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The Effect of Fractal Dimensionality on Behavioral Judgments of Built Environments

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THE EFFECT OF FRACTAL DIMENSIONALITY ON BEHAVIORAL JUDGMENTS OF BUILT ENVIRONMENTS

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by

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY William Andrew Stalker ENTITLED The Effect of Fractal Dimensionality on Behavioral Judgments of Built Environments BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Stalker, William Andrew. M.S., Department of Psychology, Wright State University, 2022. The Effect of Fractal Dimensionality on Behavioral Judgments of Built Environments

This research examines the effects of fractal dimensionality on ratings of beauty, relaxation, and interest, when these patterns are incorporated in a built space. Previous findings suggest that fractal patterns can be used to mimic the beneficial psychological and physiological effects that arise from viewing nature. This research focuses on studying the impact of fractal patterns when presented within urban environments. The findings here are primarily consistent with previous research. Medium *D* patterns are preferred over the other pattern complexities. Low *D* patterns are consistently rated as more relaxing. High *D* patterns are rated as being more interesting over low *D* patterns, but the difference between high *D* and medium *D* might be smaller than previously thought. These collective findings support the further investigation of the implementation of fractal patterns to promote a form of mental enrichment for inhabitants and a reduction of the stress in an urban environment.

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The Effect of Fractal Dimensionality on Behavioral Judgments of Built Environments

Introduction

Having conquered the natural elements, the majority of humans in today's western cultures now spend over 90% of their lives in buildings (Evans & McCoy, 1998). While humans might have escaped much of the harshness of the outdoors by primarily confining between walls, it appears that an urban refuge is not without some cost to our general wellbeing. The tradeoff is subtle but people on average do tend to both physiologically feel better and prefer natural environments compared to urban environments (Staats, Kieviet, & Hartig, 2003). While someone's feeling or preference for one environment over another may seem trivial, researchers have recently been taking this general feeling as a potential clue and a sign for a need of change in scenery (Brielmann et al., 2022). The increasing amount of time spent in man-made boxes and the recent decline in mental health that is in part attributed to the disconnection from nature has led scientists, architects, and designers to investigate how one can bring the benefits of the outdoors, in (Taylor, 2021). Interior designers have experimented within this concept by building indoor exhibits that mimic natural scenery, such as a rainforest or jungle, but these sorts of displays are hardly practical for everyday office spaces. More commonly, people bring the outdoors in by opening a window and adding plants in an attempt to liven up their bland surroundings.

While these approaches can make a space temporarily feel more in tune with nature, these options are often not practical or effective solutions. A more universal solution is needed and so instead, inspired designers have spent significant effort investigating how one might replicate and seamlessly integrate nature's patterns in our surrounding art and architecture (Coburn et al., 2020). This feat can be accomplished, but the secrets to replicating the visual beauty of the natural world has previously been reserved to only a select few artists and skilled craftsmen. Today, experts in the fields of neuroscience and physics have now brought their scientific tools to the table and have begun to study these same secrets of nature's patterns. These experts come together in hopes to better understand not only how to replicate these patterns and their beneficial effects, but to better understand why these patterns impact humans the way they do.

Since the 1960's, scholars have proposed that there is more to humans' innate preference for natural scenery than just how "beautiful" a landscape may look (Taylor, 2021). In fact, the physiological benefits of natural environments substantially account for peoples' preference for them (van den Berg, Koole, & van der Wulp, 2003). Viewing natural scenery has been reported to physiologically beneficially influence levels of stress (Coburn et al., 2020), physical recovery time after hospitalization (Ulrich, 1984) levels of diastolic blood pressure (Hartig, Evans, Jamner, Davis, & Gärling, 2003), and long-term cardiac health (Kardan, Gozdyra, et al., 2015). Thankfully, these restorative effects do not require people to be secluded deep in the wilderness, but a view of nature via a window will work as well (Brooks, Ottley, Arbuthnott, & Sevigny, 2017). Researchers have also replicated the benefits of viewing a natural landscape with virtual representations of them (Berman et al., 2008; Berto, 2005; Valtchanov et al., 2010; Valtchanov & Ellard, 2015).

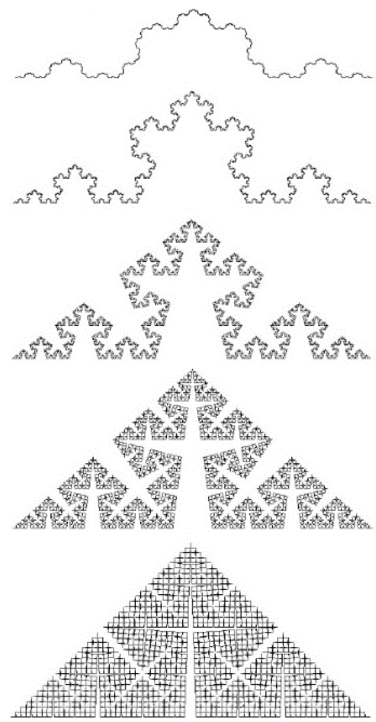
Evidence that these beneficial properties can be mimicked with purely visual stimuli, stripped of all of the other properties that come with being outside, has led researchers to believe these effects are primarily the result of an underlying visual phenomenon rather than the result of a culmination of our other senses. In the last twenty years, multiple different interdisciplinary teams have investigated this topic and found significant evidence that these beneficial effects are likely in-part influenced by some of the fractal perceptual patterns of natural scenes (Purcell, Peron, & Berto, 2001; Joye & Vanden Berg, 2011; Hagerhall et al., 2015; Hagerhall, Purcell, & Taylor, 2004; Spehar, Clifford, Newell, & Taylor, 2003; Taylor, 2021).

Fractals are reoccurring patterns that recur on finer and finer scale, often producing an immensely complex shape (Taylor et al., 2011). Most people have knowingly viewed a fractal pattern before either when using kaleidoscope, at a music festival, or on a poster in a high school physics classroom. The most famous and well-known fractal image is the Mandelbrot set, which was discovered to the world's delight with a simple equation in the 1980s (Mandelbrot, 1983). Fractal patterns can be found in many different aspects of the natural world both in the general scenery and in the finer details. Fractals come in many different shapes and sizes. The branches of trees, the billows of clouds, the forks in a bolt of lightning, and the leaf pattern of a fern are all examples of fractals (Taylor & Spehar, 2016). The difference between fractals in nature and those that are man-made is that fractals in nature are rarely as exact. Natural fractals, also known as statistical fractals, have some element of randomness to them unlike the exact fractal patterns created via computer programs (Taylor, 2021). Although having a computer is helpful, humans learned how to create fractal patterns on their own many years ago. Some artists with a particularly keen eye, like Jackson Pollock for example, have developed techniques to mimic fractal patterns and incorporate them into their artwork to great success (Taylor et al., 2011). While these uses are often dazzlingly colored, quantitative research of fractals rarely focuses on their color but primarily on a pattern's level of repetition.

Fractal patterns are characterized by their complexity, denoted as fractal dimensionality, or *D*. Fractal dimensionality is the magnitude at which the fractal pattern repeats itself (Taylor & Spehar, 2016). Fractal dimensionality ranges between 1 and 2. The higher the fractal dimensionality, the higher the magnitude and refined structure of the fractal pattern. In Figure 1, Taylor & Spehar (2016) illustrates the effect of increasing *D* of the same fractal pattern. The first iteration begins with a low *D* (1.1) and each following iteration is slightly more complex (1.3, 1.5, 1.7, and 1.9 respectively). Fractals never have a *D* value of 1 or 2, they only have values between 1 and 2. This is because a *D* value of 1 represents a smooth line and a 2 represents a completely filled-in area, causing the fractal pattern to be lost (Taylor et al., 2011). Low fractal dimensionality patterns ($1 < D \leq 1.3$) are characterized as looking soft or smooth while high dimensionality patterns ($1.6 \leq D < 2$) are more complex and jagged. Most fractal patterns in nature are mid-complexity ($1.3 < D < 1.6$) fractals, which are interchangeably referred to as medium complexity depending on the author (Abboushi et al., 2019; Taylor & Spehar, 2016).

