings on atmosphere, serve as excellent theory building, research on architectural practice suffers from a lack of theory testing, validation, and
expansion. Design as a field of science (Cross 1982), which architectural research is part of, is coming to terms with lackluster scientific theorizing, as illustrated by the recent empirically based critiques of Cash (2018; 2020). A central goal of this thesis is to begin remedying this gap in empirical architectural research that contributes to theory, by studying the concept of atmosphere in indoor spaces.

As the thesis focuses on atmosphere, it is important to explicitly define what I interpret atmosphere to mean. In this instance I refer to Gernot Böhme’s definition of the phenomenon: “Today atmosphere may be defined briefly as tuned space, i.e. a space with a certain mood. From here two more traits of the theory of atmospheres can be advanced: atmospheres are always something spatial, and atmospheres are always something emotional. We talk about atmospheres by naming their characteristics. These are their tendencies to modify my own mood (Böhme and Thibaud 2016, p. 14).” With this description, atmosphere becomes a three-part phenomenon. Firstly, spaces encompass atmospheres, and we perceive the phenomenon within them. As we enter any given space, their atmosphere envelops us, affecting our mood. Our mood then informs our emotions, and thus, we experience atmosphere through proxy. The stronger an atmosphere is in a space, the stronger its impact is on our mood. Böhme and Thibaud go on to say that atmospheres can be intentionally “produced”, that they are “quasi-objective feelings”, and that they can be influenced “by the geometry of a room” (Böhme and Thibaud 2016, p. 15-16).

This thesis consists of five chapters. In the next chapter, I describe the epistemological stance of this thesis, establish three key hypotheses that I investigated, and review potential ways in which to measure the subjective concept of atmosphere. Then, I describe the methods used in my thesis in detail, including everything from the overarching study design, to how I designed the abstract virtual reality spaces to elicit different degrees of activity. Lastly, in the final two chapters, I describe the results of my quantitative and qualitative analyses, how the findings contribute to our general understanding of architecture, how they could be used in architectural practice, and how future research could build upon this work.

Background

Epistemological positioning

This thesis is neither purely quantitative nor purely qualitative, instead adopting a mixed-methods design. I use qualitative and quantitative data to explore different questions. First, in this thesis, quantitative data is used to investigate questions of “what”, such as what are the overarching trends and what cases do and do not adhere to these trends. Then, qualitative data is used to explore “why” questions, including why some cases adhere to trends and others do not, and why some quantifications worked while others failed to explain desired phenomena. Formally, this thesis follows a convergent parallel mixed-methods design (Creswell and Creswell 2017, Fig. 10.1),
where qualitative and quantitative data were collected at the same time, analyzed intermittently, and the results compared to one another.

The epistemological backgrounds of qualitative and quantitative research differ dramatically: quantitative assumes a universal truth (positivism) while qualitative posits that truth is socially and contextually constructed (constructivism). Adding further complexity, mixed methods research typically assumes a pragmatic stance to research, roughly proposing that the nature and philosophy of knowledge matters less than its usefulness (M. L. Small 2011).

In this thesis, I adopt a positivist epistemology. By attempting to quantify the atmosphere of spaces, I assume that there are universal, measurable, and observable relationships between the physical characteristics of spaces and humans’ emotional responses to those spaces. Still, I accept that these relationships may be close to meaningless in some social or cultural contexts. The physical characteristics of the space one gives their thesis presentation matter much, much less than the fact that there is an army of faculty and peers watching you pitch research you have worked on intensively. However, my positivist argument is that the relationship between physical space and one’s emotional responses still exists in that situation as well.

My positivist epistemology is also pragmatically useful. It would make architects’ work significantly more straightforward if there was a comprehensive and universal understanding of how the physical features of spaces elicit responses in people. Even when such explicit knowledge does not currently exist, many expert architects speak and design with panache that suggests they have understood some phenomena and approaches that apply to a breadth of scenarios. Further, people’s responses to architecturally significant places tend to be strikingly similar, even for people who know little about the history of these places, suggesting that there indeed may be some “architectural laws of nature” in play. At the very least, I believe that these observations warrant an attempt at investigating atmosphere from a positivist point of view.

Thus, while the stance of this thesis is positivist, it also nods toward constructivism and pragmatism.

Hypothesis development

In his book *Atmospheres*, architect Peter Zumthor goes over places and situations which he believes constitute a strong atmosphere. What these all have in common is a sense of stillness, as they “induce a calming effect” (Zumthor 2008, p. 44). This is a commonly held belief in architectural design, as represented by one of the architects most associated with the production of atmosphere in his building design work. Zumthor alludes that a building typology such as a hospital, with its “directing” corridors and its active nature, is less conducive to what he calls atmosphere, whereas buildings like the Villa Rotonda by Andrea Palladio or the Villa Sarabhai by Le Corbusier are the opposite of this (Zumthor 2008, p. 40, 52, 54). This notion was corroborated by the interviewees in my previous
thesis as well: for example architect Juha Leiviskä associated strong atmospheres with churches (Ilvesmäki 2019, p. 80) and architect Johann Celsing associated them with art galleries (p. 100). It has been my personal experience that this trend is commonly associated with phenomenological architects and their work, and that if one wants to design spaces depicted as atmospheric, the best way to do so is to follow this trope.

The negative relationship between atmosphere and activeness can be gleaned from studies outside architecture, too. For example, at the level of dwellings, high dwelling density (e.g., many people living in one apartment) and feelings of crowding (i.e., sensing too many other people around you) have been found to contribute to residents’ mental strain (Gifford 2007). While these studies consider the presence of other humans, it can be extrapolated that physical elements could have a similar effect. Though, it must be noted that the relationships between density and strain were not observed in all contexts, as for example people living in Hong Kong with their family showed less strain than those living in multiple-family units (Mitchell 1971). Even in studies on communities, people’s attachment to an area is strongly related to the presence of natural features (such as lakes or wetlands) and open space (see, e.g., Kim and Kaplan 2004). This indicates that less active, peaceful places are key for a more positive relationship with a place, be that relationship about feeling attached to the place, identifying with it, being willing to engage with it, or forming social bonds in it. Thus, based on the propositions in architectural texts and in environmental psychology studies, I propose the following hypothesis:

**Hypothesis 1:** Less active spaces elicit a stronger emotional response, pointing to a stronger atmosphere within them.

Environmental psychology provides us with numerous studies on the impact of color on our mood. For example, colors that are brighter and more saturated are more pleasurable: pleasure increases as the brightness and saturation increase, improving our mood (Valdez and Mehrabian 1994). Importantly, cool colors tend to make people calm and warm colors make them have more energy, with bright red being especially energizing. Studies have shown that bright red “puts our pituitary glands into high gear, which gives us a boost in mental and physical energy” (Augustin, Frankel, and Coleman 2009, p. 64). With the warm-cool spectrum being most related to our “activity levels”, it makes sense to take it into account in a limited study such as this; color combinations, color patterns, and more complex cultural color connotations, etc. can be researched in further studies. Furthermore, the warm-cool spectrum has cemented itself in interior design practice in order to either activate or calm people, boosting its contextual familiarity in the experiences of potential study participants. For example, retailers generally use warm colors on the back walls of shops to draw customers in, yet place cool colors where purchase decisions are to be made, helping people “process information” in them (Augustin, Frankel, and Coleman 2009, p. 68). In addition to this, studies have shown that walls painted in warmer colors make them appear closer than they are, while walls painted in cooler colors make them appear to be further away than they actually are (Augustin, Frankel, and Coleman 2009, p. 68). This same color spectrum also impacts the perceived shape of a room, making its inclusion in architectural studies viable. Consequently, different color hues of either the warm or cool variety could be compared
to desaturated colors in order to determine how they impact the strength of the atmosphere in a room. Thus, I propose the following hypothesis:

**Hypothesis 2:** The presence of color strengthens the atmosphere of a space, thus eliciting stronger emotional responses.

