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Review

Risk analysis of biodeterioration in contemporary art collections: the poly-material challenge

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ABSTRACT

Biodeterioration is one of the most common alteration factors affecting cultural heritage, and its appearance responds to numerous factors. Awareness of the risk it poses to heritage material and the study of its development is essential. With the mass production evolution of widely accessible materials, the criteria for choosing the constituents of a work of art no longer respond to traditional premises, associating the conservation of these new materials with the flawed expectation of longevity and stable resistance to biological attack.

This work aims to update the contemporary preventive conservation practice through the review of the biodeterioration risk of indoor poly-material artworks. It also means analyzing the potential incidence of biological agents deteriorating contemporary materials stored in art collections, characterized by their industrial origin, and frequently used in the pieces produced in the current art scene. Due to their characteristic agglomeration of components, the artistic object is subjected to complicated surveillance and problematic biological control and eradication, which can often be contraindicated for some constituents.

The study encompasses four main points that make up the risk review analysis sequence: a brief art history exposition to understand poly-material creative values; a general definition of terms surrounding biodeterioration; a selection of most used contemporary materials and a study of their biodeterioration risks; and the basic preventive conservation considerations regarding biological attacks. The review concludes with a critical analysis of the complicated issue of preventive treatment compatibility, as well as a proposed model of action and consideration towards heritage pieces endangered or affected by biological attacks.

1. RESEARCH AIM

The main goal of this work was to perform a review on the risk of biodeterioration concerning contemporary artworks composed of mixed materials in art collections. Including a selection of the most used materials on contemporary artworks, the evaluation of the types and risk of biodeterioration regarding the selected materials; the risk factors and solutions to biodeterioration and to develop of a preventive conservation action model toward modern artistic supports to provide the necessary assessment tools to prevent and/or reduce biodeterioration risks.

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2. INTRODUCTION

With last century's expansion of artistic consideration boundaries, artists find it necessary to get away from academia and tradition-based techniques implementing in their practice artistic trends that motivate the introduction of a mixture of materials and elements of different nature and origin as part of the definition of the artistic object in it of itself, and therefore residing the artwork's symbolism in the existence of this material combination.

Free trade and artistic supply accessibility popularized certain choices in mediums and items, as well as opened the door to their introduction into new artworks. Because of the materials' industrial source, artists often do not question the possibility of deterioration when chosen.

Biodeterioration is one of the most frequent afflictions found in deteriorated art, although among contemporary work, given the nature of supports, base layers, adhesives, or superficial lay-

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ers used; it is not conceived as an expectation, despite its effect and proliferation being entirely possible. With this paper, a decision and consideration action model are proposed for the preventive conservation of these pieces.

The expositive structure of the work maps out the necessary process to evaluate the needs of biodeterioration-affected pieces. As a first step, the artistic contextualization exposed during the study is essential to determine an artwork's appraisal premise. Secondly, the systematic knowledge of biodeterioration behaviour is necessary to establish reliable preventive action, therefore a biological study chapter is included. Next, and given the composition nature of mixed media, familiarization with relevant and preferably used materials is an indispensable step to facilitate the decision-making process towards their conservation. Lastly, and as a result of the compiled data, it is possible to establish active and passive methods of action, and with them, exhibit and adopt a preventive action model/archetype of our own.

3. NEW ATTITUDE TOWARDS ART: NOTES ON THE ORIGINS OF POLIMATERIALISM

With the exponential evolution of the postmodern world, the global vision of historical events and socio-political circumstances nurture the necessity to search for new horizons to satisfy modern clients, needs, and artistic propositions. The French revolution acts as the definitory step of a period, defining the start of the contemporary age and welcoming artists' considerations about their own artistic and creative conscience, the existing representative styles, and uncharted avenues of production [1]. This new exploration permission is followed-up by a prolific artistic production century that ends with the stylistic challenge of the impressionist wave, exemplifying the first representation of the evolution and definition of what we identify as contemporary art [1].

The relentless development of the under-construction United States and the freedom of an independent nation from fixated traditions drive the expressionist artistic experimentation and motivation, generating a stylistic epicenter that would spread across the ocean [1]. Artists steer clear of academic techniques and aesthetics, as well as from traditional contemplation to introduce new semantic values, combinations of new materials, and complex techniques for representative evolution [2]. A literal visual representation is not pursued anymore, looking instead for the sincere interpretation and expression of the subject, treating the artwork as a definable filter [1].

Material availability grows with its industrialized production and entry into the common market, facilitating its acquisition to the trend-interested public that does not answer or does not want to answer to established technical tradition (Fig. 1). The ultimate exposition of academic distancing was displayed by the Dadaist movement, which introduced unexpected materials and approaches, like the use of collage, photomontage, or the designation of daily objects as artistic pieces by themselves. The creative process acquires conclusive importance to define the result, and notions like expression, gesture, motion or visual dynamism become definitory elements [2].

With this new era, with limitations between life and art abolished, accompanied by the flourishing economy of the late XX century, "post-traditionalism welcomes the slow introduction of pluralism, that made possible the massification of art" [3].

