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Quantitative Analysis of Contemporary Residential Bathroom Design Through AI Visual Recognition: Object-Design Characteristic Mapping of 1,500 Cases

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ABSTRACT: This study presents a novel methodology for quantitatively analyzing contemporary residential bathroom design characteristics by combining Large Language Model (LLM) image recognition capabilities with text mining techniques. We collected 1,500 bathroom images from ArchDaily and analyzed 1,492 valid cases using Claude API, applying natural language processing and topic modeling to the generated text data. Our analysis reveals a remarkable near 1∶1 balance between material nouns (physical objects) and abstract nouns (design attributes), empirically demonstrating that contemporary bathrooms have evolved from purely functional spaces to venues for aesthetic self-expression. We identified "sophisticated modern minimalism" as the dominant design language, characterized by achromatic palettes and refined simplicity. Through Latent Dirichlet Allocation (LDA) topic modeling, we uncovered six major design themes: Luxury Modern, Nature-Friendly, Functional Vanity Space, Lighting/Open-concept, Industrial, and Minimalism. This research demonstrates the viability of AI-based architectural image analysis and presents methodological innovations by applying discovery science approaches to architectural design research.

KEYWORDS: AI image recognition; bathroom design; text mining; topic modeling; architectural data analysis; Claude API; discovery science

Introduction

Background and research context

The emergence of Large Language Models (LLMs) in the 21st century has brought significant advances in artificial intelligence (AI) technology. Recent multimodal LLMs such as GPT-4 and Claude demonstrate capabilities approaching or exceeding human performance in image recognition and analysis, enabling high-level interpretations of spatial aesthetics, styles, and relationships between design elements[1,3]. While the architectural field actively explores AI applications, research has primarily focused on technical domains such as generative design and parametric modeling[4].

Large-scale analysis of aesthetic and cultural characteristics in architectural design remains dependent on subjective interpretation by human researchers, leading to critical limitations: restricted sample sizes due to manual analysis constraints, inconsistent analytical standards across researchers, and difficulty in capturing temporal

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trends objectively. These limitations are particularly acute in analyzing residential spaces where aesthetic preferences rapidly evolve alongside technological and social changes.

Among residential spaces, bathrooms represent a distinctive integration of functionality and aesthetics, reflecting technological advancement, lifestyle changes, and cultural values[5]. The bathroom has transformed from a purely utilitarian space to a site of personal expression and wellness. This space now serves as a convergence point for personal identity, self-care aspirations, and design preferences. However, systematic large-scale research on contemporary bathroom design trends remains insufficient, with existing studies limited to ergonomic considerations, universal design metrics, or small-sample qualitative analyses.

Discovery science approach in architecture

Discovery science approaches utilizing big data analysis and machine learning have produced innovative outcomes across various fields including medicine, biology, and materials science. This data-driven methodology, which inductively derives patterns from large-scale datasets rather than testing predetermined hypotheses, complements traditional hypothesis-driven research approaches. While urban big data research is increasing in architecture, large-scale data analysis of architectural design itself remains in its early stages.

The gap between available data and analytical capabilities presents a unique opportunity. Digital architectural media archives like ArchDaily have accumulated vast repositories of professionally curated project documentation, yet these remain largely unexplored through systematic quantitative analysis. By combining LLM-based image analysis with text mining, we can convert subjective design attributes into objective data, enabling analysis of large-scale projects with consistent standards previously impossible.

Research objectives and contributions

This study aims to develop and validate a novel methodology for large-scale analysis of contemporary residential bathroom design characteristics using LLM-based image recognition and text mining techniques. Our specific objectives are:

Empirical validation of AI capabilities, to verify AI's architectural space recognition capabilities through systematic extraction and analysis of objects and design features from 1,500 bathroom images, establishing benchmarks for accuracy and consistency.

Quantification of design language, to quantify compositional elements and stylistic characteristics of contemporary bathroom design through systematic analysis of material and abstract nouns, identifying the balance between functional and aesthetic descriptors.

Spatiotemporal trend identification, to identify design trends and regional characteristics according to spatiotemporal context, revealing how global standardization coexists with local preferences and how major events (e.g., COVID-19) influence design evolution.

Latent pattern discovery, to derive latent design clusters through topic modeling, uncovering implicit design themes that may not be apparent through traditional analysis methods.

This research contributes to architectural scholarship by: (a) introducing a reproducible methodology for large-scale design analysis, (b) providing empirical evidence for the evolution of bathroom spaces from functional to aesthetic-functional hybrids, and (c) demonstrating how discovery science approaches can reveal hidden patterns in architectural design data.

1 Related work

1.1 AI-Based architectural image analysis

Architectural applications of computer vision have evolved significantly over the past decade. Early work on achieved architectural style classification of building facade windows using Support Vector Machines, establishing foundational approaches for computational style recognition[7]. Subsequent research significantly improved accuracy to 94.5% using Convolutional Neural Networks (CNNs) for architectural heritage image classification, demonstrating deep learning's superior performance in recognizing architectural elements such as altars, apses, bell towers, and columns[6].

Building on these classification approaches, further research advanced the field by demonstrating deep learning's capacity to classify and measure visual similarity

between different architects' designs through the eye of artificial intelligence. Their work showed how AI could identify subtle stylistic patterns that characterize individual architects' work, providing a foundation for understanding AI's analytical capabilities in architectural aesthetics [8].

Recent research has expanded beyond classification to analytical applications. Recent research applied deep neural networks to architectural conceptual design, demonstrating how AI can evaluate existing designs, extract significant building blocks, and recombine them into novel compositions. Their work established foundational approaches for AI-assisted design analysis that inform our methodology [2].