The opposing domains theory in neuroscience posits that logical thinking suppresses socioemotional thinking, and vice versa (Jack et al. 2013). This theory is supported by vast amounts of correlational research on the activation of specific areas of the brain (i.e., neural networks) under specific activities (see the works of Anthony Jack, reviewed for example in Rochford et al. 2017). Here, the two key neural networks are the Task Positive Network, activating when one for example engages in causal reasoning, and the Default Mode Network, activating when one for example engages in emotional self-awareness. The antagonistic relationship between these neural networks can help explain various phenomena, such as why physicians tend to express less empathy toward patients as their career tenure increases (Neumann et al. 2011).

The opposing domains theory may influence architectural practice as well. Notably, architects must balance between considering human experience in spaces and the realities of what is possible to realize in the confines of the funding, collaborators, time, and other resources they have access to. These activities are likely to require switching between the Task Positive and Default Mode Networks. However, it is possible that as with physicians, architects may be vulnerable to preferring one network over the other, responding to spaces primarily through the logical/causal Task Positive Network rather than going through self-reflective and abstracting processes operated by the Default Mode Network. On the other hand, one might expect that laymen would be more free to respond emotionally to spaces, not being burdened by the practical knowledge that architects possess. While this phenomenon may not be true for all architects, there may be a systematic tendency toward causal thinking over socioemotional thinking in architects when it comes to spaces. Thus, to explore the occurrence of the opposing domains theory in architecture, I propose the following hypothesis:

**Hypothesis 3:** Architects experience weaker emotional responses to spaces than non-architects

**Measuring atmosphere**

Measuring phenomena is a core aspect of science. When a phenomenon gathers enough scientific and practical interest, measuring it can help us reach better understanding than qualitative inquiry alone. In their book on survey development, DeVellis and Thorpe provide multiple compelling examples of this (2021, p. 19). Health psychologists may be interested in systematically investigating the difference between what people want and expect to happen during a visit to the doctor. Marketing researchers may want to see whether findings from focus group interviews can be generalized to a broad enough population to warrant action. DeVellis describes how measurement helped their own research: after studying women’s experiences with domestic violence, the research team concluded that these experiences consist of six distinct constructs. However, after building and testing a survey instrument to verify
this theory, they found that all constructs behaved statistically similarly, suggesting that while the researchers saw a complicated phenomenon, the participants experienced it through one broader phenomenon. Similar to these examples, an architect designing a space is interested in how people will experience its atmosphere. The architect explores their vision and concretizes it into a space, but ultimately, there is no way to measure the outcoming atmosphere, aside from qualitative techniques, like interviews and focus groups. Would it not be exciting to, in the design phase, gather perceptions of atmosphere from large groups of people?

When considering measurement in a social context, it is important to understand the difference between the measure and the construct (DeVellis and Thorpe 2021, p. 36). While I am interested in measuring atmosphere, I do not intrinsically want to see numeric atmosphere scores that people assign for different spaces. Rather, I am interested in the construct of atmosphere and its relationships to other constructs, and all the measures are just tools for making inferences. There are strong arguments that atmosphere itself is not directly measurable, and it is not. Neither are constructs like happiness or empathy, as we can only observe numeric values about them that people write in response to standardized questions, or observe changes in the blood flow patterns in their brains in carefully curated experimental situations. But, the purpose of measurement is not to directly measure the construct. Instead, we want to use a reasonable proxy that allows us to learn about the construct we are truly interested in.

Specifically for measuring atmosphere, I considered four areas in this thesis: sensory modalities, immersion, imagination, and emotional responses. Sensory modalities refer to the ways we sense our surroundings, be it through light, temperature, sound, or other senses. By writing that individual experiences of atmosphere are compounded through various senses, Böhme and Thibaud (2016) hint at an important sensory fact from neuroscience: human sensory experiences are always compound, despite our senses being anatomically distinct (see, for example, D. M. Small and Prescott 2005). However, in our experiences with the physical world, the visual sense carries special importance. For example, research on sensory marketing has found visual distinctiveness to be important in consumer decision making (Milosavljevic et al. 2012). The theoretical grounding for this effect comes from neuroscience, where individuals have been found to fixate on visually distinct patterns longer, be the distinction from color, brightness, or some other basic component (Mannan, Kennard, and Husain 2009). Further, the length of visual fixation, or consideration, one gives a visual pattern has been found to significantly influence their decision making between patterns (Krajbich, Armel, and Rangel 2010). Thus, while the atmosphere of a space or building results from multiple variables, it can be argued that an individual’s experience of atmosphere begins from visual attention. Extending the neuroscientific arguments to atmosphere, individuals would more strongly fixate on visually distinct spaces, which would then enable more holistic and immersive experiences and behavior. Hence, in this thesis I focus on the visual sensory modality.

Immersion, i.e., being drawn into a space, is commonly alluded to by architects when describing atmosphere (Zumthor 2010). In gaming, immersion has been defined with some formality as an experience where one loses track of time, loses awareness of the real world, and feels a sense of involvement in the game environment (Jennett
et al. 2008). Using a definition from gaming is appropriate, as most architectural design today is done via 3D modeling, and these virtually-created environments lend themselves to game-like exploration, especially through virtual reality technology. Portman and colleagues (2015) reported various benefits from virtual reality in architecture, among them an enhanced spatial conception. As immersion in some form, perhaps more through an enhanced sense of being in a space, is important in experiencing atmosphere, and virtual reality technologies can enhance it during the conceptual design of spaces, I decided to carry out the experiment in this thesis in virtual reality.

While there is some debate on how realistic virtual reality should be to create immersion (see review by Portman, Natapov, and Fisher-Gewirtzman 2015), atmosphere can partially rely on the imagination of individuals (as suggested by Pallasmaa in his book the *Embodied Image*, 2011). Even in gaming, two different individuals can experience dramatically different degrees of immersion with the same game and on the same technological setup, implying that individual differences play a role in immersion. In this thesis, I have adopted Pallasmaa’s stance that individuals create a sense of atmosphere partially through imagination, suggesting that even highly abstract spaces would have distinct atmospheres. Accordingly, in the experiment I use abstract spaces to enable systematic variations of their design. Similarly abstract spaces have been used in published research as well (Shemesh et al. 2017).

Lastly, emotional responses can be considered some of the most fundamental human reactions to experiences (Baars, Ramsøy, and Laureys 2003). Even in atmosphere, Böhme and Thibaud (2016) argue that emotions play an important role in experiencing spaces. Hence, in this thesis, I use emotional responses as an indication of individuals’ experiences of atmosphere.

**Methods**

**Study design**

This study used a repeated measures design. Participants observed 10 saturated versions and 10 desaturated versions of abstract virtual reality rooms and reported their emotional responses to each room separately. Participants were also encouraged to voice their thoughts and feelings more generally while in each room.

Overall, this study follows a mixed methods design, where qualitative and quantitative data were collected and analyzed concurrently and iteratively. See Figure 1 for an overview of the study. Importantly, quantitative results informed where qualitative inquiries were focused at, while also some qualitative observations informed what quantitative analyses should be undertaken.
Participants

The dataset of this study includes 24 participants. Participants were all relatively young (median age 28.5 years, ranging from 23 to 65 years), 12 of them were male (50.0 %), and they represented various ethnic backgrounds (coming from US, India, Finland, Singapore, Greece, Mexico, South Korea, Spain, France, China, and Chile) and spoke fluent English. All participants were residing in the US at the time of the study. Further, 17 participants (70.8 %) can be considered spatial designers, having completed university-level degrees in architecture (or similar) programs around the world and/or practicing architecture in the private sector. 16 of the architect participants (94 %) were current students at the Harvard Graduate School of Design or the Massachusetts Institute of Technology. Of the 7 non-architect participants, 5 had completed a law degree, 1 had no higher education, and 1 had a university-level degree from another field. Overall the non-architects were of roughly similar socioeconomic status as the architects.