With the following environment described, artistic objects start to increase their difficulty of being categorized by traditional standards: results are each time more diverse, and the unpredictable choice of materials and techniques used is the common characteristic, thus arising the notion of poly-materialism, present in movements such as informalism, schism, abstract expressionism, or in conceptual and experimental art, whose artworks display an unprecedented mix of materials, that respond to non-traditional application techniques and media, without a previous study of their ageing, and thus prioritizing the choice of materials and objects "freed from their aesthetic slavery". The mental state of the creator defines this choice [4], often resulting in less attention and technical elaboration, use of inappropriate supports, and added elements... [2].

The restorative consideration before the treatment of these pieces must consider the evolution described. The deterioration generated on the constituent supports affects the legibility and comprehension of works that depend on an object or material that acquires the value of artistic image by itself. Alterations such as colour and aesthetic balance distortions; surface crackle; plane and overlying film deformations; or physicochemical degradation encompass a large part of the discourse and concern in the restoration of contemporary art, leaving behind the idea of unlikely deterioration of "immaculate" works, "unalterable by time" [5] due to their acrylic and synthetic component. An example of biodeterioration in contemporary art is the piece Triptych, by Sophie Taeuber-arp, in which fungal settlement in the form of "coloured specks distributed at random severely alter the constructivist composition" (Fig. 2) [6].

4. MATERIALS AND METHODS

The following work was written on the basis of 64 publications, surrounding the academic disciplines of art theory and history (a total of 2 articles, 5 books, and 1 webpage published between 1987-2016), biodeterioration (a total of 7 articles, 3 books and 4 webpages published between 1965-2020), material properties and behavior (a total of 26 articles, 2 books, 3 webpages and 1 thesis published between 1996-2021) and preventive conservation (a total of 7 articles, 2 books and 1 webpage published between 2008-2013). The research bulk was centered around specific materials and the attacking organisms that favor their biodeterioration and biodegradation. Table 1 summarizes the gathered typology in an orderly manner, encompassing, at a large scale the bibliographical data.

5. BIODETERIORATION AS A PHENOMENON AND ALTERATION AGENT ON INDOOR ART-PIECES

To define biodeterioration, it is essential to bring the concept into the rhetoric of art conservation and restoration. Hueck's 1965, almost unalterable definition: "any undesirable change in the properties of a material caused by the activity of human beings alive", is transferred to the contemporary conservative discipline as the degradation of a valuable artistic material, which infers the loss of resident artwork values, and depending on the values' discrepancy factors, the patrimonial loss degree varies [7].

Pathology emergence due to colonization or biological attack is caused by material composition (its intrinsic characteristics) and its ecosystem (the environment outside the piece). Likewise, the biotic presence results in physical or chemical material alteration, producing aesthetic or compositional deformities. The work of art itself functions as an ecological niche, its own ecosystem, in which producer organisms (the autotrophs) and consumers (the heterotrophs) constitute the trophic chain. Bacteria and plants are autotrophic beings that can cause alterations due to fouling, mechanical settlement, and metabolic products. Heterotrophic organisms (chemolithotrophic bacteria, fungi, insects) require organic matter for their nutrition been therefore able to cause irreversible damage to artistic organic materials. It is worth highlighting the laws of Liebig and Shelford, which define the relationship between biological populations and the limitation of their existence in the

Figure 1. Kurt Schwitters, *Merzbild Alf*, 1939. *Found on* https://www.wikiart.org/es/kurt-schwitters/merzbild-alf-1939 *Public domain image*

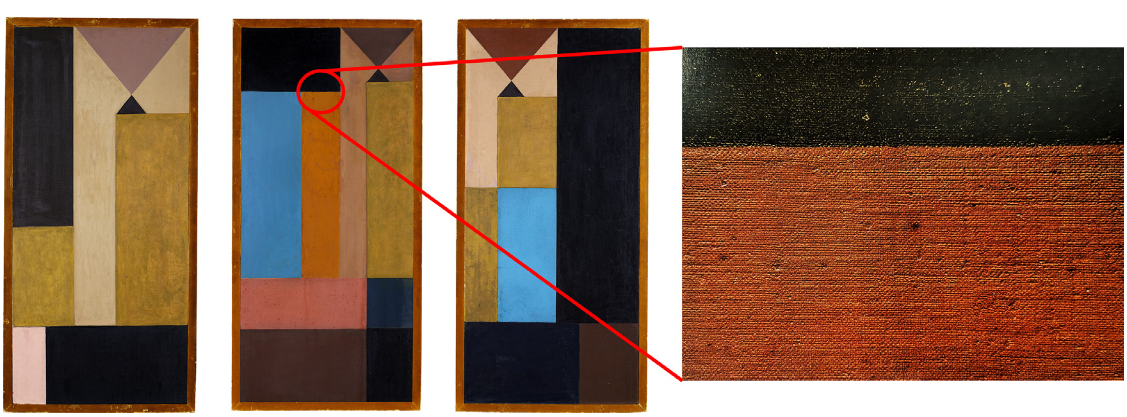

Figure 2. *Tryptich* piece as described by Althöfer and Schinzel [6]. Fungal presence alters the Dadaist artist's graphic and polish aesthetic. *Found on* https://collection.kunsthaus.ch/en/collection/item/3568/ *Public domain image* and *Restauración de pintura contemporánea: tendencias, materiales, técnica*, page 34 [6] respectively.