Figure 1

An Exemplar of Increasing Fractal Dimensionality (D) Complexity



Note: Reprinted from Taylor, R., & Spehar, B. (2016). Fractal fluency: An intimate relationship between the brain and processing of fractal stimuli. The fractal geometry of the brain. *Springer*.

The human visual system appears to be particularly adept to tracing mid-complexity fractal patterns as it can do so relatively effortlessly compared to other levels of *D* (Fairbanks & Taylor, 2011; Taylor et al., 2011). Psychologists and psychophysicists have researched and proposed explanations as to why humans are able to more easily visually scan and navigate in fractal environments of mid-complexity. The most prominent explanation is the Fractal Fluency Theory (Taylor & Spehar, 2016).

The Fractal Fluency Theory proposes that our appreciation and the reported effortlessness of viewing mid-complexity fractals is the result of humans' evolutionary past (Taylor & Spehar, 2016). Early humans were constantly required to quickly survey landscapes for potential food and foe. To do so, the human visual system had to learn to scan large swathes of land quickly and thoroughly. The Fractal Fluency Theory suggests that our visual system met this demand by evolving to better trace mid-complexity patterns and in doing so, making a potentially taxing task an easy routine (Taylor & Spehar, 2016). This effortlessness, or fluency, is thought to significantly contribute to the commonly reported positive affective and stress reducing experience of viewing the mid-complexity fractal patterns of the natural world (Brielmann et al., 2022). To find physiological evidence to support this theory, researchers looked to the patterns of the eye and discovered that our eye movements, known as saccades, move in a mid-complexity fractal search pattern when surveying land (Fairbanks & Taylor, 2011).

Since mid-complexity fractals are the most common fractal pattern in nature, it is logical to assume that the visual system would evolve to optimize for its surrounding (Brielmann et al., 2022; Taylor, 2021). This has led some researchers to wonder if this optimization was hardcoded for the mid-complexity fractal patterns found in our ancestral environment, or if the human eye could learn to re-adapt to new surroundings characterized by fractal patterns with complexities outside of the mid *D* range. To answer this question, scientists have investigated whether eye movements adapt to patterns of varying dimensionality by presenting subjects fractals of vary complexity between D = 1.1 and 1.9 (Fairbanks & Taylor, 2011). Essentially, the researchers tested whether the human eye adapted to the complexity of the fractal pattern, or if the eye instead does not adapt and continues to move in an optimal manner for viewing mid-complexity fractal patterns, regardless of the complexity of the current fractal pattern that the eye is tracing.

The findings from the experiment supported the latter claim. Regardless of the fractal images complexity, the saccade motion of the eye was insensitive to various ranges of fractal complexity and continued moving in a manner optimal for viewing mid-range *D* fractals (Fairbanks & Taylor, 2011).

This collection of evidence suggests that at least some of the past documented beneficial properties associated with viewing natural scenery could be in part due to the mid-complexity fractal perceptual properties of most natural landscapes and our seemingly evolutionarily optimized preference for these patterns. If these assumptions are true, one might hypothesize that this positive pairing could be exploited and used in areas in which natural landscapes are uncommon to generate the same effect. This line of reasoning has led to the collaboration of psychologists, designers, and architects with the goal of incorporating mid-complexity fractal patterns on man-made designs in hopes to mimic the beneficial psychological and physiological effects of viewing natural landscapes.

This collective effort has grown into a whole new area of behavioral research, focusing on how different artificial representations of fractal patterns of varying complexities influence a perceiver’s affect. Researchers have also sought to compare viewers’ ratings of man-made fractals patterns against ratings of two-dimensional representations of natural fractal patterns. Extensive work has investigated these questions and found promising results. Man-made mid-complexity fractal patterns are consistently rated as both visually pleasing (Aks & Sprott, 1996; Spehar et al., 2003; Taylor, 1998), as well as relaxing and stress reducing (Hagerhall et al., 2008, Taylor, 2006). This preference for two dimensional representations of mid-complexity pattern occurs whether the patterns were generated naturally or via a computer (Taylor et al., 2003). These findings were a promising next step but they could not explain whether the difference in reported affect was the result of the patterns themselves or because of the different fractal complexity of the two patterns. This dilemma could not be solved until the *D* value of a fractal pattern could be manipulated experimentally.

Experimenters of the past relied on finding fractal patterns of varying complexity that were similar enough as to not produce confounds when collecting subjective ratings of different *D* values. Thanks to the technological improvements of the last decade, experimenters now have the ability to generate fractal patterns and incrementally adjust their complexity, as exemplified in Figure 1, in order to compare the behavioral ratings of the same fractal pattern across different dimensionalities variations (Abboushi et al., 2019). This incremental adjustment has revealed trends, such as low *D* fractals patterns are typically described as “Calm” and “Peaceful.” As levels of *D* increase, the ratings of the patterns transition from relaxing, to increasingly towards exciting and stimulating (Abboushi et al., 2019). The ability to generate and compare artificial fractals of varying *D* has greatly helped researchers better understand how fractal complexity might influence human affect. However, the majority of these man-made implementations have focused primarily on utilizing two-dimensional, flat, visualizations, which are uncommon in the natural world (Abboushi et al., 2019, Hagerhall et al., 2008; Spehar et al., 2003, Taylor et al., 2011). Artificial two-dimensional visualizations lack the depth of a natural setting and so there is some concern among researchers that these newfound effects may not transfer as seamlessly when incorporating these artificial patterns into the setting of three-dimensional spaces.

Little research has been done on the application of these patterns to the world because of the difficulty of artificially incorporating fractal patterns in three-dimensional spaces and the cross-disciplinary team that it requires to create and study them. Research by Abboushi et al. (2019), began to explore this topic by testing how the rendering of these patterns in three dimensional spaces and viewing distance impacts a viewer's ratings of preference and interest. To better understand the impact of the setting and presentation of fractal patterns, Abboushi et al. (2019), utilized an auditorium with a projector that they configured to display Euclidian and fractal patterns of varying dimensionality onto a flat wall. In this experiment, participants sat at varying distances and rated each pattern as they were displayed. Contrary to their initial predictions, viewing distance had no significant impact on the ratings and the collected response patterns were consistent with previous research. In the second experiment, the setting that the patterns were virtually presented in was changed. Rather than displaying isolated Euclidian and fractal patterns on a wall, the researchers instead utilized rendering technology to portray the patterns as shadows cast by window shades into an office, presenting the patterns as if they were incorporated into the environment (Abboushi et al., 2019). In this second experiment, the viewers preference significantly shifted towards higher *D* patterns now that a setting had been provided. This came as a surprise considering that the fractal patterns in the second experiment were identical to the ones displayed in the earlier auditorium viewing distance experiment; the main difference being the presentation and the addition of a realistic setting (Abboushi et al., 2019). The experimental inquiry of most of the publications discussed so far has been limited to studying fractal patterns in isolation. Publications, such as Abboushi et al. (2019), suggest that the way in which the fractal pattern is presented within stimuli should also be considered.

While past research of the effects of viewing fractal patterns isolated in two-dimensional images has provided great insight, these findings and others concerns alludes to the notion that the results of the two-dimensional applications might not directly transfer to three-dimensional applications (Abboushi et al., 2019; Bies et al., 2016). More research is therefore needed before architects and designers can feel more confident that these past findings and significant relationships will apply when incorporating these fractal patterns into urban three-dimensional spaces across multiple settings (Brielmann et al., 2022).

With the goal of utilizing the perceptual mechanisms and mimicking the mid-complexity fractal patterns of nature in mind, the next step is therefore further research investigating responses to fractals patterns of varying dimensionality when they are incorporated into three-dimensional simulated built environments (Abboushi et al., 2019). Research has uncovered that the fractal visual properties of natural landscapes that may induce the restorative effects can be replicated in two-dimensional man-made visualizations (Taylor, 2021). Research is now needed to investigate how humans respond to fractal patterns when presented within built spaces. More specifically, a clearer understanding is needed about the potential differences when these fractal patterns are embedded within a built environment. Doing so will help further the goal of mimicking the beneficial psychological and physiological effects of nature in our predominantly urban environment via the incorporation of fractal patterns, potentially leading to a form of mental enrichment for inhabitants and a reduction of the stress that is partially attributed to our modern unnatural Euclidian surroundings.

