Article

The Convergence of Animation and Heritage Communication: A Digital Practice Based on Leonardo da Vinci's Botanical Manuscripts

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ABSTRACT

This paper reinterprets the botanical manuscripts of Leonardo da Vinci (1452–1519) through digital hand-drawn animation and AI-generated imagery. Against the backdrop of cultural heritage preservation, the project focuses on plant morphology, phyllotaxis (leaf arrangement), and branching structures, exploring how these elements can be visualised through both dynamic and generative media. Drawing on folio 33r of *Manuscrit G* and three botanical sketches from the Royal Collection Trust as primary visual sources, it compares frame-by-frame digital animation with text-driven AI-generated images and video, analysing how each responds to Leonardo da Vinci's observational logic and visual aesthetics, and assessing their respective strengths and limitations in terms of control, accuracy, and creative expression. By integrating methods from botany, art history, and digital media, the project establishes a cross-disciplinary pathway for reactivating historical scientific imagery and articulates a practical framework for visual storytelling in cultural heritage, with potential applications in exhibition design, STEAM education, and digital heritage communication, thereby fostering broader public engagement with botanical knowledge. This study forms part of ongoing doctoral research in artistic practice, combining drawing and animation with interdisciplinary perspectives from botany and cultural heritage through the study of Leonardo da Vinci's manuscripts. All videos were produced by the first author, and the outcomes are conceived for future application in exhibition and science communication.

KEYWORDS: digital animation; heritage communication; Leonardo da Vinci; botanical manuscripts; AI generation

INTRODUCTION

Botanical cultural heritage embodies not only scientific, historical, and artistic values, but also represents the deep interconnection between human civilisation and the natural environment. As Smith (2006: 3) notes, 'Heritage is a multilayered performance be this a performance of visiting, managing, interpretation or conservation that embodies acts of remembrance and commemoration while negotiating and constructing a sense of place, belonging and understanding in the present.' Dicks (2000a, 2000b) suggests that heritage can be seen as a culturally framed communicative practice, while Lowenthal (1985) views heritage as a means of accessing and engaging with the past.

However, traditional display formats – such as static imagery, textual interpretation, and physical exhibitions – often fail to effectively communicate the scientific principles and cultural significance of plant heritage to non-specialist audiences. This challenge is particularly pronounced in botany, where complex knowledge related to plant growth patterns, ecological adaptation, and fractal structures could benefit from more intuitive modes of expression.

Against this backdrop, animation has emerged as a powerful medium to overcome barriers in heritage communication. Through dynamic simulation, morphological reconstruction, and immersive experience, animation techniques can 'activate' static botanical illustrations, reanimating growth processes and ecological interactions while enhancing cognitive engagement and emotional resonance. As a result, animation significantly strengthens the visual literacy and accessibility of scientific communication.

Digital transformation refers both to the process and the outcome of employing digital technologies to reshape how organisations function and deliver value (Nikolaou 2024). In the context of heritage communication, such transformation has enabled audiences to become active participants in the creation of cultural meaning, supported by increasingly accessible digital infrastructures (Bounia 2022).

In recent decades, the interplay between nature and culture, as well as between biodiversity and heritage, has been widely explored through research and scholarly debate (Agnoletti 2006: 320). Research and discourse surrounding plant heritage – such as Bridgewater & Rotherham's (2019) critical examination of biocultural diversity in nature and heritage conservation, McMillen et al.'s (2017) analysis of flora in living memorials, Małczyński's (2010) interpretation of trees as living memorials, and Pejchal's (2011) inquiry into landscape authenticity – demonstrate that this is a field characterised by multiple approaches, all aimed at deepening our understanding of the cultural heritage of plants.

Similarly, in his seminal work *Posthuman Plants: Rethinking the Vegetal through Culture, Art, and Poetry*, Ryan (2015: 52) emphasises that 'the maintenance of the world's biocultural heritage should become a moral obligation.'

In this context, revisiting and reinterpreting Leonardo da Vinci's botanical manuscripts offers more than a historical tribute to Renaissance natural philosophy. It becomes an opportunity to investigate how digital animation and contemporary visual media can bridge science and art, thereby unlocking the regenerative potential of botanical heritage in today's cultural landscape.