Participants were recruited via a mix of convenience and purposeful sampling. All participants were recruited through my social networks through direct contact with me. The participants received no compensation for their participation in the study. I purposefully reached out to both architects and non-architects, aiming to recruit equal numbers of both.

Due to the exploratory nature of this study, a target sample size was not set nor calculated beforehand. However, the 24 participants did provide adequate amounts of quantitative responses for preliminary statistical analyses. With 24 participants and assuming no missing data, each room would receive 192 emotional response ratings. With 20 rooms (10 saturated and 10 desaturated), this means a maximum of 3,840 emotional response ratings could be expected.
Quantitative measures

Abstract virtual reality spaces

The spaces were designed with 5 parameters derived from environmental psychology studies outlined in the textbook *Place Advantage* (2009, p. 63-75) as key to the “activity level” (Augustin, Frankel, and Coleman 2009, p. 68) of people. These 5 parameters were (in depreciating value order):

- Number of elements per each scene half (more than five [4 pts], three to five [2 pts], less than three [0 pts])
- Type of elements (triangles [3 pts], circles [2 pts], cylinders [1 pts])
- Color of elements (warm [3 pts], cold [0 pts])
- Horizontal lines drawn by elements (none [2 pts], one [0 pts])
- Vertical lines drawn by elements (none [1 pts], multiple [0 pts])

The scale created from these was ordinal as the studies forming the basis for the results depicted in *Place Advantage* did not align with any universal system. Because of this, an intuitive numbered scale was created in order to design the study rooms, henceforth called the Room Activity Level Scale (RALS). This numbered scale included activity scores from 1 to 14. This was determined by first looking at the overall strength of each individual parameter in relation to its counterparts within a given space. The colors and elements (their number and type) appeared to increase the activity level of the spaces more than if the lines drawn by these elements were horizontal or vertical. Consequently, it was determined that these prior parameters would contribute more to the “activity level” of the room than the latter ones. This conclusion was made based on 3D modeling studies conducted in a VR space using Unreal Engine version 4.27. The validity of this scale would be investigated based on the results of this exploratory study.

The size of the VR study rooms was determined based on the sample VR rooms of the Oculus Quest platform. These rooms are the basis for all VR experiences on the Oculus Quest platform, which points to their neutrality and place as the standard setup for the technology. The activity score scale would output a variety of rooms encompassing a seemingly great variety of spatial situations. The scale and its extents were thus finalized by placing the chosen geometries into the standard VR room with the logic of the activity scores, and checking that the spaces did indeed constitute a number of different spatial qualities, conducive to the prompt of the study.

The creation of the study setup was predicated on modeling the VR rooms as scenes, viewed from one viewpoint, with particular focus placed on what kind of boundary lines each geometrical element drew within the room (Augustin, Frankel, and Coleman 2009, p. 71). The software used for this was Rhino 3D version number 7.14, running on Mac OS. Care was maintained to make sure that the spaces featured different amounts of inwardly pushing geometries arranged in a number of layers to create depth within the rooms. An area was left in the center of each room for the participants to stand in. After this initial scene creation process, the scenes were copied and
rotated 180 degrees to form complete rooms with straight edges, measuring 6 meters by 7 meters, with a height of 5 meters (henceforth referred to as the “standard”). See Figure 2 for this process. This method was chosen due to the stronger contextual (i.e. architectural) cues that the implied symmetry elicited within specific rooms (Nikos A. 2020). This method also further reduced the geometrical possibilities available to each room, and allowed one to ask the participants whether they had noticed the symmetry in the spaces; this data was only logged when participants commented on it in certain spaces. The spaces were each capped with a diffusive glass roof, which illuminated the spaces as evenly as possible, yet provided the least amount of contextual cues; any wall openings could have focused the participants’ interest at the expense of the other elements in the rooms (Alexander 1977, p. 889-892).

The elements in each of the rooms were connected either to the room boundaries or each other, and aside from this, the only other employed formal manipulation concerned curving the room boundary edges. The VR setup had sound: a room ambient sound was set up to give participants the subtle impression of crossing a threshold when putting on the VR headset. It is questionable whether this had any impact though, since the place where the study was conducted was noisy enough to mask the subtle pressure that the room ambient sound created.

In addition to the RALS, the Oculus Quest example VR room dimensions, and the method with which scenes were made into complete rooms, the study rooms were designed with distinct logic pertaining to the way geometric elements were placed in them and to the way that the rooms were arrayed in the simulation. The geometric elements were only ever connected to the 5 boundaries of a scene or to each other. This limited manner aimed at reducing the variety of arrangements found within the rooms. To complement this approach, the size of the elements was also kept at around 1-3 meters in terms of their edge or diameter sizes, thus making sure that the elements never grew too large or shrunk too small. The rooms were arrayed one after another in an order that showcased different size RALS transitions between them, maximizing the possible transitory experiences that the participants would feel during the simulation. The following section goes over how the rooms were created and what modeling logic they each followed in more detail.

![Figure 2. Transformation of 3D scene into 3D room.](image)
**Room #1**  
Activity level: 14  
Eight triangles were used in the creation of the first room. They were each modeled by extending the triangular shapes from the boundaries (the floor, walls, or the roof) of the space to one of its other boundaries. The boundaries themselves were kept standard. This room forms a pair with room #4 due to their use of a single type of element.

![Figure 3. Room 1 in saturated and desaturated hues.](image)

**Room #2**  
Activity level: 5  
Three standing cylinders were used to create this space. They were modeled standing on the floor of the space, and intersected either the walls or each other. The boundaries of the room were left standard, although with one of the cylinders blending into the wall behind it, one of the vertical edges of the room became rounded. Due to the Unreal Engine 4 shaders and lighting that was used in the study, the cylinders in this space seemed to blend into the walls of the room. This occurrence acted as a further differentiating factor for this room.

![Figure 4. Room 2 in saturated and desaturated hues.](image)
**Room #3**

Activity level: 10

This room utilizes one horizontal cylinder and three triangles. The upper edge of the cylinder was placed slightly above eye-level to create a horizontal line across the scene. Two of the triangles extended from the boundaries of the space to one other boundary within the space, with one triangle extending from the intersection line between the cylinder and the back wall to the ceiling of the space. The boundaries of the room were kept standard.

Figure 5. Room 3 in saturated and desaturated hues.

**Room #4**

Activity level: 6

Five round ellipsoid shapes were used as the geometry of this room. They all intersect the walls, floor, or ceiling of the space, and were curved along their length to create curved edges in three dimensions. The boundaries of the space had the walls and ceiling curved but its floor was left standard. Every shape within the room draws a curved line in terms of their silhouette. This room forms a pair with room #1 due to their use of a single type of element.
Room #5
Activity level: 11
This room features no elements that push into the central area of the space. All of its walls consist of folded, triangular shapes. These also depict the boundaries of the room. This room forms a pair with room #6 due to having all of its elements held back against the walls of the scene.

Room #6
Activity level: 8
This room features no elements that push into the central area of the space. All of its walls consist of folded, curved geometry. These form the boundaries of the room and draw vertical lines across their lengths. This room forms a pair with room #5 due to having all of its elements held back against the walls of the scene.
Room #7
Activity level: 12
This room consists of five circular shapes and three triangular ones. Two triangular shapes and three circular shapes each start at a boundary of the room and extend towards another boundary but terminate before reaching it. Two of the circular shapes instead extend from either a triangular shape or another circular shape, giving them a free-floating appearance. The one remaining triangular shape envelops a corner of the scene, touching three of the room boundaries. Every boundary in the room is curved.