Table 1
Review of literature on cultural heritage attacking species and specified materials

Material	Attacking species				Source
	Bacteria	Fungi	Insects	Other	
PLANT-BASED ORIGIN					
Wood		genus: *Chaetomium, Xylaria, Alternaria* species: *Coniophora puteana, Coriolus versicolor, Serpula lacrymans*	-orders: Isoptera, Hymenoptera, Lepidoptera, Dictyoptera, Coleoptera (Lyctidae, Anobiidae, Cerambycidae, Curculionidae, Bostrichidae, Scolytidae, Ptinidae and Dermestidae families)	-molluscs of the *Teredo* (*Treredo navalis L.*), *Martesia* and *Pholas* genus - crustaceans of the *Limnoria, Spaeroma* and *Chelura* genus - mammals (mechanical damage)	[9,12,8]
Wood-derived panels	genus: *Cellulomonas, Cellvibrios, Pseudomonas* and *Achromobacter*	genus: *Ceratocystis, Scytalidium* - species: *Chlorociboria aeruginescens, Gliocladium virens, Trichoderma viride, Gliocladium roseum*	-	-	[8]
Paper and cardboard	genus: *Cytophaga, Celfalcicula, Cellvibro*	genus: *Alternaria, Bacillus, Chaetomium, Chrysosporium, Cladosporium, Eladia (sacculum* sp.*), Fusarium, Mucor, Myrothecium, Neurospora, Paecilomyces, Stachybotrys (atra* sp.*), Stemphylium, Trichoderma, Trichothecium, Rhizopus, Ulocladium, Trichothecium, Aspergillus (flavus, fumigatus, niger, versicolor)* and *Penicillium (comunne, citrinum, rubrum, variable)*	genus: *Lepismatidae, Dermestes* - species: *Tineola bisselliella Hümmel Tinea pellionella L.*	Rodents, bats, rabbits, and moles	[8,19,9]
Textiles	genus: *Cytophaga Cytophaga, Microspora, Myxococcoides, Sorangium, Sporocytophaga* and *Vibrio*	genus: *Alternaria, Aspergillus, Chaetomium, Cladosporium, Curvularia, Escherichia, Fusarium, Memnoniella, Myrothecium, Neurospora, Penicillium, Phoma, Sorangium, Scopulariopsis o Stemphylium, Trichoderma* and *Trichothecium*	genus: *Lepismatidae, Dermestes* - species: *Tineola bisselliella Hümmel Tinea pellionella L.*	Rodents, bats, rabbits, and moles	[8,23,19]
Modified cellulose	genus: *Bacillus, Cellulomonas, Clostridium, Cytophaga, Micromonospora, Nocardia, Sporocytophaga, Pseudomonas, Streptomyces and Streptosporangium*	genus: *Anaeromyces, Aspergillus, Caecomyces, Chaetomium, Cladosporium, Coriolus, Fusarium, Neocallimastix, Neurospora, Orpinomyces, Piromyces, Penicillium, Pleurotu, Schizophyllum* and *Trichoderma*	-	-	[25–27]
ANIMAL ORIGIN					
Regenerated protein	Bacteria involved in the nitrogen cycle	-	-	-	[18]
SYNTHETIC ORIGIN					
Vinylic					
Polyethene	*Pseudomonas* sp., *Pseudomonas aeruginosa, Bacillus* sp. and actinomycete *Steptomyces* sp.	*Aspergillus (flavus, clavatus, fumigatus)* and *Pleurotus ostreatus*	genus *Zophobas*	-	[35-37, 38-42]
PVC	*Streptomyces rubrieticuli*	*Aspergillus flavus, Cochliobolus* sp.	-	-	[34,43,12]

(*continued on next page*)

Table 1 (*continued*)

Material	Attacking species				Source
	Bacteria	Fungi	Insects	Other	
Polypropylene	*Stenotrophomonas panacihumi*	*Phanerochaete chrysosporium, Aspergillus niger*	-	-	[44–46]
Polystyrene	*Bacillus megaterium, Pseudomonas aeruginosa, Streptococcus pyogenes*	*Cephalosporium* sp., *Mucor* spp.	genus *Zophobas*	-	[47,48,36]
PVA	*Pseudomonas* sp.	-	-	-	[49]
Non-vinylic					
Polyester	Esterase and hydrolase enzyme producing organisms				[12]
Polyurethane	genus *Bacillus, Pseudomonas, Micrococcus,* and species *Pseudomonas fluorescens, Pseudomonas chlororaphis, Comamonas acidovorans*	*Aspergillus fumigatus*	-	-	[12,50]
Polyamides	*Flavobacterium* and *Pseudomonas*	*Chromofore* fungi	-	-	[51]
Synthetic paint	genus *Bacillus*	- genus: *Alternaria, Aspergillus (niger* and *flavus), Aureobasidium, Cladosporium, Nigrospora* - species: *Aureobasidium pullulans, Chaetomium globosum, Epicoccum nigrum, Gliocladium virens, Penicillium (citrinum, purpurogenum, pinophilum, variable)*	-	*Stichococcus bariliaris*	[12,28,19]

