CLUSTERING VISUAL NARRATIVES OF SCIENCE MUSEUMS ON INSTAGRAM: A MACHINE LEARNING APPROACH TO COMMUNICATION PATTERNS

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ABSTRACT

In the context of museums' growing reliance on digital platforms, Instagram has become a key tool for science museums to engage audiences and shape their institutional narratives through visual content. This ongoing study examines a curated selection of 96 high-performing Instagram posts from eight international science museums, focusing on their aesthetic and narrative characteristics. Using deep learning-based visual embeddings and hierarchical clustering, the analysis identifies seven distinct visual clusters that reflect different communication strategies. Results suggest that images combining emotional appeal and human presence tend to generate stronger audience response, while technically polished but emotionally neutral visuals often underperform. Other visual styles—such as conceptual compositions or architecture-focused imagery—contribute to institutional positioning, audience loyalty, and editorial consistency. The typology proposed offers a practical framework to audit and enhance digital communication strategies in cultural institutions.

KEYWORDS

Science museums; Instagram; Visual narratives; Machine learning; Clustering;

1. INTRODUCTION

The 21st-century museum has evolved from a repository of heritage into a socially committed institution. Beyond conservation and research, it is increasingly expected to foster learning, participation, and community engagement—missions in which communication plays a central role (Carpentier, 2012). This shift aligns with the recognition that museums depend on their audiences for sustainability (Fletcher & Lee, 2012), prompting a move from unidirectional information delivery toward co-creative models (Amitrano et al., 2018; Claes & Deltell, 2019).

The rise of digital technologies and social media has reconfigured the museum-public relationship. Platforms like Instagram grant audiences a new participatory agency. They can challenge institutional narratives, demand transparency, and co-create content (Boix-Domènech et al., 2019; de las Heras-Pedrosa et al., 2023). While some institutions initially hesitated, many now recognize social media as vital for visibility, legitimacy, and connection (Booth et al., 2020; Rodríguez-Vera et al., 2024). In this hybrid and visual context, Instagram stands out as a platform that blends immediacy, aesthetics, and storytelling (Budge, 2020; Özdemir & Çelebi, 2017). It enables museums to connect with younger and more diverse audiences through images that are emotionally resonant, mobile-friendly, and narratively rich (Jarreau et al., 2019).

While storytelling refers broadly to the construction of institutional narratives across formats, *visual narrative* focuses specifically on the messages conveyed through visual elements alone—composition, color, framing, or human presence—without relying on text or captions. Instagram facilitates the construction of identity and supports educational and affective

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missions, helping museums appear more inclusive and socially attuned (Amalia & Hanika, 2021; Villaespesa & Wowkowych, 2020).

Visual content, in this sense, is not merely illustrative; it is strategic. Images serve as narrative and affective artifacts that shape perception, trigger emotions, and foster community (Kemp & Poole, 2016). Elements such as composition, color, human presence, and aesthetic style affect memorability, emotional tone, and institutional positioning. Emotional registers like joy, curiosity, or surprise have been empirically associated with higher audience response (Rodríguez-Vera et al., 2024). Far from neutral, museum images reflect and construct meaning through visual codes and platform logics (Arefieva et al., 2021).

Yet despite Instagram's potential, many institutions still adopt conventional broadcasting approaches. They often emphasize formal aesthetics over affective narratives, or use the platform without fully exploiting its two-way interaction possibilities (Jarreau et al., 2019). Understanding how *visual narrative* functions—not just through engagement metrics, but through its aesthetic, emotional, and strategic dimensions—has become essential for museums seeking to strengthen digital relationships and cultural relevance (Foronda-Robles et al., 2021).

This study addresses a persistent gap in museum communication research: the limited understanding of how visual content operates in digital environments. While previous studies have explored institutional strategies or engagement metrics, few have systematically analyzed the images themselves—especially in a scalable, comparative, and data-driven manner (Arefieva et al., 2021; Jarreau et al., 2019). To fill this gap, the present research focuses on the most successful Instagram images published by international science museums, using machine learning techniques to extract visual embeddings and identify latent patterns. Science museums are an ideal field of study. Indeed, they do not fully take advantage of the opportunities Instagram offers to engage the public (Jarreau et al., 2019).

