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# Exploring the Beauty of Tradition: How Fractal Geometry Influences Visual Attention in Architectural Design

## *La belleza de la tradición: Cómo influye la geometría fractal a la atención visual en el diseño arquitectónico*

## *A beleza da tradição: Como a geometria fractal influencia a atenção visual no design arquitetónico*

**Keywords** | Palabras clave | Palavras chave

Architectural complexity, Artificial intelligence, Neuroaesthetics, Pre-attentive vision, Eye-tracking simulation

Complejidad arquitectónica, Inteligencia artificial, Neuroestética, Visión preatentiva, Simulación del seguimiento ocular

Complexidade arquitetónica, Inteligência artificial, Neuroestética, Visão pré-atencional, Simulação de rastreamento ocular

**Abstract** | Resumen | Resumo

Traditional, classical, and vernacular architectural forms often exhibit fractal qualities that enhance aesthetic appeal and engage the human eye. This study explores whether the complexity and ornamentation found in traditional designs have measurable impacts on how people unconsciously perceive and visually engage with buildings. Through analyzing 28 facades generated with artificial intelligence, we calculated the fractal dimension of each one by the box-counting method. Unconscious visual attention was then predicted using eye-tracking emulation software to determine which fractal qualities capture most attention. Our results show a significant correlation: buildings with more fractality and organized visual complexity tend to capture more pre-attentive visual attention before viewer cultural associations come into play. These findings highlight the enduring appeal of the proportional complexity, fractal scaling, ornamentation, and intricate geometries found in traditional architecture. The fractal patterns inherent in traditional buildings may contribute to human visual experience, aesthetic appreciation, and psychophysiological health.

Las formas arquitectónicas tradicionales, clásicas y vernáculas a menudo poseen cualidades fractales que potencian el atractivo estético y captan la atención del ojo humano. En este estudio se analiza si la complejidad y la ornamentación de los diseños tradicionales tienen un impacto cuantificable en la manera en que las personas se sienten atraídas y perciben inconscientemente los edificios. Mediante el análisis de 28 fachadas generadas con inteligencia artificial, se calculó la dimensión fractal de cada una de ellas con el método del recuento de cajas o recuadros. A continuación, se predijo la atención visual inconsciente utilizando un software de simulación del seguimiento ocular para determinar qué cualidades fractales captan más la atención. Los resultados muestran una significativa correlación: los edificios con una mayor fractalidad y una complejidad visual organizada suelen captar más la atención visual preatentiva antes de que entren en juego las asociaciones culturales del espectador. Estas conclusiones subrayan el atractivo permanente de la complejidad proporcional, la escala fractal, la ornamentación y las geometrías intrincadas características de la arquitectura tradicional. Los fractales inherentes a las construcciones vernáculas pueden contribuir a la experiencia visual, la apreciación estética y la salud psicofisiológica de las personas.

As formas arquitetónicas tradicionais, clássicas e vernáculas apresentam frequentemente qualidades fractais que aumentam o apelo estético e cativam o olhar humano. Este estudo explora se a complexidade e a ornamentação encontradas nos designs tradicionais têm um impacto mensurável na forma como as pessoas inconscientemente percebem e interagem visualmente com os edifícios. Através da análise de 28 fachadas geradas com inteligência artificial, calculámos a dimensão fractal de cada uma delas pelo método de contagem de caixas. A atenção visual inconsciente foi então prevista usando um software de emulação de rastreamento ocular para determinar que qualidades fractais captam mais atenção. Os nossos resultados mostram uma correlação significativa: edifícios com maior fractalidade e complexidade visual organizada tendem a captar uma maior percepção visual pré-atencional, antes que as associações culturais do observador entrem em jogo. Estas descobertas destacam o apelo persistente da complexidade proporcional, escala fractal, ornamentação e geometrias intrincadas encontradas na arquitetura tradicional. Os padrões fractais inerentes aos edifícios tradicionais podem contribuir para a experiência visual humana, a apreciação estética e a saúde psicofisiológica.

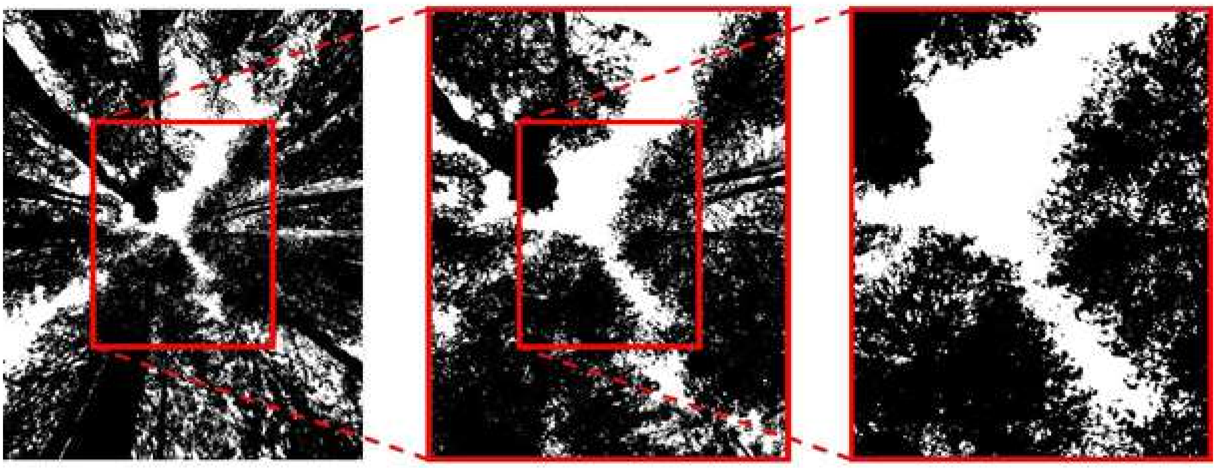
## 1. Introduction

Background and Research Question

Fractal geometry—patterns that repeat themselves on different scales—has been recognized as inherent in nature (Mandelbrot 1982). Fractals can be observed in the growth patterns of plants, especially when one looks up at the tree canopy (Fig. 1). Fractal patterns have also long been used to create visually complex and engaging architectural designs that resonate with human perception (C.B. Bovill 1996; Alexander 2002-2005; Nikos A. Salingaros 2013a). Various studies have proposed that complexity and novelty influence visual attention, aesthetic experience, and psychological responses (Daniel E. Berlyne 1971; Daniel E. Berlyne 1970; Silvia 2012).

While the aesthetic and psychological effects of fractal geometry have been acknowledged, there remains a gap in our understanding of the relationship between fractality in architecture and the visual attention it commands. Previous studies have suggested that higher fractal dimensions may enhance visual engagement and reduce physiological stress (Abboushi et al. 2019; Bies et al. 2016; Alexander Coburn et al. 2019; C.M. Hagerhall et al. 2008; C.M.P. Hagerhall et al. 2015; Nikos A. Salingaros 2012; R. Taylor 2006; R.P. Taylor and Spehar 2016; R.P. Taylor et al. 2005). Yet empirical evidence in the specific context of architectural facades is limited (Lee and Ostwald 2021, 2023; Lythgoe and Ro 2024).

Figure 1: Self-similar patterns recurring at different scales observable in Redwood trees seen from below



Objectives and Scope

Our aim is threefold: 1) to assess the fractal dimensions of building facades; 2) to evaluate the correlation between fractal complexity and visual attention; and 3) to test the hypothesis that architecture with higher fractal dimensions receives more visual attention. This hypothesis that facades with higher fractal dimensions will attract more attention connects with the idea that complexity enhances aesthewtic engagement (Joye 2007; Nikos A. Salingaros and Sussman 2020). Our analysis concentrates on the effect of geometric complexity on unconscious visual attention rooted in biological brain mechanisms, intentionally excluding more conscious cognitive processes or the brain's knowledge-meaning center linked to sociocultural variables such as education, semantic associations, personal experience, context, learned behavior, habitus, or symbols (Bourdieu 1977; Alex Coburn, Vartanian, and Chatterjee 2017; Geertz 1993; Mead and Métraux 2000). This limited scope is necessary to isolate the effects of fractal geometry on unconscious vision, but does not negate the importance of cultural and symbolic factors. Our findings are therefore to be seen as a contribution to an understanding of aesthetic perception rather than as an elucidation of holistic beauty.

We begin by reviewing the literature on fractal geometry in architecture, visual attention, and the use of artificial intelligence tools, identifying research gaps. Our methodology details the process of generating facades, calculating fractal dimension, and simulating visual attention. The last two sections present our results and discuss their implications for architectural design, together with their limitations and possible directions for future research.

## Literature Review

Fractal Geometry in Architecture

Fractal characteristics appear in self-similar patterns and scalable complexity in architectural forms. Pioneering theory has noted that many beloved traditional structures exhibit fractal scaling, such as proportional similarities, geometric repetition, and other fractal patterns to be seen in the intricate designs of Hindu temples, Islamic mosques, Gothic cathedrals, traditional Turkish housing, or Palladian villas (Trivedi 1989; Samper and Herrera 2014; Lee and Ostwald 2024; Pudine 2015; C.B. Bovill 1996; Aykal, Erbaş Özil, and Hizar 2020; Okuyucu and Baştaş 2023).