A comprehensive review of artificial intelligence applied to conceptual design in architecture, synthesizing classification, analysis, and generation approaches. Their framework establishes the theoretical foundation for applying AI to architectural design research, directly informing our methodology for analyzing bathroom design aesthetics [4].

The emergence of multimodal LLMs, marks a paradigm shift in architectural image analysis. These models demonstrate capabilities for simultaneous interpretation of functional and aesthetic characteristics, achieving human-level understanding in many contexts. However, systematic application of these capabilities to large-scale architectural datasets remains unexplored, particularly in residential interior spaces where subjective aesthetic judgments have traditionally dominated analysis.

1.2 Text mining in architectural research

Text mining applications in architecture have primarily focused on analyzing textual sources to understand design discourse and user perception patterns. Recent approaches combining AI-generated descriptions with text analysis represent a methodological innovation, where AI serves not merely as an auxiliary tool but as an analytical instrument capable of consistent, large-scale analysis.

The convergence of AI capabilities in architectural analysis—as comprehensively reviewed [4]—with text mining methodologies forms the foundation of our hybrid approach. By converting visual information to text through AI, then applying natural language processing techniques, we can extract quantitative insights from qualitative design attributes at unprecedented scale.

1.3 Bathroom design studies

Scholarly inquiry into bathroom design reflects its evolution from purely functional to culturally significant space. The foundational work "The Bathroom" [5] systematized ergonomic design principles, establishing metrics for functional efficiency that served as the baseline for bathroom design for decades. This function-first approach provides the historical reference point against which we measure contemporary bathroom design's evolution toward aesthetic-functional hybridity.

Contemporary research has traced the bathroom's transformation into a space of self-care and identity construction, examining how bathroom renovations reflect changing lifestyle aspirations and cultural values. Quantitative analyses have typically focused on specific aspects such as universal design indicators for accessibility or parametric optimization of layouts for spatial efficiency.

However, large-scale analysis of design aesthetics using AI-driven image analysis, as attempted in this study, represents an unexplored frontier in bathroom design research. By applying the AI capabilities demonstrated in architectural analysis [2,8] to this specific spatial typology, we can systematically examine how contemporary bathrooms balance functional requirements with aesthetic aspirations.

2 Methodology

2.1 Research design overview

This study employs a systematic five-phase methodology combining AI image analysis with text mining techniques, representing a dual transformation approach: visual to linguistic, then linguistic to quantitative data. This approach builds on the AI applications in architecture reviewed [4] and leverages the vision capabilities of Large Language Models [1,3].

2.2 Data collection and database construction

We collected 1, 500 residential projects containing bathroom images from ArchDaily's 'Houses' category, published between January 2015 and December 2024. Se-

lection criteria included: (1) residential projects with dedicated bathroom photography, (2)professional architectural photography (excluding renderings), and (3) complete metadata availability.

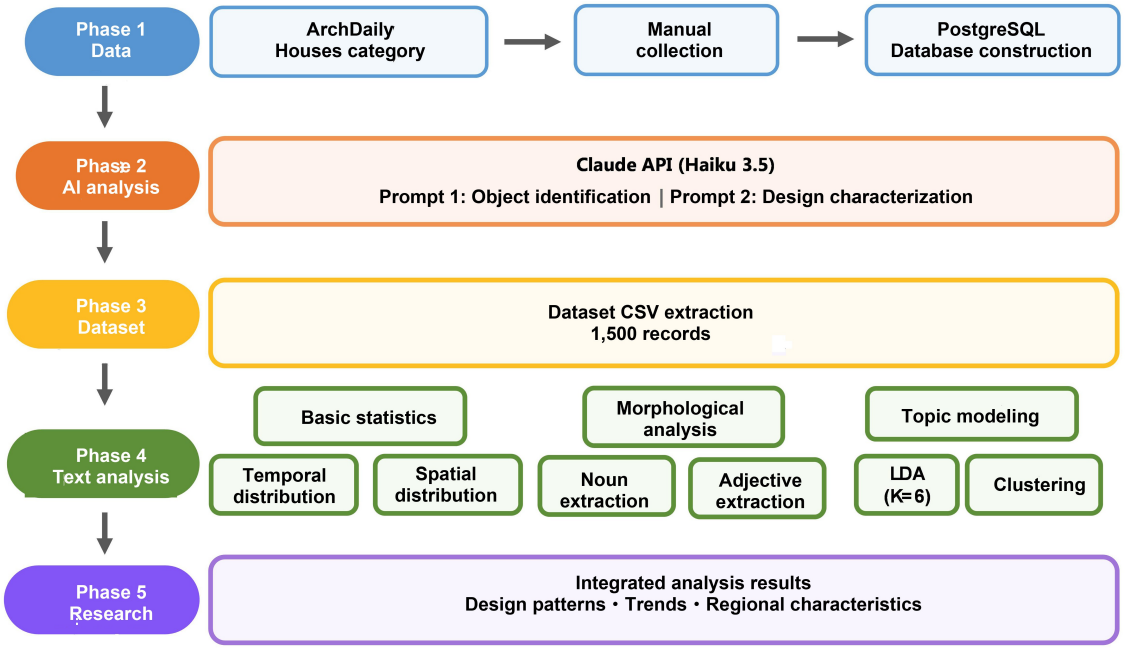


Figure 1 Research methodology flowchart

Geographic distribution was deliberately structured to capture global trends while acknowledging platform biases: Americas (40%), Europe (30%), and Asia-Pacific (30%). This distribution reflects both ArchDaily's user base and global architectural production patterns. For each project, we collected: representative bathroom image(s), project name, architect/firm, geographic location, completion year, and total floor area. Data was stored in a PostgreSQL database with image files linked via UUID references.

