Microbial Patina

Rachel: what is that black stain on the statue?

Venetian plaster wall detail with black patina, Venice, courtesy Rachel Armstrong, 2017. Venetian plaster, the polished lime-based finish synonymous with Italys architectural elegance, is traditionally ***white*** in its raw state ~ a blank canvas awaiting design, or decoration. But in Venice, where damp salt air clings to every surface, even the cleanest and newest walls and statues slowly surrender to time. Dark streaks emerge: is it the soot of centuries, the breath of microbes, or a combination of influences? The answer lies in the city's unique intersection of art, organisms and environment.

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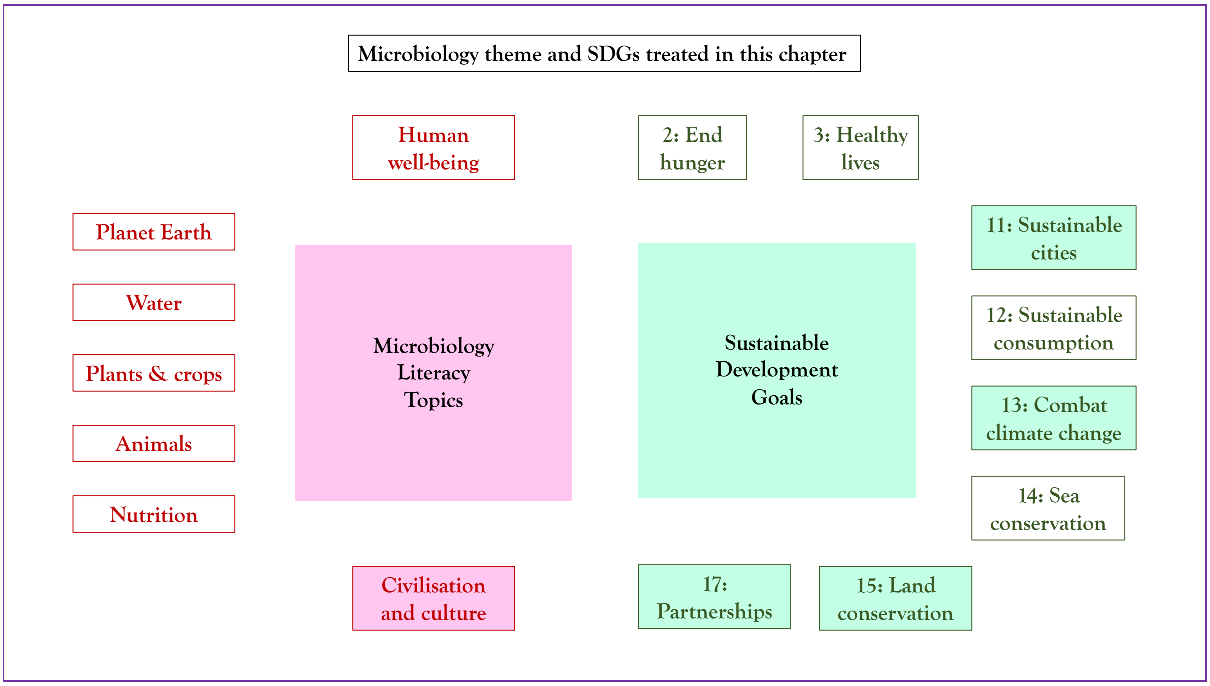
Storyline

Have you ever noticed how statues or buildings get darker in patches over time? That could be the work of tiny, invisible artists—microbes! Bacteria, fungi, and algae settle on surfaces like stone, wood, or even plastic, slowly transforming them with stains, cracks, or colorful patterns: *microbial patina*. From African masks to library books, microbes leave their mark on almost everything, adapting to materials we never thought they could break down. In places like Venice, where the air is damp and salty, microbes thrive, turning walls green or black with their growth. Microbes are not just graffiti artists—some patinas protect surfaces, and scientists even use 'good' microbes to clean ancient art. Artists have teamed up with these tiny life forms too, using bacteria like living paint to create stunning artworks. While conservators sometimes fight microbial changes with chemicals, others argue these natural transformations add history and beauty. After all, artistic expression itself is an act of creation—not just of images or forms, but of entirely new environments. Every time an artist crafts a fresh surface—stretching canvas, shaping clay, staining glass, or carving wood—they are also, unwittingly, designing uncharted territory for microbial life. Pigments bond to paper, steel weathers under paint, concrete cracks and gathers moisture—each combination a novel landscape where microbes might thrive. In this way, the artist does not merely work with materials; they forge ecosystems, inviting unseen collaborators to leave their mark. This hidden world of microbial 'painting' reminds us that humans aren't the only creators - nature is always collaborating, even when we do not notice it. By studying these changes, we learn to read stories written by nature in rust, biofilm, and decay. So next time you pass an old monument, look closely: you might be seeing a masterpiece made by time, weather, and trillions of tiny microbes.