The fractal nature of classical orders can be seen in the relative proportions of a temple front and molded column capitals (Fig. 2). Other studies have explored how these fractal relationships contribute to the overall harmony and beauty of classical architecture (C. Bovill 2008; Capo 2004; Crompton 2002). The "classical visual arts," which according to Mandelbrot include Beaux Arts architecture, are fractal in character. These arts "involve very many scales of length and favor self-similarity" and "imitate Nature"; thus "fractal art is readily accepted because it is not truly unfamiliar" (Mandelbrot 1982: 23; 2007). Hence the visual richness associated with traditional ornamentation and patterns is thought to stimulate the eye and mind in a similar manner (C.M. Hagerhall et al. 2008; Nikos A. Salingaros 2012).

By comparison, a minimalist "Bauhaus style, glass cube-type building" by Mies Van der Rohe would be considered "scalebound," since its "characteristic elements of scale,

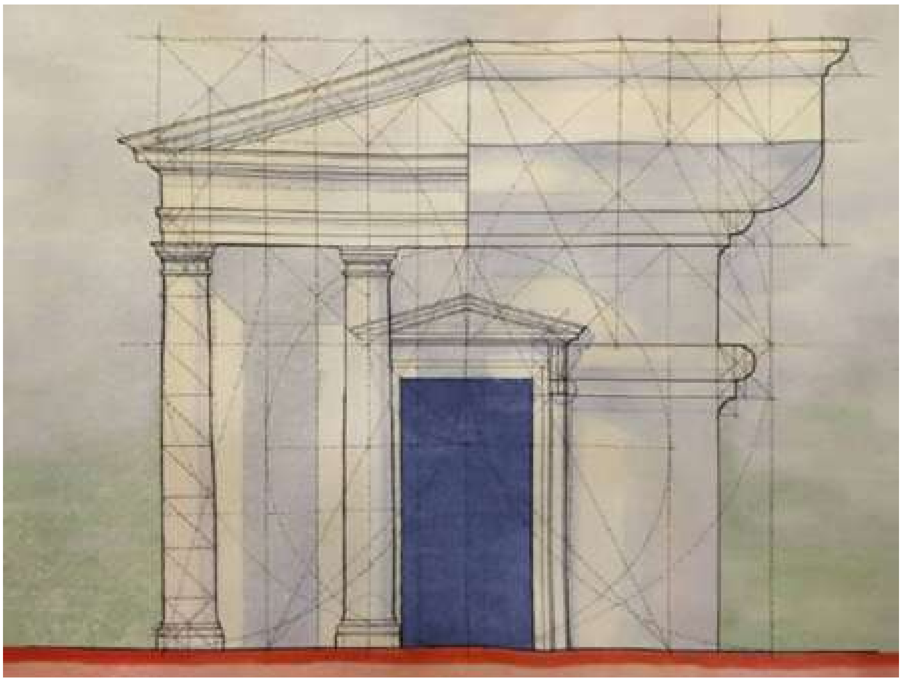


Figure 2: Classical architecture is fractal due to self-similar patterns and proportions that recur at different scales

such as length and width, are few in number and each with a clearly distinct size." But a Beaux Arts building, such as Charles Garnier's Paris opera house, has scaling with "many different elements whose scales are of any imaginable size… depending upon the viewing points of beholders" (Mandelbrot 2007: 45-46). Thus, rich fractal patterns can contribute to aesthetic appeal and cultural significance (Aisyah, Noerwasito, and Novianto 2023; C.B. Bovill 1996).

Measuring Fractals and Visual Preference

The intersection of ordered complexity and human perception is addressed by the fields of neuroaesthetics and neuroarchitecture (Eberhard 2014, 2009). These explore how design elements such as fractals can affect psychological well-being and cognitive responses (Robinson and Pallasmaa 2015; Zeisel 2006; Ruggles 2017; Sussman and Hollander 2015). Contemporary studies have quantified visual complexity in architecture by measuring fractal dimensions using the box-counting method (C.B. Bovill 1996; Ostwald and Vaughan 2016). This gauges the complexity of a pattern by counting the number of boxes of a given size needed to cover that pattern (Fig. 3) and offers a numerical value representing its fractal dimension ($D$). Previous studies have used this technique to analyze the complexity of natural and man-made environments so as to determine the extent to which fractal geometry contributes to visually engaging designs (Vaughan and Ostwald 2010; Pudine 2015; C.B. Bovill 1996).

Fractal analysis of a building aims to provide "a quantifiable measure of the progression of detail" (C.B. Bovill 1996: 127). Some studies suggest that images with mid-range fractal dimensions ($D$ = 1.3 to 1.5) are aesthetically preferred because they offer a balance between order and complexity, as mid-range fractals align with patterns in nature which we find soothing (C.M. Hagerhall et al. 2008; C.M.P. Hagerhall et al. 2015; Nikos A. Salingaros 2012; Spehar et al. 2003; R. Taylor 2006; R.P. Taylor and Spehar 2016; R.P. Taylor et al. 2005; Joye 2007). Other studies have found that humans also prefer higher fractal dimensions ($D$ = 1.5 to 1.7) for indoor environments (Abboushi et al. 2019) or when viewing exact (mathematical) fractal forms (Bies et al. 2016; Robles et al. 2020). What is unknown at present is what levels of fractality are preferred for building facades.

Visual Attention in Architectural Design

Visual attention is critical to architectural design, as part of how we perceive and interact with our environment. Research has shown that environments with higher levels of visual complexity, such as those with fractal patterns,

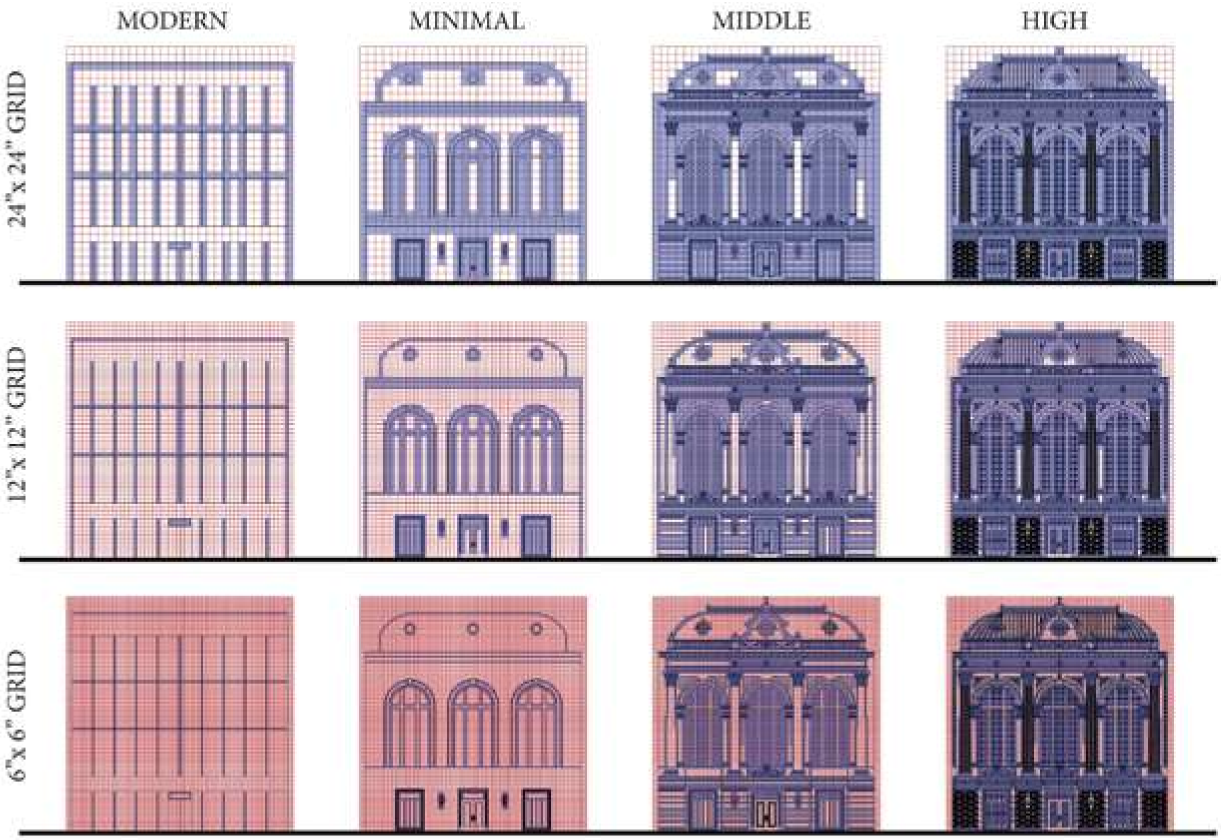



Figure 3: Box counting for fractal dimension estimation using three box sizes overlaid on facades. Fractal Dimension = 1 < $D$ < 2 (Joshua Lythgoe)

are more likely to capture and sustain attention (Ro and Huffman 2024; Rosas et al. 2023; Daniel E. Berlyne 1971; Heath, Smith, and Lim 2000). Studies using eye-tracking technology have also provided insights into how architectural elements, materials, and shapes guide visual focus during aesthetic experience (Hollander et al. 2020; Sussman and Hollander 2015; Nikos A. Salingaros and Sussman 2020; Rosas et al. 2023; Lavdas, Salingaros, and Sussman 2021). The advent of eye-tracking emulation tools has further advanced understanding of these dynamics in architecture by predicting focuses of attention without requiring live subjects (Lavdas, Salingaros, and Sussman 2021; 3M 2023; Lavdas and Salingaros 2022; Ro and Huffman 2024). This body of work generally suggests that architectural scenes rich in edges, contrasts, and hierarchical detail tend to draw the eye more effectively. This aligns with the belief that our gaze is attracted to moderate complexity and informational richness.