By applying unsupervised clustering to high-dimensional visual data, the study constructs an empirical typology of museum images based on aesthetic and narrative traits. This approach reduces subjectivity, enables cross-institutional comparisons, and reveals which styles and contents generate stronger emotional and social resonance. The main objective is to identify and characterize visual narrative strategies. Derived from this, the study addresses the following two research questions:

RQ1. What are the dominant visual and narrative patterns in the most engaging Instagram images shared by international science museums?

RQ2. How are different visual styles characterized in terms of likes, comments, engagement and caption length on Instagram?

2. METHODOLOGY AND RESULTS

2.1. Data collection

We selected eight science museums with diverse histories, management models, and positioning, with support from experts at the Science Museum of Valencia. This allowed comparison of their digital communication styles and projected or echoed visual narratives. To build a representative sample (see details in table 1), we used the free version of PathSocial, which provides the 12 most-liked posts per account. We extracted these top posts for each museum (as of October 2024), yielding a dataset of 96 images.

TABLE 1: Sample description

Museum code	**Museum**	**Data-collection date**	**Posts**	**Followers**	**Followed**	**Relevance** (followers/followed) (Peralta, 2014)	**Follower-to-post** (followers/posts) (Boix-Domènech et al., 2019)	**Engagement sample posts**[2] (Caerols et al., 2017)

[2] (likes+comments)/(followers*posts)

1	**CACSA – Museu de les Ciències (Valencia, Spain)**	16th Oct. 2024	2757	60300	337	178,93	21,87	2,75%
2	**CosmoCaixa (Barcelona, Spain)**	16th Oct. 2024	1186	53700	521	103,07	45,28	1,81%
3	**Cité des Sciences et de l'Industrie (Paris, France)**	20th Oct. 2024	3143	40900	29878	1,37	13,01	0,98%
4	**Deutsches Museum (Munich, Germany)**	20th Oct. 2024	1827	20800	393	52,93	11,38	3,16%
5	**Experimentarium (Copenhagen, Denmark)**	20th Oct. 2024	2000	13800	2264	6,10	6,90	1,99%
6	**Exploratorium (San Francisco, USA)**	20th Oct. 2024	4205	106000	695	152,52	25,21	32,94%
7	**Parque de las Ciencias (Granada, Spain)**	16th Oct. 2024	1474	11000	312	35,26	7,46	4,56%
8	**Museo Nacional de Ciencia y Tecnología (Madrid, Alcobendas y La Coruña, Spain)**	16th Oct. 2024	623	6871	885	7,76	11,03	12,10%

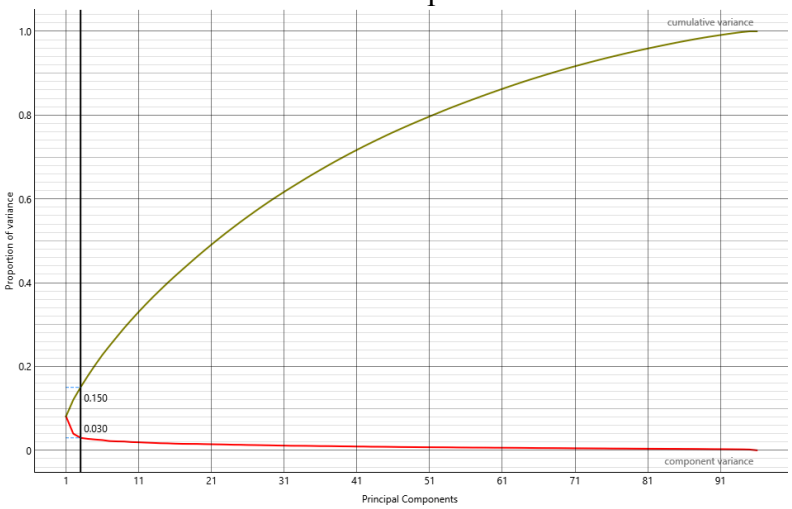
2.2. Extraction of visual characteristics

For the visual analysis, we used Google's Inception v3 model (trained on ImageNet) to embed images as 2,048-dimensional vectors representing high-level visual descriptors. Processing was conducted in Orange Machine Learning, which integrates advanced analytics through a visual workflow interface (Popchev & Orozova, 2023).