The Microbiology and Societal Context

The microbiology: Microbial patinas are dynamic ecosystems where bacteria, fungi, and algae colonize urban surfaces like stone, metal, and concrete, transforming them through biochemical processes. These microorganisms thrive in the intersection of architecture and nature, metabolizing pollutants, moisture, and even the materials themselves to produce visible marks—dark biofilms from sulfur-oxidizing bacteria, green algal streaks in damp areas, or protective mineral crusts. Certain microbes, like extremophiles, adapt to harsh urban conditions, while others accelerate decay by secreting acids that etch fissures into monuments. Yet some species unexpectedly preserve surfaces by forming stable, weathering-resistant layers. These microbial communities can be considered as biological archives, revealing centuries of environmental history embedded in their genetic and chemical signatures. *And, peripherally for completeness of the storyline*: Beyond their biological roles, microbial patinas challenge traditional notions of heritage and agency. They blur the line between natural processes and human culture, as seen in debates over whether to remove "unsightly" biofilms from monuments or preserve them as ecological records. The conservation industry grapples with this tension, balancing commercial demands (like tourism-driven aesthetics) against the ethical implications of using toxic biocides. Meanwhile, artists and designers find ways of "collaborating" with microbes, employing them as living tools to create bio-art or rehabilitate degraded structures. These interactions comprise a broader narrative: urban patinas are not mere decay but active participants in shaping the visual and ecological identity of our cities. *Sustainability issues*: Attention to microbial patinas forces cities to confront interconnected sustainability challenges. **Health** risks emerge as airborne spores from urban biofilms mix with pollution, potentially affecting respiratory health. **Economic** pressures mount, with conservation costs straining budgets while tourism revenue depends on maintaining "pristine" heritage sites. **Environmental** trade-offs abound: chemical treatments pollute waterways, whereas some microbial patinas naturally sequester toxins or stabilize surfaces. **Climate change** amplifies these issues, as warming temperatures and extreme weather alter microbial communities—accelerating decay in humid regions or introducing invasive species to new areas. Addressing these challenges demands innovative approaches, from microbial biocleaning to policies that reframe patinas not as problems to eradicate, but as vital details in the urban fabric.