Artificial Intelligence in Architectural Analysis

The integration of artificial intelligence (AI) into architectural design has opened new possibilities for creating complex patterns (Jacobus and Kelly 2023; Leach 2022; Ro 2025, forthcoming). AI generative tools can quickly produce architectural forms with varying levels of fractal complexity which researchers and designers may use to explore aesthetic outcomes. In similar fashion, AI diagnostic tools are increasingly employed to consider how these forms impact visual attention and user experience. For instance, 3M's Visual Attention Software (3M-VAS) is trained on biometric data to mimic human pre-attentive vision with a claimed 92% accuracy. It functions as a kind of "visual spellcheck", predicting which areas of an image are likely to be noticed in the first 3-5 seconds of viewing (3M 2010, 2023). The application has been tested on design elements with the aim of enhancing visual engagement and even improving psychological well-being by guiding attention (Lavdas, Salingaros, and Sussman 2021; Nikos A. Salingaros and Sussman 2020). AI tools can help architects design not "anxiety-inducing structures" but biologically based objective beauty (Nikos A Salingaros 2022; Lavdas, Mehaffy, and Salingaros 2023; Lavdas and Salingaros 2022). Such tools enable optimization of design to suit the way humans process visual information. Thus this study leverages AI both to generate stimuli (facades) and to simulate visual attention. We remain mindful that these techniques model only certain aspects of aesthetic perception, not the whole embodied architectural experience.

Gaps in Existing Literature

Despite advances in the understanding of fractal geometry and visual attention in architecture, there is a need for empirical studies that directly link these concepts. Previous studies have analyzed only a limited number of buildings, which makes their findings hard to generalize. Additionally, methodological limitations persist in how fractality is measured. For example, some architectural studies have used too few box sizes or unconventional scaling steps that can undermine accuracy (Lee and Ostwald 2021, 2023; Lythgoe and Ro 2024; C.B. Bovill 1996).

This new study aims to address these gaps by analyzing the relationship between fractal dimension and visual attention across a larger set of systematically varied building facades. We use a broader and more systematic range of box sizes to improve measurement of fractality in architectural images. By employing an AI visual attention prediction tool, we build on previous research while refining the methodology for understanding why building facades with higher fractal dimensions may attract more visual attention (Lee and Ostwald 2021, 2023; Lythgoe and Ro 2024).

## Methodology

AI-Generated Facades

To explore the relationship between fractality and visual attention, building facades were generated using the AI image generator Midjourney (version 6.1). A series of four facades of varying complexity from a prior study (Fig. 4) were used to guide the AI prompts (Lythgoe and Ro 2024). Three of the original four facades follow a traditional design technique called "progressive omission" in which classical orders, moldings, and details are first applied to a building elevation and then incrementally removed (Adam 1990: 138-141). The fourth facade was a minimalist modern design. The four complexity levels for the AI images included the following prompts:

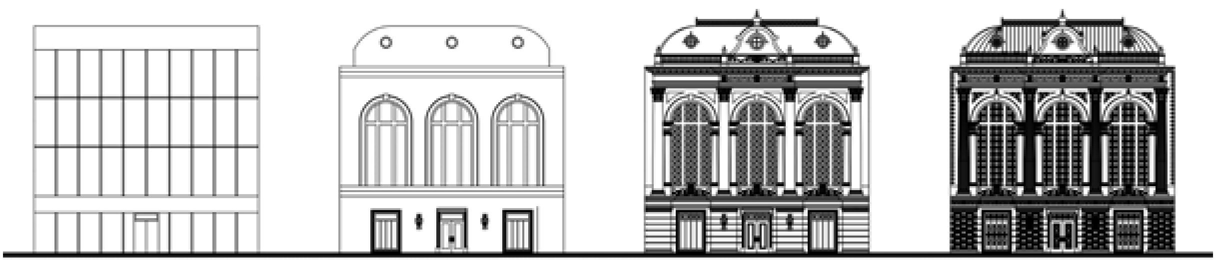


Figure 4: Original facades used to create AI-generated designs (Joshua Lythgoe)

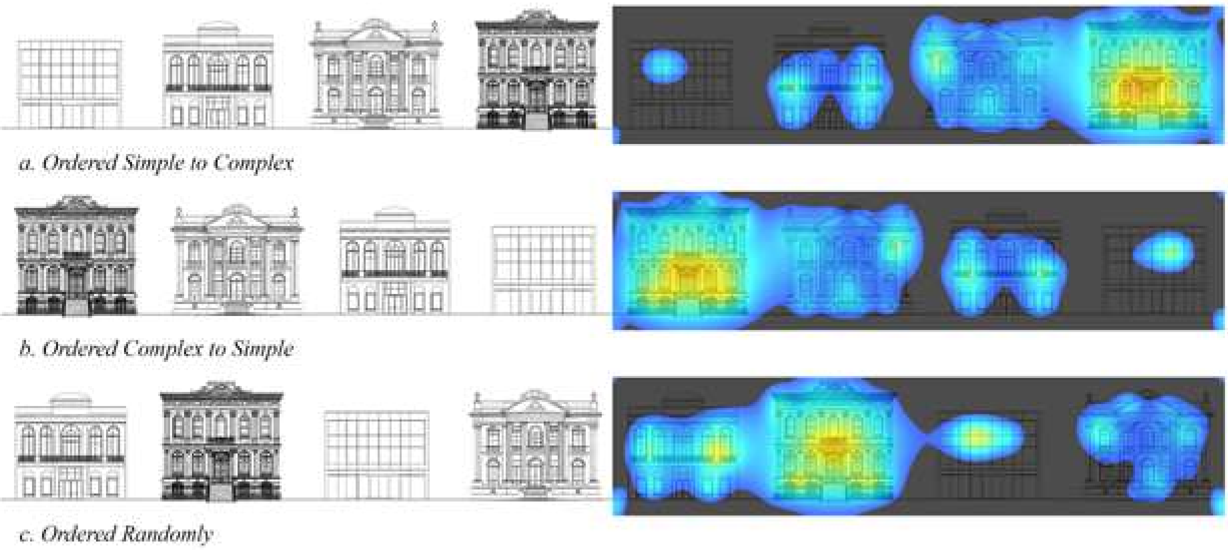



Figure 5: Exploration of left-to-right bias with 3M VAS heatmaps using different ordering

1. A (very) (simple) black and white schematic of a (minimalistic) modern (building/apartment block/ mansion)

2. A (very) simple black and white schematic of a (front elevation of a) (beautiful) (building/apartment block)

3. A simple black and white schematic of a (front elevation of a) beautiful (classical/1800s/1900s/1910s) (building/apartment block)

4. A detailed black and white schematic of a (front elevation of a) (1800s/1900s/1910s) beautiful (building/apartment block)

As a result, 28 unique facades were generated, with four different ones at each level of complexity: 1) modern minimalistic; 2) bare classical with minimal ornament; 3) classical with moderate ornament; and 4) detailed ornate classical. This yielded a diverse set of facades that could be systematically analyzed for both fractal dimension and visual attention score.

The 28 facades were arranged into seven distinct groups, each containing one building from each complexity level (1 through 4). The facades in each group montage (Figs. 6-12) were arranged left to right from level 1 (Modern) to 4 (Detailed Classical) with increasing complexity, providing a clear framework for comparison across groups.

