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Big Bacteria for Micro-Humans

Bacteria as an archeological - ecological nexus for an integrative form of health and heritage research

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Abstract

This article sketches out some aspects of an integrated mode of health and heritage research, in reference to the research network entitled *Big Bacteria*. Its aim is to establish an interdisciplinary research platform between the natural and the health sciences the arts and the humanities, in order to strengthen the latter in the light of rapid biotechnological advances and related worldviews. The text presents necessary methodological bridges and a model case with ambition to advance the "transitory" resort between the Arts and the Sciences entitled *Micro-Humanities*. Its minimal goal is to supplement the visual culture approach with the one based on material culture. Since bacterium as *res vivens* exhibits a form of organization that is responsible for interpreting and changing the processes it is involved in, it serves as central model for individuation, agency and selfhood, observing and interpreting systems. Being the oldest, smallest, most abundant and structurally simplest organisms, bacteria are ubiquitous, diverse and variant, as well as vital for all other life forms. They require to be treated not only as indispensable motives, metaphors and models of knowledge, but also as material, medium and methods for its acquiring as well. As their taxonomy unambiguously suggests, bacteria are the facts of the permanently changing and sensing living matter. The contribution focuses on an important case of the bacteria's agency to be systematized and related to the research on bioremediation and biodeterioration (breakdown of materials by microbial action).

Keywords

bacteriology and arts, health and heritage, biodeterioration and bioremediation, Colosseum

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Grandes bacterias para microhumanos

Las bacterias como un nexo arqueológico-ecológico para una forma integradora de investigación sanitaria y del patrimonio

Resumen

En este artículo se esbozan algunos aspectos de un modo integrado de investigación sanitaria y del patrimonio, con referencia a la red de investigación titulada Big Bacteria. *Su objetivo es establecer una plataforma de investigación interdisciplinaria entre las ciencias de la naturaleza y de la salud, las disciplinas artísticas y las humanidades, con el objetivo de fortalecer estas últimas a la luz de los rápidos avances biotecnológicos y las concepciones del mundo asociadas a ellas. El texto presenta los puentes metodológicos necesarios y un caso modelo cuya ambición es presentar el recurso «transitorio» entre el arte y las ciencias, denominado* microhumanidades. *Su meta primordial es complementar el enfoque cultural visual con el enfoque basado en la cultura material. Dado que la bacteria como* res vivens *presenta una forma de organización que es responsable de la interpretación y la alteración de los procesos en los que está implicada, esta sirve de modelo central para la individuación, la entidad y la identidad, así como para los sistemas de observación e interpretación. Las bacterias, como organismos más antiguos, pequeños, abundantes y simples estructuralmente, son ubicuas, diversas y variables, además de vitales para el resto de formas de vida. Por su condición, tienen que tratarse no solo como motivos, metáforas y modelos de conocimiento indispensables, sino también cada vez más como materiales, medios y métodos para su adquisición. Tal y como su taxonomía inequívocamente sugiere, las bacterias son los hechos de la materia viva que cambia y siente de forma constante. La contribución se centra en un caso importante de entidad de la bacteria que se debe sistematizar y relacionar con la investigación en bioremediación y biodeterioro (desglose de materiales por acción microbiana).*

Palabras clave

bacteriología y arte, salud y patrimonio, biodeterioro y bioremediación, Coliseo

1. Theoretical prospects

By defining and crossing the differences among research through art, research that uses art, and research about art, the art-based and related research is generally defined as the systematic use of the artistic process as a primary way of understanding and examining experience by researchers, institutions and the "public". As such, it delivers insight into larger the epistemological process of artistic – but not only artistic – knowledge and inquiry, highly relevant for future higher education and professional practice. We aim to provide a brief overview below related to the strands of methodology, where[1] – being situated between the Arts and the Sciences – we admittedly operate between the devil and the deep blue sea. In providing methodological bridges and model cases, our joint ambition is not least to advance our own, "transitory" resort, which I would like to call *Micro-Humanities*. Its minimal goal is to supplement the visual culture approach with the one based on material culture. But the project is supposed to go further in a systematic deconstruction of the theoretical antirealist trend which Quentin Meillassoux termed *correlationism* and defined as "the idea according to which we only ever have access to the correlation between thinking and being, and never to either term considered apart from the other".[2] The "speculative" nature of the realism espoused by the younger generation of thinkers also includes Ray Brassier, Graham Harman, Ian Grant and Levi Bryant, representatives of a much wider circle, including the older generation, such as Alain Badiou, Slavoj Zizek and others. Their shared goal lies in the abandoning of the critical, the linguistic, and implicitly, I would argue, the iconic and pictorial turns including their immanent antirealist tendency as well

1. This is not the place to tackle the often less than fruitful Art/Technology debates with their penchant for release-and-rescue rhetoric. For critical summaries, see Zilberg (2011, 2012, 2013) and Evans and Malina (2012) and Malina (2010, 2014).
2. Meillassoux (2008, p. 5).