environment. The minimum law expresses the need for a minimum number of essential substances for biological growth so that external agents that approach the threshold of the minimum required for the development of life are the limiting factors. The second law, the law of tolerance, indicates that the presence of essential agents displays a maximum projection of living organisms' growth, thus arising a tolerance interval of values that are too high and low for each species and range [8].

5.1. DEVELOPMENT INFLUENCES

As mentioned in section 4, the emergence of living beings on a substrate responds to factors intrinsic to the work and agents outside it.

5.1.1. Material and biological influence

Responding to the characteristics of the constituent object. Its composition, nature, and structure are considered development influences. Regarding works of art, physical condition is crucial: the presence of cracks, cavities, pores, and roughness…facilitates the biological insertion into the material topography (Fig. 3).

The accumulation of dust or environmental particulates, and the tendency for increased humidity levels in some materials, also result in an invitation to biological growth. The construction method defines the structure of the piece, so a poor preparation or combination of incompatible materials are potentiators of biological risk. Regarding the objects' nature, the organisms' nutritional requirements determine their presence in specific layers. Inorganic material (without the presence of hydrocarbon groups) will serve as a medium for autotrophic organisms, capable of independently synthesizing the organic substances necessary for their development. On the other hand, an organic material enables the establishment of heterotrophic species, which depend on the environment for their nutrition [9].

5.1.2. Environmental influences

Abiotic agents of the environment motivate the subsequent appearance of biotic agents, which generally act together. To classify the environmental influences that may be present in the context of an art collection, actors like water, temperature, light, and ambient air composition must be analyzed.

Water is almost always incorporated within the artwork as part of its construction (base preparation, paint layers, adhesives, or varnishes) or found in its cavities, as well as in the environment in the form of vapour. Humidity is harmful to hygroscopic materials, components that react chemically to contact or contain soluble substances. To quantify spatial humidity, the Relative Humidity value is calculated: the ratio of the absolute humidity (mass of water vapour between the total volume of air) is divided between the condensing humidity (which is defined as the volume required to complete condensation in each instance) and is expressed as a percentage.

With increasing absolute humidity, the temperature value also increases, and the RH value decreases, being inversely proportional. Therefore, it should be possible to control one of these values as a function of the other since most organisms grow around the 65 - 70% RH range [10].

Temperature is not considered an independent environmental risk factor. Its danger is qualified together with the effects of humidity and on occasions when variations are abrupt. Indoor temperature is not a limiting factor for biotic growth; sometimes it can act as a proactive agent if there is artificial heating. The determining event, however, is the continuous variation of temperature levels, which not only influences the value of relative humid-

Figure 3. The cavities in the calcareous surface of artificial rock serve as an ideal space for growth of bacteria, fungi, and as depicted in the image, mosses

ity (a factor that, if exposed to fluctuation, can be harmful) but also subjects materials to contraction and expansion phenomena, which can generate cracks, crazing, cavities, etc. establishing the settlement of biological communities in those areas favourable and to potential cracking due to their growth [8].

Light is the vital source for all photosynthetic organisms, along with its periodicity and duration. Heliophilous species require high values for their growth, and sciophilous species require low values. There are also species whose survival is hindered by light, such as lucifugous or heliophobic species (termites, bookworms, or some fungi) [11].

The **composition of the ambient air** surrounds not only the artwork but also living beings, so its components will have the capacity to alter the objects and limit or allow biological activity. Air is composed mainly of nitrogen (about 78%) and oxygen (21%), as well as carbon dioxide (0.02%). The presence of these gases enables the succession of processes necessary for life as we know it (the nutrition of nitrogen-fixing organisms, respiration by oxygen, or the performance of photosynthesis thanks to CO_2), but they can also act as limiting factors for biological development. Standard air components such as nitrogen oxides, sulphur oxides, hydrates, etc., can be harmful if their concentration is high [8].

5.2. ALTERATIONS

Biological presence and/or activity adjacent to any substrate could alter the contact material in all cases. This alteration may be evident or go unnoticed to the untrained eye, as the manifestation of an aesthetic change is not always the best premise for determining the occurrence and effect of the attack. With this, two types of material alterations are differentiated: physical and/or mechanical and biochemical.