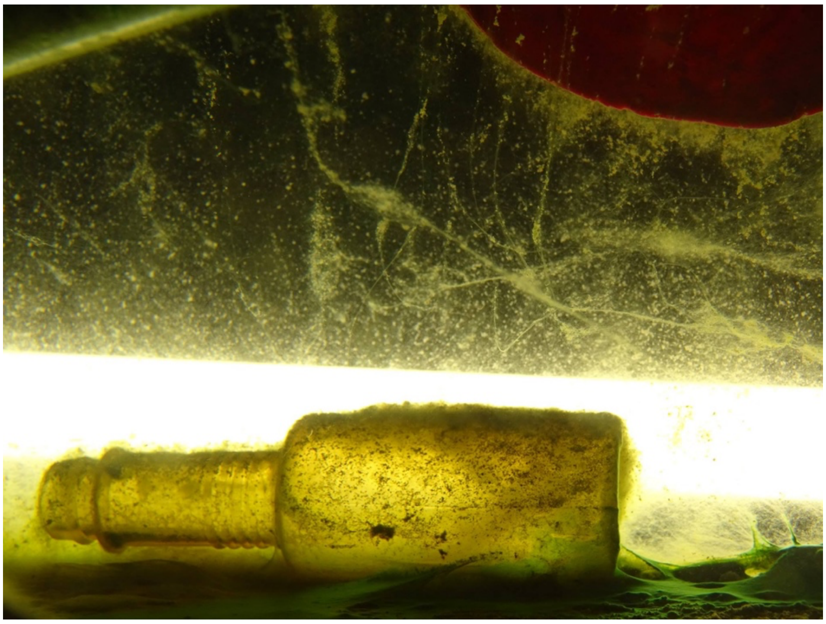
Microbial Patina: the Microbiology

1. ***Cultural artefacts.*** Humanity takes immense pride in its extraordinary ability to create profound marks, which embody our thoughts, creativity and intentions. Through the artistic endeavors of writing, drawing, and shaping cultural artifacts, we have discovered a powerful medium to share ideas, dreams, and stories with each other. The search to make some of these varied expressive forms last for more than fleeting moments, employed symbols, marks and sculptural representations to capture our concepts in a range of materials. While most of these marks have left transient imprints, others have bravely endured the relentless march of time in a range of materials, becoming cherished hallmarks of our collective human experience. While tenacious, these value-laden objects are not immortal and are steadily transformed over time by atmospheric agents, condensation, ambient temperature, human action, and microorganisms.

Graffiti with palimpsest of meaning in Kiev, courtesy Rachel Armstrong, 2015

2. ***Preserving Heritage.*** The specific longevity of the deliberate traces we make lies within the intricate interplay of chemical and physical processes. As they unfold, intricate fissures emerge, expanding the surface area and granting fertile ground for the colonization of living organisms. While we often perceive ourselves as the sole authors and artists, we are not alone in our creative endeavors. Every mark we make becomes a space occupied by microscopic life. Thus, these traces not only stand as testaments to our creative spirit but become vibrant sites for construction by microbes that are nourished by the very substances we employ to decorate them, be it paint pigment or plaster.

3. ***Environmental Microbes meet Human Traces***. Microbes form the base of the biosphere and possess an innate adaptability to a wide range of environmental conditions, thriving and persisting even in the most extreme of habitats. The immense diversity embodied by Bacteria, Archaea, and microbial Eukaryotes is a testament to their ability to harness a vast spectrum of energy and carbon sources, which are particularly important for their survival. These heterotrophic microorganisms thrive particularly where: i) water is available; ii) they can derive energy from light or organic and inorganic compounds; iii) sources of carbon and nitrogen are available; and iv) vital trace elements are available for their proper growth.



Patina forming on discarded plastic bottle, Azerbaijan Pavilion, Venice, courtesy Rachel Armstrong, 2016

4. ***The process of patina formation.*** Microbes, diminutive in stature, operate on far longer timescales than we do. As co-authors of our artefacts, their imprints leave their own marks upon our cherished creations. The appreciation or aversion to these changes has always been influenced by the prevailing tastes and trends of each era. The term 'patina,' was first defined by Filippo Baldinucci in his 1681 compendium of art to indicate as the temporal darkening that befalls frescoes and oil paintings. These changes arise as a consequence of the inexorable passage of time, the decay of materials, and the multifaceted impact of the environment, encompassing its biological aspects. Patina is formed by a diverse array of organisms, such as Bacteria, Fungi, Algae, and Plants and represents an extraordinarily intricate process that is expressed on a range of media where a range of microorganisms orchestrate the physical and chemical modifications of the material constituents, leaving their indelible imprint on its very essence.

Various processes of deterioration at work on a Venetian wall including weathering by wind, efflorescence, and biological infiltration, courtesy Rachel Armstrong, 2017

Largely regarded as agents of deterioration, microbes are particularly adept at transforming the character of cultural artefacts depending on the specific type and size of the microorganism involved, their metabolism, the colonized materials, and the amount of pollution present. While biodeterioration serves as an integral part of the environmental cycle of matter, it may also lead to the loss of valuable cultural treasures through profoundly altering the composition and structure of the constituent material. Assuming the guise of a historical artifact, patina mirrors the stratigraphic layers of archaeological significance, like the microscopic stromatolites embedded within geological formations, they meticulously document the ever-changing climate, the vicissitudes of exposure, and even betray past human interventions.