2.3. Dimensionality Reduction (PCA)

Before clustering, we applied Principal Component Analysis (PCA) to reduce dimensionality and visualize similarities. These deep-learning embeddings were transformed into a reduced space preserving maximum variance. Three principal components explained 15% of total variance—an adequate interpretive threshold (Figure 1). PCA also reduces noise and avoids overfitting by concentrating the most relevant information. This approach follows best practices in high-dimensional exploratory analysis (Aggarwal et al., 2001; Van Der Maaten et al., 2009), and is effective for detecting latent similarity patterns in museum images.

FIGURE 1: 3 components PCA



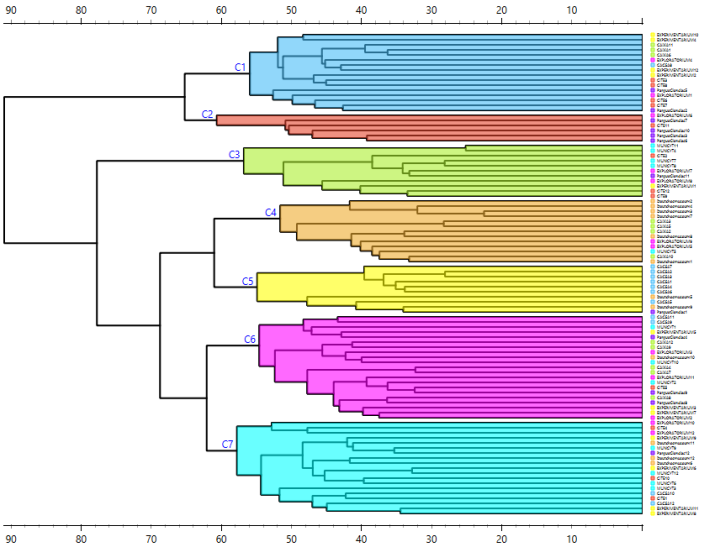
2.4. Clustering analysis

To detect latent visual patterns and answer RQ1, we applied hierarchical clustering to the PCA-reduced distance matrix. The 2,048-dimensional vectors were normalized, and Euclidean distance was used. We employed the Ward method, which minimizes intra-cluster

variance and is well-suited for compact structures in high-dimensional spaces. The resulting dendrogram (Figure 2) groups the 96 images by visual similarity, revealing seven clusters. This unsupervised approach reveals stylistic and narrative similarities across institutions, highlighting convergences or divergences in visual strategies.

The silhouette index assesses clustering quality by measuring how well each image fits within its assigned group compared to others. Only cluster C5 shows a positive silhouette value (0.285), indicating strong internal coherence and clear differentiation. It includes institutional or architectural images with high visual homogeneity. The other clusters show negative values, suggesting stylistic or thematic overlaps and diffuse boundaries. Clusters C1 and C6—significant for their size or engagement—have the lowest indices (–0.357 and –0.339) due to high internal heterogeneity. Clusters C3 and C4 (–0.212 and –0.236) also show ambiguity, while C7 and C2 (–0.141 and –0.165) suggest moderate separation.

FIGURE 2: Dendrogram of the hierarchical clustering



2.5. Results: analysis and discussion

The data in Table 2 provide a concise characterization of each cluster's visual profile and social performance, further illustrated by the images in Table 3.