Room #8
Activity level: 7
This room consists of one horizontal cylinder and three vertical cylinders arranged on the back wall of the scene. The horizontal cylinder was raised to the ceiling of the room. Due to the horizontal cylinder, and the uniformity of
the other elements in the room, this space was easy to read as symmetrical, lending it a more contextual, less abstract appearance. The boundaries of the space were kept standard. This room forms a pair with room #9 due to their apparent symmetry.

Figure 10. Room 8 in saturated and desaturated hues.

**Room #9**

Activity level: 1

A single horizontal cylinder makes up the geometric elements of this room. Its upper edge was placed at eye-level height. Due to the horizontal cylinder, this space was easy to read as symmetrical, lending it a more contextual, less abstract appearance. The boundaries of the space were kept standard. This room forms a pair with room #8 due to their apparent symmetry.

Figure 11. Room 9 in saturated and desaturated hues.
Room #10
Activity level: 13
This room was made up of nine triangular shapes and two circular shapes. They were arranged across the room in a haphazard, yet layered manner, with many of them pushing into the central area of the room. The shapes either extend from a boundary in the room or one of the other elements in the space. They either terminate at one of the other room boundaries, one of the other geometric elements, or before reaching any intersection whatsoever.

Figure 12. Room 10 in saturated and desaturated hues.

The validity of RALS was preliminarily investigated through its correlation with a survey item asking participants about their feelings of activeness in each space (see the following section for details on the survey). As the intention of RALS was to indicate activity, it should correlate with how active people felt in the space. Accordingly, the correlation between the RALS of rooms and self-reported activeness was 0.68, indicating moderate positive correlation. Thus, RALS was deemed to sufficiently indicate space activity.

It should be noted, that due to the nature of the study, participants were primed to reflect on their emotions and thus notice the atmosphere in the spaces they were in. Thus, it was assumed that each participant was able to perceive the atmosphere in the room as long as they self-reported feeling immersed in the spatial experience during the study. This was confirmed at the end of each survey.

Emotional responses to spaces
Participants self-reported their emotional responses through a modified version of the Positive and Negative Affect Schedule (PANAS, Watson, Clark, and Tellegen 1988). While the original PANAS includes 20 items, the survey was shortened to 8 items for the purposes of the current study. Shortening the PANAS has been done in various studies, with many variations of the instrument exhibiting good validity (e.g., Thompson 2007; Mackinnon et al. 1999). The modified survey included 4 items describing positive emotions (attentive, interested, inspired, and excited) and 3
items describing negative emotions (nervous, afraid, and irritable), with the item “active” used for experimental validation in this study. Like the original PANAS, the modified survey used a 5-point Likert scale to report the strength of distinct emotional states, ranging from “very slightly or not at all” to “extremely.” Participants also had the option to not respond to individual emotions.

The internal consistency of the modified PANAS was assessed with Cronbach’s alpha. Both the 4-item positive emotion scale and the 3-item negative emotion scale exceeded the value of 0.7, making their internal consistency above “acceptable” (DeVellis and Thorpe 2021).

Control variables

Participants reported three types of demographic information that were used to explore differences between groups in emotional responses. These variables were experience in a spatial design field (yes / none), experience with VR devices (yes / some / none), and height (in centimeters). Experience in a spatial design field and in VR was asked verbally from each participant, and the responses were assigned to categories afterward.

Data collection

Surveys were set up at times convenient for each participant. When they arrived, they were explained how the study would be conducted and what they were supposed to do. They were first asked questions regarding the control variables, and then asked whether they understood each of the adjectives they would be inquired about during the study. While going over these, they were briefed on the number of spaces that they would be experiencing in VR, told that their feelings would be investigated with said adjectives, and that each room questionnaire would be followed by an open question, where they could freely go over their comments, thoughts, or feelings about a given room. The questionnaire answer scale was explained to them, and with it, the difference between value numbers one and zero was stressed; zero meaning that the participant thought that the question was not valid, applicable, or simply something they did not want to answer, while value one meant that the participant did not feel the respective feeling. The participants were not told what was being investigated or how their results would be analyzed.

After explaining the PANAS scale sheet (Appendix I), they were given the VR headset and its respective controllers, guided in setting it up ergonomically for their head, and briefed on the functionality of the Oculus Quest Guardian Boundary feature. The participants were given time to become confident in moving around the Guardian Boundary, and shown what happened if they walked beyond it; the Oculus Quest exterior cameras would kick in when this happened, and the participants would be able to view the outside world momentarily, in order to avoid hitting any obstacles. The participants were reassured that they would be safe while within the Guardian Boundary. After they were comfortable using the VR headset, they were shown four of the study rooms (numbers 1, 4, 7, and 9) in order to give them a frame of reference for reflecting on their feelings within the abstract spaces. While this was
happening, they were told to expect further abstract spaces like the ones they were viewing, and that no animated features or elements would be jumping out at them during the study.

The VR setup used for the study included a computer running the Windows 10 operating system, the Oculus Quest 1 headset, and assorted peripherals for using the computer (mouse, keyboard) and for connecting the VR headset to it (a five-meter-long USB type C cable that had sufficient bandwidth and power throughput to both charge the headset and transfer the VR image to it). The VR spaces were run in Unreal Engine 4.27, which was also used to create the lighting and shaders for the study rooms. The computer used for the study had the following technical specification: an Intel i7 processor, an RTX 3060 Ti graphics card, 32 Gb of RAM, 1 Tb of SSD storage, a B560i ITX Motherboard, and sufficient power and cooling to run the device competently.

Each experiment took 45 to 60 minutes to complete. The participants were first given enough time to explore each VR room before questions were asked from them. Once they confirmed that they were ready for each questionnaire, their feelings were asked about like they had been told in the previous step. After each room questionnaire had been completed, the participants were asked if they were ready to proceed to the next VR space. Once the participants had seen all of the saturated rooms, they were asked to remove the headset and take a break from VR while I changed the room colors from saturated to desaturated. As was mentioned in the previous section, participants were asked whether they felt immersed in the VR spaces during the study; pretty much everyone self-reported that they had felt immersed and that they were inside the VR rooms during the study.

The study was conducted on the second floor of the Harvard Graduate school of Design, in a booth reserved for student work (see Figure 13). While the surrounding environment was noisy, many participants reported (when asked at the end of each survey) that the noise did not impact their immersion in VR. Each survey was recorded, field notes about the responses of the participants were gathered while each survey was taking place, and participants were allowed to comment on their experiences throughout the study.

Figure 13. Place where study took place.
There were no material incentives for the participants to joining and completing the study but they were all interested in the process and felt like they were doing me a favor. VR was inherently exciting for most participants (according to their own comments), and many showed great interest in taking part in the study, so any further incentive was deemed unnecessary. At the end of their surveys, most participants commented on how exciting or interesting the study had felt.

Data analysis

Quantitative data analysis

SPSS Statistics 27 was used for all statistical analysis procedures.

Missing data

One participant was completely excluded from the study because they did not follow the study protocol. Another participant began feeling nauseous due to the virtual reality glasses after rating the first room, and stopped after that. Their responses regarding the first room were included in the analysis. Removing this data reduced the maximum number of emotional responses by 312, to a final number of 3,528.

Beyond missing all or most data from two participants, several participants chose to not report individual scores on certain emotions for certain rooms. Altogether, 101 (2.86%) of a theoretical maximum 3,528 data points were left empty, making the final dataset comprise 3,427 emotional responses. Anytime a participant had data missing, they were excluded from the scale that the missing data point belonged to. Thus, the number of participants included in each room’s analysis varies between 19 and 23. This discrepancy is unlikely to influence the results significantly.