In this research endeavor, I aim to focus on the representation of fractal patterns of varying complexity within built environment, utilizing insight from the findings characterizing the relationship between affective response and fractal patterns. More precisely, this study will focus on how people respond to fractal patterns of varying complexity as incorporated in patterns in a built space. To accomplish this goal, an analytic investigation will be done using archival data collected previously in the Human Neuroscience and Visualization Lab as part of a collaboration with Dr. Joori Suh and her research group, Spatial Interaction Lab (DAAP, UC).

In line with past findings, I hypothesize that simulated built spaces with fractal patterns of mid-complexity *D* will be significantly preferred, manifesting in higher ratings in beauty, over built spaces with patterns of low or high fractal *D*. This hypothesis is based on consistent previous findings that subjects prefer viewing mid-complexity fractals and rate them higher compared to those of other varying dimensionalities (Aks & Sprott, 1996; Spehar et al., 2003; Taylor et al., 2011; Taylor, 1998). Based on the studies reviewed above, I predict that this past preference for mid-complexity fractals will be replicated in this study and reflected by higher ratings of the positive traits of beauty. These specific dimensions, along with the others discussed below, were selected due to their past success in differentiating between complex aspects of architectural experience (Coburn et al., 2020).

I also hypothesize that simulated fractal patterns in built spaces with fractal patterns of low complexity *D* will be rated as more relaxing than built spaces with mid or high complexity *D* fractal patterns. Past evidence from studies using isolated representations of fractal patterns of varying complexity supports this hypothesis. Taylor (2006) demonstrated that participants who viewed mid and low complexity fractal patterns had significantly greater reduction of stress compared to those participants who viewed higher complexity fractal patterns. There is no current evidence suggesting that representations of fractals in built spaces would be any different and so I expect this effect to be prevalent within our stimuli set as well.

Continuing this line of thought, I hypothesize that those of high complexity *D* will be more stimulating, signified by higher ratings of interest compared to the built spaces with fractal patterns of low and mid complexity *D*. High complexity fractal patterns are consistently rated as more exciting and arousing than mid and low complexity patterns (Abboushi et al., 2019), and we expect this trend to carry over into representations in built spaces.

Methods

Participants

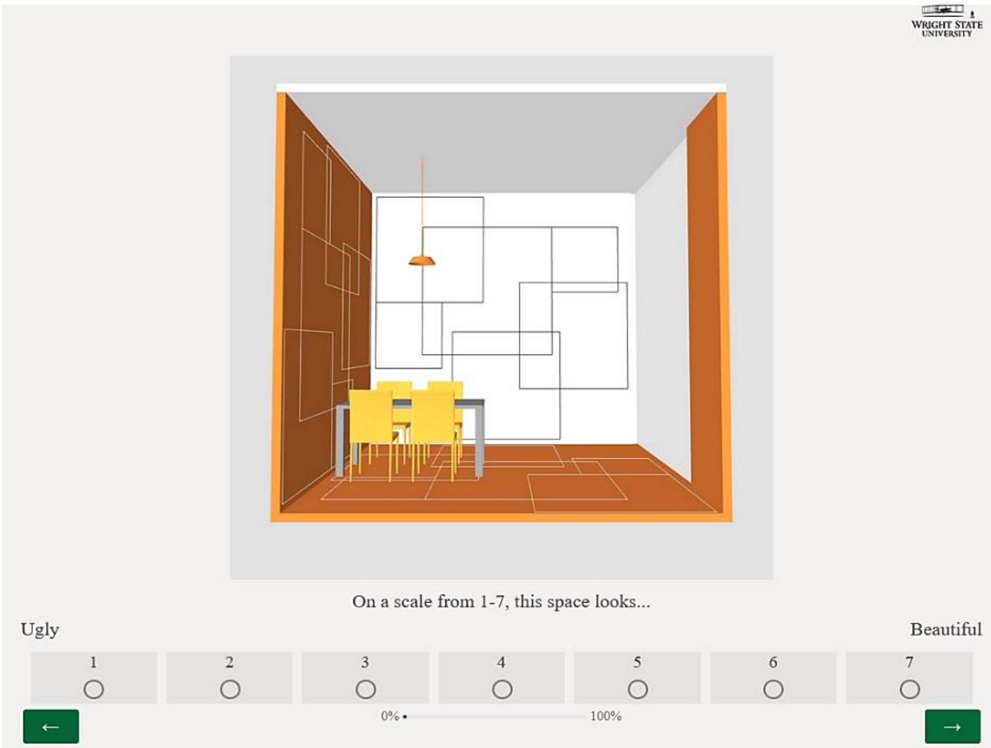
The archival dataset was collected from 200 participants ages 18 and older recruited from Wright State University in exchange for course credit. A near equal proportion of participants (100 each) were recruited for both versions of the survey. Demographic information was collected following subjects' consent to participate in the study. Relative response time and long string analysis, both precautions from the careless responding literature (Huang et al., 2012; Meade & Craige, 2012), were used to screen for insufficient effort.

Stimuli

The stimulus set was created by Dr. Joori Suh and her research group, Spatial Interaction Lab (DAAP, UC). It consists of a total of 270 images of three-dimensional fractal environments of varying fractal dimensionality (*D*: low, medium, high) and depth of pattern application (shallow, middle, deep). The 270 images were split into halves (135) between the two versions of the survey. Each combination of fractal dimensionality and depth of pattern application were represented by 30 exemplars, making 15 exemplars for each condition combination for each study (Survey Version A = Exemplars 1-15, Survey Version B = Exemplars 16-30). The order of the stimuli was randomized to minimize potential order and sequence effects. Participants were presented with a new exemplar after completing the 6 different rating scales for each exemplar image during data collection. Images were presented in the center of the screen with a 7-point dichotomous continuum scale underneath as shown in Figure 2 below. All stimuli were set to the size 565px by 565px to ensure the subjects can view the exemplar when filling out the scale.

Figure 2

An Exemplar from the Perspective of the Participant



Fractal dimensionality was validated by Dr. Steen Pedersen (CoSM, WSU). The fractal dimensionality of the stimuli was validated using a box-counting technique. This technique involves overlaying a grid of squares over a pattern. This is then repeated using grids with smaller and smaller squares. This analysis of these varyingly sized grids is what allows researchers to study how the detail of a pattern changes with scale. The more a pattern repeats at the smaller scale, the more complex it is and the higher its *D* value.

For the purposes of this study, all variations of fractal dimensionality will be compared but only the stimuli with the shallow depth of pattern application will be utilized. This simplifies the stimuli set of interest to 90 images.

Measures

The rating scales were adapted from a previous study investigating the psychological responses to architectural interiors (Coburn et al., 2020). Rather than have participants rate stimuli using 16 different scales, the collected dataset focused on the six most relevant rating scales (Beauty, Interest, Valence, Relaxation, Approachability, and Explorability). When this archival data set was collected, these rating scales were selected not only due to their past success in differentiating between complex aspects of architectural experience, but also because they have also been used in fMRI studies investigating neural activation and architecture which might be of interest in future experiments. Each scale starts with a prompt and consists of a low anchor and high anchor. For example, the rating scale measuring beauty has the low anchor of “Ugly” and a high anchor of “Beautiful.” Examples of all rating prompts can be found in Appendix A. For the purposes of this study, only the ratings of three of the six assessed traits will be studied (Beauty, Interest, Relaxation). These three rating scales were selected due to their high frequency of inclusion in similar past studies and because of their lack of construct overlap / covariance (Coburn et al., 2020).