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as a preoccupation with death and finitude, aversion to science and its focus on language, culture, and subjectivity.[3] In Brassier's analysis, the basis of Deleuze and Latour's post-modern scenario lacks a distinction between the noumenal and phenomenal, the real and virtual, which means that it is similarly anti-scientific, failing to be informative, and is arbitrarily indisputable. Latour's "irreductionism" in particular presents the "urbane face of post-modern irrationalism".[4] By reducing reason to taste, science to force, and scientific knowledge to practical competence (and art to craft), Latour shrinks the argument by means of his recourse to master metaphors, such as "actor", "ally", "force", "power", "strength", "resistance", and "network".[5] The genuinely postmodern (if we may permit ourselves such a *contradictio in adjecto*) and cognophobic aspects of Latour's project are his attempts "to liquidate epistemology by dissolving representation" and ultimately "to reassure those who do not really want to know (p. 52)".[6] While the described syndrome might be baptized as "capitalist idealism", we wish to pursue a targeted "resource materialism" closely related to the abovementioned, general "micro-humanistic" approach in which the bacteria are not just "recognized" as possible agents, "emancipated" onto the human level, but understood as major material and cognitive resources.

Since the cell as *res vivens*[7] (mediating between the dichotomies based on *res cogitans* and *res extensa*) exhibits a form of organization that is responsible for interpreting and changing the processes it is involved in. Bacteria serve as central models for individuation, agency and selfhood, observing and interpreting systems.[8] The historiography, the experimental and medical praxis, art and literature deliver the best documented (if barely interpreted in-depth) field, onto which the centuries of bacteria based epidemic twists must be projected. Being the oldest, smallest, most abundant, and structurally simplest organisms, bacteria are ubiquitous, diverse and variant, as well as vital for all other life forms. They require to be treated not only as indispensable motives, metaphors and models of knowledge, but increasingly as material, medium and methods for its acquiring as well. As their taxonomy unambiguously suggests, bacteria are the facts of the permanently changing and sensing living matter. Microbial "dust"[9] and "patina"[10] theoretically enframed as material and medium, represent an important case of bacteria's agency to be systematized and related to the research on bioremediation[11] and biodeterioration (breakdown of materials by microbial action).[12] This is why we advocate an overcoming of the reductionism implied in the identificatory use of culture as capital or nature as resource. The mentioned *capitalist idealism* is losing ground to the narrative of the mediating "micro-humanistic" and "resource-materialistic" approach. From our perspective, the narrative of the non-human agencies which aggregates colonies and materials in question goes from *Closed Circuit*[13] to *Big Bacteria* and from "live" to "life", so leading to the convergences and bridges between research into health and heritage – a modest expression for it in a nutshell might be *Big Bacteria for Micro Humans*.

2. Practical decisions

In what follows, I wish to briefly sketch out some aspects of an integrated mode of health and heritage research, in reference to the research network that has been emerging also as part of

Figure 1. Sabine Kacunko, *Invincible. Coliseum* – Rome. Live illumination scheduled for12th - 20th Sep 2015. A first test projection *in situ* as took place on March 17, 2015. © Sabine Kacunko.

3. Bryant *et al.* (2011, p. 4).
4. Bryant *et al.* (2011a, p. 51).
5. See Latour (1998, 2007) and Kacunko (2015, Ch. 10).
6. For further critique of different anti-rationalist perspectives see Kitcher (1993) and Boghossian (2007), works especially pointed out by Harman (Kacunko 2015, p. 16.).
7. See Cheung (2008).
8. See Hoffmeyer (2010).
9. See Gethmann, Wagner (2013), Kacunko (2011), Kacunko and Gorbushina (2013).
10. See Toyka (1996), Krumbein (2003), Gorbushina *et al.* (2000).
11. See Lovley (2001) and Wassenaar (2012).
12. See Krummbein *et al.* (2012).
13. See Kacunko (2004).

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Sabine Kacunko's and my collaborative work. Sabine's bacteria art has increasingly become a matter of our collaboration over the past years, and therefore a source of inspiration for my own art-historical research. Therefore, I would like to start by mentioning Sabine Kacunko's current project entitled *Invincible* (fig. 1).

The project is granted through the UNESCO-patronage in the context of the International Year of Light and Light-Based Technologies 2015. Its underlying purpose is to address concepts of sustainability, ecological structures and social models by calling attention to one of the most iconic World Cultural and Natural Heritage sites – the Colosseum in Rome. The Colosseum will be illuminated with a huge live projection by its smallest inhabitants – bacteria – taken from and projected onto the Colosseum's most exposed northwest side. For cultural travellers, the Colosseum has always been a highlight and final destination of the grand tour. *Invincible* is designed to offer an interdisciplinary discussion platform that connects art, science, archaeology, art history, politics and economics. The intention Sabine pursues here, like in several previous projects, is to "re-convey"or "re-mediate" the visibility of chosen objects of special interest and initiate their "healing" process. Besides the elements of Multimedia-Performance, Sound and Dance, the planned web application will retrace, for example, the Rome-wide spoliation of the Colosseum throughout the centuries.[14] The largest amphitheatre in the world thus becomes by artistic purpose a model with strategic potential to boost and engender interdisciplinary cooperation – art history, archaeology, cultural and natural studies are only the most obvious disciplines that come to mind. Therefore, we are building together with colleagues from Italy, Germany and Denmark a *Big Bacteria*-network that pools together a wide range of disciplines to address the proverbial diversity, variety, ubiquity and other well-known superlatives of bacteria (fig. 2).