This study not only compares two modes of digital visualisation but also examines how such experiments can inform future applications in heritage exhibitions and digital education, thus linking Leonardo's legacy with contemporary public engagement.

LEONARDO DA VINCI'S BOTANICAL STUDIES

In 2019, to commemorate the 500th anniversary of Leonardo da Vinci's death, three major exhibitions were held in Florence, Italy. The first, held at Palazzo Strozzi, focused on Leonardo's teacher, Andrea del Verrocchio. The second featured selected pages from the *Codex Atlanticus* and was displayed at Palazzo Vecchio. The third was

a dedicated exhibition titled *The Botany of Leonardo, A Vision of Science Bridging Art and Nature* (Santa Maria Novella 2019), held from 13 September to 15 December in the Santa Maria Novella complex. The exhibition was organised around three thematic threads – 'Plants and Geometry', 'Plants and Art', and 'Plants and Science' – and extended across several city spaces, including Piazza Santa Maria Novella, Piazza della Signoria, Piazza della Stazione, and Fortezza da Basso.

The exhibition adopted a dodecahedron as its visual symbol, representing the entire universe, while the mulberry tree (*Morus alba* L.), one of Leonardo da Vinci's key botanical motifs, reflected his contemplation of nature and geometric order. It also referenced Leonardo's 1498 work in the Sala delle Asse at the Sforza Castle in Milan, where he created a *trompe-l'œil*[1] mural that intertwined mulberry branches with architectural elements, illustrating the spatial integration of plant and structure. At the same time, the Royal Collection Trust in the United Kingdom organised twelve related exhibitions, including a display of twelve botanical drawings at the Kelvingrove Art Gallery and Museum (Royal Collection Trust 2019) highlighting the global significance of Leonardo's botanical research.

Douady (2024: 42) notes that 'Leonardo da Vinci was the first person to record specific patterns in plants'. Yet, unlike most of his other scientific inquiries, Leonardo's exploration of botany began relatively late in his life (Capra 2013: 97). His early interest in plants was primarily rooted in his artistic practice, focusing not only on morphological accuracy but also on the use of colour, light (Leonardo da Vinci [c.1490]: ch. 848–916), and the narrative role of plants within composition. Between 1508 and 1510, his botanical drawing skills reached their peak. After the age of sixty, however, his attention gradually shifted toward a more scientific investigation of plants, emphasising their morphology and physiological processes (Capra 2013: 97).

Leonardo's botanical manuscripts are now dispersed across three major collections: the *Codex Atlanticus* at the Biblioteca Ambrosiana in Milan, the Royal Collection Trust in the United Kingdom, and the Bibliothèques de l'Institut de France in Paris.

As the botanist William A. Emboden observes:

> 'Free from formal definitions that characterise Mantegna, Ghirlandaio, Perugino, and Botticelli in their use of plant motifs, Leonardo introduced an enormous vitality into his plant figurations. Beyond the iconographic use of plants, [he] considered the ecological context, seasonal correctness, and careful botanical depiction. [...] Leonardo's forceful environments seem charged and infused with an organic unity' (Emboden 1987: 139).

Capra (2007: 160) also points out the following:

> 'One revolutionary change Leonardo brought to natural philosophy in the fifteenth century was his relentless reliance on direct observation of nature. While the Greek philosophers and scientists had shunned experimentation, and most of the Renaissance humanists uncritically repeated the pronouncements of the classical texts, Leonardo never tired of emphasising the importance of *sperienza*, the direct experience of natural phenomena.'

In paintings such as the *Virgin of the Rocks*, Leonardo da Vinci demonstrated a remarkable sensitivity to geological formations and plant ecology. He not only depicted

1 *Trompe-l'œil* (French for 'deceive the eye') refers to an artistic technique that creates the illusion of three-dimensional space or objects on a two-dimensional surface, most often associated with painting. See *Oxford Art Online*, s.v. 'Trompe l'oeil'.

the weathering of rocks with scientific but also placed plants realistically in ecological niches such as rock crevices and moist surfaces, reflecting a profound understanding of the relationship between plant physiology and habitat (Capra 2013: 102). This painting has been referred to as a 'geological tour de force' for its astonishingly accurate portrayal of complex geological structures (Capra 2013: 77).