2.3 AI image analysis protocol

We utilized Anthropic's Claude API (claude-3-haiku-20240307) for image analysis, selected based on the technical specifications and vision capabilities documented in the Claude 3 Technical Report [1]. The model's multimodal capabilities, as analyzed in the context of artificial general intelligence emergence [3], provided the foundation for consistent architectural description generation. Two distinct prompts were applied to each image:

Prompt 1 (object identification), describe all objects visible in this bathroom image. List each item you can identify, including fixtures, furniture, materials, and decorative elements.

Prompt 2 (design characterization), describe the interior design characteristics of this bathroom. Focus on style, atmosphere, color scheme, materials, lighting, and overall aesthetic qualities.

API responses were parsed in JSON format and stored with timestamps and version tracking. Quality control involved manual verification of 150 randomly selected responses (10% sample), achieving 96% adequacy rating for relevant content extraction.

2.4 Text processing and classification

AI-generated texts underwent systematic preprocessing using R and the KoNLP package for Korean natural language processing:

Morphological analysis, Extracted nouns and adjectives of two or more characters using extractNoun() and SimplePos09 functions.

Stopword removal, Developed a domain-specific dictionary of 220 stopwords including morphological errors (e.g., 'image', 'visible') and generic terms (e.g., 'provide', 'use', 'component') that added no analytical value.

Synonym consolidation, Merged semantically equivalent terms (e.g., 'wash basin'/'sink', 'grey'/'gray') u-

sing a manually curated synonym dictionary.

Noun classification, categorized extracted nouns into two distinct classes based on physical tangibility.

Material nouns, physical objects or materials that can be touched (e.g., 'sink', 'tile', 'mirror').

Abstract nouns, concepts, attributes, or qualities without physical form (e.g., 'design', 'luxury', 'comfort').

This classification enabled analysis of the balance between functional and aesthetic descriptors in bathroom design language, directly testing the evolution from the function-first approach [5].

2.5 Quantitative analysis methods

We performed comprehensive statistical analyses including:

Frequency Analysis, calculated occurrence frequencies for all nouns and adjectives, identifying dominant design vocabulary.

Co-occurrence Analysis, examined pairwise relationships between adjectives and nouns to understand design attribute associations.

Temporal trend analysis, applied moving averages and regression analysis to identify design evolution patterns.

Geographic comparison, conducted ANOVA and post-hoc tests to identify regional design preferences (significance level: $p < 0.05$).

Balance score calculation, developed a metric to quantify the ratio between material and abstract descriptors.

2.6 Topic Modeling Implementation

Latent Dirichlet Allocation (LDA) was applied to identify underlying design themes, following approaches used in architectural style analysis [8]. Model optimization involved:

Parameter tuning, tested topic numbers $K = 4$ through $K = 12$, evaluating perplexity (lower is better) and coherence scores (C_v measure, higher is better).

Optimal selection, determined $K = 6$ as optimal based on interpretability and statistical metrics (coherence score: 0.52).

Topic labeling, named topics based on top 10 keywords per topic, validated through expert review.

Temporal analysis, tracked topic prevalence changes across time periods to identify trend shifts.

3 Results and analysis

3.1 Dataset characteristics and spatiotemporal distribution

The final dataset comprises 1,500 bathroom projects with 16 variables (8 metadata, 2 AI-generated texts, 6 derived metrics). AI-generated text showed 100% completeness with average lengths of 127 words (Object prompt) and 93 words (Design prompt).

Temporal distribution and pandemic impact, analysis revealed significant temporal clustering, with 71% of projects concentrated between 2019-2022, peaking in 2021 (290 projects, 19.3%). This surge reflects pandemic-driven priorities, providing a unique window into COVID-era design preferences, though limiting long-term trend analysis (Figure 2a).

Geographic bias and cultural representation, geographic distribution revealed expected Western-centric bias: Europe (33.1%) and Americas (28.4%) dominated with 61.5% combined representation. Asia (23.4%) showed growing presence, while Oceania (11.9%) and Africa (1.2%) remained underrepresented. This bias reflects both ArchDaily's audience and global architectural media production patterns, suggesting findings primarily represent Western and developed Asian markets (Figure 2b).

Project scale analysis, floor area distribution exhibited extreme positive skewness (mean: 1,102 m^2, median: 280 m^2), indicating influence of luxury outliers. Temporal analysis revealed intriguing patterns:

(1) 2016-2020: Preference for larger projects (mean 1,532 m^2), reflecting pre-pandemic luxury residential boom.

(2) 2021-2025: Shift toward compact housing (mean 492 m^2), suggesting pandemic-influenced priorities toward efficiency and sustainability.

Regional variations in project scale reflected cultural and economic contexts. Japan demonstrated remarkable homogeneity (mean= 154 m^2, median= 130 m^2, SD= 48 m^2), embodying compact living culture. Australia showed extreme variance (mean 3,466 m^2, median 300 m^2), indicating polarized market between modest homes and luxury estates.