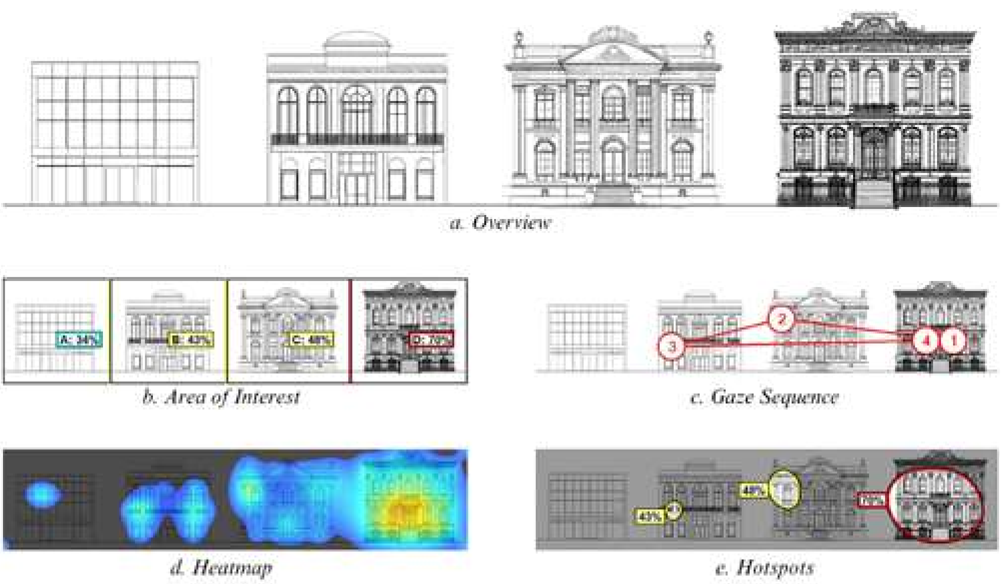



Figure 6: Building group 1

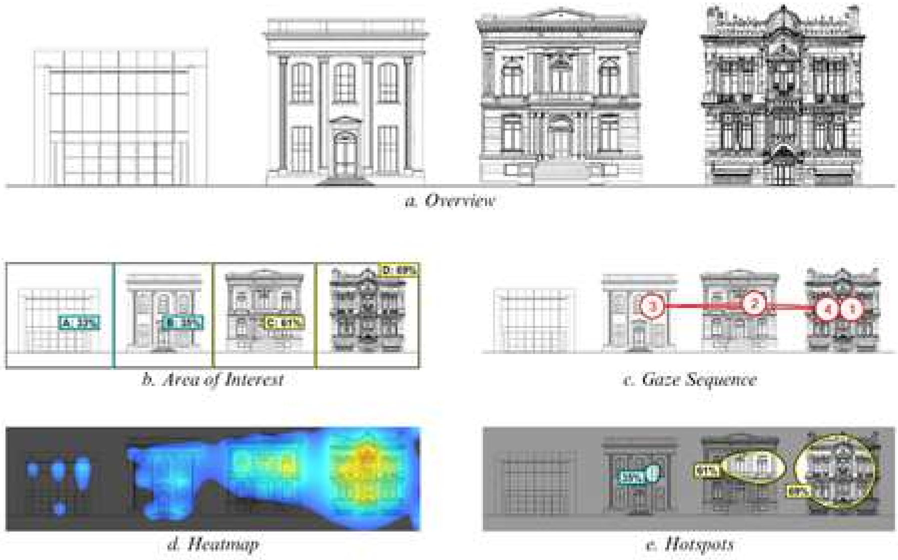



Figure 7: Building group 2


Figure 8: Building group 3

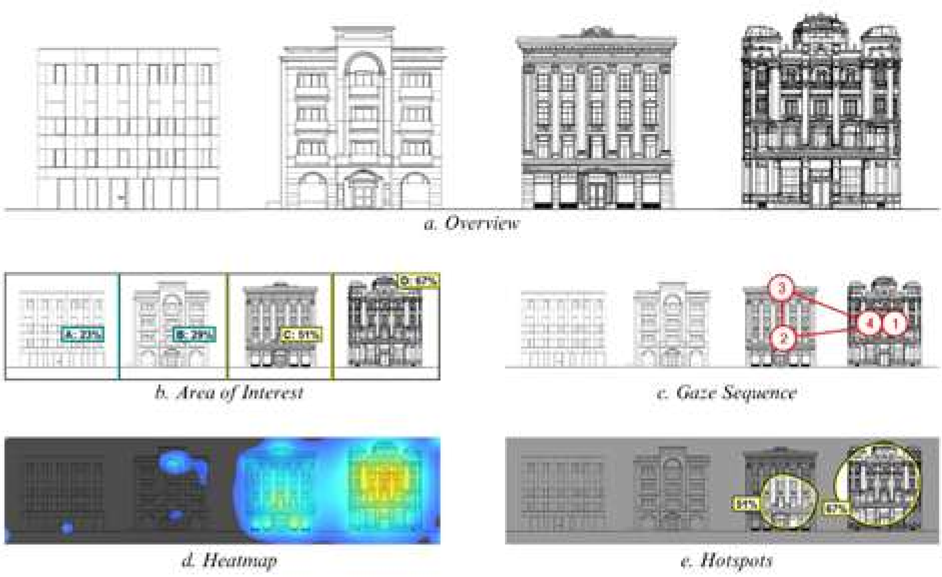



Figure 9: Building group 4

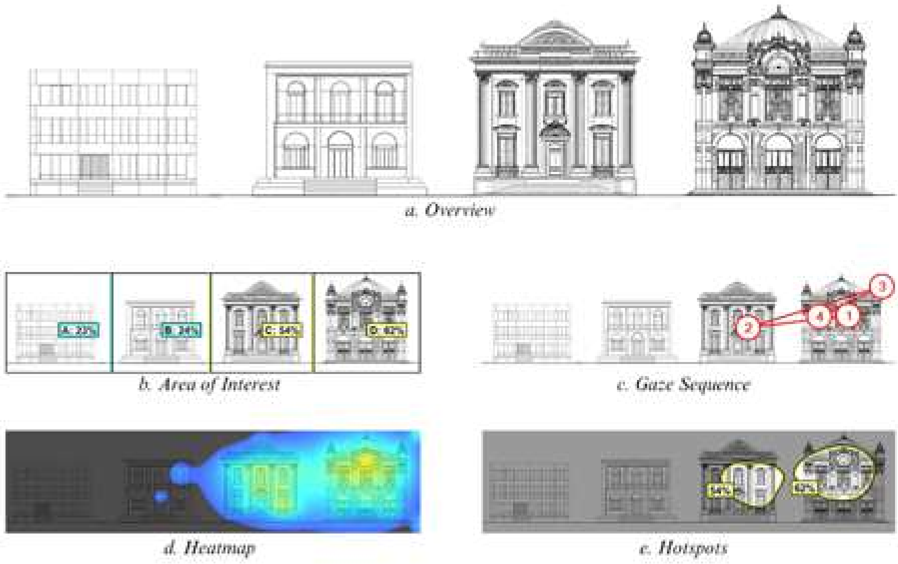



Figure 10: Building group 5

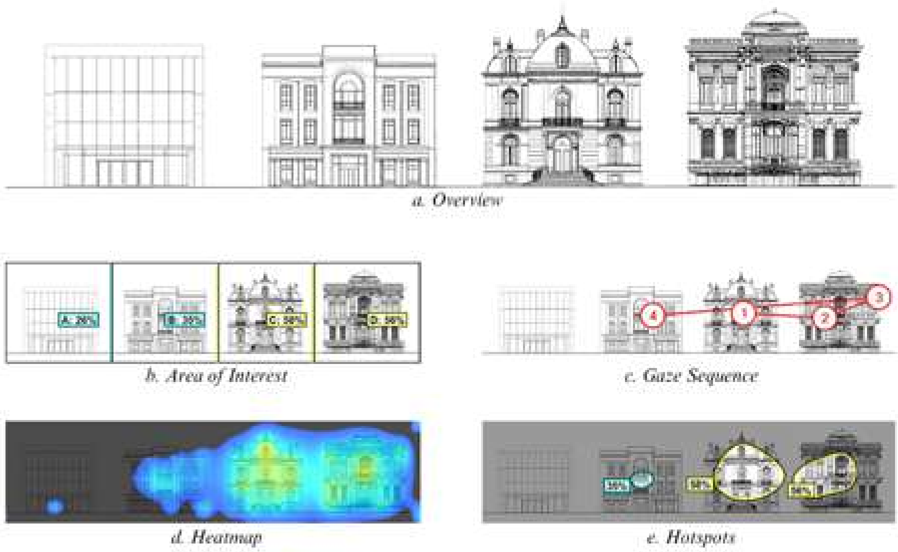



Figure 11: Building group 6

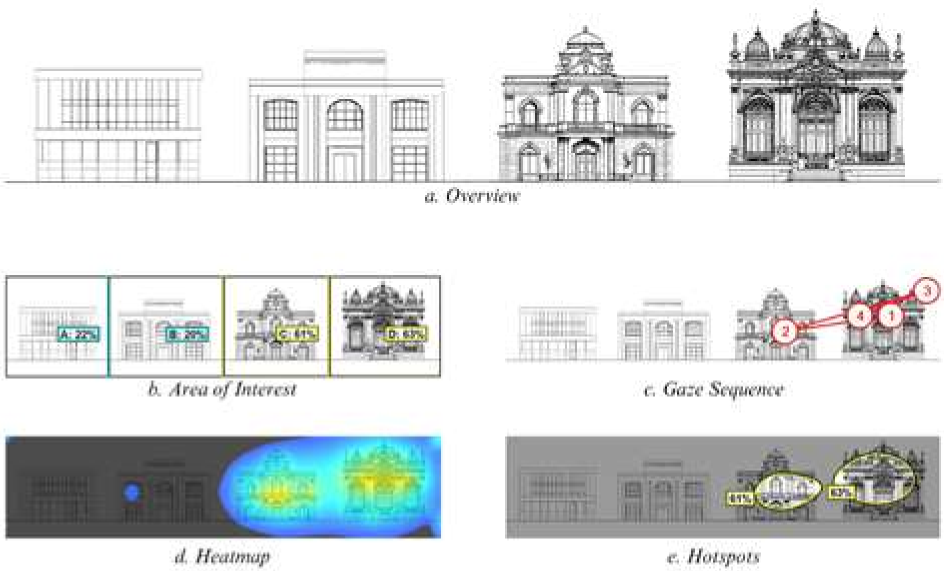



Figure 12: Building group 7

We recognize that this arrangement, or alternatives such as random order or grouping by style, could influence patterns of visual attention and introduce bias. In particular, a fixed left-to-right layout or viewers' native reading direction might encourage them (or the 3M-VAS algorithm) to favor one side of the sequence, as seen in other studies (Foulsham, Frost, and Sage 2018; A.K. Smith et al. 2015).