Statue in Stavne Cemetry, Trondheim clothed in complex patina, courtesy Rachel Armstrong, 2017

a. Bioreceptivity of Materials. The ability of a material to be colonized by one or more groups of living organisms is known as its bioreceptivity but the mere presence of organisms on surfaces does not automatically lead to destructive actions. In some cases, the presence of microbes may only spoil the appearance of a cultural artefact or potentially have a protective role against weather-related aggression. The bioreceptivity of a material depends on its properties that facilitate the spread and establishment of flora and/or fauna. For example, in the case of stone surfaces, bioreceptivity primarily relies on factors such as surface roughness, moisture content, and the chemical composition of the rocks.

The ‘primary bioreceptivity’ is initial potential of colonization of an intact stone. Then, over a period of time colonizing organisms and environmental factors, encourage ‘secondary bioreceptivity’. The applied conservative treatments on stone influence a ‘tertiary bioreceptivity’. In ‘extrinsic bioreceptivity’ the stone colonization is essentially due to the presence of settled matter not associated with the stone beneath. Bioreceptivity index of a particular material can be used to determine the susceptibility of the material to biodeterioration. Suitable specifications are to be used to quantify microbial biomass and to characterize stony material.

Differential bioreceptivity demonstrated on a Venetian wall with attachments by shellfish, algae, bryophytes and microbes, courtesy Rachel Armstrong, 2017.

b. Types of Changes. The metabolic activities of organisms that colonize stone result in the production of diverse substances, including organic and inorganic acids, chelating compounds, extracellular polymers, and colored pigments. As these organisms grow, their structures exert mechanical pressure on the stone, leading to various types of changes.

i. *Physical Changes.* Organism growth influences physical damage, causing the detachment of grains and particles, exfoliation, chipping, and an increase in surface porosity. Filamentous fungi significantly amplify these effects through their hyphal networks, which mechanically penetrate substrates like microscopic drills - their branching hyphae exert radial pressure on material grain boundaries, forcing apart mineral matrices and creating fracture networks. This also results in an expansion of the reactive surface area, as fungal hyphae create thousands of microscopic tunnels that expose fresh material to weathering agents. The mechanical forces exerted by the organisms lead to the development of fractures of varying sizes, with fungal colonization often following pre-existing microfissures and systematically widening them through both physical expansion and enzymatic weakening of cementing materials.

ii. *Chemical Changes.* Chemical changes occur due to both pollutants and microbial growth products. Lichens, bacteria, and fungi produce organic acids, such as oxalic acid, and other secreted metabolites, with filamentous fungi deploying these compounds most aggressively through their extending hyphal tips. These agents contribute to chemical etching around the areas of penetration, where fungal hyphae create "acid highways" that concentrate corrosive compounds along precise growth fronts. Chemicals produced by algae, fungi, and cyanobacteria can also lead to alkalinization of the rock surface, though filamentous fungi often modify these effects by creating localized pH gradients along their hyphal networks. This results in dissolution and fragmentation of smaller grains through a combination of acidic etching at hyphal tips and secondary mineral deposition along hyphal shafts, producing characteristic biodeterioration patterns visible under microscopy.

iii. *Aesthetic Changes.* Fluorescence White spots, known as fluorescence, are produced when dissolved salts migrate and evaporate from the water present on the surface of porous rocks.

Biodeterioration of a decorative wall mosaic and plaster cast on a Venetian wall infiltrated by algae, bryophytes and microbes, courtesy Rachel Armstrong, 2017.

c. Mechanism of Biodeterioration. The deterioration of cultural artefacts is influenced by physical, chemical, and biological weathering, with many mechanisms being interdependent and involving multiple factors. Various bacteria, cyanobacteria, algae, and fungi have been found to contribute to degradation. Adequate humidity and nutrient availability promote the colonization of organisms. While microbial growth depends on key nutrients, some of these can be supplied by the environment in which an artefact is situated. For instance, research by Chris Greening demonstrates that trace gases such as hydrogen in air and water can sustain microbial communities, meaning that some microorganisms require only a surface to proliferate. However, their growth efficiency is ultimately influenced by competitive interactions with other microbes. The primary underlying responsible mechanisms of biodeterioration are a combination of biogeochemical and biophysical processes, which exert differing effects depending on the various media that the cultural artefact, or archaeological site are composed from.