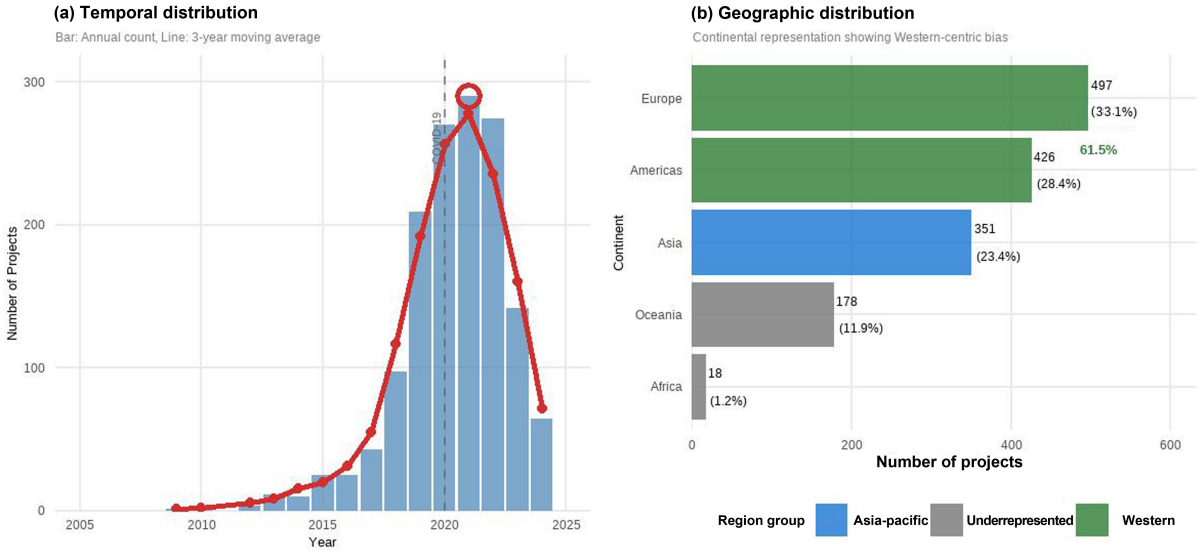


Figure 2 Spatiotemporal distribution (n=1,500). (a) Annual projects with 3-year average. (b) Continental distribution

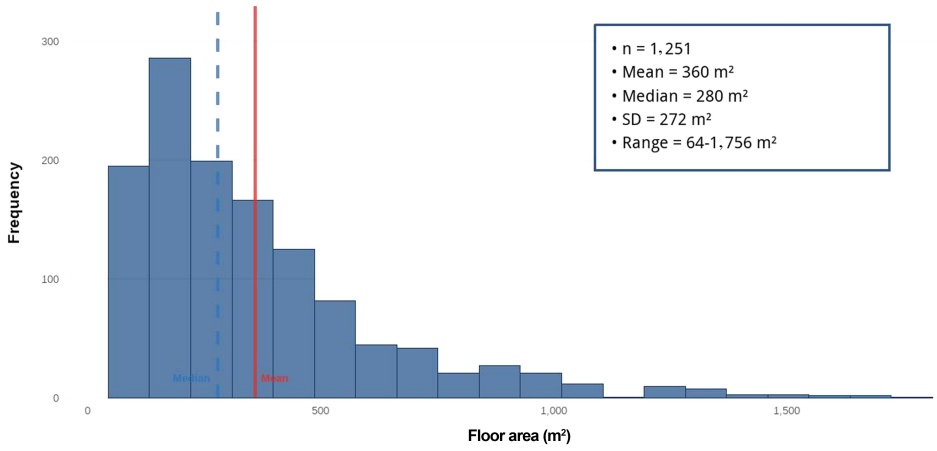


Figure 3 Area distribution histogram with regional overlays (excluding top/bottom 5%)

3.2 Bathroom components: The Material-abstract balance

After data cleaning and validation, 1,492 records (99.5% of the original 1,500) were deemed suitable for analysis. From these 1,492 valid records, we extracted 1,366 unique nouns appearing 36,990 times total. After excluding compound terms and proper nouns (6,299 occurrences, 17.0%), classification of the remaining 30,691 occurrences revealed significant insight into contemporary bathroom conceptualization:

The 1∶1 Balance principle, material nouns (185 unique, 15,728 occurrences, 42.5%) and abstract nouns (188 unique, 14,963 occurrences, 40.5%) demonstrated near-perfect balance. Individual descriptions averaged 10.5 material nouns and 10.1 abstract nouns, confirming equal attention to physical components and design attributes. This near-perfect 1∶1 ratio (42.5% vs 40.5%) provides quantitative evidence that bathrooms have transcended pure functionality to become spaces of aesthetic expression, supporting the proposition that contemporary bathrooms serve as sites of identity construction.

Material noun hierarchy, top material nouns revealed clear functional hierarchy:

Essential fixtures, sink (1,044), mirror (620), toilet (498).

Finishing materials, tile (891), wood (601), stone (456).

Structural elements, wall (794), floor (623), ceiling (387).

Ambience creators, lighting (752), window (751),

plant (340).

The high frequency of ‘window’ (751) and ‘plant’ (340) signals contemporary emphasis on natural light and biophilic design, reflecting growing wellness priorities in residential design. This represents a shift from the function-first approach [5] to holistic environmental design.

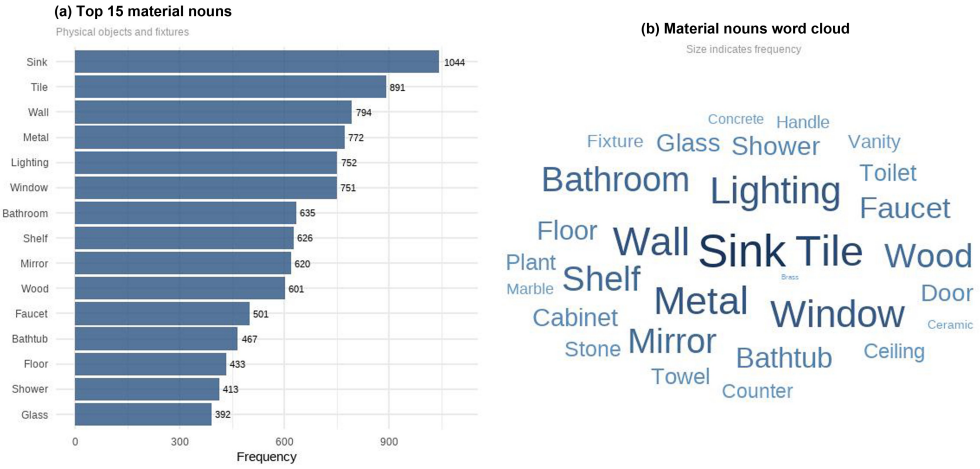


Figure 4 Top 15 material nouns-hierarchical bar chart and word cloud

Abstract noun patterns, Abstract nouns revealed design language standardization:

(1) Conceptual dominance, design (999), frame (711), material (697), installation (691).