Experimental Design and Procedures

The experiment used a repeated-measures design with levels of Fractal Dimensionality as the independent variable. To reduce length of the experiment, the survey was divided into two equivalent portions. This was done to reduce participant fatigue and the likelihood of careless responding (Meade & Craig, 2012). Both surveys consisted of 15 unique exemplars for each of the 3x3 conditions (135 exemplars each) with 6 questions per exemplar (810 questions each). Participants had the opportunity to participate in one or both surveys. Carryover effects are unlikely should subjects participate in both versions of the survey. Each survey was given a near identical name and description in the institution's research participation system to indicate that they are similar studies and that they do not need to be completed in a particular order.

Subjects completed the survey on a desktop computer or laptop to ensure that the stimuli were properly displayed and not distorted. Subjects were warned and prohibited from completing the survey on a mobile device such as a smartphone, tablet, or E-reader. The study software (Qualtrics) implemented a precautionary check after obtaining consent to ensure participants are using the appropriate device type. The study implemented forced choice and automatically progress to the next question after receiving a response to reduce the duration.

Participants completed one of the two Qualtrics surveys by accessing the link via the institution's research participation system. Failure to provide consent or use of a mobile device prohibited the participant from progressing. After consent was obtained, participants were asked to voluntarily submit demographic information. Subjects were then randomly presented one of the 135 exemplars and asked to rate the exemplar using six different 7-point rating scales. The rating scales were each presented one at a time to ensure the participant could view the exemplar and the scale without having to scroll down the page. Each scale was forced choice to reduce the amount of incomplete data. After providing a rating, the survey automatically progresses to the next scale.

Participants had the option to return to a previous rating but would unlikely do so due to the nature of the experiment. The order of scale presentation was consistent throughout to reduce potential confusion. After completing the 6 different scales, the participant was presented with a new exemplar. Once all 135 exemplars had been rated, a thank you message appeared, and the subjects were asked to close the browser tab.

Data Processing

Preprocessing

Catching incomplete and careless responses is crucial to the integrity of a survey, especially when conducting item development (Meade & Craig, 2012). We suspected some participants may exhibit a content non-responsivity response bias, meaning responding without regard to item content. This bias is likely because of the considerable length of the survey, the repetitive nature of the task, potential environmental distractions, and the lack of social contact between the researchers and the subjects (Bowling et al., 2021). While bogus items and self-report engagement questions have been used by other researchers to detect careless responding, this study relied on post-hoc measures. More priority was given to maintaining the flow of the study which would be disrupted by adding bogus items. To detect careless responding, we used measures of response time, outlier analysis, and response patterns as suggested by the relevant literature (Curran, 2016).

First, incomplete data was removed from the collected archival dataset. Next duplicate entries were removed, retaining only the first entry as it is likely to be most like the responses of those who completed the survey only once (Meade & Craig, 2012). Next the amount of time a participant spent completing the survey was reviewed as it is considered as a potential indicator of careless responding (Curran, 2016). The median amount of the time spent on the survey was used to better determine if a participant displayed insufficient effort when responding to the survey. The median was used as the average in this case because of misleading impact of outliers on the reported mean. Responses were removed if their completion time is above the third quartile × 1.5 of the interquartile range (IQR) or if it is shorter than half of the amount of time that it took pilot study participants to complete the survey. Implementation of these response time outlier catchers will likely detect some of the participants who did not invest an adequate amount of effort into completing the task of the experiment (Bowling et al., 2021).

The last check for careless responding before conducting an analysis of variances (ANOVA) is the problem of uniformity responding. Various response patterns, such as consistently responding with the same answer or a patterned approach, are potential indicators of insufficient effort on a set of items (Meade & Craig, 2012). While these patterns might typically be easily noticed by scanning the data, this is not the case for this dataset because of the software used to collect it. Unfortunately, Qualtrics does not provide a view that displays the questions in the order at which a participant completed the survey. The software application does however provide a column listing the order of the items were presented to the participant which was used to manually reorganize the data.

The last 10 items (60 questions) that each participants rated was reviewed for potential indicators of insufficient effort. Potential response pattern indicators include repeated unbroken long strings of endorsements of the same response option (Ex: “1,1,1,1,1,1,”), known as long strings, or repeated altering endorsement of only two to three of the seven response option (Ex: “2,3,2,3,2,3”), all seemingly regardless of the context of question or image (Curran, 2016). An occasional unbroken sequence of the same response option / pattern does not necessarily indicate careless responding but a frequent habit of it does raise suspicion. To help better sort between the two, we adopted a conservative rule of thumb from the literature and considered individuals who consistently used long string responses equal or greater than half the length of the scale as displaying insufficient effort (Curran, 2016). This rule was applied to the selected 60 questions rather than 810 since this analysis will be completed manually. The percentage of long strings of 3 or more and repeated altering endorsement will be calculated. To make comparisons between subjects easier, these percentages were used to assign each participant a score from 1 to 5 to reflect their likeliness of careless responding, with a score of 1 representing very unlikely and 5 representing very likely. Flagged participants with scores of 2s and 3s will consist of a few long string sequences and other somewhat suspicious response patterns but not enough to reasonably cast out. Scores of 4s and 5s were reserved for participants whose response to the final 60 questions consisted primarily of unbroken sequences of repeated endorsement and obvious carelessness. Following the above-mentioned rule, participants with scores of 4s and 5s were removed.

Analysis

First, an item validation analysis was conducted with a confirmatory factor analysis in RStudio. This test allows one to examine how exemplars of the selected condition combinations compare to one another (Kline, 2016). Items that are designed to fit within the same condition set should receive similar ratings to one another. If an item is statistically different than its peers, it may not belong in that condition set. A confirmatory factor analysis reveals if there are any significant differences in the ratings of an item within its set after all of the data has been collected. Items that are statistically significantly different from the other items in their condition across all three dependent variables were excluded for construct purity purposes.

Further data analysis was conducted in RStudio via 3 two-way ANOVAs per construct (Beauty, Interest, Relaxation) per survey (Version A, Version B). Designing the ANOVAs in this manner allowed for the examination of how fractal *D* impacts the ratings of the three constructs, if survey version has an impact, and if there was an interaction effect between fractal *D* and survey version. Survey version nor its interaction with fractal *D* was expected to account for any statistically significant differences in the rating.

Results

The three hypotheses of this study were tested using data from 57 participants. Only the participant data that passed standard survey and questionnaire data cleaning techniques was kept for analysis (see Methods for details). The confirmatory factor analysis revealed that 3 items were statistically different from the rest of the item in their condition set across all three constructs. This suggests that something about these items is unintentionally differentiating them from the other items in the condition set that they were designed to belong to. Responses to these outlier items were therefore excluded from the final analysis (Kline, 2016). Including items that are outliers within their condition set can potentially skew the results. The dataset was analyzed with and without the outlier items; the conclusions were not significantly different from one another.