To assess this possibility, we conducted a brief secondary analysis using different orderings for building group 1: a. simple to complex; b. complex to simple; and c. randomized (Fig. 5). This showed no evidence of systematic left/right bias, but reading direction or presentation order could indeed influence scanning behavior. We prioritized clarity and comparability with a fixed order, but future research should randomize image positions or rotate layouts across trials. This would help disentangle the effects of facade complexity from sequencing effects and further test whether cultural directionality influences visual attention.

Fractal Dimension Calculation with ImageJ

The box-counting method is a well-established way of quantifying the complexity of fractal patterns in nature (Mandelbrot 1982), art (Spehar et al. 2003), and architecture (Vaughan and Ostwald 2010; C.B. Bovill 1996). It involves laying a grid of boxes of varying sizes over an image and counting the boxes that contain part of the pattern (Fig. 3). In our case, "the counted boxes represent the areas of the façade where there is something to look at" (C.B. Bovill 1996: 123). The fractal dimension is then derived from the correlation between the box size and the number of occupied boxes. The box-count fractal dimension ($D$) is expressed mathematically:

$$D = \lim_{\epsilon \to 0} \frac{\log(N(\epsilon))}{\log(1/\epsilon)}$$

Where $D$ is the fractal dimension, $\epsilon$ is the size of the boxes or grid cells, and $N(\epsilon)$ is the number of boxes needed to cover the object at scale $\epsilon$ (Barnsley 1993). The slope of the linear regression line in a log-log plot through the data points represents the fractal dimension ($D$). This ranges as a fractional value between 1 and 2 ($1 < D > 2$). Thus a simple object that is scalebound—containing few elements—will have a fractal dimension value close to 1. A more complex object with diverse scaling elements will have a fractal dimension approaching 2.

We used ImageJ's default box sizes (2, 3, 4, 6, 8, 12, 16, 32, 64) to calculate the fractal dimensions of each facade. We included both powers of 2 as well as non-powers of 2 to capture intermediate steps of scaling, detect anomalies, and comprehensively cover non-fractal features. Our method deviates from previous architectural studies, which often relied on only three box sizes or used unconventional scaling steps, such as the golden ratio (Lee and Ostwald 2021, 2023; Lythgoe and Ro 2024). Limited box sizes may restrict accuracy, especially where the subject buildings do not follow a uniform scaling system. For instance, classical buildings frequently have a variety of proportions within a single design (1:1, 1:1.618, 1:2, 1:4, 2:3, 3:4, etc.), while other styles such as Romanesque or Gothic may incorporate more complex ratios (1:√2, 1:√3, etc.). Applying scaling such as the golden ratio across diverse architectural styles may thus obscure nuances of proportion. Our expanded selection of box sizes offers a more versatile and accurate analysis across styles.

In ImageJ, we converted each facade image to grayscale and auto-adjusted the threshold prior to the analysis. The software provides a log-log plot of box size versus count, number of boxes, and fractal dimension. The latter provided a numerical measure of each facade's fractality represented by a *D*-value. The 28 facades were independently tested to determine each fractal dimension. As defined in other studies, "*D* is taken as a measure of the aesthetic character of visual attraction, i.e. visual complexity" (Lee and Ostwald 2023: 44).

Visual Attention Prediction – Eye-Tracking Emulation

Visual attention was predicted using eye-tracking emulation with 3M's Visual Attention Software (3M-VAS) to determine which facade may attract most pre-attentive vision before age, gender, culture, and education come into play (Lavdas, Salingaros, and Sussman 2021; 3M 2023). This software simulates human visual behavior by predicting how elements may attract and hold attention on an unconscious level, providing insights into how facades will likely be perceived in the real world (Hollander et al. 2020; Nikos A. Salingaros and Sussman 2020).

Each of the seven groups of facades discussed above were tested using 3M-VAS. Each group of four, of differing complexity, was evaluated by pairwise comparison based on the results of the four 3M-VAS reports (Figs. 6-12), namely:

- Heatmap: A 3M-VAS heatmap shows areas that are likely to be noticed within the first 3-5 seconds and uses color intensity to indicate areas of visual interest. We used ImageJ to create a Region of Interest (ROI) by tracing each facade's outline and measuring the percentage of heatmap coverage. This combined use of 3M-VAS and ImageJ has been validated by recent research assessing visual engagement with architectural images (Lavdas and Salingaros 2022, 13; Ro and Huffman 2024).

- Hotspots: 3M-VAS hotspots are key areas on an image that are likely to attract attention. Our study regards facades with any hotspot region as more visually engaging. As in previous studies, a building with a higher hotspot percentage within an image group is seen as having a more engaging facade (Ro and Huffman 2024).

- Gaze Sequence: The 3M-VAS gaze sequence is the order of the first four locations a viewer is likely to notice. Our study regards facades that capture one or more of these locations early in the sequence as successful in attracting unconscious visual attention. Each gaze sequence location on a building is tallied as 25 percentage points, as in an earlier study (Ro and Huffman 2024).

- Areas of Interest: A 3M-VAS area of interest (AOI) is a focal area around a subject whose likelihood of being seen at first glance is measured. Areas are scored on the basis of visual elements such as edges, contrasts, and intensity. Our study used a rectangular outline for each facade, like earlier studies (Ro and Huffman 2024). A higher AOI score indicates a greater chance of attracting attention.

As in a previous study (Ro and Huffman 2024), the mean percentage score of all four 3M-VAS reports (ΣVAS/4) was tabulated to create a "visual attention coherence" (VAC) score. This single value summarizes a facade's overall ability to attract visual attention. A higher VAC score means that the building consistently draws attention across multiple measures. The VAC score is also designed to facilitate comparison within each group of four facades, since each group's VAC values indicate a ranking of attention capture by degree of complexity.

All 3M-VAS analyses were done in batches with identical contextual parameters (image size, analysis settings, background, absence of distractors) to ensure comparability. It is important to note that 3M-VAS predicts a pre-attentive or unconscious visual attention response, like an unthinking first glance, rather than appreciation or prolonged attention which could be influenced by recognition or meaning.

<u>Statistical Analysis</u>

The relationship between fractal dimension and visual attention was statistically analyzed across the dataset. We first examined simple correlations. Pearson's correlation coefficient was calculated between each facade's *D*-value and VAC score to quantify correlation strength and direction. Next, we performed regression analysis to explore the predictive power of fractal dimension (*D*) on visual attention (VAC). Given the grouped nature of the data (seven independent groups of facades), we also qualitatively checked within-group trends. The statistical analysis was conducted with standard tools such as Jamovi 2.4, using R language, to ensure robustness and reliability of results. The significance level was set at $\alpha = 0.05$ for hypothesis testing. We reported correlation coefficients ($r$) along with $p$-values and regression $R^2$ values to indicate the proportion of variance in attention attributable to fractality. We also computed basic descriptive statistics (means and standard deviations) of D and VAC for each complexity category (1 through 4) to supplement the group results.

## Results

<u>Building Group Findings</u>

Across all seven building groups, a consistent pattern emerged: facades with more fractal complexity (higher *D*) received higher predicted visual attention coherence (VAC) scores. In each group, the "Detailed Classical" (Level 4) facade achieved the highest values on all visual attention metrics, reflecting significant visual engagement. Meanwhile, the "Modern" (Level 1) facade consistently captured the least visual attention. The "Classical" (Level 3) and "Bare Classical" (Level 2) facades fell in between, generally following the complexity hierarchy. There follows a brief overview of results for each building group.

<u>Building Group 1</u>

The 3M-VAS reports and fractal dimensions (*D*) for the four levels of complexity in building group 1 (Table 1) show that the "Detailed Classical" facade consistently outperforms the others across all categories (Fig. 6). The high visual attention coherence score (72.5%) suggests strong visual engagement and attention capture. This is further supported by the highest fractal dimension score in the group ($D = 1.83$), indicating rich visual complexity.

In contrast, the "Modern" facade attracts least attention with only partial heatmap coverage (13.7%) and no hotspots or gaze sequence locations. This results in the lowest overall coherence score (11.9%), with the lowest fractal dimension ($D = 1.39$). The "Bare Classical" and "Classical" facades come next with moderate levels of visual attention and fractal complexity. These findings indicate a clear correlation between greater fractality and increased visual attention for building group 1. Detailed classical facades appear to consistently capture more viewer interest than less detailed ones.