In figure 3, we can see a selection of the projected images composed of the own made light-microscope recordings with the images taken by Dr. Volker Brinkmann, leader of the Core Facility Microscopy at the Planck Institute for infection Biology in Berlin and images acquired on a FEI Quanta 3D FEG at The Core facility for Integrated Microscopy, Faculty of Health and Medical Sciences, University of Copenhagen. The latter images were captured by Michael Larsen and sample preparation was supervised by Klaus Qvortrup and Thomas Bjarnsholt. They show electron micrographs of a sample including bacteria and other microorganisms, collected from the travertine wall of the Colosseum, Rome. The images are evidence of immense bioactivity that ranges from remnants of long-dead bacteria to what appears to be very vigorous biofilms and living fungi. Samples were further processed in collaboration with the

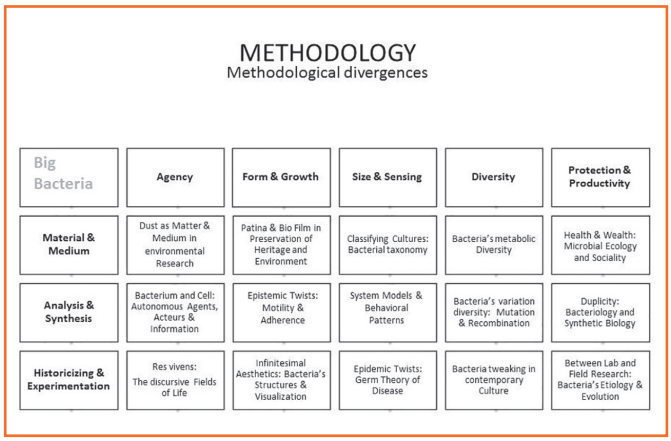

Figure 2. Visualization of the methodological divergences related to the fields of interdisciplinary bacteria research. © Slavko Kacunko.

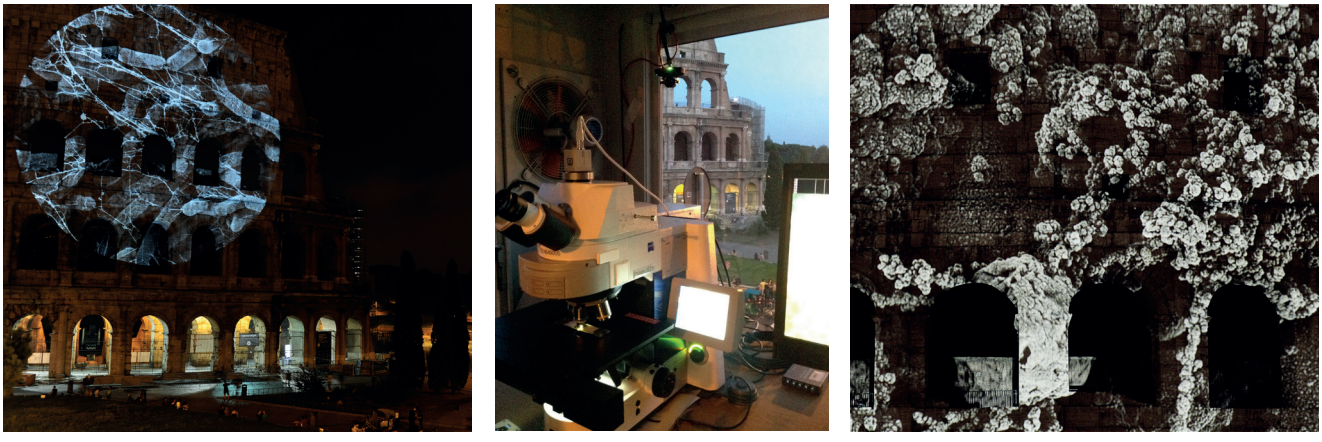

Figure 3. Sabine Kacunko, *Invincible*, Rome 17-19. September 2015. Impressions from the Colosseum site. © Sabine Kacunko.

14. Eg. Palazzo Barberini, Sant'Agostino, San Pietro in Vaticano, Palazzo della Cancelleria, Palazzo Venezia, S.G. in Laterano etc.