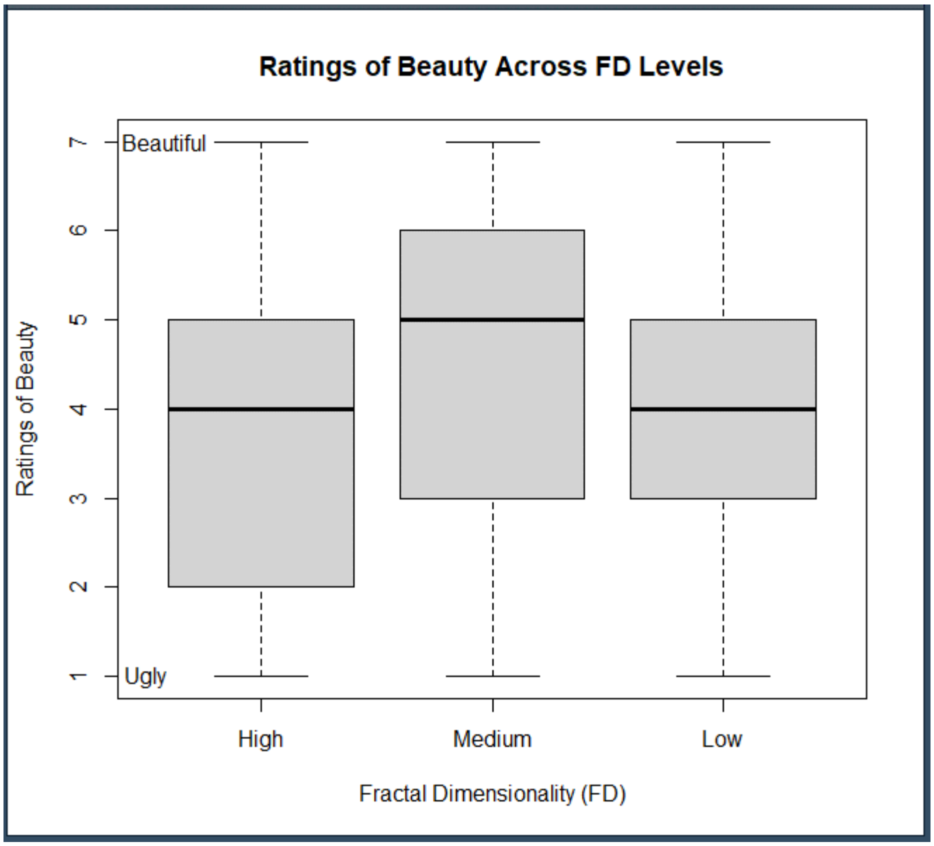
A total of three two-way ANOVAs were conducted, one for each hypothesis. These three models were created using level of fractal dimensionality (*D*: low, medium, and high) and survey version type (A or B) as the independent variables. The dependent variable of each model varied between measures of beauty, relaxation, and interest. Each variable was rated along a 7-point continuum with dichotomous ends.

Beauty

The first hypothesis was that simulated built spaces with fractal patterns of mid-complexity *D* will be aesthetically preferred, manifesting in higher ratings in beauty, over built spaces with patterns of low or high *D*. This hypothesis was tested by comparing the measures of beauty attributed to the exemplars of the three types of *D* groups. The two-way ANOVA revealed that the mean ratings (Figure 3) were significantly different across the three *D* conditions, ($F(2, 2559) = 50.446$, $p < 0.001$), and there were no significant differences between survey versions ($F(1, 2559) < 1.00$). There was no significant interaction between *D* and Survey Version ($F(2, 2559) = 1.512$, $p = 0.22$).

Figure 3

Ratings of Beauty Across Fractal Dimensionality Levels



Note: The averages were calculated using the data from both surveys.

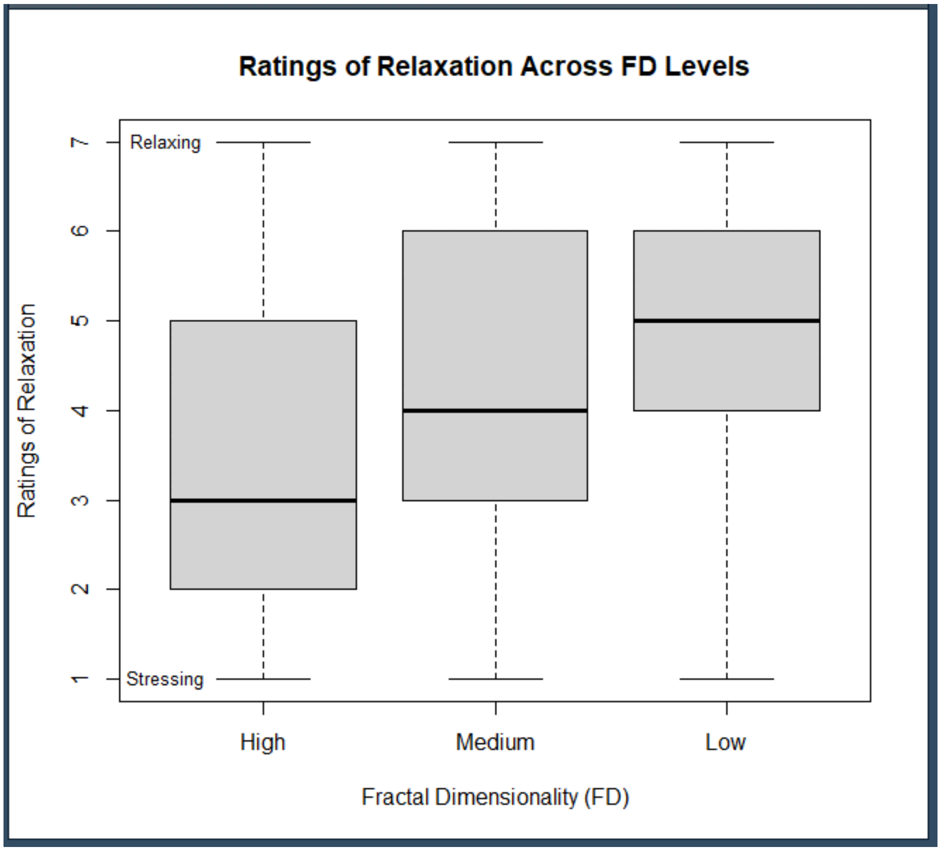
A post-hoc multiple comparison using Tukey's honest significance test (HSD) revealed that spaces from the low ($M = 4.04$, $SE = 0.06$), and medium ($M = 4.40$, $SE = 0.06$) *D* conditions were rated as significantly more beautiful than exemplars from the high *D* condition ($M = 3.53$, $SE = 0.07$) ($p < 0.001$). This post-hoc test also revealed that there is a significant difference between the low and medium *D* conditions, with spaces of the medium *D* condition being rated as significantly more beautiful than spaces from the low *D* condition ($p < 0.001$). Given that these findings were significant, Cohen's *d* tests were used to measure the effect size. The effect size of the contrast between the medium *D* and high *D* group was relatively small ($d = 0.48$, 95% CI [0.38, 0.57]). The effect size of the difference between the low *D* and high *D* conditions was small ($d = 0.28$, 95% CI [0.18, 0.37]). The effect size between the low *D* and medium *D* group was small ($d = 0.21$, 95% CI [-0.30, -0.11]. These findings support Hypothesis 1, which predicted that medium *D* exemplars would be rated as significantly more beautiful than the *D* exemplars of the other two conditions.

Relaxing

The second hypothesis was that simulated built spaces with fractal patterns of low complexity will be rated as more relaxing than built spaces with mid- or high *D*. This hypothesis was tested by comparing the relaxation attributed to the three *D* conditions from both survey versions. The two-way ANOVA revealed that the mean ratings (Figure 4) were significantly different across the three *D* conditions ($F(2, 2559) = 135.553$, $p < 0.001$), and a significant difference between survey versions, ($F(1, 2559) = 9.063$, $p < 0.01$). The latter effect was not expected. However, there was no significant interaction between *D* and Version ($F(2, 2559) = 2.029$, $p = 0.132$).

Figure 4

Ratings of Relaxation Across Fractal Dimensionality Levels



Note: The averages were calculated using the data from surveys.

A post-hoc multiple comparison using Tukey's honest significance test (HSD) revealed that the low ($M = 4.57$, $SE = 0.05$) and medium ($M = 4.37$, $SE = 0.06$) *D* spaces were rated as significantly more relaxing than the high *D* spaces ($M = 3.32$, $SE = 0.06$) ($p < 0.001$). This post-hoc test also revealed that there is a significant difference between the low and medium *D* conditions, with low *D* spaces being rated as significantly more relaxing than medium *D* spaces ($p < 0.05$). Given that these findings were significant, Cohen's *d* tests were used to measure the effect size. The effect size of the difference between the medium *D* and high *D* group was medium ($d = 0.60$, 95% CI [0.51, 0.70]). The effect size of the difference between the low *D* and high *D* group was medium ($d =$