5. Types of Substrate Subjected to Biodeterioration by Patina formation

a. Inorganic Substrates. Inorganic materials such as glass, metals, and stones, are often integral components of monuments, cultural artefacts and archaeological sites. Although they are less prone to biological attacks over a human time frame, natural or human-induced weathering factors accelerates the decay process of rocks and exposed monumental stones. Various types of organisms can thrive using the mineral components and surface deposits of stones, where pollutants and their secondary reaction products contribute to surface effects, resulting in particle deposits, black encrustations, and the formation of secondary reaction products on stone surfaces.

Mineralising wooden African mask and plastic lobster with complex patina forming in the Mother Shipton well, Knaresborough, courtesy Rachel Armstrong, 2014.

b. Organic Substrates. Artistic objects such as easel and panel paintings, wooden sculptures, library materials, prints, and textiles consist of natural organic materials. These objects, being biodegradable, are typically confined to specific environments. Biological degradation of these objects occurs under unfavorable conservation conditions, such as high humidity levels, contact with soil, poor ventilation, and infrequent maintenance operations. The following examples provide brief accounts that demonstrate the variety of strategies used by microbes in forming their patina that results in biodeterioration of the different cultural artefacts and is not attempt to be an exhaustive list.

i. *Wood.* When the moisture content of wood is high, above 20%, it is susceptible to microbial attacks. Micro fungi primarily contribute to wood decay, whereas bacteria and actinomycetes play a lesser role due to their higher moisture requirements. Fungi can develop on the wood's surface or within its internal structures, leading to changes in cell integrity through the production of exoenzymes. The activity of fungal strains mainly targets the structural biological polymers of wood. Insects also feed on wood and use it for shelter, and site for laying their eggs, posing a significant threat to wooden objects stored in museums or indoor environments.

ii. *Parchment.* Parchment is used as a writing surface and is made up of collagen, keratin, and elastin, with a small amount of albumin and globulin. Its vulnerability depends on the raw materials used, the production method, and how the hide was preserved. The speed of biodeterioration is influenced by factors such as temperature, humidity, pH, and UV exposure. Anaerobic bacteria of the *Clostridium* genus produce collagenases that can hydrolyze collagen, resulting in discolored spots, white films, and fading texts. In aerobic conditions, non-specific proteolytic enzymes produced by various bacteria (e.g., *Bacillus mesentericus, Pseudomonas, Bacteroides, Sarcina* sp.) and certain fungi of the *Aspergillus, Cladosporium, Fusarium, Ophiostoma, Penicillium, Scopulariopsis, Trichoderma* genera, can also attack partially decomposed collagen.

iii. *Leather.* Leather has a similar chemical composition to parchment, where untanned leather under high humidity is vulnerable to bacterial attack, while tanned leathers are more susceptible to fungal attacks. After tanning, leather typically has a pH of approximately 3 to 5, which provides a more favorable environment for fungal growth. Fungi that attack tanned leather often belong to lipolytic species that use any fats present in leather as their main carbon source.

iv. *Composite Materials.* Most artworks are made from a combination of different organic and inorganic materials where the risk of biological attack is determined by the most vulnerable component and biodeterioration in these composite materials share similar characteristics and effects with those observed in individual components.

v. *Paintings.* Paintings are composed from a support material (canvas, wood, paper, or parchment), a preparatory layer, and a paint layer. The chemical composition of the paint layer varies depending on the painting technique used (such as oil paints, distemper, or watercolor), the type of paints employed, and the historical period. For canvas paintings, the preparatory layer is typically composed of lime or gypsum, often with the addition of animal or vegetal glue. Paintings deteriorate owing to the combined actions of multiple interconnected agents that encompass a broad range of factors from meteorological events like earthquakes, fires, and floods, to factors such as terrorism, vandalism, neglect, tourism, prior treatments, wind, rain, frost, temperature fluctuations, chemical attacks, salt growth and pollution. Biodeterioration in paintings on canvas commonly starts on their reverse side owing to the increased susceptibility of textiles from microbes caused by the glue sizing.