5.2.1. Physical and/or mechanical alterations

Physical alterations are discernible because they distort the appearance of the material itself. Often, this type of damage does not imply the loss of material for organism nutrition: the growth, impact, or movements of living beings, produce pathologies such as cracks, loss of cohesion, fissures, and deformations due to impact… [12]. Including mechanical detachments and erosion derived from nutritive action or by generating considerable damage to any layer, the action of insects on wood and cellulose surfaces is a good example. On the other hand, alterations related to the staining and appearance of the object can also exist, which do not, in principle, decompose the surface; for example, discolouration produced by chromogenic fungi. It is important to note that chemical alterations and corrosion are presumed given these visual changes due to the direct cellular contact of the microorganisms with the material layers. Furthermore, upon organic materials, aesthetic alteration and chemical reactions are almost equivalent terms, while upon inorganic supports, there is the possibility of only aesthetic alteration [9].

5.2.2. Biochemical alterations

In this case, a biochemical alteration causes a material change due to chemical interactions between the organism and the substrate, causing a disintegration of the initial chemical composition of the object. Assimilatory and dissimilatory chemical biodeterioration stand out; in the former, the substrate serves as a nutritional source, and in the latter, the alteration is caused by metabolic waste or specific secretions [12].

Deriving from cell metabolism, biodeterioration agents release acids (such as uric, carbonic, acetic, lactic, and butyric) and alkaline substances, which in addition to modifying the pH value, can cause material decomposition and staining. Pigment release is common

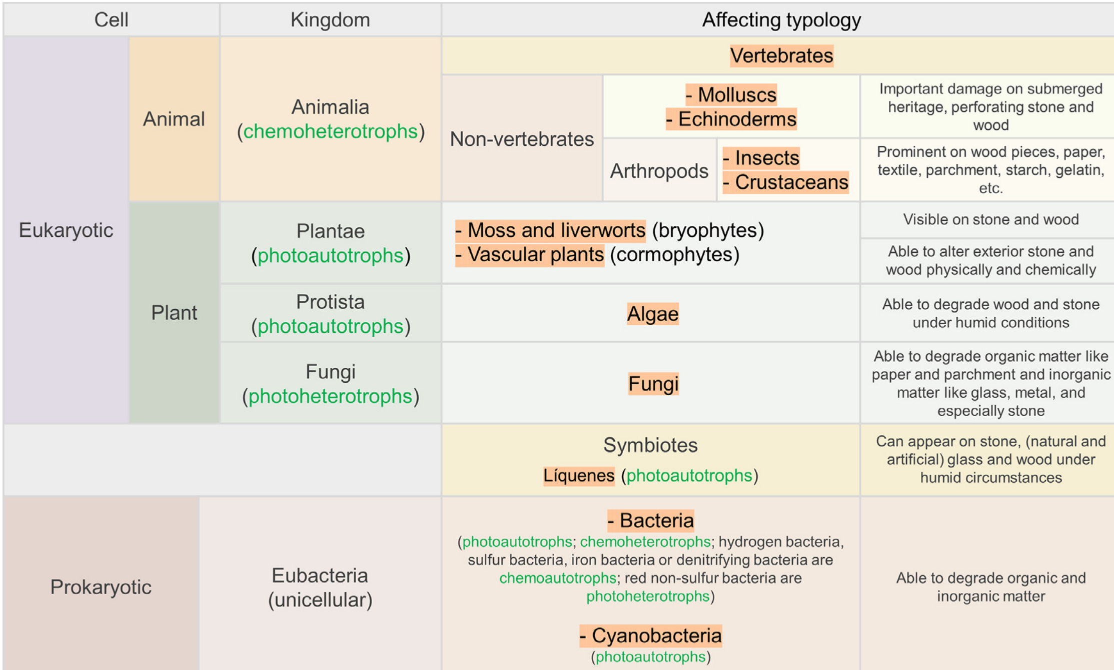

Figure 4. Attacking organisms on artistic objects grouped in a general biological classification

among fungal and bacterial species, resulting in biological crusts and patinas that alter the medium (*foxing* on paper is an example).

Finally, the basic enzymatic function, both for the survival of heterotrophic microorganisms and their decomposing ability, should be emphasized. Enzymes are protein elements generated by cells in their interior (called endoenzymes) and released onto the exterior (exoenzymes) and nutritive matter, which are responsible for the breakdown of protein or sugar macromolecules into simpler groups such as amino acids or monosaccharides, making possible their solubilization in water and later digestion. Compounds such as cellulose, lignin, keratin, collagen, starch, or even manganese, iron, or dyes can be broken down by enzymes if the temperature, humidity, and pH conditions are suitable [13]. Fig. 4 illustrates a biological organisation tailored to the aforementioned concepts, classifying them in the context of conservation and restoration.

6. MOST USED MATERIALS ON MODERN AND CONTEMPORARY ART AND THEY BIODETERIORATION SUSCEPTIBILITY

The entropic process generated around artistic creation over the last century makes it impossible for a thorough list of materials to be presented. Poly-materialism or the search for multiform materiality [14] arises from the belief in each material's disposition of an evocative language. In the European post-war period and influenced by the expressionist paintings produced in the USA[1], an informalist tendency was born that sought spontaneity, crudeness, and naturality. Through mixed medium paints and organic, found, and/or symbolic elements; gathered in a common visual residence, the painting's two-dimensionality was challenged, giving rise to a prominent informalist current in France and Spain, and *Arte povera* in Italy (Fig. 5) [15].