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***INVINCIBLE* – a selection from the media coverage (TV and Internet):**

<http://www.theguardian.com/artanddesign/2015/sep/09/colosseum-the-invincible-big-bacteria-project-sabine-kacunko>
<http://www.reuters.com/video/2015/09/18/bacteria-light-up-romes-colosseum?videoId= 365644066&videoChannel=117760>
<http://www.arte.rai.it/articoli/la-vita-invisibile-del-colosseo/31021/default.aspx>
<http://www.vbox7.com/play:efe2781d9f>
<https://ruptly.tv/vod/view/34635/italy-colosseum-becomes-living-art-as-own-bacteria-is-projected-onto-facade>
<http://video.news.com.au/v/396312/Italy-Bacteria-living-on-Colosseum-projectedon-its-facade-by-artist-Sabine-Kacunko>
<https://www.youtube.com/watch?v=_fvTpnTrcgE>
<http://blogs.zeiss.com/microscopy/news/en/invincible-science-meets-art-as-the-colosseum-becomes-a-living-artwork/>
<http://news.yahoo.com/bacteria-light-romes-colosseum-message-peace-123824104.html>
<http://ricerca.repubblica.it/repubblica/archivio/repubblica/2015/09/16/e-i-batte-ridel-colosseo-diventano-arteRoma24.html?refresh_ce>

A forthcoming monograph "Sabine Kacunko. Bacteria, Art and other Bagatelles" (Vienna, December 2015, 272 pages) includes an introductory essay by the author which follows the major tracks of her artistic development.

3. Methods and models

Apart from the attempts to overview and systematize strands of methodology, we remain well aware of the fact that the different approaches and alleged research mentalities in the Arts and Sciences always appear in different light, respectively, producing clichés and methodological shortcomings. Being situated between art and the sciences and in the context of our emerging research network, we see our responsibility in helping to provide the material and conceptual bridges between the hypothesis-proof-methodology of the sciences and the allegedly "heuristic" approach of the arts. It happens qua approach via non-human agencies, aggregates, colonies and not least material resources.

The first convergence or bridge, as we see it, is that of environmental and medical microbiology as conveyed via biofilm. I became acquainted with this fascinating and surprisingly new research field back in 2004 through Sabine's collaboration with a geologist, sedimentologist, and microbiologist Wolfgang Krumbein (Prof. Emeritus from the University of Oldenburg). In the 1980s, Krumbein pioneered research into hypersaline ecosystems and especially the biofilm as sites of biodeterioration and bioremediation. As Thomas Bjarnsholt rightly emphasizes in his habilitation piece,[15] biofilm research is everything but an exact science, however (or: therefore), we recognised its potential as a likely "booster" for integrating research in Health and Environmental Sciences.

The convergences or bridges between environmental and medical microbiology reveal deeper layers of our methodological interests. One of them, on the one hand, is the dialectic between what I would like to call the structuralism of microscopy and on the other, the circuitry of processes (including process art).[16] Both approaches related to either or both microscopy and live-transmission are evident in artistic practice such as Sabine Kacunko's, when the decision must be made to use either "live" specimens and light microscopy or "dead" ones and electronic microscopy.

Emergent fields of study like Metagenomic Sequencing are a good example of what we would like to label an environmental approach. In this case, we can safely indulge in a little hyperbole and speak of the difference between the interest in cultural diversity on one hand and non-cultured microdiversity on the other. The latter, in turn, confirms bacteria's role as key players in larger ecosystems, while the metagenomic sequencing projects to date (Craig Venter's *Global Ocean Survey* [GOS] project for example) "have identified a wealth of genetic richness". We can only agree with Trudy Wassenaar's observation that "pure cultures are a rarity in Nature, and mixed cultures are the norm".[17] When Thomas Bjarnsholt also writes about the "pure culture period" in the past tense, we can recognize convergences with media and cultural studies with reference to Yvonne Spielmann, Irmela Schneider and the discussion about "hybrid cultures" from the 1990s on.

Our approach manifests yet another convergence – that of inherited (genetic) and habituated or learned, (environmental) interest. The innovative nature of the envisioned collaboration between Health Sciences and Humanities lays therefore not least in the search for sharing hypotheses. Regarding bacteria, the "eco-evo" perspective on pathogen-host interactions emphasizes the influences of ecology and the environment on pathogen evolution. For example, we can immerse

15. Bjarnsholt (2013, p. 21).
16. While the former reveals itself in preferring the (3-D) biofilm-matrix to the interest in surfaces and images, the latter reveals its own quasi-iconoclastic potential through the focus on the so called 'karyokinesis' and the processes of the osmotic pressure and cohesion both on intracellular and intercellular level (extracellular polymeric substances [EPS]), as the early research of Wentworth Thompson or LeDuc demonstrated. See Leduc (1912) and Thompson (1917).
17. Wassenaar (2012, p. 178).

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ourselves into the global history, genealogy and transformation of *Yersinia pestis*, a bacterium that is responsible for the Black Death or plague, as well as other pathogens and their impact on our history and culture.[18] What we understand under resource-materialistic or micro-humanistic approach also includes a methodological reconsideration of the allegedly "overcoming" of the materialism-idealism impasse qua phenomenology or (bio-)semiotic. What occupies our joint interest in the first place is the question of avoiding further complication through concretization and careful choices of models and motives applicable for what we wish to call an integrated Health and Heritage research.

The first step is to involve a range of carefully chosen 1. model sites. The Colosseum is therefore taken with its paradigmatic importance for a wide range of studies including its 2. "model plants", followed by 3. model microorganisms (building biofilms in the rhizosphere of the catalogued plants), 4. model material (travertine), and finally 5. model modes or methods of biodeterioration and its bioremediation. (fig. 4).