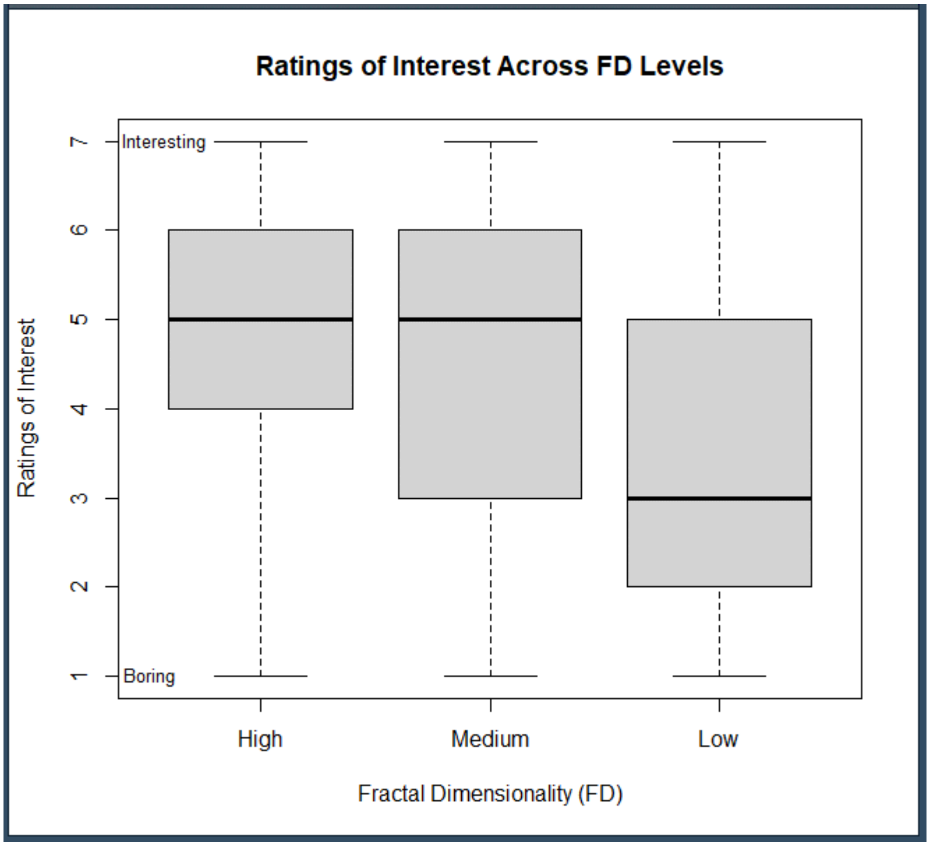
0.73, 95% CI [0.63, 0.83]). The effect size of the difference between the low *D* and medium *D* group was negligible (d = 0.13, 95% CI [0.03, 0.22]). These findings support Hypothesis 2, which predicted that low *D* exemplars would be rated as significantly more relaxing than the *D* exemplars of the other two conditions, though the difference between the low and medium *D* conditions was smaller than expected.

Interesting

The third hypothesis was that simulated fractal patterns in built spaces with high complexity *D* will be more stimulating, signified by higher ratings of interest compared to the built spaces with fractal patterns of low and mid complexity *D*. This hypothesis was tested by comparing the relaxation attributed to the three types of *D* conditions from both survey versions. The two-way ANOVA revealed that the mean ratings (Figure 5) were significantly different across the three *D* conditions ($F(2, 2559) = 123.230$, $p < 0.001$), there were no significant differences between survey versions ($F(1, 2559) = 2.961$, $p = 0.085$). There was no significant interaction between *D* and Survey Version ($F(2, 2559) < 1.00$).

Figure 5

Ratings of Interest Across Fractal Dimensionality Levels



Note: The averages were calculated using the data from surveys.

A post-hoc multiple comparison using Tukey's honest significance test (HSD) revealed that the medium (M = 4.73, SE = 0.06) and high (M = 4.79, SE = 0.07) D spaces were rated as significantly more interesting than the low D spaces (M = 3.59, SE = 0.06) ($p < 0.001$). This post-hoc test also revealed that there is no statistically significant difference between the medium and high D conditions (p = 0.72). Given that some of these findings were significant, Cohen's d tests were used to measure the effect size. The effect size of the difference between the medium and high D conditions was negligible (d = 0.04, 95% CI [-0.13, 0.06]). The effect size of the difference between the low and high D group was medium (d = 0.65, 95% CI [-0.75, -0.56]). The effect size of the difference between the low and medium *D* group was medium (d = 0.64, 95% CI [-0.74, -0.54]). These findings partially support Hypothesis 3, which predicted that high *D* spaces would be rated as significantly more interesting than the spaces of the other two *D* conditions. While the high *D* spaces did receive statistically significantly higher ratings of interest compared to the low *D* spaces, the difference between the high *D* spaces and low *D* spaces was negligible.

Discussion

Careful science can reveal to us useful tools that we can then use to shape our environment. With many of these tools, we are still just beginning to learn why they work, how to use them, and where to best apply them. Fractals and their impact on our perception is with no doubt one of these new tools that we are still learning how to use to its full potential. This study hoped to remove some of this uncertainty via the examination of the effects of fractal dimensionality on ratings of beauty, relaxation, and interest, when these patterns are incorporated in a built space. The three constructs / rating scales were selected due to their high frequency of inclusion in similar past studies and because of their lack of construct overlap / covariance (Coburn et al., 2020).

Discovery of this tool, fractal dimensionality, first arose from growing interest in the rich literature on the positive physiological and psychological benefits of viewing natural environments (Hartig et al., 2003; Ulrich, 1984; van den Berg, Koole, & van der Wulp, 2003; Kardan, Gozdyra, et al., 2015). Researchers sought to bring the outside in and learned that similar benefits could be invoked with visual renditions of fractal patterns that mimic natural scenery (Purcell, Peron, & Berto, 2001; Joye & Vanden Berg, 2011; Hagerhall et al., 2015; Hagerhall, Purcell, & Taylor, 2004; Spehar, Clifford, Newell, & Taylor, 2003; Taylor, 2021). This discovery has led to a series of experiments investigating the relationship between fractal dimensionality (*D*) and human perception (Abboushi et al., 2019, Aks & Sprott, 1996; Spehar et al., 2003; Taylor et al., 2011; Taylor, 1998). The goal of the current study was to expand upon these previous findings and to provide better understanding of how to mimic the beneficial physiological and psychological effects of nature in our predominantly urban environment via the incorporation of fractal patterns in built settings.

The influence of fractal dimensionality (*D*) on human perception has primarily been studied using pictures of patterns isolated of any setting. These patterns of varying complexity are presented as an image on a screen and the participant is typically asked to rate the image of the fractal pattern using a dichotomous scale of the desired construct. Most of the previous research that has studied the effects of fractal complexity in this manner has been consistent. Medium *D* patterns are preferred over the other fractal pattern complexities (Aks & Sprott, 1996; Spehar et al., 2003; Taylor et al., 2011; Taylor, 1998). Low *D* patterns are consistently rated as more relaxing than high *D* patterns (Taylor, 2006). High *D* patterns are more rated as being more interesting over medium low *D* patterns (Abboushi et al., 2019). New research, including the present study, has begun to move away from studying fractals in this isolated manner and has transitioned towards studying these same patterns but now within a built space or man-made setting. This transition in research-approach was the next logical step along this endeavor to learn how to bring some of the previously reported benefits of viewing nature to an urban setting. A few inconsistent findings can divert the trajectory, or worse, bring the entire expedition to a halt. The current experiment picks up the journey where it was last left off by studying how the effects of fractal dimensionality on ratings of beauty, relaxation, and interest translate when these patterns are presented in a built environment.

Figure 6

Examples of the Medium Fractal Dimensionality Stimuli

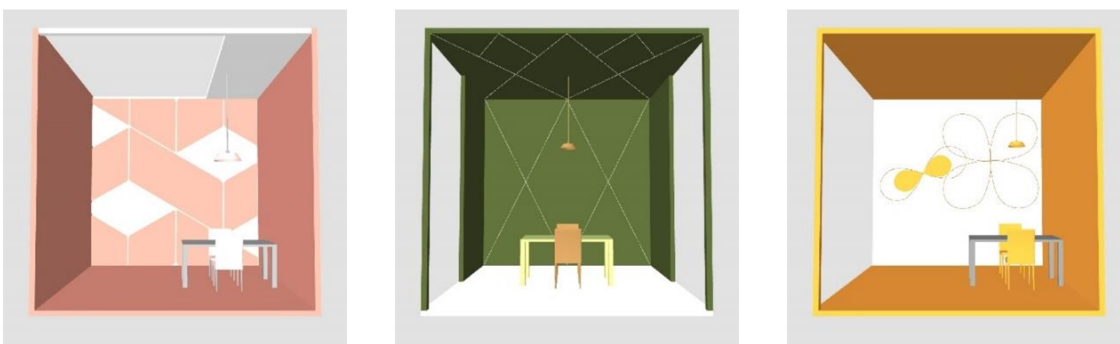
Note: These images were created by Dr. Joori Suh and her research group, the Spatial Integration Lab (DAAP, UC).