Nowadays, for the base support, the use of textiles and wood, especially wood-based panels, stands out. The fabrics vary from natural origin (linen, hemp, cotton, jute) to organic-synthetic composition (artificial cellulose fiber; nylon, polyester, glass fibers; acrylic fibers).

Wood as the base support almost surpasses fabric diversifying in the form of densified wood, chipboard, fibreboard, or plywood [16]. Paper and cardboard are also typically chosen as substrates for the support layer sharing their cellulosic nature with wood and natural textiles [2].

The use of industrial preparations like gesso, synthetic resins (acrylic and vinyl latex), polyvinyl acetate (PVA) and synthetic varnishes, extremely popular among contemporary artists, should be highlighted.

The colour layer belongs to the typology of oil, acrylic, nitrocellulose, and binders in the form of alkyd resin or polyvinyl acetate. Finally, the use of perishable metals, plastics, and organic matter should be mentioned, as they are quite common: material mix does not respond to rules or expectations of creation [2].

In the present work, two groups of modern and contemporary art materials have been chosen, containing all the materials mentioned, historically and currently used: materials of a cellulosic nature and those of a polymeric organization. These two broad general groupings include most elements used in contemporary art, serving multiple functions, thus providing a useful material overview for evaluating their biological degradation to establish their priority within preventive consideration and generate a proposal for care and treatment (Fig. 6).

6.1. CELLULOSIC MATERIAL

Cellulose is the elementary linear polysaccharide component of plant cell walls, essential in the structuring of plants (together with lignin in taller plants) as well as fungi [12]. 58-60% of cellulose is contained in coniferous wood; 77% in hemp, 80% in flax, and 95% in cotton [8].

The sugar composition of the macromolecule along with its varied productive typology and rapid recycling cycle gives cellulose a quick biodeterioration property. The amorphous structure that its chemical arrangement acquires in most artistic supports also contributes to the hydrolysis of the compound. The assimilation of cellulose, and thus its biological degradation, is completed

[1] Representative figures: Robert Motherwell and Clyfford Still

Figure 5. Espejo del duende by Manuel Rivera in 1963: multi-material work with cellulosic, inorganic and vinyl elements. Found on https://www.wikiart.org/es/manuel-rivera/espejo-del-duende-1963 © Manuel Rivera under Fair Use

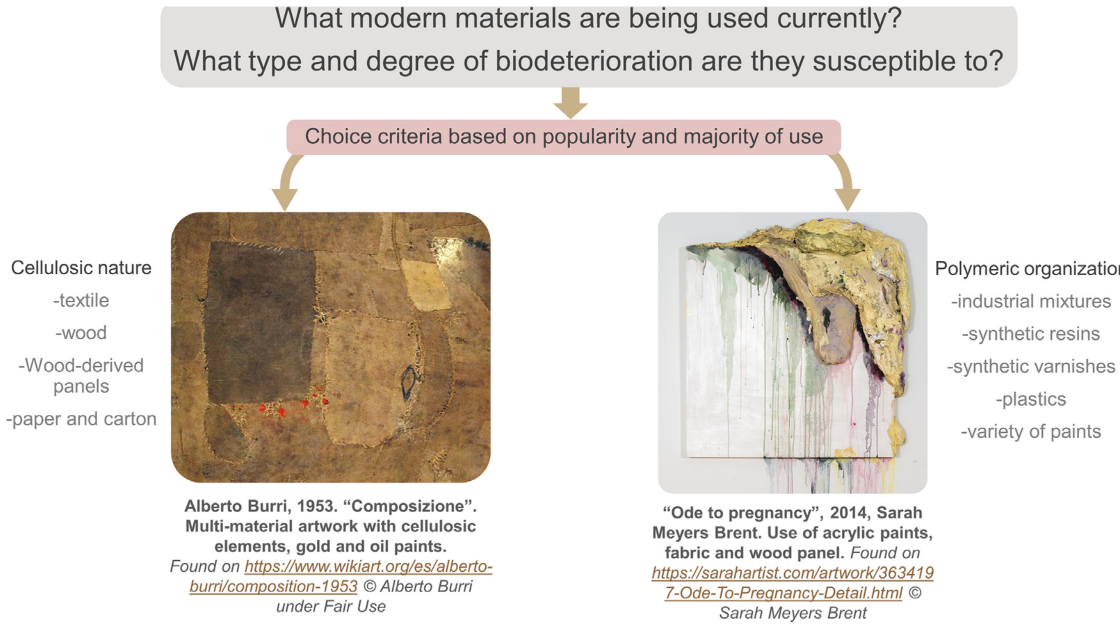

Figure 6. Visual outline of the materials studied and their relevance

by enzymes, which simplify the sugar compound into glucose, a monomer easily digested by microorganisms.

The key problem with enzymatic activity is extracellular production: these enzymes are not dependent on living cells once secreted and can continue to simplify the polysaccharide even after cell death or application of a biocide [12].