Leonardo da Vinci's botanical theory centres on two core themes: the organic forms and structural patterns found in nature, and the metabolic and growth processes that sustain these forms. His studies had a lasting impact and laid the groundwork for the development of modern plant morphology and plant physiology (Capra 2013: 113).

One of Leonardo da Vinci's most forward-looking contributions in his drawing notes and botanical manuscripts was his systematic observation of phyllotaxis (leaf arrangement). He was the first to have a precise understanding of phyllotaxis (Uzielli 1869: 7) and the first scholar to classify its patterns and accurately document their structural logic. He identified three fundamental types of leaf arrangement:

> Spiral: Leaves grow in a helical pattern around the stem – such as in the 'quincuncial' form, where every five leaves complete a cycle, and the sixth leaf aligns vertically with the first;
> Opposite: Two leaves grow symmetrically at each node, arranged in a crosswise (decussate) pattern;
> Whorled: Several leaves grow in a circular pattern at each node, but are seldom aligned vertically with those in the whorls immediately above or below.
> (Leonardo da Vinci [c.1510–15] s.a.: 33r; Uzielli 1869:8; Bennett 1870: 42; Douady 2024: 43).

Figure 1 shows one of Leonardo da Vinci's original sketches illustrating these phyllotactic arrangements, found on folio 33r of *Manuscrit G*, held at the Bibliothèques de l'Institut de France.

Additionally, Leonardo observed a close relationship between the arrangement of leaves and the development of branches, noting that branches emerge from the leaf axils. This perception reflects his prescient foresight of the causal link between the flow of sap and the patterns of phyllotaxis (Capra 2013: 116).

Leonardo da Vinci regarded plants as microcosms of nature's order. His notebooks not only provided foundational data on plant morphology but also offered forward-looking insights into plant physiology. These records enriched artistic expression and later served as valuable visual and theoretical resources for the development of botany, natural philosophy, and ecology.

In the following sections, I will examine how this content has been visualised through digital animation.

THE APPLICATION OF DIGITAL TECHNOLOGY TO PLANT REPRESENTATION

Among Leonardo's dispersed botanical manuscripts, *Manuscrit G* stands out for its systematic depictions of phyllotaxis, branching patterns, and the structural logic of plant growth. These drawings exemplify his integration of scientific inquiry with visual construction, offering one of the clearest demonstrations of how careful observation could be transformed into visual experimentation. This legacy continues in digital media today, where contemporary technologies expand the expressive potential of botanical forms through dynamic simulation and generative visualisation.

Digital tools such as animation, 3D modelling, and artificial intelligence have transformed botanical representations from static visual representations into subjects of dynamic processes. As Ryan notes, 'tangible botanical heritage and intangible botanical heritage are inextricably related in theory and practice' (Ryan 2015: 54). The visual representation of plants is shifting from depictions of natural entities to