Factor analysis

PANAS is typically used to measure the general emotional states of participants, for example to control for them in an unrelated experiment. However, in this thesis, PANAS was used to assess emotional responses to spaces. Thus, despite PANAS typically showing a stable 2-factor structure, the unique study context in this thesis warranted reassessing the factor structure.

An exploratory factor analysis (EFA) was conducted to verify the structure of PANAS in the study. Confirmatory factor analysis was not used due to its significantly larger sample size requirements. Still, it was determined that if EFA resulted in the same two-factor structure as defined for PANAS by Watson and colleagues (1988). The EFA was conducted with principal axis factoring extraction method and direct oblimin rotation, for all rooms together (e.g., for “attentiveness”, responses for rooms 1-10 were analyzed in one model). No items were removed based on the analysis, but the activeness item was excluded due to its use as validation for the RALS instrument. The
“attentiveness” item was slightly cross-loaded, but still fit significantly better into positive emotions than negative ones. For the final scale, the Kaiser-Mayer-Olkin measure verified sampling adequacy at KMO = 0.770, with all individual KMO values greater than the acceptable limit of 0.5. Three factors had eigenvalues over Keiser’s criterion of 1 (see Figure 14 for a scree plot visualization), and in combination explained 78.06% of variance in the scale. The factor clustering suggests that factor 1 represents positive emotional responses and factor 2 negative emotional responses. This adheres to the structure of the original PANAS, suggesting that the instrument works as intended in this study. Table 1 shows the detailed factor loadings after rotation.

![Scree Plot](image)

Figure 14. Scree plot indicating two factors in the modified PANAS scale.

Table 1. Summary of the exploratory factor analysis. Note that factor loadings below 0.3 are not displayed in the table.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Items</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive emotional response</td>
<td>Attentive</td>
<td>0.684</td>
<td>0.306</td>
</tr>
<tr>
<td></td>
<td>Interested</td>
<td>0.897</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inspired</td>
<td>0.868</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Excited</td>
<td>0.885</td>
<td></td>
</tr>
<tr>
<td>Negative emotional response</td>
<td>Nervous</td>
<td>0.929</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Afraid</td>
<td>0.915</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irritated</td>
<td>0.900</td>
<td></td>
</tr>
<tr>
<td>Eigenvalue</td>
<td></td>
<td>3.13</td>
<td>2.33</td>
</tr>
<tr>
<td>% of variance</td>
<td></td>
<td>44.77</td>
<td>33.30</td>
</tr>
</tbody>
</table>
Despite promising exploratory factor analysis results, it should be noted that all three negative emotion items were skewed toward smaller values. Specifically, “nervous” had a skewness score of 0.857, “afraid” 1.172, and “irritated” 1.126. See Figure 15 for an example of the difference in distributions between the positive item “interested” and the negative item “afraid.” While the negative emotion scale was still included in statistical analyses, improvements to the items were sought through qualitative analysis.

Figure 15. An example of the skewed distribution in negative emotion items, compared to the normal distribution in positive emotion items.

Differences between groups

Differences in participant groups’ PANAS scores were analyzed using the Independent-Samples Kruskal-Wallis Test and the Independent-Samples Mann-Whitney U test. These tests are essentially non-parametric versions of the students’ t-test. They are suited for relatively small sample sizes and do not require data that is normally distributed. The Kruskal-Wallis test was used when there were more than 2 groups to compare. The analyses were done for both the 1-factor emotional arousal scale, and the 2-factor PANAS, for exploratory purposes. The following paragraphs report the results.

There were no statistically significant differences between genders (p > 0.2 for all rooms). Hence, differences between genders were not considered in subsequent statistical analyses.

There were no statistically significant differences between degrees of experience with VR devices (p > 0.1), except for one instance. Negative emotions reported for the desaturated version of room 3 were significantly different between degrees of VR experience at p = 0.018, with the strength of emotions decreasing with increased VR experience. However, as it could be expected that experience with VR devices would influence emotional experiences for all spaces instead of just one, this result was interpreted as chance. Hence, differences in VR experience were not considered in further statistical analyses.
There were no statistically significant correlations found between the reported emotions and participant age, nor reported emotions and participant height (p > 0.1 in both cases). Hence, these variables were not considered in further statistical analyses.

Outliers in room-level data

Data was analyzed at the room level, where the dependent variable was each room’s energy score, defined by its physical elements and colors. The independent variables were the negative and positive emotion scores averaged across all participants.

The room-level data was visually examined for outliers (see Figures 16 and 17). Several potential outliers were identified, but none were excluded, because they could not be attributed to mistakes in the experimental protocol nor room design, nor participants systematically misreporting their emotional states. Still, each outlier was investigated further through qualitative analysis, as the emotions elicited by them were not adequately explained by the physical-feature-based score. Thus, the outliers were thought to provide insights for improving RALS and any potential tools measuring atmosphere. The outliers identified were:

- Desaturated version of Room 1, inducing higher than expected negative emotions
- Saturated version of Room 3, inducing higher than expected negative emotions
- Saturated version of Room 4, inducing higher than expected positive emotions
- Saturated version of Room 5, inducing lower than expected positive emotions
- Saturated version of Room 6, inducing lower than expected negative emotions

![Figure 16. Relationship between reported negative emotions and room energy based on its physical elements.](image)
Figure 17. Relationship between reported positive emotions and room energy based on its physical elements.

Assumption testing

The assumptions for linear regression were systematically checked in the room-level dataset. Normality of the data was investigated through histograms (see Figures 18 and 19). The data is approximately normally distributed. The normality of error terms was investigated through histograms and P-P plots, both of which indicated a normal distribution for both positive and negative emotions. Homoscedasticity was investigated by inspecting a scatterplot of residuals and predicted values, and no indications of heteroscedasticity were found. The Durbin-Watson test for autocorrelation in the residuals provided a d-statistic of 2.013 for positive emotions and 1.751 for negative emotions, indicating no autocorrelation. Lastly, Tolerance (0.766) and VIF (1.306) values indicated no multicollinearity. Thus, no assumptions of linear regression were violated, making it a viable analysis tool.

Figure 18. Distribution of positive emotion scale scores.
Hypothesis testing and interpretation

Hypothesis 1: Negative relationship between RALS and emotional responses – Not supported

The RALS, positive emotional responses, and negative emotional responses were all correlated at $r > 0.4$ and $p < 0.05$. See Table 2 for the specific values and descriptive statistics.

Table 2. Descriptive statistics and correlations among all room-level measures.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>ALS</th>
<th>Pos. em.</th>
<th>Neg. em.</th>
</tr>
</thead>
</table>

Figure 19. Distribution of negative emotion scores.
Room-level data was analyzed using hierarchical linear regression modeling. Table 3 presents the results of hypothesis testing. No support was found for the hypothesis that less energetic spaces would induce stronger emotional responses. In fact, support was found for the opposite: the more energetic the space, the stronger the emotional response. This was true for both negative ($b = 4.54$, 95% CI [0.21, 8.86], $p < 0.05$) and positive emotions ($b = 3.58$, 95% CI [-0.09, 7.26], $p < 0.10$). Ways to interpret this result were sought from literature and the collected qualitative data, and are reported in the following “Notes on measuring atmosphere” section.

Table 3. Regression results.