<u>Building Group 2</u>

The results for group 2 (Fig. 7; Table 2) mirror those of group 1. "Detailed Classical" again comes first in both coherence (72%) and fractal dimension ($D = 1.79$), while "Modern" ranks lowest (coherence 12.6%, $D = 1.37$). The intermediate "Bare Classical" and "Classical" facades show the same trend of increasing attention with higher complexity ($D = 1.55–1.70$).

| VAS Report Category | 1. Modern | 2. Bare Classical | 3. Classical | 4. Detailed Classical |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 13.7% | 66.9% | 96.3% | 100% |
| VAS2 – Hotspots (probability region score) | 0% | 43% | 48% | 70% |
| VAS3 – Gaze sequence (locations) | 0% | 25% | 25% | 50% |
| VAS4 – Area of interest (probability score) | 34% | 43% | 48% | 70% |
| Visual attention coherence score (ΣVAS/4) | **11.9%** | **44.5%** | **54.3%** | **72.5%** |
| **Fractal dimension (*D*)** | **1.36** | **1.58** | **1.67** | **1.83** |

Table 1. Summary of fractal dimension and VAS report findings for building group 1

| VAS Report Category | 1. Modern | 2. Bare Classical | 3. Classical | 4. Detailed Classical |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 17.2% | 71.7% | 77.8% | 99.9% |
| VAS2 – Hotspots (probability region score) | 0% | 35% | 61% | 69% |
| VAS3 – Gaze sequence (locations) | 0% | 25% | 25% | 50% |
| VAS4 – Area of interest (probability score) | 33% | 35% | 61% | 69% |
| Visual attention coherence score (ΣVAS/4) | **12.6%** | **41.7%** | **56.2%** | **72%** |
| **Fractal dimension (*D*)** | **1.37** | **1.55** | **1.70** | **1.79** |

Table 2. Summary of fractal dimension and VAS report findings for building group 2

| VAS Report Category | 1. Modern | 2. Bare Classical | 3. Classical | 4. Detailed Classical |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 0% | 0% | 100% | 100% |
| VAS2 – Hotspots (probability region score) | 0% | 0% | 63% | 59% |
| VAS3 – Gaze sequence (locations) | 0% | 0% | 25% | 75% |
| VAS4 – Area of interest (probability score) | 28% | 16% | 63% | 59% |
| Visual attention coherence score (ΣVAS/4) | **7.0%** | **4.0%** | **62.8%** | **73.3%** |
| **Fractal dimension (*D*)** | **1.26** | **1.48** | **1.69** | **1.78** |

Table 3.Summary of fractal dimension and VAS report findings for building group 3

Building Group 3

Group 3 (Fig. 8; Table 3) follows the same pattern, with "Detailed Classical" coming first (73.3%, *D* = 1.78) and "Classical" in second place (62.8%, D = 1.69). Notably, both "Modern" and "Bare Classical" scored very low in coherence (7.0% and 4.0%). "Bare Classical" unexpectedly underperformed despite a higher fractal dimension (*D* = 1.48) than "Modern" (*D* = 1.26).

Building Group 4

Group 4 follows the same trend (Fig. 9; Table 4). "Detailed Classical" (71.0%, *D* = 1.80) and "Classical" (63.0%, *D* = 1.72) dominate the attention metrics, with "Modern" (6.1%, *D* = 1.33) and "Bare Classical" (11.4%, *D* = 1.52) far behind. The 3M-VAS heatmaps show stark contrasts in coverage between ornate and simple designs.

Table 4. Summary of fractal dimension and VAS report findings for building group 4

| **VAS Report Category** | **1. Modern** | **2. Bare Classical** | **3. Classical** | **4. Detailed Classical** |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 1.2% | 16.4% | 99.9% | 100% |
| VAS2 – Hotspots (probability region score) | 0% | 0% | 51% | 67% |
| VAS3 – Gaze sequence (locations) | 0% | 0% | 50% | 50% |
| VAS4 – Area of interest (probability score) | 23% | 29% | 51% | 67% |
| Visual attention coherence score (ΣVAS/4) | **6.1%** | **11.4%** | **63.0%** | **71.0%** |
| **Fractal dimension (*D*)** | **1.33** | **1.52** | **1.72** | **1.80** |

Table 5. Summary of fractal dimension and VAS report findings for building group 5

| **VAS Report Category** | **1. Modern** | **2. Bare Classical** | **3. Classical** | **4. Detailed Classical** |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 0% | 12.4% | 99.2% | 100% |
| VAS2 – Hotspots (probability region score) | 0% | 0% | 54% | 62% |
| VAS3 – Gaze sequence (locations) | 0% | 0% | 25% | 75% |
| VAS4 – Area of interest (probability score) | 23% | 24% | 54% | 62% |
| Visual attention coherence score (ΣVAS/4) | **5.8%** | **9.1%** | **58.1%** | **74.8%** |
| **Fractal dimension (*D*)** | **1.34** | **1.43** | **1.69** | **1.75** |

Table 6. Summary of fractal dimension and VAS report findings for building group 6

| **VAS Report Category** | **1. Modern** | **2. Bare Classical** | **3. Classical** | **4. Detailed Classical** |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 3.6% | 66.9% | 100% | 99.8% |
| VAS2 – Hotspots (probability region score) | 0% | 35% | 58% | 56% |
| VAS3 – Gaze sequence (locations) | 0% | 25% | 25% | 50% |
| VAS4 – Area of interest (probability score) | 26% | 35% | 58% | 56% |
| Visual attention coherence score (ΣVAS/4) | **7.4%** | **40.5%** | **60.3%** | **65.5%** |
| **Fractal dimension (*D*)** | **1.30** | **1.55** | **1.66** | **1.77** |

Building Group 5

Group 5 sees a similar pattern (Fig. 10; Table 5). "Detailed Classical" has full heatmap coverage (100%), high coherence (74.8%), and a high fractal score ($D$ = 1.75). "Classical" also scores high (99.2% coverage, 58.1%, $D$ = 1.69). "Modern" (5.8%, $D$ = 1.34) and "Bare Classical" (9.1%, $D$ = 1.43) remain the least engaging.

Building Group 6

Much like groups 1 and 2, group 6 (Fig. 11; Table 6) suggests that simple forms and less complex geometry struggle to attract and sustain viewer attention compared to more detailed and complex designs. "Detailed Classical" (65.5%, $D$ = 1.77) and "Classical" (60.3%, $D$ = 1.66) show strong results, whereas "Bare Classical" scores moderately

| VAS Report Category | 1. Modern | 2. Bare Classical | 3. Classical | 4. Detailed Classical |
|---|---|---|---|---|
| VAS1 – Heatmap (ImageJ coverage) | 0% | 3.7% | 100% | 100% |
| VAS2 – Hotspots (probability region score) | 0% | 0% | 61% | 63% |
| VAS3 – Gaze sequence (locations) | 0% | 0% | 25% | 75% |
| VAS4 – Area of interest (probability score) | 22% | 20% | 61% | 63% |
| Visual attention coherence score (ΣVAS/4) | **5.5%** | **5.9%** | **61.8%** | **75.3%** |
| **Fractal dimension (*D*)** | **1.24** | **1.46** | **1.65** | **1.77** |

Table 7. Summary of fractal dimension and VAS report findings for building group 7

(40.5%, *D* = 1.55) and "Modern" again shows the weakest visual engagement (7.4%, *D* = 1.30).

Building Group 7

Group 7 (Fig. 12; Table 7) follows the same hierarchy but with a notable near-tie in hotspots and AOI scores between "Detailed Classical" (75.3%, *D* = 1.77) and "Classical" (61.8%, *D* = 1.65). "Modern" (5.5%, *D* = 1.24) and "Bare Classical" (5.9%, *D* = 1.46) both attract little attention despite the latter's higher complexity. Thus more complex architectural forms and detailing are significantly more successful at capturing visual attention as compared to simpler designs.

Fractal Dimension Results

The analysis of the 28 facades revealed a wide range of fractal dimensions (*D*), reflecting diverse visual complexity, from 1.24 to 1.83 (see Table 8). As expected, facades with more intricate scalable patterns exhibited greater fractality. This is consistent with the principles of fractal geometry, involving self-similar detail across various scales (C.B. Bovill 1996). When the facades are categorized by the four nominal complexity levels (Modern = 1, Bare Classical = 2, Classical = 3, Detailed Classical = 4), the mean *D* for each category increases in rank order. Analysis further indicated a relatively high degree of similarity within categories, as evidenced by the low standard deviation values calculated for each one. This in-category homogeneity is also visually apparent in the four clusters (Fig. 13). The traditional facades (levels 3 and 4) fall into the upper range of complexity, aligning with previous suggestions that classical architecture tends to have higher fractal dimensions and possibly greater visual coherence (Capo 2004; Samper and Herrera 2014).

| Building Category – Complexity Level | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| **1. Modern** | 7 | 1.32 | 0.0536 | 1.24 | 1.39 |
| **2. Bare Classical** | 7 | 1.51 | 0.0545 | 1.43 | 1.58 |
| **3. Classical** | 7 | 1.68 | 0.0256 | 1.65 | 1.72 |
| **4. Detailed Classical** | 7 | 1.78 | 0.0256 | 1.75 | 1.83 |

Table 8. Fractal dimension of building facades by complexity level

| Building Category – Complexity Level | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| **1. Modern** | 7 | 0.0803 | 0.0296 | 0.0550 | 0.126 |
| **2. Bare Classical** | 7 | 0.2243 | 0.1868 | 0.0400 | 0.445 |
| **3. Classical** | 7 | 0.5947 | 0.0337 | 0.5433 | 0.630 |
| **4. Detailed Classical** | 7 | 0.7202 | 0.0326 | 0.6545 | 0.752 |

Table 9. Visual attention coherence scores of building facades by complexity level

Visual Attention Coherence Scores

The visual attention coherence (VAC) scores obtained with 3M-VAS also spanned a broad range, from 6 to 75% (see Table 9). Plotted by facade group (Fig. 14) they show a clear pattern. Complexity levels 4 and 3 consistently had the highest VAC scores, and levels 1 and 2 the lowest. In several groups, the "Modern" and "Bare Classical" facades scored so low that they attracted hardly any predicted attention—often resulting in VAC values under 10% and an absence of gaze sequence points or hotspots. In such cases, the difference between level 1 and 2 became negligible, and sometimes the ordering changed by a slight margin. By contrast, the "Classical" and "Detailed Classical" facades almost always registered multiple hotspots and widespread heatmap coverage, indicating that a viewer's gaze would be drawn to many features. The consistency of this pattern across groups again shows that ornamentation and complexity are more likely to capture viewers' immediate attention.