(2) Color hegemony, white (650), gray (630), black (535)—achromatic palette accounting for 68% of color mentions.

(3) Sensory descriptors, texture (423), atmosphere (387), warmth (234).

The overwhelming dominance of achromatic colors (white/gray/black: 1,815 combined mentions vs. all chromatic colors: 823) indicates significant standardization in contemporary bathroom aesthetics, possibly driven by global design media influence and resale value considerations.

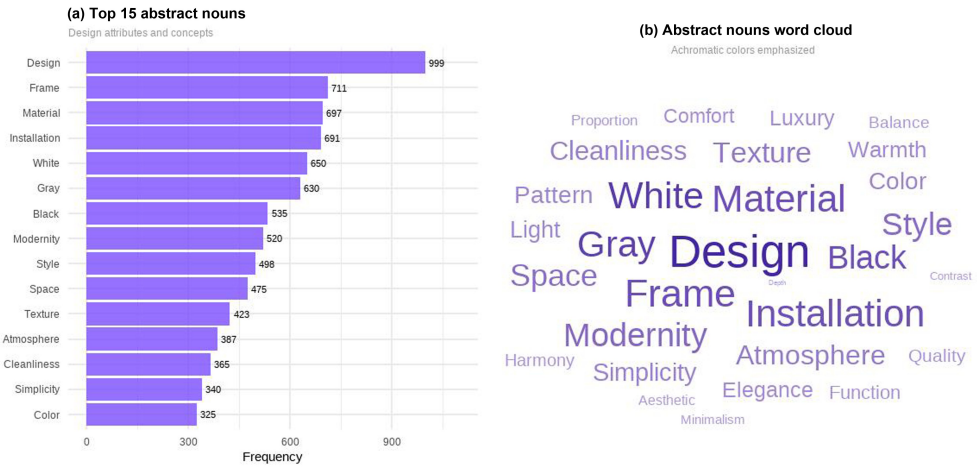


Figure 5 Top 15 abstract nouns-hierarchical bar chart and word cloud

3.3 Design language: “Sophisticated modern minimalism”

Adjective analysis revealed the establishment of a dominant design vernacular. From 11,407 total adjective occurrences (82 unique terms), the distribution followed the Pareto principle, with the top 10 terms accounting for 65% of all occurrences.

The Sophistication Paradigm: ‘Sophisticated’ (1,476 occurrences) exceeded ‘modern’ (911) by 62%, contrary to common assumptions about contemporary design priorities. This suggests evolution beyond mere modernism toward refined, nuanced aesthetics. The adjective hierarchy-sophisticated> modern> clean> minimal> elegant-defines

what we term "Sophisticated Modern Minimalism" as the prevailing bathroom design language.

Figure 6 Adjective frequency word cloud with sophistication emphasis

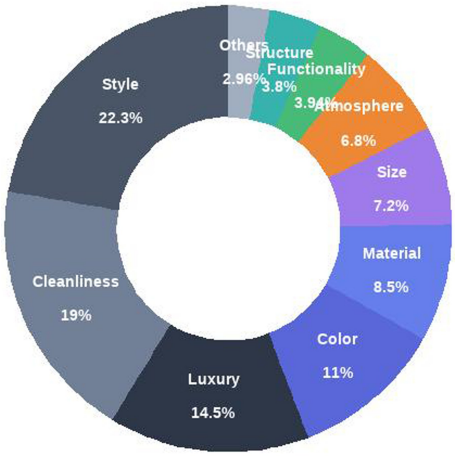
Categorical analysis of spatial attributes, classification into 10 attribute categories revealed design priorities:

Style (22.3%) and cleanliness (19.0%): Core axes forming 41.3% of descriptions.

Luxury (14.5%) and color (11.0%): Key differentiators in competitive market.

Functionality (3.94%): Lowest frequency, suggesting functionality as implicit baseline rather than differentiator.

This distribution indicates that in contemporary discourse, bathrooms are presumed functional; differentiation occurs through style and experience. This represents a significant departure from mid-20th century priorities where function was the primary consideration.



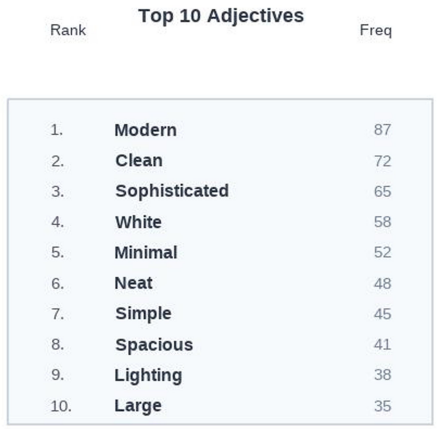


Figure 7 Spatial characteristic distribution with temporal overlay

Temporal evolution of design priorities, time-series analysis (2015-2024) revealed remarkable stability rather than dramatic shifts:

'Modern' category, dominant and stable at 31%-34% throughout the period.

'Cleanliness', consistently maintained at 25%-27%, unaffected by pandemic.