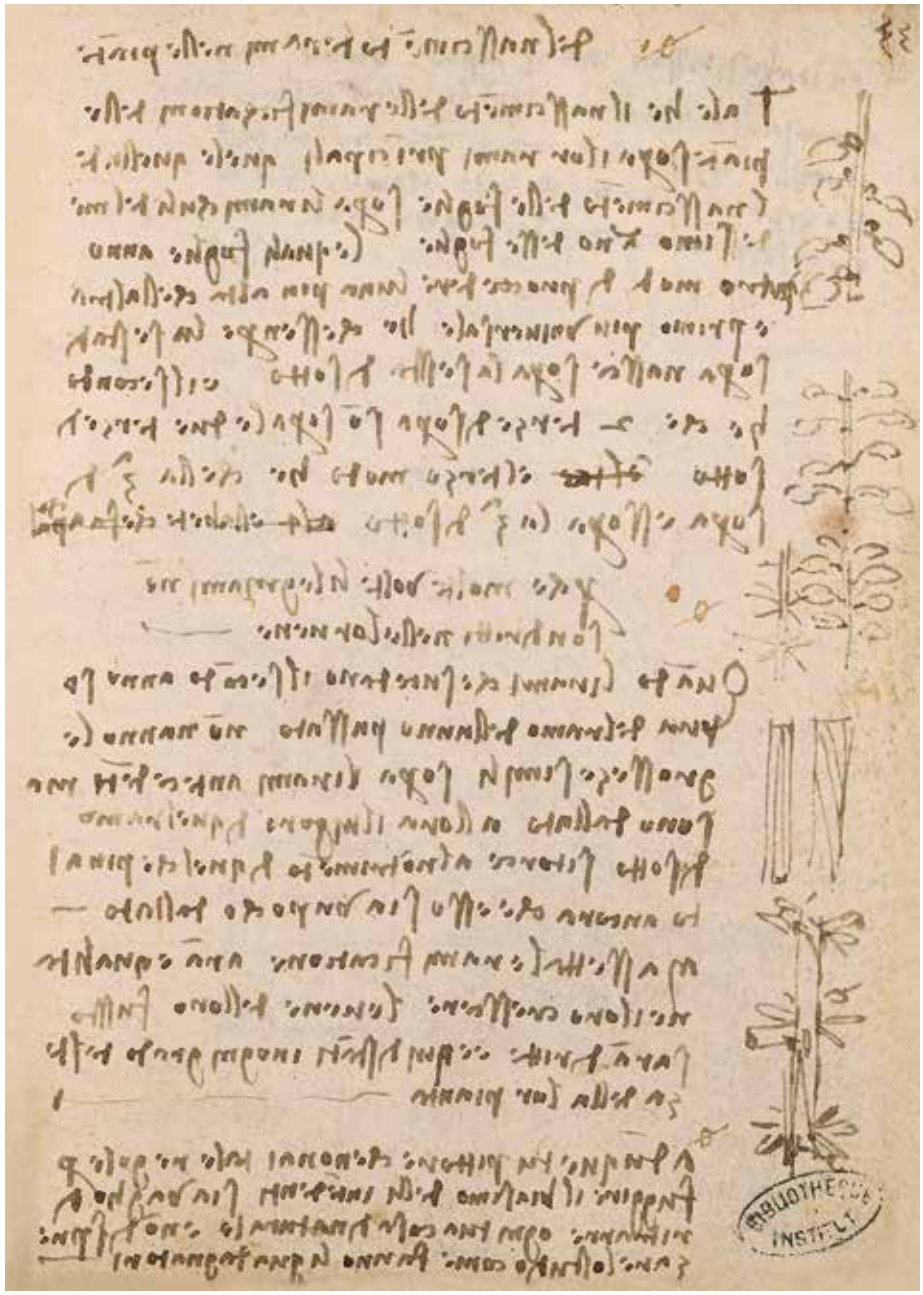


FIGURE 1. Leonardo da Vinci, folio 33r of *Manuscrit G*.
Source: Bibliothèques de l'Institut de France

participatory roles within informational environments, where the boundary between the natural and digital becomes increasingly blurred.

Botanical art thus emerges as a dynamic and evolving space of interpretation. This perspective has been explored by researchers such as D. Shavlygin and A. Obmorokova (2015), and V. Shcheglov (2017), who examine the relationship between digital media and artistic language. Within this framework, plants are no longer merely aesthetic objects or symbols of environmental preservation, but are instead positioned as active agents mediating between the natural and the virtual within a single artwork (Hitchings 2003; Latour 1987, 2005; Tsing 2010).

In the field of computational plant, R. Lecoustre et al. (1992: 200) utilised the AMAP 3D software to simulate the growth of *Begonias* species. Their approach involved the regulation of three main categories of parameters: topological parameters (such as leaf production and preformed organs in buds), the parameters in the functioning of bud (including growth, mortality, and branching processes), and geometric parameters (such as phyllotaxis, branching angles, and internode lengths). The study also examined the alternate growth pattern of left and right leaves, as well as the geometric arrangement of flowers and foliage. These parameters are influenced by internal traits such as bud vigour, as well as external stimuli including phototropism and gravitropism – enabling the generation of highly detailed and biologically realistic 3D botanical models.