Beauty: *Hypothesis 1*

The first hypothesis of the study was that simulated built spaces with fractal patterns of mid-complexity *D* would be significantly preferred, manifesting in higher beauty ratings, over built spaces with patterns of low or high fractal *D*. The results of this study were that fractal patterns of medium complexity were significantly preferred over patterns of low or high fractal *D*. Patterns of medium complexity were rated as being the most beautiful on average, followed by patterns of low complexity. Built spaces in the highest *D* group were the least preferred of all three groups. These current results confirm Hypothesis 1 and align with most of the previous research which also found a preference for medium complexity fractals over other dimensionalities (Aks & Sprott, 1996; Spehar et al., 2003; Taylor et al., 2011; Taylor, 1998). The finding that built spaces in the highest *D* group were the least preferred of all three groups directly contrasts the findings from Abboushi et al., (2019) which found the exact opposite. Given that the findings of the present experiment are consistent with most of the previous research that studied fractal pattern complexity, it appears that this new rendition does not disrupt the documented trend in preference. Fractal patterns of medium *D* are rated as more beautiful and significantly preferred over those of other dimensionalities. These findings support the notion that medium complexity fractal patterns should be used when beauty and visual preference is the goal. Those seeking to create a space that promotes wellbeing should consider using medium complexity fractal patterns in their design. Potential places of applications for these patterns includes shopping plazas, restaurants, or almost any other urban space where people go for enjoyment and to be pleasantly engaged.

Figure 7

Examples of the Low Fractal Dimensionality Stimuli



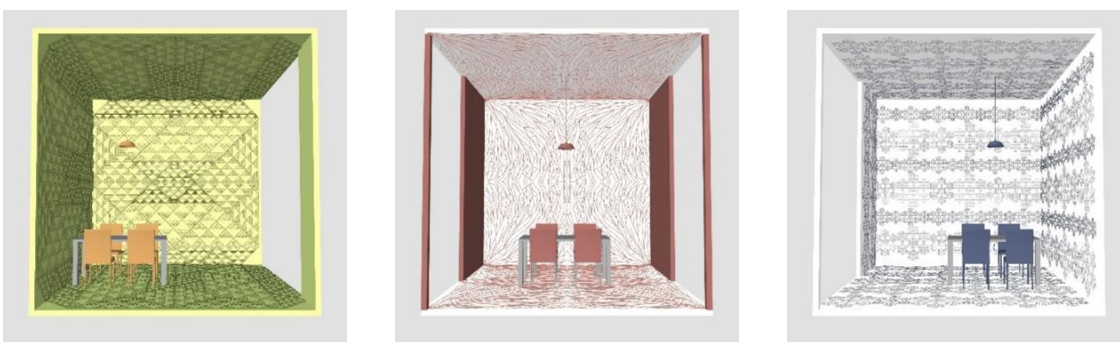
Note: These images were created by Dr. Joori Suh and her research group, the Spatial Integration Lab (DAAP, UC).

Relax: *Hypothesis 2*

The second hypothesis was that simulated fractal patterns in built spaces with fractal patterns of low complexity *D* would be rated as more relaxing than built spaces with mid or high complexity *D* fractal patterns. The results of this study were that fractal patterns of low complexity were rated as significantly more relaxing over patterns of medium and high fractal *D*. These results confirm Hypothesis 2 and are consistent with the previous research which demonstrated that both medium and low complexity patterns are less stress inducing than high complexity patterns (Taylor, 2006). The results from this study expand upon this idea, revealing that low complexity fractal patterns provide a stronger benefit than medium complexity patterns. These findings support the notion that low complexity fractal patterns should be used when a designer wants to maximize stress reduction and invoke feelings of calm and relaxation. Potential places of applications for these patterns include spaces that people go to seek peace, such as spas and libraries. Other beneficials places to apply these patterns are in spaces that are generally uncomfortable and particularly stressful for people, like hospitals or in airplanes.

Figure 8

Examples of the High Fractal Dimensionality Stimuli



Note: These images were created by Dr. Joori Suh and her research group, the Spatial Integration Lab (DAAP, UC).

Interest: *Hypothesis 3*

The last hypothesis was that high complexity *D* would be more stimulating, signified by higher ratings of interest compared to the built spaces with fractal patterns of low and mid complexity *D*. The results of this study were that the high complexity fractal patterns were rated as significantly more interesting than low complexity patterns. The average rating of interest for high complexity fractal patterns however was not significantly higher than the rating for medium complexity fractal patterns; the means for these two conditions are almost the identical. However, as seen in Figure 5, there is less variance in the ratings of the high complexity condition, suggesting that exemplars of this condition were more consistently rated as being higher in stimulation. Thus, while these results do not fully support this hypothesis or the previous findings that reported that high complexity fractal patterns are consistently rated as more exciting and arousing than other fractal complexity patterns (Abboushi et al., 2019), they do partially support it. A potential post-hoc explanation as to why this previously reported difference was not seen here is that the measurement of “interest” used in this study might be too broad of a term when attempting to measure stimulation. Things that are inherently interesting are also generally “exciting,” and “stimulating,” which is why I had hypothesized that the results would be consistent with past findings and high complexity fractal patterns would receive the highest rating of stimulation. However, things that are inherently interesting are also generally “beautiful” or “captivating.” I suspect that the wording of the measure of stimulation was unintentionally also partially capturing ratings of “beauty,” thus explaining why the group of medium complexity images received higher scores in stimulation than expected (Coburn et al., 2020). Future research might consider using different, potentially seemingly redundant terms, to see if this is the case. These collective findings support that high *D* patterns are significantly more stimulating than low *D* group and given that the variance in the high *D* group is smaller and that of medium *D* group, they also offer partial support that high complexity *D* patterns may be more stimulating than medium *D* groups. Further research with more careful measurement is needed to confirm this last finding. Potential places of applications for these patterns includes places that are trying to stimulate or attract interest. Businesses that profit by grabbing your attention may potentially apply these high *D* patterns to their storefronts, magazine covers, and billboard advertisements to draw and hold the viewer's gaze. Educators may also use these same patterns to attract interest to previously overlooked information by applying them to a display in a museum. Various entities are already trying to attract our attention and this may be one additional means of subtly doing so.

Implications

Overall, the results from the present experiment are very promising. The trends from ratings of varying fractal complexity pattens from previous similar studies (Aks & Sprott, 1996; Spehar et al., 2003; Taylor et al., 2011; Taylor, 1998; Taylor, 2006) remain consistent with the newest renditions presented in this study. The results of the current experiment that do not completely align with previous research is at least partially support by them (Abboushi et al., 2019). This study provides further evidence of the beneficial properties of fractal imagery and how designers might capitalize on these patterns when attempting to elicit different feelings. This research supports that medium complexity fractal patterns should be used when beauty and preference is the goal while low complexity fractal patterns should be used when the designer wants to invoke feelings of calm and relaxation. The present experiment also discovered a new finding not expected or previously reported in the literature to our knowledge; levels of interest and stimulation appear to be statistically similar between the medium and high *D* complexity conditions. While this might be due to a potential measurement error (see Limitations, below), regardless, designers seeking to elicit the most stimulating patterns should consider that the high complexity fractal patterns were rated as more stressful (low ratings of relaxation) than the medium complexity fractal patterns. These collective findings lay down the newest sturdy steppingstone along the path towards mimicking the beneficial psychological and physiological effects of nature in our predominantly urban environment via the incorporation of fractal patterns.