6.1.1. Wood-derived panels

Ligneous support of synthetic origin and industrial manufacture stands out for its popularity among contemporary artists and is presented in variations such as plywood; interposing several sheets of wood and perpendicular fibres; or fibreboards with different densities depending on the pressure exerted on the particles, shavings or chips that make up the resinous board [16]. These boards incorporate adhesives or resins to maintain their structure, as well as additives and coating layers.

As mentioned above, wood is considered very susceptible to biological damage, due to its organic nature and cellulosic composition. Wood-derived panels share properties with natural wood like hygroscopicity: similar physical behaviour and biological incidence can be expected. Wood in thin, large sized sheets is used to make plywood boards. Materials such as chips, particulates, fibres, etc. are reserved for wood pulp chipboard. Therefore, the traditional association with wood as an art medium is acceptable in terms of origin, but not regarding behaviour or future projection.

Factory-ready wood, especially that destined for wood-based panels manufacture, is composed of the sapwood extracted from trees (usually gymnosperms) and consequently not fully cured and softer in nature, features that advance its decomposition and biotic attraction [12]. The availability of nutrients is indispensable for biotic development, requiring a suitable carbon-nitrogen ratio (5:1 for bacteria and 10:1 for fungi) that defines the occurrence of biodeterioration [17].

Wood is susceptible to attack by various biological types like xylophagous, parasitic and insects; earthworms; molluscs or crustaceans and vertebrate animals. Likewise, cellulolytic bacteria *Cellulomonas* and *Cellvibrios*, and species of *Pseudomonas* and *Achromobacter*, erode the surface and increase the permeability of the support [8]. Fungi are considered the primary consumers of wood-derived boards. Chromophorous fungi that alter the appearance of the boards, such as *Ceratocystis, Scytalidium, Chlorociboria aeruginascens* or *Gliocladium virens*, as well as species that feed on depolymerised cellulose like *Trichoderma viride* or *Gliocladium roseum* (Fig. 7) can also damage wood panels [8].

Regenerated proteins (urea-formaldehyde, melamine-formaldehyde, or phenol-formaldehyde) are effectively introduced into the boards as the adhesive component [16]. These polymers tend to hydrolyse easily, thus absorbing water, and threatening the stability of the carboxyl groups present in their formulation, increasing susceptibility to microbial attack [12]. Bacteria involved in the nitrogen cycle, are particularly common because they transform compounds like urea into ammonia [18].

Given the physical characteristics of the boards, like the ease of deformation and splintering; the polymerization of adhesives and resins; moisture absorption or disintegration of their structure; among others, the access of biodeterioration agents is relatively simple and accessible. To prevent biological action on derived boards, the use of zinc borate and salt concentrations that serve as inhibitors of fungal activity, like benzalkonium chloride, Algochene N®, Preventol® RI 50, Per-xil 10® are frequently used [19]. It is worth mentioning the growing research interest in essential oils as alternative green biocides, such as garlic (*Allium sativum*), oregano (*Origanum vulgare L.*), lemon leaves (*Citrus limonum*), sage (*Salvia officinalis*), mugwort (*Artemisia vulgaris L.*) or butterbur (*Petasites officinalis*) [20].

6.1.2. Paper and cardboard

To make paper pulp, the cellulose macromolecule must be un-lignified; moreover, with the chemical breakdown of natural cellulose bonds (whose structure presents an almost crystalline arrangement), this physicochemical process generates numerous amorphous areas, increasing the probability of attack.

When paper is exhibited with other attack sources such as inks, glues, or graphic techniques, it becomes a highly susceptible material to biological attack. Fungi are the most common attackers, especially the *Aspergillus* (*flavus, fumigatus, niger, versicolor*) and *Penicillium* (*comunne, citrinum, rubrum, variabile*) genus [19]. They stain[2] the paper and prepare it for the subsequent attack of other

[2] Produced by genus *Cladosporium, Chaetomium, Aspergillus* and *Helicosporium*