<table>
<thead>
<tr>
<th></th>
<th>$b$</th>
<th>SE $B$</th>
<th>B</th>
<th>p-value</th>
<th>$R^2$ (adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-2.63</td>
<td>5.03</td>
<td>-13.20</td>
<td>7.94</td>
<td>0.607</td>
</tr>
<tr>
<td>Positive emotions</td>
<td>3.58</td>
<td>1.749</td>
<td>-0.09</td>
<td>7.26</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-1.08</td>
<td>3.99</td>
<td>-9.47</td>
<td>7.30</td>
<td>0.789</td>
</tr>
<tr>
<td>Negative emotions</td>
<td>4.54</td>
<td>2.06</td>
<td>0.21</td>
<td>8.86</td>
<td>0.46</td>
</tr>
<tr>
<td><strong>Model 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-5.05</td>
<td>5.21</td>
<td>-16.05</td>
<td>5.94</td>
<td>0.346</td>
</tr>
<tr>
<td>Positive emotions</td>
<td>2.28</td>
<td>1.95</td>
<td>-1.84</td>
<td>6.39</td>
<td>0.28</td>
</tr>
<tr>
<td>Negative emotions</td>
<td>3.22</td>
<td>2.33</td>
<td>-1.69</td>
<td>8.13</td>
<td>0.33</td>
</tr>
</tbody>
</table>

* = p < 0.05, ** = p < 0.05
Spaces with higher activity levels induced stronger emotional responses despite hypothesis

Rooms higher on the RALS induced stronger emotional responses despite the hypothesis of the study stating that the opposite should be true. It can thus be determined that the typical notion of atmosphere being stronger in calm or “mindful” architectural spaces (Dai and Zheng 2021) points to something other than the strength of the atmosphere within these spaces. Atmosphere is instead most likely more perceivable in such spaces, because a person’s concentration is less distracted by the goings-on of their surroundings, and thus they are better able to perceive the atmosphere of the space. According to my study, this however does not mean that such an atmosphere would necessarily be stronger than one found in more active environments. Essentially, the hypothesis was predicated on correlating the strength of atmosphere with the ease of perceiving the phenomenon, but as it turns out, these two are not related. In order to study how easily one perceives atmosphere in a given space, a future research is required.

Rooms that did not adhere to the linear regression model

The outliers to the study results were analyzed based on the field notes gathered during the survey. These included the open questions asked from the participants at the end of each VR room questionnaire. These outliers will be discussed in the following paragraphs.

**Room 1**
Almost all participants reported feeling either indifferent or tranquil in the first desaturated room, yet the quantitative data shows that the negative emotions in this room are higher than the linear regression model would seem to predict. Only one participant reported experiencing this room as dangerous, saying that it reminded them of “daggers, danger.” The discrepancy seen here could be due to the participants shifting to the desaturated rooms after looking at all of the rooms previously in color. This however cannot be validated based on the field notes gathered during the survey. Based on the data I cannot offer a conclusive explanation.

**Room 3**
The data for the saturated version of room 3 marks it out as an outlier in terms of its heightened negative emotions, which do not align with the linear regression model. Many participants reported feeling “pressured” by the elements of the room pushing into the center of the space, with one saying that they “did not feel like they belonged” in the space. The triangular shapes close to the ceiling felt unsteady to many participants, like they might fall on top of them, while the horizontal cylinder felt like it was “encroaching” on the area reserved for the participants to stand in. This space was also each participant's first experience of a horizontal cylinder pushing into the center of the space, which may have impacted the strength of the negative emotions experienced here.

**Room 4**
The saturated version of room 4 induced higher than expected values for positive emotions in terms of the data predicted by the linear regression model. Many participants reported liking this room, explaining that they “liked” the curved shapes. Special interest was also shown towards the round shapes that pierced the ceiling, becoming more
hazy as they moved further beyond the ceiling. Many participants also reported feeling “calm” here, with some explaining that they felt like being “underwater” or “in a pool” here. This was the only space that featured only round, curved shapes, which seems to have struck a balance between interesting and tranquil. The blue color further heightened these aspects. It may also be that this room seemed more peaceful thanks to it coming after the colored version of room three, which was an outlier in terms of heightened negative emotions.

**Room 5**
The saturated room’s data showed lower than expected levels for positive feelings among the participants. Many participants reported feeling indifferent about this room, saying that it was “empty” and “boring”. This, along with the fact that it was experienced after multiple rooms with many geometric elements, most likely had an impact on the scores the participants gave the room.

**Room 6**
The saturated version of this room showed lower negative emotions than the linear regression model predicted. Most of the participants connected the primary geometric shape within the room to “curtains.” This strong contextual connection must have made the room appear more familiar to the participants, leading to the lower than expected negative scores.

**Hypothesis 2: Saturated spaces elicit stronger emotional responses than desaturated spaces – Sporadic support; more research required**

Systematic differences between participants’ emotional responses to saturated and desaturated rooms were investigated for each room separately, using the Related-Samples Wilcoxon Signed Rank test. This nonparametric test does not require normally distributed data and is well-suited for smaller datasets. The results are summarized in Table 4 for positive emotions and Table 5 for negative emotions. Only 5 rooms showed significant differences between saturated and desaturated versions, and no room showed differences in both positive and negative emotional responses. Hence, in these rooms, the influence of color was more significant than in other rooms. This finding was further explored through qualitative analysis.

Table 4. Differences in positive emotional responses between saturated and desaturated rooms.

<table>
<thead>
<tr>
<th>Room</th>
<th>Significant differences</th>
<th>Mean saturated</th>
<th>Mean desaturated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>Yes**</td>
<td>2.59</td>
<td>2.05</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>Yes*</td>
<td>3.60</td>
<td>3.11</td>
</tr>
</tbody>
</table>
Spaces where color had a significant influence on emotional responses

**Room 1**

The saturated version of room 1 elicited slightly less negative emotions than the desaturated version of the room. Many participants talked about how the color shift made the space more “tranquil” or “neutral”. A surprising number of participants also commented on how the desaturated space still felt like its saturated counterpart, with some of them noting how the color change actually made the space look light blue. Based on the field notes, it can be surmised that the color shift and its resultant surprise had the biggest impact on the first space the participants saw.
Room 2
The saturated version of room 2 elicited significantly more positive emotions than its desaturated version. While this room was not too popular with the participants overall, there were some who said that it felt “bouncy” or like being enveloped in a “cloud”. One participant went on to compare the saturated and desaturated versions of the room directly, saying that the desaturation “seized the room from existing”, pointing to the “flatness” of its shaders being a contributor to this. Another participant at first said that the space felt “cloud-like” and “soft” but regarded the desaturated version of the room as “boring”. Many participants who said that they disliked the room, disliked it even more once they saw it again desaturated, and most likely because of this, scored their positive emotions related to it even lower than before.

Room 3
The saturated version of the room elicited significantly more negative emotions than its desaturated counterpart. This could be due to the room being the first to feature a stronger color contrast compared to the rooms the participants had seen before it. This was apparent especially in the triangular elements above the participants, as some commented on their “black” appearance, as well as on the bottom of the cylindrical elements, which featured a strong shadow along their bottom edge. One participant said that “you want to watch out for moving parts” in the room, claiming that it felt “industrial”. This would point to the significant impact that the color had on the activity level of the room, which in this case made the room seem potentially dangerous.

Room 4
The saturated version of the room elicited slightly more positive emotions than its desaturated version. With multiple participants saying that the room made them feel like they were “underwater”, it can be surmised that the blue color had a great deal to do with this. As this association was connected by most participants to something positive, it stands to reason that removing the blue color from the room would lessen this association, thus leading to a reduction in positive feelings.

Room 6
The saturated version of the room elicited slightly less negative emotions than its desaturated counterpart. Many participants commented that the “wavy” shape in the room felt more like it was moving or “peeling” when the room was in color, with some noting how the desaturated version of the room made the geometry feel more monolithic. It could be surmised that the sense of movement attributed to the shape added to the participants associating the shape with a curtain, adding to its contextuality, and thus to its familiarity, which deterred negative feelings in this instance.
Hypothesis 3: Weaker emotional responses in architects than in non-architects
– Not supported

There were no statistically significant differences between architects and non-architects (p > 0.185), except for one instance. Positive emotions reported for the desaturated version of room 7 were significantly different between architects (mean = 2.78) and non-architects (mean = 3.75) at p = 0.004. This difference was investigated further through qualitative analysis below. However, as one room represented only a small portion of the dataset, this result was not taken into consideration in further statistical analyses.