'Luxury' category, minor fluctuations around 19%-21% (+ 2 percentage points).

'Brightness', gradual decline from 15%-11% (-4 percentage points).

'Nature-related', minimal presence at 6%-8%, with negligible COVID-19 impact.

These patterns indicate a consolidation of minimalist aesthetics as the dominant paradigm, with pandemic effects proving insignificant (< 2% change across all categories). The stability suggests bathroom design preferences are driven by long-term cultural shifts rather than sudden external disruptions.

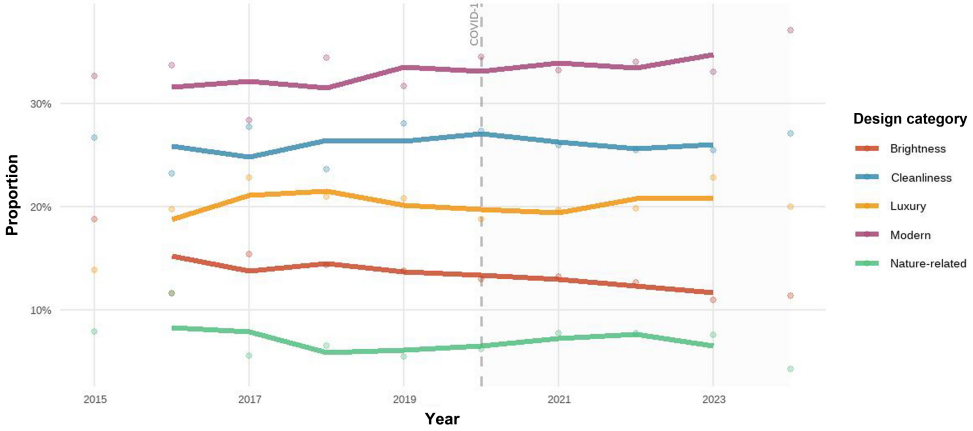


Figure 8 Design trend evolution with COVID-19 marker

3.4 Latent design themes through topic modeling

LDA analysis revealed six coherent design themes, each representing distinct aesthetic approaches:

Luxury modern (18.2%), marble, luxury, sophisticated, gold, chandelier.

• Represents premium market segment emphasizing material opulence.

• Associated with largest project sizes (median 412 m^2).

Nature-friendly (17.7%), wood, natural, plant, warm, organic, beige.

• Embodies biophilic design principles and wellness orientation.

• Represents 17.7% of topics in LDA modeling, while temporal frequency analysis shows stable presence at 6%-8% of actual descriptions across the study period.

Functional vanity space (17.0%), sink, mirror, storage, cabinet, practical.

• Focuses on utilitarian efficiency and organization.

• Popular in smaller projects (median 238 m^2).

Lighting & open-concept (14.4%), window, skylight, natural-light, spacious, airy.

• Emphasizes spatial perception and connection to exterior.

• Strongly associated with contemporary architecture.

Industrial (15.6%), concrete, metal, exposed, raw, black, urban.

• Represents alternative aesthetic challenging mainstream minimalism.

• Shows regional concentration in urban markets.

Minimalism (17.0%), white, clean, simple, zen, uncluttered.

• Classic modernist approach remaining consistently popular.

• Highest in European markets (21.1%).

3.4.1 Temporal dynamics and COVID-19 impact

The relatively even distribution (14.4%-18.2%) suggests contemporary bathroom design as pluralistic field. Topic distribution remained stable throughout 2015-2024, with all themes showing < 3% variation despite pandemic disruption. This stability indicates bathroom design aesthetics are governed by longer-term cultural preferences rather than external shocks.

3.4.2 Regional design cultures

Continental analysis revealed distinct cultural preferences:

Asia, luxury (22.8%) + Nature-Friendly (21.5%)-material richness with natural elements.

Americas, similar to Asia but more balanced distribution.

Europe, hygiene/cleanliness (21.1%) + Minimalism (18.9%)-functional pragmatism.

Oceania, lighting/Open (24.3%)-indoor-outdoor connection.

These patterns reflect deep cultural values: Asian markets balancing prosperity display with harmony principles, European emphasis on practical sustainability, and Oceanic integration with landscape.

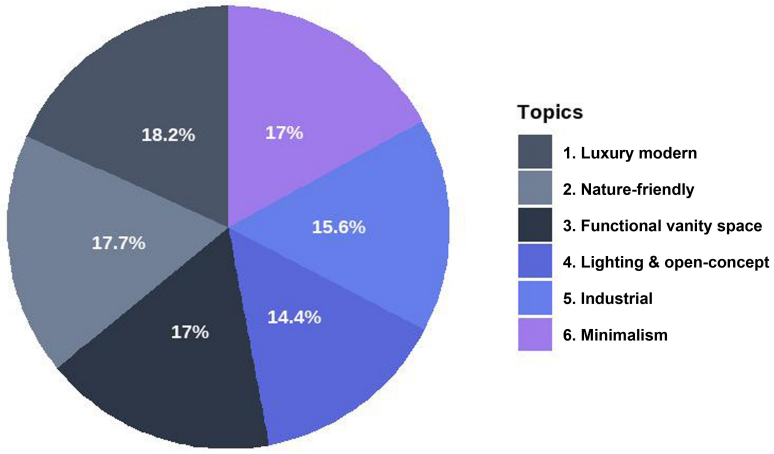


Figure 9 Topic distribution pie chart (n=1,492)