6. ***Conservation Measures.*** Current conservation approaches prioritize human aesthetic and historical values when protecting cultural artifacts, implementing measures designed to minimize biological colonization on surfaces. However, due to microbes' remarkable metabolic adaptability, these interventions often produce unintended negative consequences—including new forms of discoloration or accelerated corrosion—that may compromise the very materials they aim to preserve.

a. Biocidal Treatments. Biocides are substances used to eliminate and inhibit the growth of biological organisms such as bacteria, fungi, algae, and weeds. They impact the metabolic activities of these organisms, causing significant damage and even their death. Before applying biocides to monuments, their effectiveness against the target organisms, resistance of the target organisms, human toxicity risks, potential for environmental pollution, compatibility with stone, and potential interactions with other chemical conservation treatments need to be assessed.

Various biocides, such as polybor (a mixture of polyborates and boric acid), borax, and Clorox, can be used to control microbial growth. Surface-active quaternary compounds exhibit strong biocidal properties, effectively inhibiting microbial growth on sandstone monuments. Lichens can be temporarily inhibited by using aqueous solutions of benzalkonium chloride (20%), sodium hypochlorite (13%), and formaldehyde (5%). This involves soaking cotton strips in the solution for approximately 16 hours, followed by scrubbing with a brush and water. Although such treatments can kill organisms and microorganisms, they do not provide long-term protection against future recolonization. Consequently, biocides need to be regularly applied to control biological growth and may chemically damage the underlying matrix of the cultural artefact.

b. Non-biocidal Approaches – Introducing Microbes to Combat Microbes! Advancements in biotechnology have developed viable alternatives to conventional conservation measures in the field of cultural heritage. Leveraging the metabolic potential of microorganisms, an eco-friendly approach based on natural reactions to optimizing biological processes in controlled environments. The underlying concept of these innovative biological methods, namely biocleaning and bioconsolidation, is based on the understanding that only a small fraction of microorganisms contribute to the deterioration of natural processes, while the majority engage in beneficial activities. By employing various cultures of viable bacteria, such as *Desulfovibrio desulfuricans* and *Desulfovibrio vulgaris* (sulphate-reducing bacteria) and *Pseudomonas stutzeri* (nitrate-reducing bacteria), biotechnologies have successfully addressed diverse artistic issues encountered in materials like monumental stone, wall paintings, and marble statues, including the removal of organic substances, elimination of black crusts, and reduction of mineral salts.

7. ***Biodeteriogens as Artwork: Embracing the creativity of Microbes.*** Microbes are not merely contaminants but agents for producing artwork, and can form decorative crusts in a controlled manner. Microbiologist Simon Park explores this concept by employing microbes as both mediums and traces. Working alone and with artists he applies his knowledge of the inherent capabilities of microbes to create captivating and thought-provoking artworks that bridge the gap between science and art.

Cotton Paper/Living Ink Tests. Simon Park experimenting with Sarah Craske using cotton paper with two living inks (red: *Serratia marcescens* and purple: *Chromobacterium violaceum*). The paper though seems to have its own hidden bacterial life, which once awoken by the agar, spreads beyond the confines of the paper to decorate it like a living lace, courtesy Simon Park, 2015.

In his artistic practice, Park collaborates with artists to unlock the hidden mysteries of the microbial world. He harnesses the natural talents of microorganisms, employing them as living pigments and agents of transformation. Through careful selection of specific strains with distinct colors and behaviors, Park cultivates and manipulates these tiny organisms. By providing them with suitable environments and nutrients, he allows them to flourish and exert their creative influence.

The collaboration between Park and the microbial world becomes the subject and medium of the artworks. Through techniques like agar art and microbial photography, they create visually stunning representations of the microbial landscape. These artworks reveal the intricate patterns, textures, and forms that emerge as the microorganisms grow, interact, and leave their mark that often complement and enhance cultural artefacts such as lace and a 300 year old copy of Ovid's metamorphosis.

Park's intention is to bridge the gap between science and art, inviting viewers to contemplate the hidden wonders of the microbial realm. These artworks challenge our perception of the invisible world surrounding us, evoking curiosity and fostering a deeper understanding of the complex relationships between humans and microorganisms.