TABLE 2: PCA dimension means, engagement and social metrics

Cluster	Nº images included	PCA1	PCA2	PCA3	Engagement (Caerols et al., 2017)	Likes	Comments	Post length
C1	16	12,60	4,10	-4,09	8,87	9169,19	7,62	570,75
C2	6	21,73	-3,88	0,64	0,39	64,17	1,33	724,33
C3	11	-18,28	12,44	-2,67	0,32	58,91	7,64	477,55
C4	13	-11,28	-6,82	-1,32	0,38	105,46	3,92	1236,31
C5	10	-2,70	-12,36	-0,85	0,82	399,90	7,40	553,00
C6	21	3,11	-3,83	-1,41	0,46	95,29	4,33	748,33
C7	19	-1,18	5,97	7,70	0,25	64,68	1,05	656,32

Before detailing each cluster, a summary highlights key insights. Cluster 1 exemplifies effective visual storytelling, combining emotional appeal and human presence for the highest engagement. Cluster 2 shows that technical quality alone does not ensure impact, while Cluster 3 demonstrates that conceptual visuals can spark interaction despite limited reach. Clusters 4 and 5 strengthen brand identity and loyalty through calm, informative aesthetics.

Cluster 6, with its diversity, serves as a structural pillar for editorial planning. Cluster 7 reveals a gap between aesthetic intensity and social engagement, underscoring the need for more emotionally resonant formats. The following sections describe each cluster in detail.

Cluster 1 – High visual visibility and strong social response.

This cluster shows very high PCA1 and PCA2 values, reflecting a dominant visual presence. It also records the highest engagement (8.87) and over 9,000 likes per image, indicating a strong audience connection.

Images are striking—well-composed, colorful, high-contrast, and emotionally expressive. Many depict people in dynamic scenes (e.g., CITE8, CAIXA1, EXPLORATORIUM4), with centered framing, quality lighting, and clear narratives. Some use humorous or emotional text overlays (e.g., EXPLORATORIUM2), further enhancing appeal.

Strategically, Cluster 1 sets a benchmark for science museum content. It aligns with Instagram's mobile-first grammar, where human presence, interaction, and immediacy drive engagement. Replicating this style strengthens community ties and positions museums as visually and emotionally engaging experiences.

Cluster 2 – High visual intensity, low social response.

This cluster has very high PCA1 values, indicating strong visual intensity. However, engagement is the lowest (0.39), showing that aesthetic appeal doesn't ensure audience connection.

Images are polished—sometimes technically or artistically impressive—but lack emotional traction. They often show institutional scenes: official visits, academic events, or formal portraits (e.g., ParqueCiencias3, 6, 7), with occasional dramatic lighting (e.g., CITE11, EXPLORATORIUM6). Yet compositions remain static, impersonal, and narratively flat. These visuals project authority and formality but not empathy or engagement—key to virality on social media.

Strategically, Cluster 2 stresses the need for more human-centered narratives. Greater spontaneity, quotes, or close framing could improve connection. While serving archival and branding functions, these posts should be balanced with more expressive content to enhance engagement.

Cluster 3 – Distinctive aesthetics, high comments but low overall engagement.

It shows an atypical visual profile (low PCA1, high PCA2, negative PCA3), reflecting a non-conventional aesthetic. Although overall engagement is low (0.32), the high number of comments suggests these posts prompt reflection and discussion.

Content often includes flat or monochromatic backgrounds with graphic or textual elements (e.g., CITE12, EXPERIMENTARIUM1, MUNCYT14), as well as infographics or conceptual messages (e.g., EXPERIMENTARIUM7, MUNCYT11, MUNCYT7). These images move away from emotional or figurative appeal, favoring symbolic or intellectual content. This minimalist cluster is not meant to entertain but to inform, provoke thought, or reinforce institutional positioning. Its appeal lies in its conceptual clarity and narrative depth, attracting more intellectually engaged audiences.

Strategically, Cluster 3 contributes to editorial, commemorative, or educational aims. Though not viral, it strengthens thematic positioning and fosters dialogue—ideal for purpose-driven communication.

Cluster 4 – Neutral tendency with extended captions.

It presents intermediate-to-negative values across all three PCA axes, indicating a modest or visually neutral profile. Its distinctive trait lies in its long captions—averaging 1,236 characters—suggesting a strategy aimed at loyal or content-seeking audiences.

Visuals are mostly static, focused on exhibitions, architecture, or details (e.g., Deutschesmuseum7, CAIXA3, CAIXA10), with little aesthetic treatment. Non-human

subjects dominate—buildings, birds, technical elements—though some posts include groups or exhibits (e.g., EXPLORATORIUM5, EXPLORATORIUM8).