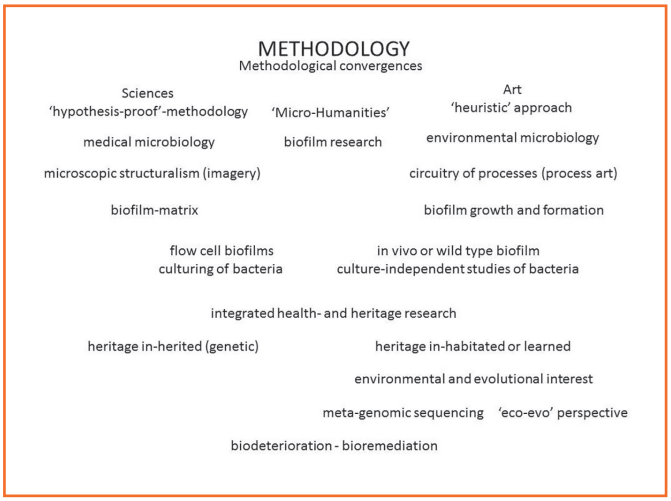

Figure 4. Visualization of the methodological convergences related to the integrated health- and heritage research. © Slavko Kacunko.

I shall briefly specify the mentioned methodology of modelling the case through the choices of correlated model entities. As announced, we are conducting an exemplary study using the world's largest urban plant microcosm and a unique archaeological site with the longest records of plant and natural biofilm growth and development – the Colosseum in Rome.[19] The natural patina formed on an object and not least the resultant biofilm is an ideal breeding ground for evolving plant species. We rely on the work of some predecessors including the mapping projects of the plant biotope of the Colosseum and the more recent general inquiries on *Plant Biology for Cultural Heritage* by Prof. G. Caneva and others. Looking for reliable research specimens, we begin with model plant-organisms and relate them to assumed health and cultural codes. At this early stage, we have opted for a fairly conservative pattern: from a total of about 600 registered plant species, we picked first the examples that are documented in the entire 6 mapping projects from the seventeenth century to 2001 and that also appear on all 5 levels of the building (fig. 5).

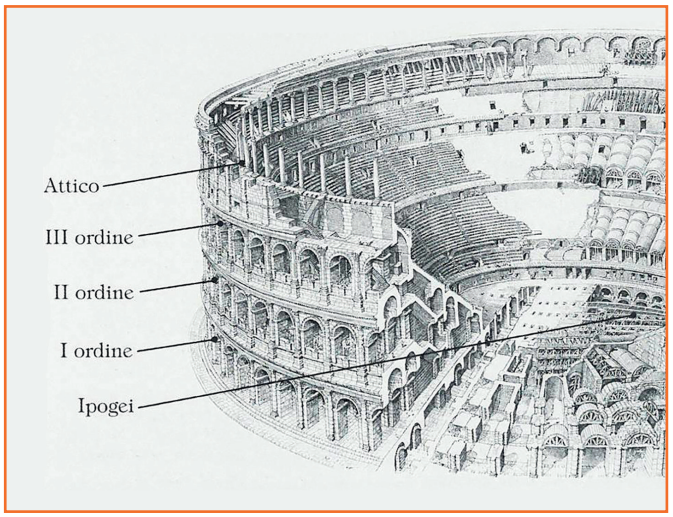

Figure 5. Five levels of Colosseum in Rome. On all levels and during all 6 plant mapping projects in 1643, 1815, 1855, 1874, 1951 and 2001 only a few plant species were found: *Capparis spinosa*, *Cymbalaria muralis (Coliseum ivy)* and *Ficus carica*.

Within this frame, very few candidates for model plants remain, but those offer further interesting hypotheses relevant both to human health and heritage -"health".[20] In *Capparis spinosa L.*, for example, various flavonoids were identified. For example, capers contain more quercetin per weight than any other plant. Quercetin is an anti-oxidant substance which can forestall allergic and inflammatory reactions. It may contribute to cancer prevention and the authors of the Classical world, from Theoprastus (371 – c. 287 BCE) to Pliny the Elder (23 BC– August 25, CE 79)[21] and Athenaeus of Naucratis (died 192 CE)[22] wrote extensively about the medicinal properties of capers (fig. 6).

18. At this point, I can only warmly recommend to those who are still new in the field, Trudy Wassenaar´s introductory book.
19. Cf. Deakin (1855), Wegerhoff (2012), Caneva (2004, 2008).
20. At all 5 levels and throughout present at 1643, 1815, 1855, 1874, 1951 and 2001 are only *Capparis spinosa*, (caper), *Cymbalaria muralis* (Coliseum ivy) and *Ficus carica* (fig).
21. Pliny the Elder, *Natural History*, 27.71.
22. See his *Deipnosophistaí*.