Plants have also demonstrated unique creative potential in digital art. In *Interactive Plant Growing* (1992) by Sommerer and Mignonneau (1993: 408–414), real plants are combined with virtual imagery to explore the interactions between human, biological, and digital agents, thereby redefining the agency of plants in artistic contexts. Such works not only challenge the traditional notion of plants as passive natural objects but also provoke new discussions around plant consciousness and behaviour. Similarly, *Seed, Image, Ground* by Parikka and Gil-Fournier (2021: 16–30) employs a dual structure of video and text to examine the relationship between plants, agriculture, and the surface of the biosphere in relation to media surfaces such as screens and images. Drawing on Harun Farocki's concepts of 'operational images' and 'soft montage,'[2] the work reveals the logic of vegetal growth and generation within digital media environments.

In the realm of digital life simulation, Wang-Chak Chan has made a significant contribution. He developed an artificial life system known as *Lenia* that, based on an optimised cellular automaton algorithm, can evolve a wide variety of digital lifeforms. These entities exhibit fundamental biological properties such as self-organisation, regeneration, metabolism, and responsiveness to the environment. To date, more than 400 'artificial species' across 18 families have been identified. Unlike traditional models, *Lenia* demonstrates a greater degree of fluidity, adaptability, and geometric coherence, forming what appears to be a new programme-driven phylogeny of synthetic organisms (Chan 2019: 251; Chan 2020; Wen 2025: 218–219).

The application of artificial intelligence in visual art has begun to take shape. In 2018, *Edmond de Belamy*, an AI-generated artwork, was auctioned at Christie's in New York (Cohn 2018) attracting global attention. Microsoft's 'Next Rembrandt' project, which combined machine learning with 3D printing technology, recreated a portrait in the style of Rembrandt (Todorovic 2024: 6).

Tamiko Thiel's *Unexpected Growth* (2018) and Clement Valla's *Surface Proxy* (2015) employ augmented reality (AR) and image-processing technologies to recon-

2 *Soft Montage* is a concept introduced by the renowned German filmmaker and visual artist Harun Farocki to describe a visual narrative technique that has been particularly applied in multi-channel video installations. This concept breaks away from traditional linear storytelling rules by employing a non-linear, dynamically interwoven approach to imagery and information delivery, creating a complex and immersive visual and intellectual experience.

struct the mediating relationship between plants and their environments (Zausen 2020). These works merge the immersive qualities of digital media with the cultural role of plants as carriers of visual, ecological, and mnemonic meaning, creating digital landscapes that exist between nature and the virtual.

Collectively, these projects underscore the creative potential of digital media in contemporary botanical art. Building upon Leonardo's rigorous observation of nature and his commitment to visual synthesis, this study explores how his botanical vision can be reinterpreted through digital animation and AI-generated imagery.

THE APPLICATION OF DIGITAL ANIMATION AND AI GENERATION IN THE REINTERPRETATION OF LEONARDO DA VINCI'S BOTANICAL MANUSCRIPTS

This study reinterprets Leonardo da Vinci's botanical manuscripts through two experimental approaches: frame-by-frame digital hand-drawn animation and AI-based text-to-image and video generation. This research design takes as its starting point folio 33r of *Manuscrit G*, held at the Bibliothèques de l'Institut de France, and selects as core materials three botanical drawings from the Royal Collection Trust: *A Sprig of Blackberry (Rubus fruticosus)* (c.1505–1510, 9.0 × 6.0 cm, sheet of paper, RCIN 912425), *A Star-of-Bethlehem, Wood Anemone and Spurge* (c.1505–1510, 19.8 × 16.0 cm, sheet of paper, RCIN 912424), and *A Branched Bur-reed* (c.1506–1512, 20.1 × 14.3 cm, red chalk on orange-red prepared paper, RCIN 912430). These sources provide the foundation for comparing how different digital media can extend Leonardo's observational logic into contemporary expression.

In the digital animation pathway, Photoshop and Procreate were employed as primary creative tools. Photoshop simulated Leonardo's possible drawing process, while Procreate enabled 360-degree dynamic visualisation of plant structures. Frame-by-frame rendering techniques were used to depict leaf unfolding and bifurcation logic, emphasising continuity and microstructural development. Selected frames are shown in **Figure 2**, while the complete sequence is provided in Supplementary Video 1[3].

In contrast, the AI-based method relied on natural language prompts to generate both dynamic animations and still images. Two complementary platforms were employed: Tongyi Wanxiang AI, optimised for short video sequences, and Kling AI, primarily for high-resolution still imagery.