We also observed that in some mixed-complexity groups the simpler facades not only had low scores but failed to engage the model at all. Hence the comparison between low and medium complexity can suffer from a floor effect. This limitation in the data is reflected in the larger variance of VAC scores among simpler facades (levels 1-2) relative to more complex ones (levels 3-4). Despite this, statistical analysis across all 28 facades confirms a very strong positive correlation between fractal dimension and VAC score (Pearson's $r = 0.946$; $p < 0.001$). Linear regression analysis further demonstrated that as fractality increases, so do VAC scores; thus the strong model fit and statistically significant predictor suggest that fractal dimension is a strong determinant of visual attention ($R^2 = 0.896$; $p < .001$). This is visualized in the scatter plot (Fig. 15). There are also significant statistical correlations between VAS reports and fractal dimensions, including heatmaps (Pearson's $r = 0.932$; $p < 0.001$), hotspots (Pearson's $r = 0.935$; $p < 0.001$), gaze sequence (Pearson's $r = 0.865$; $p < 0.001$), and areas of interest (Pearson's $r = 0.902$; $p < 0.001$). These findings suggest that scalable fractal complexity is a key factor in determining the visual impact of architectural designs.

In summary, our visual attention results support the hypothesis that ornate traditional designs capture more of the viewer's pre-attentive vision, confirming that complexity enhances visual engagement (R. Taylor 2006; Daniel E. Berlyne 1971). Likewise, our results align with previous findings that visually complex environments tend to be more engaging, aesthetically pleasing, and visually preferable to humans (Lavdas, Salingaros, and Sussman 2021; Lavdas and Salingaros 2022; Ro and Huffman 2024; Rosas et al. 2023; Lee and Ostwald 2021). Yet we interpret these results with caution, acknowledging that our simulation captures only one aspect of "attention"—an immediate, unconscious orienting response—and does not measure long-term preference or aesthetic appraisal.

## Discussion

Interpretation of Results

Our findings provide strong evidence that fractal complexity in architectural facades is associated with enhanced visual attention. The correlation through our set of AI-generated images between fractal dimension and predicted attention supports the notion that intricate traditional architectural forms, with their inherent fractality, are more engaging to the human eye than plain designs (Alexander 2002-2005; Nikos A. Salingaros 2013b). This finding aligns with the broader literature on visual attention and aesthetics, which highlights the role of organized complexity in capturing and sustaining interest (Daniel E. Berlyne 1970; Daniel E. Berlyne 1971; Silvia 2005). It also resonates with neuroaesthetic theories that humans may be biologically "hard-wired" to respond positively to patterns reminiscent of nature's fractals (R. Taylor 2006; C.M.P. Hagerhall et al. 2015). Our study extends these concepts to architectural facades, adding empirical weight to longstanding intuitions: richly detailed facades not only attract the eye initially but also please the senses more than plain ones.

At the same time, our approach sheds light on the unconscious, pre-attentive component of this association. The use of an AI vision model allowed us to isolate an immediate visual response free from biases such as personal taste, familiarity, or cultural conditioning that would inform conscious evaluation. Even without such higher-level factors, the model consistently favored fractal-rich images—implying that our first glance might universally favor complexity and ornament. One study using live subjects supports this theory: buildings with fractal geometry like that of nature tend to attract attention quicker ("time to first fixation") and hold it longer ("dwell time"), as "complexity informs the brain of stimuli worth examining more closely" (Rosas et al. 2023). In the words of the architect Robert A. M. Stern, "when your eye is bored, your brain is bored" (Robert A.M. Stern: *Always a Student*, 2019). This lends credence to the idea of a biologically based unconscious aesthetic response (Nikos A. Salingaros 2012; Kellert 2005).

We should again not overgeneralize these findings into a claim of a "universal preference" for more fractal buildings. Our results concern initial visual attention, not long-term preference or holistic perception. After the initial attraction, it may be that it is viewers' cultural background and personal experience that determine whether they find a fractal-rich facade beautiful or overelaborate. According to Bourdieu's theory of *habitus*, individual upbringing and social context cultivate our tastes. Someone accustomed to minimalist modernism, for instance, might consciously favor a plain facade even if their eye is momentarily caught by a Baroque one. Three independent surveys using questionnaires, eye-tracking biometrics, and predictive simulations to ascertain whether people prefer modern or traditional federal

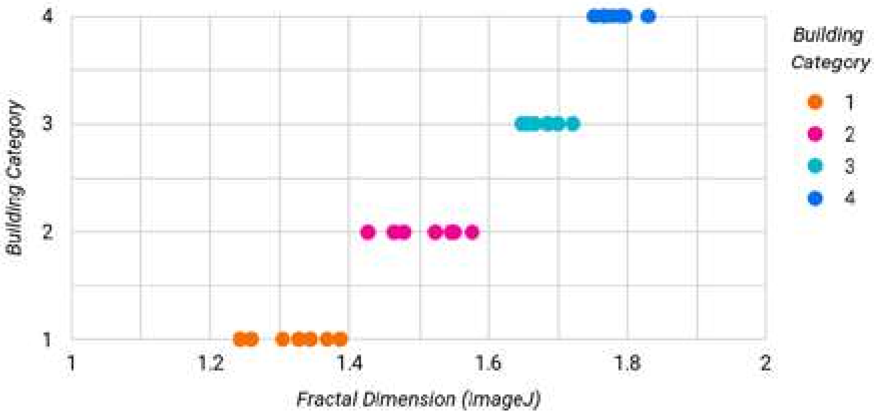



Figure 13: Four distinct clusters are visible for the fractal dimension ($D$-value) of the four complexity types

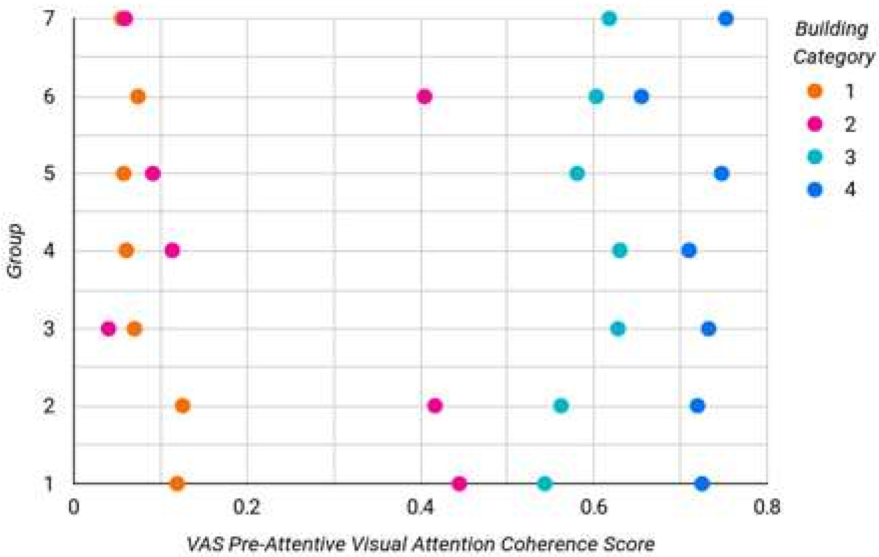



Figure 14: The 7 groups and the visual attention coherence scores of each facade, colored by complexity type