Limitations

There are three limitations to the current experiment that warrant further investigation. The first being that a convenience sample was used as participants were solely undergraduates enrolled in a psychology course at a midwestern university. This is a limitation of external validity; the validity to which the findings may generalize to other situations, people, and settings. While the relevant literature and the proposed underlying mechanisms behind the fractal complexity phenomena does not suggest that there should be regional or cultural differences, I believe it would be ideal if the dataset also included samples from outside of the United States. If this research is to impact the design decisions around the world, it is important to ensure that the findings properly generalize. Non-generalizable findings masquerading as generalizable could contribute to future researchers mistakenly burying their findings because they do not align with the established literature. At worse, non-generalizable findings could cost misled designers to waste massive sums of resources to incorporate fractal patterns when their effects may not be consistent across settings and cultures.

The second limitation was that each construct was only measured via one scale. This is a limitation of content validity; the validity to which the test or scale evaluates all aspects of the construct it was designed to measure. While researchers may intend a scale prompt to measure a particular construct, participants may interpret the prompt differently and fill it out with an alternative construct or facet of the construct in mind. In the worst instances, this problem results in a researcher's findings not being replicable. This dilemma can be avoided by providing the participants with definitions of each construct before asking them to assess the stimuli. Introducing redundancy by having two different scale prompts measure the same construct may help alleviate this problem. If the two different prompts from the same construct have similar ratings, it is more likely that the participant is rating the exemplar with the intended construct in mind. If their ratings vary substantially from one another, this could signify a distinction in the way that the participant conceptualizes a construct or that the participant is not putting in sufficient effort and is careless responding. Helping the participant understand the definition of the construct is critical but this very same problem can also occur with researchers. If two researchers have different interpretations of what exactly their scales are measuring, they may walk away and report their results using slightly different wording. This may unintentionally cause a pair of similar outcomes to be reported as two very different findings, even if they are using the same scale or scales with similar wording. Future researchers should remember to be precise in their speech and to be cautious not to embellish the phrasing of their results to the point that it may twist the interpretation of the findings.

The third limitation of the current study was the means in which the dataset was collected. The dataset was collected during the COVID-19 pandemic and so all data collection was conducted remotely in accordance with the IRBs social distancing guidelines at the time. While not ideal, these steps were taken to remove any chance of endangering the health of the participants or the researchers. It is well known that remote and unproctored data collection efforts are consistently plagued by a substantial number of careless responders (Meade & Craige, 2012). This becomes a problem as high amounts of careless responding leads to feelings of doubt about the overall findings and can lead to replication issues. The potential problems associated with remote data collection process were mitigated by ensuring that participants could only use a non-mobile device and via the implementation of multiple researcher-backed checks for careless responding. Researchers should also employ similar safeguards when concerned about their data sample (Meade & Craige, 2012).

Future Research

This research endeavor has begun to answer some of the questions related to how fractal dimensionality can be implemented in different settings, but there are still many more paths to be explored. Before addressing these big picture questions though, here are few suggestions on how to improve the research methodology of similar studies. Future research investigating the impact of fractal complexity should consider all the limitations mentioned above; collect broad and diverse samples to improve external validity, define the constructs to improve content validity, implement redundant measures or at minimum consider that one's scale may not be measuring what its intended to, and conduct proctored experiments in person while being wary of careless responding. Researchers should be just as careful in their selection of stimuli as they are in their methodology. Future fractal researchers should pay close attention to all of the visual properties of their stimuli. Although the primary focus is on the impact of the fractal dimensionality, other visual factors such as the contrast, the colors used, and the presences of textures may impact a viewer's perception and judgment. This can lead to problems in the interpretability of a study's fractal *D* findings if not properly accounted for. The spaciousness, the level of scale, and the amount of clutter are examples of important factors one should also consider when studying fractals in built environments. These factors were taken into consideration when the stimuli set was developed for this experiment. While not done in this study, researchers should also consider the perceivers familiarity with different fractal patterns or whether they have any visual processing or eye conditions. Peoples' preference for different fractal complexities outside of the medium *D* range is not yet entirely understood. Accounting for these two factors and similar aspects about the perceiver may explain future differences found between different sets of subjects. Consideration of all of these factors when designing similar experiments should strengthen the reliability and validity of one's findings.

Future research avenues of interest can be divided between two topic categories, biology and applicability. On the biological front, additional research should investigate how truly universal the preferences are for particular ranges of fractal dimensionality. Assuming that our preference for medium complexity fractal is a byproduct of our evolution (Taylor & Spehar, 2016), do humans of different ancestral origins have different preferences for fractal dimensionality ranges that more closely mimic the natural environment of their ancestors? If so, this could bring into question the generalizability of some findings and influence designers to consider their target demographic before implementing fractal patterns into their design. I suspect that this is unlikely but it is worth considering. If our preference is a byproduct of our evolution (Taylor & Spehar, 2016), do other primates have similar preferences for mid-*D* environments? How far back does this evolutionary preference go? Answering these questions will not only help us better understanding the biological history of perception of fractal patterns, but it could also lead to research and advocation for fractal environments that are designed for animals that are enclosed in built spaces.

Speaking of animals enclosed in non-natural built spaces, future research should explore new means to measure the impact of setting on humans' perception of fractal dimensionality. Future researchers should consider using virtual reality technology when exploring this relationship. Conducting this type of research in virtual reality allows participants to view fractal patterns within the setting of a built space in a more life-like manner while simultaneously keeping the resource cost lower than what would be required to build an actual physical full-scale model. This research direction may reveal that the impact of presence that comes with using virtual reality may strengthen previous perceptions. Alternatively, it may reveal whether these effects can only be replicated in the real world when a participant is viewing the fractal pattern at a particular angle and direction. In other words, how does the view or location of the pattern impact fractal dimensionality. This very factor may have impacted how our participants perceived a few of our items. In this study, we had three items that received significantly different ratings across all factors when compared to the rest of the exemplars in their condition. A post-hoc review of these items led to the discovery that each of these items had a substantial amount of their fractal pattern obscured by the objects in the environment or not directly in sight. In one example, the back wall was open and the pattern was difficult to view without changing the angle. Rotating the perspective was not possible with our current design but different methodologies can work around this issue. This proposes the question whether the amount of clutter in the setting or line of sight of the pattern impacts the relationship between fractal dimensionality and perception. The current study should give architects and designers confidence that these trends can be applied outside academia; the next step is to compare ratings of the same patterns of fractal complexity without a setting, within the setting of a built environment like this experiment, and within the setting of built environment that the participant can move about it (see Brielmann et al., 2022; for references investigating how the brain responds to its architectural environment).

Conclusion

The purpose of this study was to examine the effects of fractal dimensionality on ratings of beauty, relaxation, and interest, when these patterns are incorporated in a built space. The goal was to expand upon previous findings and better understand how to mimic the beneficial psychological and physiological effects of nature in our predominantly urban environment via the incorporation of fractal patterns. The findings here are primarily consistent with previous research. Medium *D* patterns are preferred over the other pattern complexities. Low *D* patterns are consistently rated as more relaxing. High *D* patterns are rated as being more interesting over low *D* patterns, but the difference between high *D* and medium *D* might be smaller than previously thought. These collective findings support the further investigation of the implementation of fractal patterns to promote a form of mental enrichment for inhabitants and a reduction of the stress in an urban environment.

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Appendix

Appendix A: Aesthetic Rating Scale Sampled from Coburn et al., 2020

Aesthetic Property	Rating Prompt	Low Anchor	High Anchor
Beauty	On a scale from 1-7, this space looks…	Ugly	Beautiful
Interest	On a scale from 1-7, this space looks…	Boring	Interesting
Valence	On a scale from 1-7, this space makes me feel…	Bad	Good
Relaxation	On a scale from 1-7, this space makes me feel…	Stressed	Relaxed
Approachability	On a scale from 1-7, if I saw this space, I'd…	Leave	Enter
Explorability	On a scale from 1-7, if I saw this space, I'd…	Ignore it	Explore it