Tongyi Wanxiang AI (Video Sequences): Tongyi Wanxiang AI was employed to produce dynamic video sequences simulating plant growth. Iterative prompts were designed to emphasise temporal unfolding (e.g., 'gradual sprouting from bud to leaf', 'sequential bifurcation over time'). Unlike the hand-drawn method, which builds continuity frame by frame, Tongyi Wanxiang animations often depicted growth as discontinuous macro-transformations, where forms emerged in bursts rather than through incremental progression. This revealed the algorithm's interpretive autonomy, producing outputs that merged botanical rhythms with unexpected temporal distortions.

Prompts were designed to simulate the temporal dynamics of plant growth, encouraging the model to produce sequential stages of flowering, fruiting, and decay. Examples included the following:

- 'Generate a three-dimensional rotating video in the style of a raspberry plant, showing its continuous growth: flowering, blooming, fruit set, fruit ripening, followed by the gradual withering of leaves until only a bare stem remains'.
- 'Produce a rotating time-lapse of a raspberry plant's growth trajectory, depicting sequential stages of flower-

3 Supplementary Video 1. Zhang, Yun. *Da Vinci Botanical Animation – Hand-Drawn Version*. YouTube video, 2025. https://youtu.be/CdmM4VtC2cg (accessed 12 May 2025).

FIGURE 2. Selected keyframes from a frame-by-frame hand-drawn animation based on Leonardo's folio 33r of *Manuscrit G* (see Figure 1). The animation was produced with Photoshop and Procreate

FIGURE 3. Keyframes from an AI-generated animation based on Leonardo da Vinci's *A Sprig of Blackberry (Rubus fruticosus)*. The animation was created with Kling AI and Tongyi Wanxiang AI. Image source: © Royal Collection Enterprises Limited 2025 | Royal Collection Trust

ing and falling petals, fruit formation, ripening, and the gradual decline of foliage into a withered structure'.
- 'Render a progressive 3D rotation beginning from a skeletal raspberry stem, then showing leaves sprouting and wilting, flowers opening and closing, fruit forming and maturing, until the plant returns to a bare state'.

An AI-generated plant growth sequence is provided in Supplementary Video 2[4] with representative frames illustrated in Figure 3.

Kling AI (Still Images):
Kling AI was chosen for its capacity to render botanical morphology and surface textures with striking detail. Prompts combined scientific terminology (e.g., 'spiral phyllotaxis', 'alternate branching') with descriptive natural language (e.g., 'delicate unfolding of leaves', 'organic growth from stem to branch'), producing images that simultaneously referenced botanical plausibility and imaginative abstraction. The results often displayed identifiable phyllotactic spirals and branching logic. A representative prompt was:

'Generate an illustration of a sprig of blackberry in the style of red chalk on orange-red paper. The composition features a central stem with a dense side branch extending to the right. Smaller branchlets emerge along the shoot, each tipped with blossoms and clusters of ripe blackberries. Please respect the stylistic reference of Leonardo da Vinci's *A Sprig of Blackberry*.' (see Figure 4)

Other prompts instructed the model to generate a Star-of-Bethlehem with elongated, twisted leaves, accompanied by Wood Anemone and Spurge (see Figure 5), and a Branched Bur-reed study with detailed foliage (see Figure 6).

In addition to static imagery, Kling AI was also tested for multimodal generation, including attempts to create text-to-image sequences and simulated video outputs referencing Leonardo's manuscripts; however, these trials often produced results with stylistic deviations too great to be usable, underscoring the current limitations of applying image-generation models to video synthesis when constrained by historical manuscript styles.