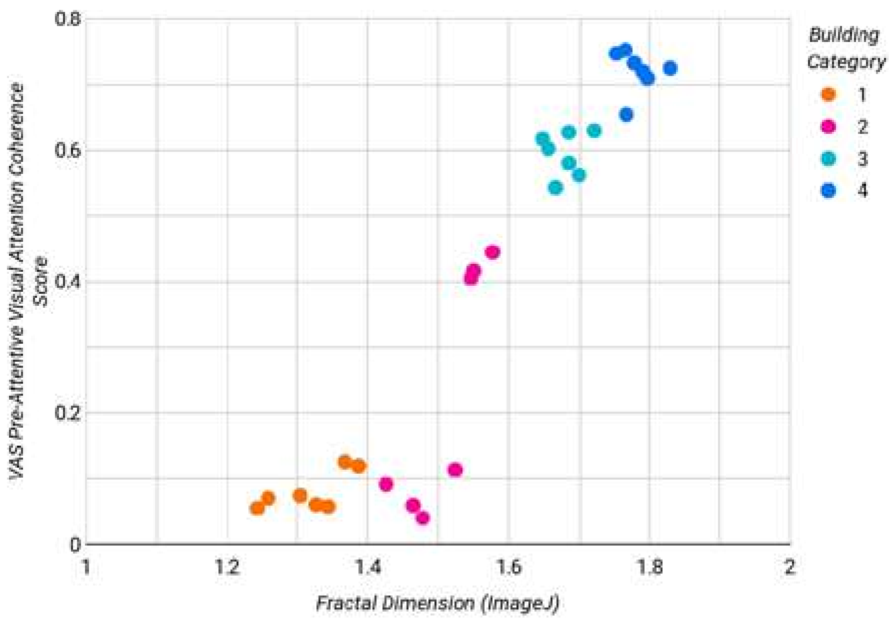



Figure 15: Scatter plot of fractal dimension against visual attention coherence score, colored by building type

buildings have found that traditional styles are not only consciously preferred by Americans (in one case by 72%) regardless of gender, age, geographic region, household income, education, political affiliation, and race/ethnicity ("Americans' Preferred Architecture for Federal Buildings: A National Civic Art Society Survey conducted by the Harris Poll" October 2020), but that these same styles also tend to attract unconscious visual attention as well as retain it after conscious awareness more than modern ones (Rosas et al. 2023; Ro and Huffman 2024). Thus, we interpret our findings as highlighting just one piece of the aesthetic puzzle: fractal geometry gives a facade a better chance of being noticed and visually processed early on, but an ultimate appraisal of beauty involves subsequent cognitive and cultural filtering.

Implications for Architectural Design

These findings have implications for architectural practice and urban design. Architects and designers seeking to create engaging and psychologically restorative environments could consider incorporating fractal geometry or self-similar patterns into facades to increase the likelihood of capturing attention and encourage visual exploration. Our results support the view of advocates of traditional and biophilic design that ornamentation and complexity are not wasteful uses of materials but rather have tangible benefits for human experience (Nikos A. Salingaros and Sussman 2020; Kellert 2005). Incorporating fractal scaling might make a building facade not only more interesting to look at but potentially more restorative by echoing the way that fractal natural scenes reduce stress (Kellert 2005; R. Taylor 2006; Nikos A. Salingaros 2012).

From a technological standpoint, our use of AI tools points to an avenue for evidence-based design evaluation. Designers may generate multiple facade options with AI and then test them with a vision prediction model to get rapid feedback as to which designs are likely to be eye-catching. Such an approach could help bridge the gap between architects' aesthetics and public preferences, as there is often a disconnect between what architects and laypersons find appealing (Chávez and Milner 2019; Ro and Huffman 2024; Frangos Feb. 7, 2007; Brown and Gifford 2001; Darke 1984; Devlin and Nasar 1989; Devlin 1990; N.B. Smith 2019). Our study contributes to this debate by quantifying one aspect of what the "general public" might unconsciously notice. If traditional, ornamentally complex facades inherently draw more immediate attention (and possibly positive physiological responses), this could partly explain why laypeople often favor historical styles over austere modernist ones (Frangos Feb. 7, 2007; "Americans' Preferred Architecture for Federal Buildings: A National Civic Art Society Survey conducted by the Harris Poll" October 2020). In practice, architects could use tools such as 3M-VAS early in the design process to assess visual interest. This should be balanced with other considerations, as complexity can be overwhelming or costly. But our results suggest, at least as regards visual attention, that erring on the side of richer detail may be beneficial.

Finally, urban planners might consider that maintaining or reintroducing traditional facade complexity in streetscapes could enhance pedestrian experience. When many buildings are competing for our attention, not to mention other stimuli such as signage and screens (Pallasmaa 2011), understanding which architectural qualities naturally stand out could inform more human-friendly urbanism. So while a row of monotonous facades might prompt people to disengage from their surroundings, a visually varied, fractal-rich streetscape could promote place-making through visual interest and pleasure. Our findings contribute to a growing recognition that the visual intricacy inherent in traditional architecture has quantifiable value in today's built environment. Rather than viewing ornament as "crime" (Loos 1908), designers may leverage ornament and pattern to create buildings that not only look and feel engaging but also benefit human health and well-being (Ro 2024).

Limitations and Future Work

Despite its promising results, this study has limitations that must moderate our conclusions. The use of AI-generated facades, while innovative in controlling design variables, may not fully capture the complexity and cultural significance of real architecture (Alexander 2002-2005). Black-and-white AI images lack the textural and material qualities present in real buildings as well as historical and cultural context. By focusing on the geometric and unconscious aspects of vision, we also exclude sociocultural and cognitive variables. We justify this exclusion as a way to isolate one component of aesthetic perception, but it remains a scope limitation. Aesthetic experience of architecture, of which our model addresses only one facet, is holistic.

Additionally, our reliance on the 3M-VAS tool means that we modeled only low-level, pre-attentive visual response. Any eye-tracking predictions, as opposed to real observer data, may introduce bias (Ro and Huffman 2024; Hollander et al. 2020; Rosas et al. 2023). Future research would benefit from empirical eye-tracking trials with human participants.

Another limitation is that the visual attention coherence (VAC) score was not calculated for each facade individually but assigned to each member of a group and then analyzed collectively. While this method is effective for establishing a visual attention hierarchy within the group, it does not reflect the characteristics of individual facades. Rather, the score represents the relative "weight" of attention that each facade commands in relation to others. Consequently, the same facade might receive a different VAC score if analyzed within another group.

A corollary of this approach is that facades receiving minimal attention within a group may have their VAC score computed in a sample that is too small, potentially misrepresenting their comparative ability to attract attention. This effect is observed in groups 3, 4, 5, and 7, where attention is overwhelmingly directed toward buildings of complexity levels 3 and 4. As a result, the VAC score for complexity levels 1 and 2 both fall to near zero and can change in order. This suggests that while our grouping method may reflect realistic scenarios (a streetscape with varied buildings), it also complicates interpretation of the absolute attention-catching ability of simpler facades. Future studies could consider grouping buildings of similar complexity together or presenting facades one at a time to measure their attention capture in isolation. This would help determine, for example, if a bare classical facade consistently outperforms a modern one in absolute terms or if their performance is context-dependent.

This study moreover addresses the unconscious or pre-attentive phase of vision, not any conscious preference for visual complexity. An intriguing question arises: do people prefer the most fractal facades, or is there an optimal middle range that maximizes appeal? Our work shows that higher complexity attracts attention, but one could also ask viewers directly about their preferences after viewing. Future research should complement attention predictions with surveys of conscious preference and emotional response to see how fractal dimension correlates with stated preferences across cultural groups. This would explore whether the facades that attract visual attention are also those that people find beautiful or whether other factors (perhaps cultural conditioning, familiarity, or style bias) inform the final verdict of taste.

In summary, this study demonstrates a clear link between fractality and immediate visual attention on architectural facades using novel AI tools for stimulus generation and response measurement, showing the value of self-similar scaling patterns and organized complexity in architectural design. Our findings suggest that fractal patterns—common in traditional architecture—stimulate visual engagement by echoing natural geometries that resonate with the human brain. This supports the idea that certain architectural design principles, such as proportionality, fractal scaling, ornament, and intricate detailing, have a perceptual and cognitive rationale.

As contemporary architecture continues to explore minimalism and abstraction for the sake of efficiency and cost reduction, our study highlights the enduring relevance of tradition in fostering visual and emotional connections with built environments. Yet our contribution should be seen as one piece of a larger puzzle in aesthetic research. By isolating and quantifying one effect (fractal complexity on visual attention), we hope to inform ongoing debates and encourage further studies. These could guide design practice as to how a traditional aesthetic interacts with the eye, brain, and body. Architects and urban planners should strive ultimately to design buildings that are both visually engaging and beneficial to human psychophysiological health.

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## Biographies | Biografías | Biografias

### Brandon R. Ro

Brandon R. Ro, AIA, NCARB, ICAA is an award-winning architect, researcher, and educator. He is the Principal and founder of Tetrad Architecture and Planning. His projects have received awards from the U.S. Green Building Council, American Institute of Architects, American Planning Association, and Walt Disney Imagineering, among others. As co-founder of Utah Valley University's professional degree in architecture, he was instrumental in developing new curricula rooted in the classical tradition. As Assistant Professor, he taught design studios as well as architectural history and theory. His published research aims at improving interconnectivity between architecture, culture, and experience.

### Xavier Parareda

Xavier Parareda is a data scientist who uses data-driven approaches to rethink how we view and interact with our world and the built environment. Xavier grew up in Burgos, Spain, where he now resides. He has lived for three years in Italy and for ten in the Netherlands, where he started out in data science. Together with a group of urban advocates, in 2023 he founded the Resurgir Estético Burgos movement, a citizen initiative aimed at restoring beauty to all parts of the city, not just the historic center.