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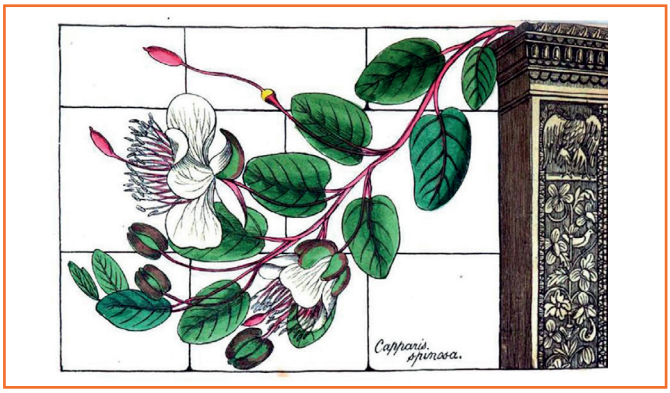

Figure 6. Richard Deakin, a drawing of *Capparis spinosa*. From Deakin 1855.

Table 1.2 Appearance of biological alterations of cultural heritage

	Wood	Paper	Textiles	Parchment, Leather	Stone	Glass	Metals
Autotrophic Bacteria	nd	nd	nd	nd	Black crusts, black patinas, exfoliations, powdering	Pitting, opacification, black spots, blackening of water-logged materials	Corrosion
Heterotrophic Bacteria	Changes in mechanical characteristics	Stains, changes in mechanical characteristics (felting and fragility)	Stains, discoloration, loss of strength	Staining, loss of tensile strength, softening	Black crusts, mucilaginous patinas, exfoliations, color change, stains	Same as above	Corrosion
Actinomycetes	Same as above	Same as above	Same as above	Stains, white patches, loss of tensile strength	Grayish-white powder and patinas, grayish-white efflorescences	nd	nd
Fungi	Stains, alterations in color, cracking, changes in mechanical characteristics	Same as above	Stains, alterations in color, loss of strength	Stains, loss of tensile strength, rigidity	Staining, exfoliations, pitting	Opacification, black spots	nd
Cyanobacteria and Algae	Patinas of different colors (especially green)	nd	patinas	nd	Patinas and films of varying color and consistency	nd	nd
Lichens	Incrustations, patches	nd	nd	nd	Incrustations, patches, pitting	Pitting, opacification	nd
Mosses and Liverworts	Greenish/gray thalli and greenish stains in the initial stages	nd	nd	nd	Greenish/gray thalli and greenish stains in the initial stages	nd	nd
Higher Plants	nd	nd	nd	nd	Grasses, shrubs, and woody species induce fractures, collapsing of structures, detachment of materials	nd	nd

Key: nd = not described

Figure 7. Appearance of biological alterations of cultural heritage (according to Caneva *et al.*, 2008).

As for Classical writing as such, it is interesting to note in our context that in Pliny´s *Naturalis Historia* neither the division between natural and cultural studies exist, nor that between visual and material culture.

The step from plant biology related to cultural heritage to our interest in *bacteriology from the health and heritage* points of view leads to a better understanding of microbial ecology including what Th. Bjarnsholt calls *sociomicrobiology*[23] and other interdisciplinary aspects.[24] This leads us to microbiology proper:[25] The general recognition of bacteria as "models for study of humans"[26] becomes more concrete in the natural and cultural health and heritage context where knowledge about the bioremediation function of different bacteria species and their application in concrete cases of biodeterioration is still in its infancy.[27] The number of not-yet described interactions between the microbial species and the different materials is, with the exception of stone, still considerable (fig. 7).

The process of "biocleaning" and the advanced biotechnologies based on the usage of microorganisms to remove patinas rich in sulphates and nitrates is therefore an interesting application field of research, which obviously needs to be carried out at the artistic, *micro-humanistic*, and scientific level. One of the bacteria specimens discovered on a first trial check of a sample from a capital at the Colosseum displayed a diversity of quite "common" Gram-negative bacteria, among them *Bacillus cereus,* which is already known for its property of consolidation of related stone, while being toxic in human food. What we learn by opening a perspective of microbial mapping of such "common" (and still – seen as a whole – quasi endemic) urban biotopes is not only to include and optimize the applying of live biological cultures onto monuments with the purpose of their bioremediation, but also to understand both monuments' – and humans' health – self-bioremediation and what we metaphorically used to call *growth*.

4. Material matters

This leads us to the chemical and physical layers of an interdisciplinary inquiry that must acknowledge the close relationship between the inorganic substrates and the bacteria that influence or even produce

23. Bjarnsholt (2013, p. 25).
24. One layer beyond lays the *rhizosphere*, a sensitive layer of soil immediately circumscribing the roots of plants which is the breeding paradise for bacteria and for building the biofilm. See early research on this topic, including the fluorescent microscopy (Trolldenier, 1965).
25. In her general inquiry about plant biology for cultural heritage (Caneva, 2005, 2008), Prof. Caneva and colleagues are quoting almost throughout the pioneering results of Prof. Krumbein's research conducted together with his spouse Prof. Ana Gorbushina on biodeterioration. Sabine Kacunko and I have even published together with A. Gorbushina some results on Sabine's work on biofilm included in A.v. Humboldt's Sahara-dust in the Christian Ehrenberg collection in Berlin. See Kacunko and Gorbushina (2013).
26. Wassenaar (2012, p. 166).
27. See Caneva *et al.* (eds) (2008 on Bioremediation p. 340ff).