EXPERIMENTAL ANALYSIS: TRANSLATING LEONARDO'S BOTANICAL ILLUSTRATIONS INTO DYNAMIC MEDIA

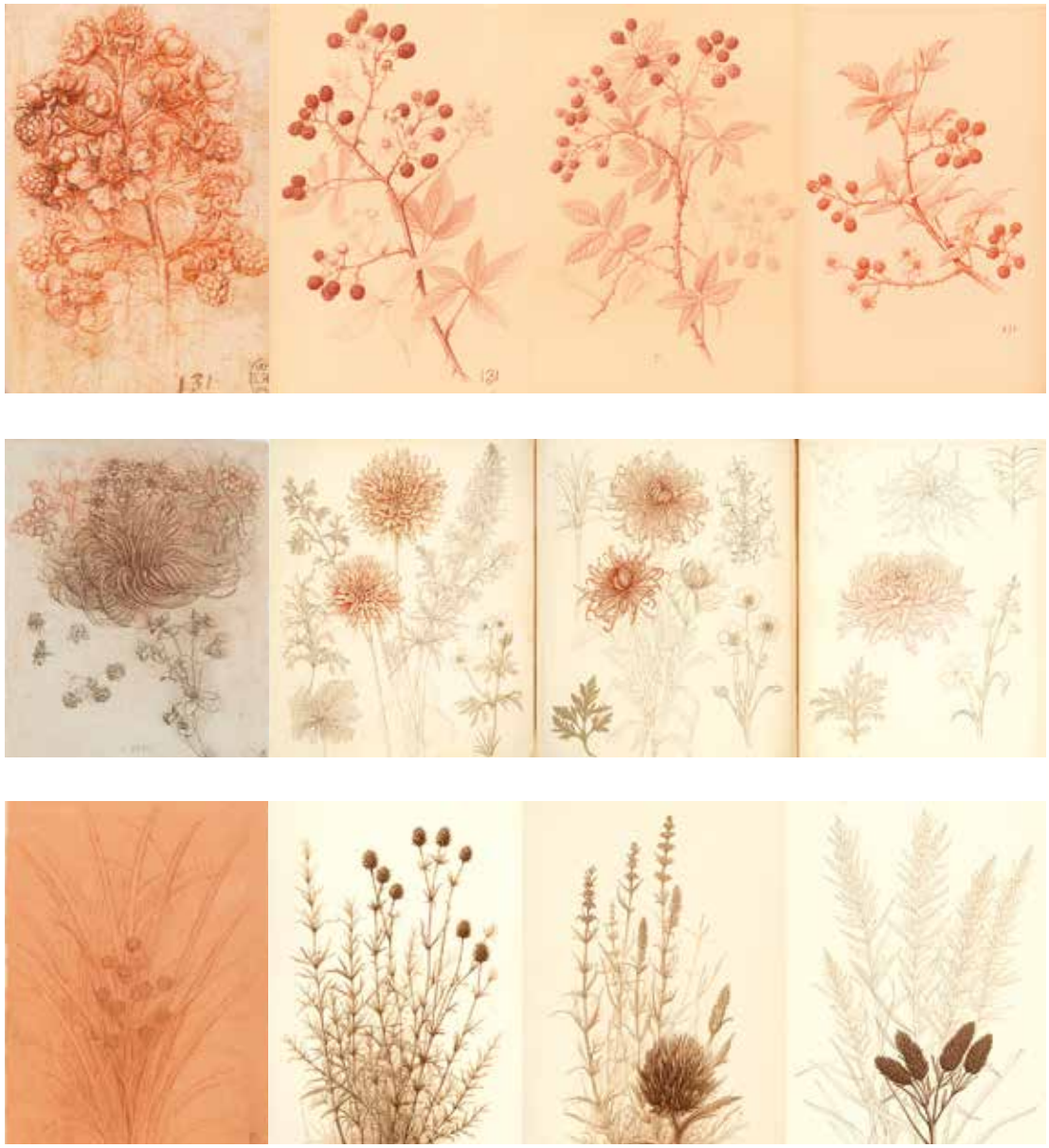
This study investigates how digital media can extend Leonardo's tradition of natural observation into new forms of contemporary expression. Situated within an artistic research framework, the comparison of frame-by-frame digital hand-drawn animation and text-driven AI-generated imagery is not merely a technical experiment but a critical exploration of how different media strategies embody distinct epistemologies of nature.

Digital hand-drawn animation emphasises the creator's active engagement and attention to detail, following Leonardo da Vinci's method of 'observation–comprehension–reconstruction'. Each frame is based on direct simulation of plant growth structures, combining scientific plausibility with visual coherence to construct a visual language that integrates rational logic with artistic expression.