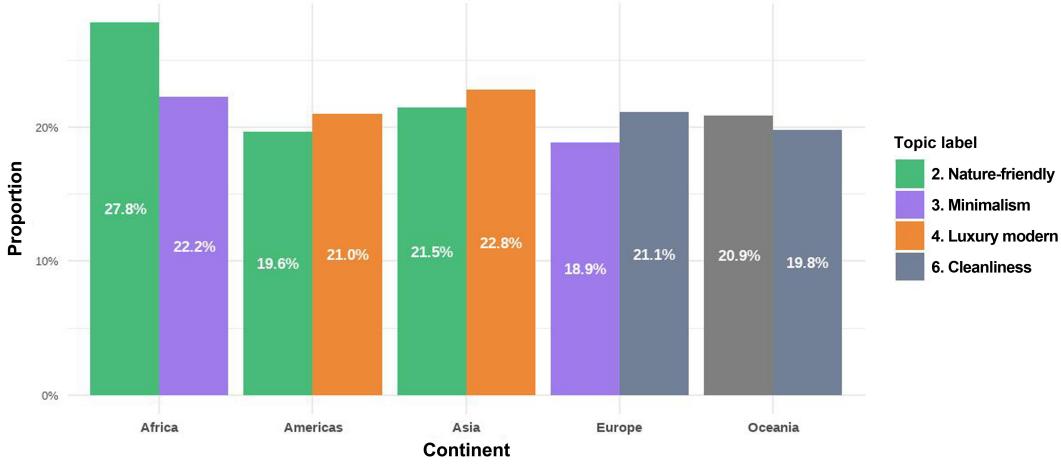


Figure 10 Regional topic preferences

4 Discussion

4.1 Key findings and theoretical implications

This research provides empirical evidence for several theoretical propositions about contemporary bathroom design:

From function to experience, the near-equal balance of material to abstract nouns (42.5% vs 40.5%) quantitatively validates bathroom's evolution from purely functional space to experiential environment. This empirical finding supports the conceptual shift from the function-first approach [5] to contemporary bathrooms as spaces of self-construction, where identity and wellness aspirations materialize through design choices. The dominance of 'sophisticated' over 'modern' suggests users seek not just contemporary aesthetics but refined, culturally resonant experiences.

Standardized pluralism, while "sophisticated modern minimalism" emerges as standard language, the even distribution of six design themes reveals paradoxical standardized pluralism. This pattern reflects the influence of global design media—as observed in architectural AI studies [2,4] —creating common vocabulary while allowing diverse interpretations within that framework.

Stability despite crisis, contrary to expectations, bathroom design aesthetic preferences showed remarkable stability during COVID-19, with all style categories showing < 2% variation. The nature-friendly theme, while comprising 17.7% of the LDA topic distribution, maintained a consistent 6%-8% frequency in actual bathroom descriptions throughout the period, demonstrating that its prominence as a latent topic did not translate to increased adoption during the pandemic. This stability suggests bathroom design aesthetics are

governed by long-term cultural preferences rather than external shocks.

Design democracy limitations, despite democratizing trends in design media, correlation between certain themes and project size reveals persistent exclusivity. Luxury Modern and Lighting/Open concepts remain spatially constrained, suggesting class-based design stratification persists despite aesthetic democratization, a pattern consistent with broader observations in architectural design research [4].

4.2 Methodological contributions and validation

The dual transformation methodology-visual to linguistic to quantitative-opens new research possibilities:

Consistency and scale, AI-generated descriptions achieved 96% adequacy with perfect completeness, surpassing human analysis limitations. This validates the vision capabilities documented in recent LLM research [1,3] for architectural applications. The ability to maintain consistent analytical standards across 1,500 cases exceeds previous studies by an order of magnitude, demonstrating the scalability potential identified [4].

Discovery science validation, topic modeling revealed patterns invisible to traditional analysis. The nature-friendly surge and regional design cultures emerged from data rather than predetermined hypotheses, validating discovery science approaches in architecture consistent with inductive methodologies in computational design research [8].

Reproducibility framework, by documenting prompts, preprocessing steps, and classification criteria, we establish reproducible protocol for future studies. This addresses critical reproducibility crisis in architectural research where subjective interpretation typically dominates, extending the systematic approaches demonstrated in heritage classification and style recognition [6-8].

4.3 Limitations and future directions

Several limitations warrant acknowledgment:

Platform bias, archDaily's curatorial process favors professionally photographed, architecturally significant projects, potentially overstating luxury and sophistication prevalence. Cross-platform validation using real estate listings or social media could provide broader market representation.

Temporal concentration, data clustering around 2020-2021 provides pandemic snapshot but limits long-term trend analysis. Longitudinal studies spanning decades could reveal cyclical patterns versus permanent shifts.

Spatial resolution, using total floor area rather than bathroom-specific dimensions introduces noise. Future research should develop methods for extracting room-specific areas from architectural documentation, potentially using the spatial understanding capabilities demonstrated in recent AI research [2].

Cultural representation, western-centric bias (61.5%) limits global applicability. Targeted data collection from underrepresented regions could reveal alternative design paradigms beyond those captured in current AI training data [1].

4.4 Practical implications

For design practitioners and industry stakeholders, findings offer actionable insights:

Product development, the material-abstract balance indicates equal importance of functional performance and aesthetic experience. Product designers should consider sensory and emotional attributes alongside technical specifications. The sink's prominence as most frequent object (1,044 mentions) suggests prioritizing this as visual focal point in bathroom design compositions.

Market segmentation, six distinct themes provide framework for targeted product lines and marketing strategies. The nature-friendly theme's dual presence—17.7% weight in topic modeling yet stable 6%-8% frequency in actual descriptions—suggests a latent market opportunity: while strongly defined as a design approach, it remains underutilized in practice.

Regional customization, significant continental variations indicate need for localized strategies. European emphasis on Minimalism (18.9%) versus Asian preference for Luxury (22.8%) requires differentiated approaches despite global standardization trends.