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the dynamic behaviour of these substrates. One method which bears potential for parallel consideration between the health and heritage applications is biocalcification as a means of consolidating stone, especially highly calcareous stone like travertine, the core, load-bearing constituent of the Colosseum (fig. 8).[28]

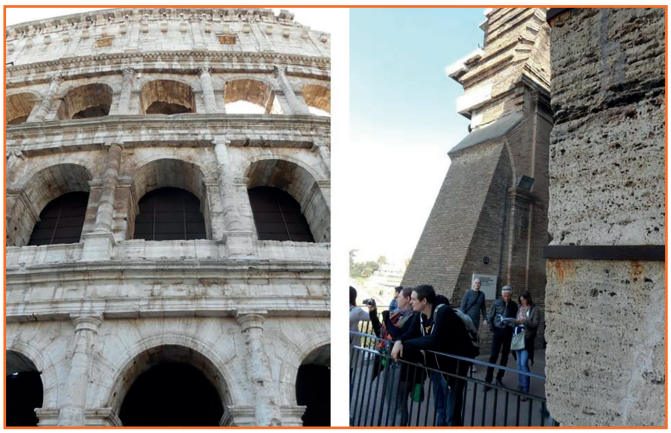

Figure 8. Travertine stone bearing and covering the Colosseum in Rome. © Slavko Kacunko

The Travertine of the Colosseum supplies the best and most famous "case history" of reducing the superficial porosity of the stone. Extensive deposits over ninety meters thick exist and have been quarried for over two thousand years at Bagni di Tivoli (the Latin Tibur), twenty kilometers east of Rome. Quarrying began from the moment the conqueror of Jerusalem and the founder of the Flavian Dinasty, Vespesian, built a road to Rome to transport Tivoli stone, or lapis tiburtinus – travertine –, to Nero's gigantic fish-pond at his Domus Aurea to built the Colosseum in its place. The job took until 80 CE.

In art history and archaeology, our colleagues, starting with Georg Dehio and Alois Riegl, have focused on this aesthetic material full of theoretical, institutional, and political consequences, in the writing "*schicksalhafte Bindung des Denkmals an die Einmaligkeit seiner Materie*".[29] Our own take on the matter focuses less on the cultural drama than on the sober facts of travertine as a sedimentary (evaporitic) chemical rock formed by a process of rapid precipitation of calcium carbonate (CaCO3).[30] Sobering as that point of departure may be, but the deeper interest in the geochemistry of travertine rewards us with recognition of the three factors or forms of deterioration, patinas (which are essentially regarded as biofilms), stains, and pitting. We believe that it makes sense to deepen the systematic study of them, but to extend that perception in parallel to both human health and to our natural-cultural heritage.[31] Fig. 9 shows an example of staining as an initial stage of the "savaging" of the stone at the Villa Adriana in Tivoli through diffusion of lichens on stone.

Figure 9. Tivoli [lat. *Tibur*], Villa Adriana. Lichens on stone. © Sabine Kacunko.

Here, photosynthesizing pigments like carotenoids (carotene, xanthophyll etc.), which are mostly yellow, are at work. They are related to flavonoids (like the above mentioned quercetin in capers). These yellow substances develop as a result of bacterial co-production (and sulphur- and iron-staining), which are responsible for the ground-colour of most travertines as well. Similarly and directly related to the pitting of stone, lithotrope, that is, stone-eating, bacteria belong to the main deteriorants. Endolitic (living inside the stone) Cyanobacteria[32] and algae belong to these substrate-pitting species.

This brings us to the final model: modes of biodeterioration and bioremediation (fig. 10).

28. Cf. Caneva *et al.* (2008, p. 344ff.) – Knowledge about travertine's chemical nature, physical structure, and geological origin are researched intensively by sedimentology, where further interdisciplinary aspects interesting for our inquiry can be found.
29. Quoted after Toyka (1996, ed., p. 40).
30. Carbonate precipitates in the water if there is a lowering of the level of CO_2 dissolved in it. Cyanobacteria, algae, and mosses can contribute to the precipitation of $CaCO_3$. See Caneva 2008, pp. 130-133. The biodeteriorationin of travertine is mainly the result of Acidolysis, associated with the release of acids (H+ ions or protons), such as seen in the process of the release of strong inorganic acids, that leads to corrosion. When sulphuric acid (H_2SO_4) produced by sulphur-oxidizing bacteria comes in contact with $CaCO_3$, the soluble salts are formed, as expressed in the equation $CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2CO_3$. In an aqueous environment such as Bagni di Tivoli, the carbon dioxide (CO_2) is produced during respiration by aerobic organisms, producing carbonic acid (H_2CO_3) as expressed in the equation $CO_2 + H_2O \rightarrow H_2CO_3$. The latter gives rise to acidolysis phenomena on stone, resulting in dissolution of the carbonates of calcium from the calcareous stone and producing of highly soluble calcium bicarbonate $Ca(HCO_3)_2$. See Caneva (2008, p. 21-22).
31. See Caneva (2008, p. 137).
32. See Caneva (2008, p. 136).