In contrast, AI-generated imagery and animation rely on model training and algorithmic inference, resulting in a higher degree of algorithmic autonomy and unpredictability. Although textual prompts attempt to guide the model toward a natural logic of growth, the resulting plant forms often exhibit supernatural or exaggerated features. This distinction indicates that digital drawing tends toward the replication of nature, while AI generation leans toward its reimagining.

Figures 4–6 present AI-generated digital reinterpretations of three botanical

4 Supplementary Video 2. Zhang, Yun. *AI-Generated Visualization of A Sprig of Blackberry.* YouTube video, 2025. https://youtu.be/Gh9CwGmLt2E (accessed 12 May 2025).



FIGURES 4–6. Leonardo da Vinci, *A Sprig of Blackberry (Rubus fruticosus)*; *A Star-of-Bethlehem, Wood Anemone and Spurge*; and *A Branched Bur-reed*. Visual comparison of Leonardo's originals (left) and AI-generated reinterpretations (right), created with Kling AI.
Image source: Royal Collection Trust / © Royal Collection Enterprises Limited 2025.

drawings by Leonardo da Vinci. Figure 4 depicts *A Sprig of Blackberry* (*Rubus fruticosus*), Figure 5 shows *A Star-of-Bethlehem*, *Wood Anemone*, *and Spurge,* while Figure 6 illustrates *A Branched Bur-reed*.

In terms of dynamic rhythm, hand-drawn animation finely controls the continuity and cadence of plant development through successive frames, closely echoing Leonardo's analytical observation of natural evolution in his manuscripts. AI-generated animations, by contrast, often depict growth as a series of macro-level, discontinuous transformations, producing a visual rhythm that reconfigures temporal logic.

Furthermore, hand-drawn animation adheres to natural principles while preserving the artist's subjective control over motion and form, embodying a dynamic balance between 'artificial selection' and 'natural law'. AI generation, on the other hand, forms a self-organising image system through repeated training and the accumulation of data. While it may partially simulate mechanisms such as plant morphology, it ultimately reflects a technologically driven schema of visual evolution and algorithmic aesthetics.

In summary, digital media offers multidimensional pathways for the reinterpretation of Leonardo's botanical imagery. The hand-drawn approach not only carries forward the scientific and artistic essence of his work but also demonstrates how sequential reconstruction can translate observational logic into time-based media. By contrast, AI generation introduces forms of indeterminacy that challenge conventional notions of fidelity and open the manuscripts to speculative reimaginings of plant morphology. Taken together, these approaches do not merely confirm the familiar distinction between control and unpredictability; they reveal how historical scientific imagery can be reactivated as a site of negotiation between accuracy, creativity, and cultural memory. In this sense, Leonardo's botanical thought is revitalised not simply through technological novelty, but through its repositioning within contemporary debates on digital art, heritage communication, and the epistemology of visual knowledge.

CONCLUSION

Leonardo da Vinci's botanical manuscripts embody a fusion of scientific observation and artistic expression. His depictions of phyllotaxis, growth structures, and natural order have provided foundational resources for the visual narration of plant imagery. With the advancement of digital painting, animation, and artificial intelligence, this tradition has found new avenues for reinterpretation. Through experimental comparison of digital hand-drawing and AI text-to-image generation, this study highlights the strengths of hand-drawing in structural accuracy and stylistic continuity, while also revealing the exploratory potential of AI in generative image production and morphological transformation.

This trend toward digitalisation has already shown practical impact. For instance, the Museo Leonardo da Vinci in Florence employs interactive mechanical models and immersive digital displays to transform Leonardo's scientific visions into multisensory experiences. Such applications offer effective models for the digital dissemination of botanical heritage. Looking ahead, the digital storytelling of plant imagery is poised to move beyond academic reconstruction, playing a growing role in museum communication, STEAM education, and public cultural engagement – enhancing both the accessibility and aesthetic appreciation of botanical knowledge.

Beyond the methodological comparison, the study demonstrates how historical scientific drawings can be reanimated as dynamic tools for science communication. By situating Leonardo da Vinci's manuscripts within contemporary digital media, the research highlights a transferable model that may inform museum exhibitions, interdisciplinary curricula, and broader cultural heritage engagement. This reframes Leonardo's botanical thought not only as a subject of interest for art history, but also as a living resource for twenty-first century science communication.

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