Strategically, Cluster 4 follows a documentary or educational logic. Despite modest engagement (0.38), extended captions provide narrative depth, supporting institutional positioning, loyalty, and community-building. These posts work best when paired with more striking visuals that highlight the museum's mission.

Cluster 5 – High engagement with moderate aesthetics.

It presents slightly negative values across all PCA components, indicating a restrained visual style. Despite this, it achieves relatively high engagement (0.82), with solid averages in likes and comments—showing that strong audience connection can occur without visual spectacle.

Images focus on architecture: clean, well-lit shots of interiors and buildings (e.g., CACSA 1–6, Deutschesmuseum9, ParqueCiencias1). They convey calm, order, and prestige, often evoking institutional identity and spatial grandeur.

Strategically, this cluster proves that emotional resonance doesn't require bold visuals. It builds connection through familiarity and elegance, reinforcing brand identity and pride of place. As a consistent, low-risk format, it suits institutional campaigns, anniversaries, and efforts to convey trust and continuity.

Cluster 6 – Heterogeneous and balanced group.

It shows moderate values across all PCA components, reflecting a visually neutral profile. Engagement is average (0.46), suggesting steady but unremarkable performance.

The content is highly varied—portraits, architecture, interiors, display cases, visitor activities, objects, and urban scenes—ranging from sober (MUNCYT1, CAIXA12) to more dynamic (ParqueCiencias8, EXPLORATORIUM11). Many posts adopt an informational or testimonial tone, documenting exhibitions or audience interaction.

Strategically, this cluster offers consistency and flexibility. Its heterogeneity makes it a visual "wild card," useful for maintaining editorial rhythm, showcasing institutional diversity, and supporting cohesive communication. Though not designed for virality, it plays a key structural role, complementing more emotional or visually striking content.

Cluster 7 – Visually intense but socially disengaged.

This cluster shows PCA1 near zero, moderate-high PCA2, and high PCA3. Despite visual sophistication, these images record the lowest engagement (0.25), exposing a gap between aesthetic appeal and audience connection.

Content relies on neon lights, saturated colors, digital effects, posters, infographics, and scientific illustrations (e.g., CITE1, EXPERIMENTARIUM11, MUNCYT12), often tied to events like GLOW. These polished but emotionally neutral designs work better in exhibitions than on social media, where immediacy, emotion, and storytelling prevail.

Strategically, the cluster holds potential: museums could add testimonials, context, or interactive elements, and reformat visuals into carousels, stories, or reels. The aim is to evolve from pure design to content that connects and inspires.

TABLE 3: Images grouped by cluster

Cluster	Images included in each cluster
C1	

3. CONCLUSION

This study applies a data-driven analysis of Instagram images to uncover aesthetic and emotional patterns driving audience engagement in science museums. Findings highlight human presence, emotional tone, and composition as key factors of digital performance. The proposed clustering typology provides a replicable model to analyze how museums construct meaning and identity visually in algorithmic contexts, while serving as a practical tool to audit and refine visual strategies by balancing consistency, variety, and emotional resonance.Three actionable guidelines emerge from a managerial point of view:

- Emotionally expressive and people-centered images generate higher engagement than technically polished but impersonal visuals. Prioritizing narrative clarity and emotional cues is essential.
- Conceptual or educational posts—though less viral—support positioning, depth, and loyalty. These formats should be valued for their long-term impact.
- Underperforming content with strong visuals can be reworked through narrative framing, use of testimonials, or dynamic formats (reels, carousels) to improve resonance.

This study has several limitations. The dataset includes only 96 top-performing images, excluding less popular but potentially relevant content, and captures a single time point without seasonal variation. It focuses solely on visuals, omitting captions or formats like reels or stories. Neural embeddings, though efficient, lack interpretability, and engagement is treated only as a proxy for impact.

These constraints suggest future research avenues: longitudinal analyses, multimodal and comment analysis, and alternative clustering methods. ANOVA could test differences in audience response, while cross-platform comparisons and a museum-specific visual typology

would enrich insights. Finally, qualitative methods such as interviews or focus groups could deepen understanding of how audiences interpret and re-signify images.

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