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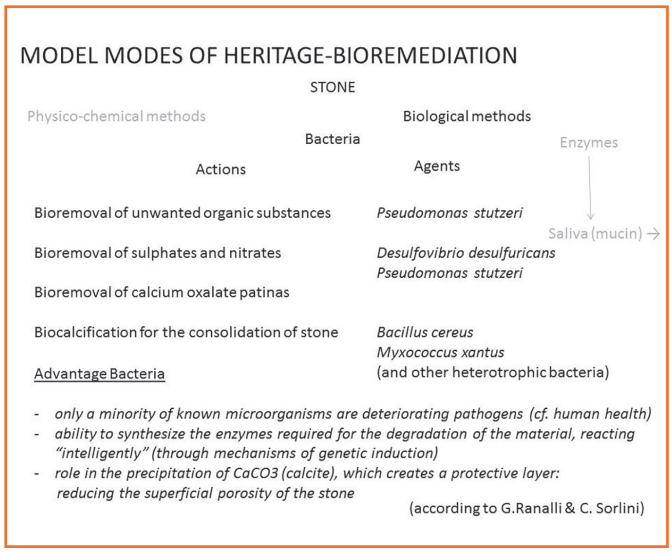

Figure 10. Model modes of heritage bioremediation, related to stone. © Slavko Kacunko.

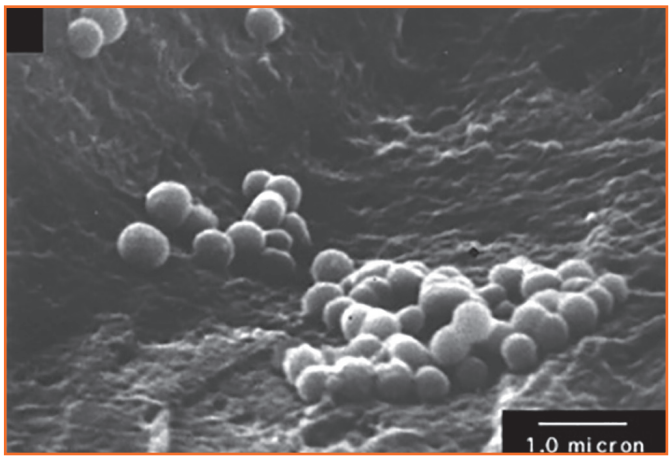

Figure 11. The nanometer-scale spheroidal and ovoid features were first discovered in carbonate minerals forming in hot springs like Tivoli or Viterbo. Robert Folk claims these structures are made by nannobacterial biomineralization. Photo courtesy of R. Folk's Nannobacteria Photo Gallery.

Bioremediation of such surfaces and deeper layers of substrate including stone and soil is often carried out by using sulphur-reducing and nitrate-reducing bacteria, like in this case of the applying of a strong denitrifier like *Pseudomonas stutzeri* applied directly on fresco. Finally, we recall that the material we're talking about when referring to travertine includes the most common mineral in the human body – the calcium needed for healthy teeth, bones and other body tissues; the benefit from an integrative health and heritage approach which we advocate is obvious. The example of nanobes or nan(n)obacteria, as they are called, may merge fact and fiction and science and art a little more than we would prefer, but it serves well for our purpose of intensifying the debate: I refer here to Robert L. Folk, a sedimentary geologist from Austin, Texas (Emeritus of the Department of Geological Sciences), who back in the late 1970s presumed the presence of spherical structures in an assortment of geologic materials. Early SEM (Scan Electron Microscopy) methods revealed nanobe structures 0.05 – 0.2 µm within organisms as well as rocks, i.e. only up to 1/5 of the "average" size of the most known bacteria species (fig. 11).

Nanobacteria, allegedly found in human blood, may be related to health issues such as the formation of kidney stones or arterial plaque due to their biomineralization processes: Calcification can be therefore regarded as an agent of biodeterioration and bioremediation at the same time. Folk made his first discoveries during field research on travertine in Tivoli and especially Viterbo.

The fact that biofilm, stains, and pitting occur in both the "skin" and "substrate" of heritage and homo sapiens alike points to the permanent exposure of both to a myriad of bacteria. We must not forget that these "colonists" are not only "infections" or "pathogenic" by nature, but in most cases either transient or simply resident. The foundations of studies in the humanities, not least of "post-colonial studies", may profit substantially from such a micro-humanities approach.

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33. Cf. Caneva (2008, p. 342).
34. *Desulfovibrio* is found both in anaerobic sediments and in the intestinal tracts of humans and animals.
35. This has been met with some resistance, as some argue that this biomineralization is caused by the nucleation of non-living biological molecules. Cf. Folk (1997) and Young and Martel (2010).
36. Cf. Lange-Asschenfeldt *et al.* (2011). With thanks to Thomas Bjarnsholt for hints and references.

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