Sustainability integration, nature-friendly theme's growth suggests sustainability messaging resonates when combined with wellness and aesthetic benefits rather than purely environmental arguments, reflecting holistic design approaches in contemporary architectural practice.

Conclusion

This study systematically analyzed design characteristics of 1,500 contemporary residential bathrooms using AI visual recognition and text mining, revealing multiple layers of insight into contemporary design culture. The research makes three primary contributions:

Methodological innovation, the dual transformation methodology combining AI image recognition with text mining overcomes traditional limitations of subjective interpretation in architectural analysis. By converting visual information to linguistic data, then to quantitative metrics, we establish reproducible protocol for large-scale design research. The 96% adequacy rate and perfect completeness validate AI as a reliable analytical instrument, building on the capabilities demonstrated in recent LLM research [1, 3] and extending applications shown in architectural AI studies [2,4].

Empirical evidence, we empirically demonstrated contemporary bathroom design's evolution from functional to experiential spaces through the near-equal balance of material and abstract nouns (42.5% vs 40.5%). The emergence of "sophisticated modern minimalism" alongside six coexisting design themes reveals a standardized pluralism in global design culture, validating the shift from the function-first paradigm [5] to contemporary multivalent design approaches.

Theoretical extension, applying discovery science approaches to architectural design validates inductive pattern discovery in aesthetic domains traditionally dominated by deductive reasoning. The divergence between topic prominence (e.g., nature-friendly at 17.7% in topics) and actual frequency (6%-8% in descriptions), combined with stability despite pandemic disruptions, provides data-driven evidence for theoretical propositions about latent versus realized design preferences, cultural resilience in aesthetic choices, and the persistent influence of socioeconomic factors on spatial decisions. This extends the analytical frameworks demonstrated in architectural classification research [6-8]to interior design analysis.

The methodology presented here extends beyond bathrooms to any architectural element amenable to visual documentation. Future research should address identified limitations through multi-platform validation, extended temporal coverage, and improved spatial resolution. The analytical capabilities demonstrated in recent AI research [2,8] suggest potential for extending this methodology to other architectural typologies and design domains.

This research fundamentally demonstrates how architectural databases—long considered passive repositories of visual documentation—can be transformed from silent archives accessible only through manual browsing into active resources for systematic knowledge discovery. The convergence of AI's visual understanding capabilities [1, 3]and analytical precision [2,8] reveals that vast architectural media collections contain untapped empirical insights about how humanity shapes and inhabits space. As AI capabilities mature and architectural documentation proliferates, we stand at the threshold of a new era where the accumulated visual history of architecture becomes a living laboratory for understanding the complex interplay between design, culture, and human experience—transforming architectural research from an interpretive art into a data-driven science without sacrificing its humanistic core.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Sources of Figures and Tables

Figures 1-10: Author's own work.

Note

The analysis is based on 1,500 bathroom images sourced from ArchDaily (www.archdaily.com). A permission request was submitted to contributors.support@archdaily.com on 12 Sep 2025 and remains pending. Images used for non-commercial academic research purposes.

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Appendix A：AI image analysis prompts and implementation

A.1 API implementation code

```
def analyze_image_with_claude(image_path, prompt):
    """
    Analyzes bathroom images using Claude 3 Haiku API.

    Parameters:
    -image_path: Path to the bathroom image file
    -prompt: Structured prompt for analysis

    Returns:
    -Structured text description of bathroom features
    """
    api_key= os.getenv('ANTHROPIC_API_KEY')
    #  ··· API key validation ···

    client= anthropic.Anthropic(api_key= api_key)

    #  Encode image to base64
    with open(image_path, 'rb') as image_file:
        image_bytes= image_file.read()
    image_data= base64.b64encode(image_bytes).decode('utf-8')

    #  Claude API call
    message= client.messages.create(
        model= "claude-3-haiku-20240307", #  Model specification
        max_tokens= 1500, #  Maximum token limit
        messages= [
            {
                "role": "user",
                "content": [
                    {"type": "text", "text": prompt},      #  Text prompt
                    {"type": "image", "source": {          #  Image data
                        "type": "base64",
                        "media_type": "image/png",
                        "data": image_data
                    }}
                ]
            }
        ]
    )
    return message.content
```

A.2 Structured analysis prompt

```
def get_bathroom_analysis_prompt():
    """
    Returns the standardized prompt used for all bathroom image analyses.
    The prompt ensures consistent, structured output across all 1,500 images.
    """
    return (
        "Analyze the attached image and provide detailed responses to the following "
        "two questions with maximum specificity and comprehensiveness.\ n\ n"

        "Format all responses in Markdown with items clearly delineated using lists "
        "( • or 1. 2. etc.). Each response should be numbered (1, 2) with descriptive "
        "subheadings (e.g., 'Identifiable Objects and Characteristics', "
        "'Interior Design Features'). Use concise, descriptive statements without "
        "formal endings; employ telegraphic style where appropriate.\ n\ n"

        "1. Identify and describe all discernible objects in the image with their "
        "characteristics in comprehensive detail without redundancy:\ n"
        " -Include material composition, color, spatial positioning, functional "
        " purpose, design features, and placement rationale for each object.\ n"

        "2. Describe the interior design characteristics comprehensively without "
        "redundancy:\ n"
        " -Address overall ambiance, color palette, spatial configuration, "
        " natural/artificial lighting, material harmony, visual focal points, "
        " design intent, stylistic elements, and functional considerations.\ n"
        " -Present notable features as numbered lists (1. 2. 3. ⋯) with "
        " specific details.\ n"

        "While responses need not artificially reach 10 lines, provide rich, "
        "non-redundant descriptions that capture all relevant aspects."
    )
```