Figure 20. Rank differences between architects and non-architects positive emotions in the desaturated room 7.

Differences in experience between architects and non-architects

Room 7 was experienced differently by architects and non-architects, with architects ranking their positive experiences significantly lower in the desaturated version of the space. This was however not supported by the field notes taken during the study, as most architects seemed to respond positively to the room, saying that the desaturation made the space “nicer” or more “exciting”. Similarly, non-architects said that it was “comfortable” and “fun”. The statistical difference is likely to be a result of chance.

Interestingly, there were no differences related to how architects and non-architects responded to room 8, despite many designers audibly associating the geometric cues of the space with the work of Le Corbusier. This was especially apparent in the desaturated version of the room, as the gray color made the geometry look more like concrete. Such contextual familiarity could have suggested an impact in responses, like it did with the “curtains” of room 6, but alas, no statistical differences between architects and non-architects was found.
Notes on measuring atmosphere

The regression model fit worsened when both positive and negative emotions were included. The adjusted $R^2$ increased only marginally when negative emotions were included after positive emotions (from 0.144 to 0.185), and the increase was not statistically significant ($p > 0.1$). This development was unexpected, as assumption checks indicated no multicollinearity, and both variables correlated significantly with RALS. Still, the poor fit of the multiple regression model indicates that there may be multicollinearity in the variables. In practice, this would mean that they explain similar aspects of the variance in RALS, and thus adding both in a regression model only increases the number of variables without improving model accuracy. This result suggests that positive and negative emotions, while distinct constructs in the PANAS instrument and in the study participants’ minds, do not have distinct relationships with RALS. Indeed, perhaps the best way to interpret the regression results is to say: emotional arousal, instead of positive or negative emotional responses specifically, has a positive relationship with RALS.

This interpretation supports the earlier-identified need for more ways to measure individual responses to spaces, which is addressed in the following qualitative results section.

Better words for measuring negative room experiences

Since the negative emotions were not normally distributed, better words for describing negative spatial experiences could be considered for future studies based on the answers gathered for the open questions at the end of each room questionnaire. Such words could be for example: “uncomfortable”, “compressed”, “confined”, “disturbed”, and threatened (as many participants talked about how “dangerous” some of the rooms felt). It should however also be noted that many participants did use words such as “annoying”, “scary”, or “anxious” in their open answers, which link directly to the negative emotions that they were asked about in the study. Of course, this could be simply due to the familiarity of the items that were asked from the participants during the survey, or it could point to the words having some value in the questionnaire.

Limitations

Despite cultural differences, participants were relatively homogenous: basically all from two Ivy League schools in Cambridge, MA. The participants were from a prestigious educational background that most likely impacted the way they engaged with the study rooms. In addition to this, only three participants were above the age of 33, making for a narrow age range. Lastly, the sample size of the study could be expanded, which would make for more relevant statistical data. These limitations are crucial issues that future studies could seek to address.

The lack of scope in the participants’ ages correlated with the reduced amount of professional experience that they held. Many of the participants had a spatial design background or were architects but could still have been considered inexperienced in their respective spatial design fields. A future study could include experienced
designers from specific professional specializations to focus the research into investigating different design professionals.

While the study setup was complimented by many of the participants, and noted as being sufficiently calm so that their immersion in VR was not impaired, further studies could experiment with closed, quiet places for their setups. The participants were also confined to an Oculus Guardian Boundary measuring about 2 by 3 meters, which was not sufficient to encompass the entirety of the VR rooms. A future study could experiment with a larger study space.

**Future research**

Looking at the issues that arose in the quantitative analysis, future research could concentrate on developing purpose-fit instruments for measuring atmosphere. While PANAS was used as an instrument for this study (due to its position as a standard utility for research), and served its purpose as an exploratory tool, a deeper focus on the choice of words connected to atmosphere could yield useful insights into the phenomenon. The participants used words such as “serene”, “tranquil”, “peaceful”, “comfortable”, etc. in their open answers, pointing to a wealth of options for describing their feelings while in the VR study rooms. These could be used to create a better instrument for future research. It would be interesting to compare results from a study conducted with more purpose-fit instruments to what was found here: would such a study provide different insights into the strength of atmosphere?

As was concluded earlier, the strength of atmosphere does not necessarily correlate with our ability to perceive it. Based on the disproved main hypothesis of this study, future research could look at the environments that make us primed to perceive atmosphere. Do they align with Gernot Böhme’s view that “mindful” spaces create a setting within which one can more easily perceive atmosphere (Dai and Zheng 2021)? Creating strong atmospheric places in architectural design could be considered less important than the creation of spaces where one actually perceives their atmosphere. Thus, this avenue of research could be considered more important than what was studied here.

I have previously discussed the impact of context on atmosphere with professors Toshiko Mori and Allen Sayegh from the Harvard Graduate School of design. The discourse has largely revolved around the effect of different building typologies on the perception of atmosphere. Due to our cultural contexts, we are primed to anticipate a certain atmosphere in a specific building typology (compare museums to hospitals for example). Discussions with the aforementioned professors have not yielded credible ways to reduce the number of variables that impact atmosphere in different building typologies, making a scientific study difficult. It is difficult to synthesize building typologies to their constituent parts, because even a cursory glance into the subject shows how little different buildings of any given building typology have in common with each other. You can easily find exceptions to any rules you might come up with when looking at typologies. In addition to this, it is difficult to determine how to represent buildings in 3D: an appropriate level of realism would have to be established, at the expense of participants relying on imagination as they did in this study. Nonetheless, the context and our familiarity with it
surely has a great impact on how we perceive atmosphere within a given architectural space, as alluded to by the response participants had for the “curtains” of room 6. Future research could look at more specific architectural cues — even trends — and measure whether architects and non-architects respond to them differently.

Conclusion

This study focused on assessing the strength of the emotional responses people had in abstract rooms experienced via a virtual reality simulation. These results were collected with a questionnaire that was analyzed via quantitative and qualitative methods. It was hypothesized that spaces, which were lower on the RALS and which were colored would elicit stronger emotional responses in the study participants. In addition to this, it was hypothesized that participants with a background in spatial design fields would experience weaker emotional responses within the VR rooms due to their professional perspective, and the detachment that ensues from it. Hypothesis #1 and #3 were not supported by the study findings, while hypothesis #2 gained sporadic support.

As the RALS and the strength of the reported emotional responses showed a negative relationship (hypothesis #1), it can be concluded that the strength of any given atmosphere does not necessarily correlate with the ease with which people perceive it. This throws into question the commonly held belief among phenomenological architects that the creation of calm or mindful spaces is key to creating strong atmospheres in architectural design. Further study into the architectural cues that make us perceive atmosphere is warranted.

As hypothesis #3 was also disproven, it can be surmised, that architects are likely as good at perceiving room atmosphere as non-architects. Consequently, the intuitive process at the heart of architectural design can be considered sufficient for creating universally applicable atmospheres, as long as the architects engaging in said process know how to create atmospheric spaces in the first place; the possibility of this was contested in the interview study I did previously (Ilvesmäki 2019).