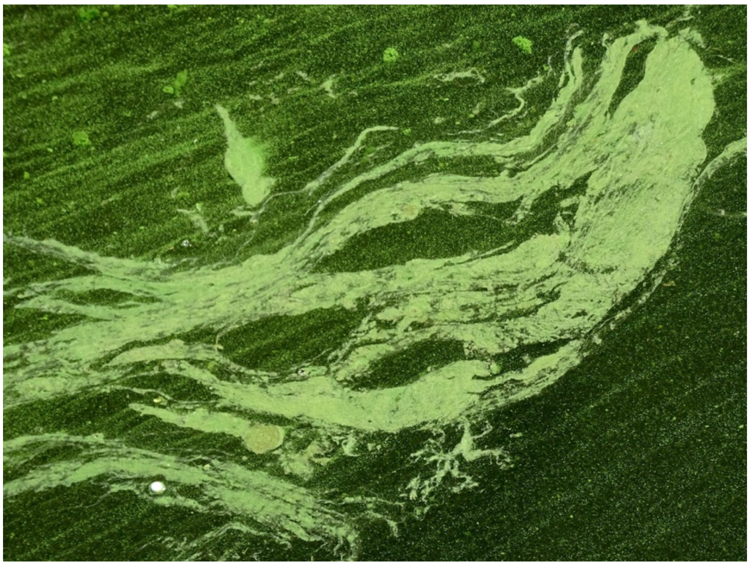
Simon Park's pioneering work demonstrates that the microbial world possesses an inherent aesthetic quality that can be translated into captivating visual expressions. His collaborations with artists serve as a testament to the profound interconnections between science, art, and the natural world, unveiling the beauty and significance of the microbial domain to a broader audience. Park embraces patina-formation as a gardened activity and integral part of the cultural heritage and artistic legacy of artworks.

Metamorphosis: on the transformation of blood. Over many months now the bacteria from a 300 year-old copy of Ovid's Metamorposis have worked upon the blood agar plates on which they grow. During this period the bacteria have converted a red, bloody, and opaque medium into a transluscent one. The components of the medium have been transformed and incorporated into complex bacterial sructures, so that it now acts as an organic and selective lens through which we can view an ever present, but usually invisible, reality, courtesy Simon Park, 2016.

Multiforms. I don't use this word lightly but I find these works by Sarah Roberts and bacteria truly sublime. Symbioses on so many levels, between artist and scientist, and between artist and bacteria. So many stories. Reminiscent of Tyson's Nature Paintings, there are also references here to Rothko's "breath of life" and Hiorn's concept of the autogenetic. They bring tears to the eyes of a jaded arts/science collaborator! Courtesy Simon Park, 2011.

Neither Art or Science But That Beautiful Place Inbetween. Printing with bioluminescent bacteria and the unexpected. I love the way that the ink is independent so that its message transcends that of the text. Some kind of segregation is at play. Genetic/Epigenetic, I don't know. I'm pretty certain this is new to science though, courtesy Simon Park 2011.

Through our cultural artefacts, buildings, and our propensity for mark-making, it is possible for us to communicate with the microbial world through a common language situated in the environment, as a microscale reading of specific niche, nutrient and energy sources, which will help us pay closer attention to our environment so that we may potentially decipher, understand and respond to what the microbiomes all around us have to say about the living realm.



Algal bloom in the Dnieper, Kiev, courtesy Rachel Armstrong, 2015

8. ***Conclusion.*** Within the vast timescale of evolution, it is imperative that we delve into the interactions between microbial niches and ourselves, taking deliberate actions to enhance

the biodiversity of our biosphere. Given that microbes constitute the majority of all biodiversity on our planet, establishing a dialogue between the human and nonhuman realms becomes paramount, regardless of whether we perceive it through the lens of science, culture, or even as an artistic endeavor in itself. By acquiring the ability to comprehend and decipher the activities of environmental microbes, we can cultivate a profound appreciation for the intricate relationship that patina make possible connecting art, culture, and the microbial inhabitants that encompass our human microbiomes and the many sorts of microbiome all around us. In doing so, we gain a better understanding of our role as agents fostering life within the broader tapestry of existence.

Relevance for Sustainable Development Goals and Grand Challenges

- SDG 11: Sustainable Cities and Communities
  - Microbial patinas serve as **bio-indicators** of urban pollution and climate impacts on cultural heritage, helping monitor environmental changes in historic cities.
  - Natural patinas can **reduce conservation costs** by forming protective layers, supporting sustainable heritage management.

- SDG 13: Climate Action
  - Patinas **record climate history** through microbial responses to temperature/humidity changes, providing data for climate models.
  - Biodeterioration **accelerates with extreme weather** (e.g., floods, heatwaves), highlighting vulnerabilities in cultural sites.