Hypothesis #2 regarding the impact of color on the strength of room atmosphere showed sporadic support, meaning that further research into the relationship between color and atmosphere is needed. This result could however suggest that using saturated hues in the design of spaces is important. The impact of interior design on architectural experiences should thus not be underestimated. Architects often prioritize the showcasing of construction materials in their natural finishes. Perhaps they should instead take heed of the color research conducted in environmental psychology, and thus follow the example set by interior designers.
Acknowledgements

I would like to thank my advisor, Professor Allen Sayegh, for guiding me through two semesters of study. His insistence on reducing the scope of the research to its current format was vital for the project to succeed. Secondly, I would like to thank Professor Silvia Benedito for shaking up this thesis in April 2022, and explaining to me how it should inform architectural discourse; as this is an architectural thesis and not just a scientific article. Thirdly, I would like to thank Professor Rahul Bhui from MIT Sloan School of Management, whose course “Marketing Innovation” introduced me to linear regression models, and statistics in general. Fourthly, I would like to thank Indrajeet Haldar, a student at Harvard Graduate School of Design, who helped me make the Unreal Engine simulation smoother by setting up the code to change the study rooms at the press of a button. Last, but by no means least, I would like to call attention to the immense gratitude that I hold towards Antti Surma-aho, PhD candidate and friend at Aalto University, who coached me throughout the process of writing this thesis, helped a great deal in realizing its quantitative analysis, and provided emotional support throughout my thesis semester.
References


Neumann, Melanie, Friedrich Edelhäuser, Diethard Tauschel, Martin Fischer, Markus Wirtz, Christiane Woopen,
Appendix I: Modified PANAS

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Appendix II: Survey results

Have you ever used VR before?  yes few times

Height: 157 cm

name: Reena, a family of four, who like the

names want to explore, pretty in size and

name: Mahima, want to climb

name: Nandita, likes to walk through a

name: Shobha, lives in India

name: Swati, not sure

name: Shobha, feels like she was taken through
different experiences
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**Feelings**

- Felt immersed in the virtual space.
- academics involved in the experience.
- felt excited and engaged.
- felt nervous and apprehensive.
- felt afraid and anxious.
- felt active and involved.
- felt inspired and motivated.
- felt excited and enthusiastic.

** Likert Scale **

1: Very slightly, 2: A little, 3: Moderately, 4: Quite, 5: Extensively
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- critical viewpoint for rooms, there why eg. more didn't seem relevant
- no connects about the change of color, some random more apparent in red
- felt like maybe he was overcorrecting due to knowing the psychology of the color
Have you used VB before?

ft

Are you from Singapore?

Yes, height: 1.74 m

Male, 29 years old

What do you study?

Computer Science

Did you learn to code before?

Yes, I learned it at university.
Have you used VR before? Yes, but not for years.

What gender do you identify as? She/her.

What is your profession? Architectural designer/editor.

Does your background in any spatial design field (eg: architecture, urban design, landscape architecture, etc.) Yes.

Room 1: Attractive, interested, nervous, excited, afraid, irritable, excited.
Room 2: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 3: Attractive, interested, nervous, afraid, active, irritible, excited.
Room 4: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 5: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 6: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 7: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 8: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 9: Attractive, interested, nervous, afraid, active, irritable, excited.
Room 10: Attractive, interested, nervous, afraid, active, irritable, excited.

Sentence for an uneasy feeling: Access spaces that spur anxiety, make you uneasy, or logical. Is there a visible solution to this? No.

The space feels confusing. The overall space has a lot of windows, but it’s darker. The space feels crowded, and the windows make it feel more crowded. There are clear glass reflections that won’t allow you to see through them.
Have you used VR before?

No.

How tall are you?

167 cm.

Are you interested in learning more about VR?

No.

Do you have any hobbies or interests that you think would benefit from VR technology?

No.

Please write a sentence describing what you find most interesting about technology in general.

I find technology fascinating because it has the potential to revolutionize so many aspects of our lives, from healthcare to transportation.
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**Overall Comment:**
- Likes: little detail other than color doesn't like space
- Dislikes: language and detail doesn't like color around
- Feelings: makes him feel this space
- Overall: doesn't like it

**From Mexico**

**Male, Student Architect**

Have you used VR before? Yes, months before?

Weight: 173

Not applicable

**Room 6:**

1. Little detail other than color doesn't like space
2. Language is detail doesn't like color around
3. Feels more crowded without color
4. Doesn't like it

**Room 7:**

1. Can't comment the lack of color
2. Feels more crowded without color
3. Doesn't like it

**Room 8:**

1. Can't comment the lack of color
2. Feels more crowded without color
3. Doesn't like it

**Room 9:**

1. Can't comment the lack of color
2. Feels more crowded without color
3. Doesn't like it

**Room 10:**

1. Can't comment the lack of color
2. Feels more crowded without color
3. Doesn't like it

**From Mexico**

**Male, Student Architect**

Have you used VR before? Yes, months before?

Weight: 173

Not applicable

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2. Feels more crowded without color
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**Room 10:**

1. Can't comment the lack of color
2. Feels more crowded without color
3. Doesn't like it
**Have you used VR before?**

- From India

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**felt somewhat immersed**

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**Not applicable**

- Seeing shadows
- Bathing
- Differences in BW
- Shadows in BW
- Colors in BW
- Why are colors in BW?
- Shadows in BW
- Colors in BW
- Why are colors in BW?

**Curves are nice but suddenly only in this space**

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**feels like**

- Good room
- Nice
- Nice
- Nice
- Nice

**remembers well**

- Everything
- Stuff
- Stuff
- Stuff
- Stuff

**likes it**

- Little
- Little
- Little
- Little
- Little

**not much**

- Likes it
- Likes it
- Likes it
- Likes it
- Likes it

**resembles street art**

- Clouds
- Clouds
- Clouds
- Clouds
- Clouds

**work in BW**

- In BW
- In BW
- In BW
- In BW
- In BW
Have you used VR before?

Yes, last summer.

From China.

914 N.

P.S.

For course 2.5.

Are you proficient in space? (Self-evaluated)

Yes.
Have you used VR before?
Yes

Height: 152 cm
From India

<table>
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Note: The table represents the responses to various questions regarding the user's experience and emotional state during an interaction with a virtual environment.
What age are you? 23
What gender do you identify as? Female
What is your height? 5'4
Which country do you come from? USA
What is your profession? Grad student
Do you have a background in any spatial design field? Yes
Have you used a VR headset before? No

Room #1
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.

Room #2
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.

Room #3
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.

Room #4
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.

Room #5
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.

Room #6
- Attentive: 5
- Interested: 4
- Nervous: 3
- Inspired: 2
- Afraid: 1
- Active: 0
- Not excited: 0
- Color: Blue
- OMG: Nothing
- This one is much better than the last one. It feels closer to shapes, no longer intimidating.
- Graphics seem to blend without color, which makes the scene feel smooth.
- In the prior round, it was more relaxing without color, but this one lacks color.
- It feels like being in a virtual reality environment.
felt immersed

PANAS
MDes Thesis 2022
Hannah Dowseki

What age are you?
26

What gender do you identify with?
female

What is your height? (min 1.58 m)
1.58 m

What country do you come from?
China

Student

Do you have any background in any spatial design field (eg. architecture, urban design, landscape architecture, etc)?

Yes

Have you used a VR headset before? If so, when was this?
No

Not applicable or not at all

Very slightly

Slightly

Moderately

A little

Quite

Very

Extremely

Real

Structured

Reality

Excl

Feelings

Room 1

Room 2

Room 3

Room 4

Room 5

Room 6

Room 7

Room 8

Room 9

Room 10

Feel very quiet when
feeling circle, good place
for remembrance

Less interesting
around room with not walls,
feels trapped because doors
and windows are absent

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Felt like floor

Feels similar
to before

Safe, would
like to
stay here

Peaceful, simplicity
wants to
touch things

We because
see her face

Move all players
start points flower

Room 3

Room 4

Room 5

Room 6

Room 7

Room 8

Room 9

Room 10

Attention
interested

Interested

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Interestingly, very simple,
complex, vanishing, like a	puzzle game, wants to know
why these players are there

Black overall felt better for her,
also in terms of flatnesses
felt immersed
in the space