- SDG 15: Life on Land
  - Microbial communities in patinas **enhance urban biodiversity**, creating microhabitats for other organisms (e.g., lichens, insects).
  - They contribute to **biogeochemical cycles** (e.g., carbon sequestration in mineralized biofilms).

- SDG 17: Partnerships for the Goals
  - Interdisciplinary collaboration (artists, scientists, conservators) leverages patinas for **innovative conservation** (e.g., biocleaning with bacteria).

Please note: *SDG 3 (Health)* has limited direct links, though airborne spores from patinas might marginally affect, or be an indicator of, air quality (SDG 3).

Potential Implications for Decisions

1. ***Individual/Cultural Priorities***

a. **Microbial vs. non-microbial factors** aligned with conservation ethics (*Do the aesthetic/historical benefits of patina removal outweigh ecological and scientific value of microbial records?*)
b. **High-biodeterioration vs. low-biodeterioration materials** (*e.g., porous limestone vs. stainless steel–environmental impact proportional to material vulnerability*)
c. Localized vs. widespread patina (*Energy/cost footprint of treatment scales with surface area*

affected)

d. Non-microbial parameters: Cultural significance of patinated artifacts, cost of conservation (biocides, labor), tourism revenue vs. preservation costs.

2. Community Policies

a. Local environmental consequences:

- Patinas as pollution indicators (e.g., sulfur-oxidizing biofilms marking air quality)
- Runoff from chemical treatments contaminating water bodies

b. Public health costs: Airborne spores from urban biofilms exacerbating respiratory conditions

c. Non-microbial parameters:

- Support for local conservation industries (specialized labour, eco-friendly biocleaning startups)
- Policies balancing heritage aesthetics with ecological preservation (*e.g., Venice's "controlled patina" zones*)

3. National/Global Policies

a. Healthcare economics: Monitoring microbial aerosols in urban areas with dense patina growth

b. Environmental pollution: Regulatory limits on biocides that damage ecosystems

c. Water security: Preventing biocide/patina byproducts from entering drinking supplies

d. Eutrophication: Nutrient runoff from patina treatments fueling algal blooms

e. Greenhouse gas emissions: Energy-intensive conservation vs. natural patina stabilization

f. Land/resource use: Allocating funds for sustainable alternatives (microbial biocleaning)

g. Non-microbial parameters:

- Heritage policies: Uniform vs. tiered conservation budgets (*equity for less-funded regions*)
- Tax incentives for eco-friendly patina management

Pupil Participation

1. Class Discussion of Microbial Patina

a. What is patina? (*Show examples: green statues, blackened walls, rusty metal*)

b. Is patina "natural" or "pollution"? Debate: *Should we clean it off historic buildings?*

c. How might microbes and pollution work together to create these patterns?

2. Pupil Stakeholder Awareness

a. *Patina has good and bad effects on cities and the SDGs*. As a class:

- Which matter most? (*e.g., SDG 11 [heritage] vs. SDG 15 [biodiversity]*). Vote!

b. *Reducing negative impacts*:

- How could we clean patina without harsh chemicals? (*Ideas: scrubbing vs. bacteria-eating microbes*)

c. *Personal actions*:

- Could we design a "patina-friendly" city? Or building? Or home? Or façade tile / paving stone? What would it look like?

3. Exercises

a. Urban Patina Mapping (Field Trip or Photo Survey):

- Split into teams to document patina types around school (*e.g., black streaks, rust, moss*).
- Map hotspots: *Is patina near roads (pollution?) or shady areas (moisture?).*

b. Graveyard/Building Survey (Science + History):

- Compare older vs. newer graves/buildings: *Which has more patina? Why?*
- Take rubbings of textures or sketch patterns.

c. Home Object Investigation:

- Bring in old coins, pipes, or tiles. Observe patina with magnifiers.
- Experiment: *Place metal objects in damp jars—predict which will develop patina fastest!*

d. "Design a Super-Microbe" (Creative Thinking):

- Invent / design / imagine a microbe that *cleans* patina harmlessly or protects monuments. Draw its "superpowers"!

The Evidence Base, Further Reading and Teaching Aids

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