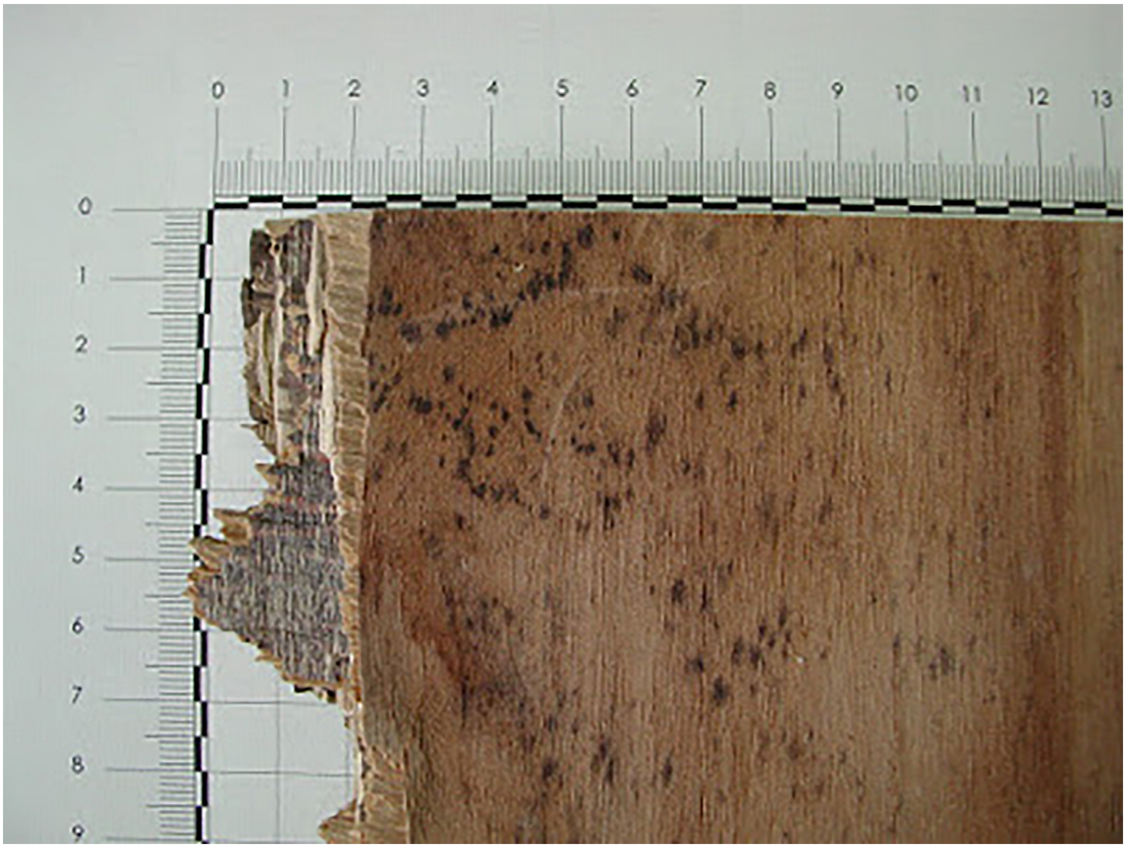

Figure 7. Fungal attack on plywood board. Found on http://aitiminforma.blogspot.com/2002/03/que-son-los-hongos-cromogenos.html © AITIMinforma

higher species. Feeding on cellulose specifically, and thus potential paper corrupters, the cellulolytic genera involved are *Alternaria, Bacillus, Chaetomium, Chrysosporium, Cladosporium, Eladia* (*sacculum* sp.), *Fusarium, Mucor, Myrothecium, Paecilomyces, Stachybotrys* (*atra* sp.), *Stemphylium, Trichoderma, Trichothecium, Rhizopus or Ulocladium* [8].

The felt-like appearance and texture is usually an indicator of fungal attack, due to deep depolymerisation from the metabolism of cellulose to obtain carbon and energy. Furthermore, pathologies such as loss of resistance or orange stains would cause *foxing* on the paper due to fungal metabolism products (organic acids, oligosaccharides and protein compounds) that chemically react with the material under specific conditions (low water activity, high temperatures) thus synthesizing pigmented metabolites [21].

Bacteria need a minimum of 85% humidity to develop species such as *Cytophaga, Celfalcicula* or *Cellvibro*, although they are rarely present. *Coleoptera, Isoptera* or *Zygentoma* insects can erode paper and create gaps, as well as feeding on the surface gelatine of photographs [9].

In terms of extermination treatments, it is worth mentioning the fungicidal effect of ethanolic solutions, to which parabens can be added (methyl and propyl, 1- 0.5%) [19]. Aminoalkylalkoxysilanes (AAAS) has been recently investigated applied on papers with high lignin content [22].

6.1.3. Textiles

They also stand out for their use in contemporary compositions, either as the support base for the artwork or added as part of a mixed material combination. Plant-derived textiles that stand out for their use are cotton or linen, as notorious supports for canvases; hemp, jute and sisal can be found as well.

Susceptibility to biodeterioration will depend on the cellulose content of the textile. High content of the polysaccharide is generally beneficial under optimum conservation conditions, but extra components like starch, carbohydrates or dextrin attract biological activity [8]. The size of the weft should be noted, which allows the introduction of foreign substances if it is too wide, thus inviting biological settling.

On textiles, there are attacks by fungi (not necessarily cellulolytic), which stain the fabrics; bacteria (very rare occurrence) and insects (orders Zygentoma and blattids, rarely termites), which erode the fibres and generate material losses [9]. It is important to highlight the incidence of the fungal genera *Alternaria* spp., *Aspergillus* spp., *Fusarium* spp., *Memnoniella* spp., *Myrothecium* spp., *Neurospora* spp., *Penicillium* spp., *Sorangium* spp., *Scopulariopsis* spp. or *Stemphylium* spp.; *Chaetomium* spp., *Curvularia* spp., *Escherichia* spp., *Memnoniella* spp., *Myrothecium* spp. and *Trichoderma* spp. especially on cotton; and *Cladosporium* spp., *Phoma* spp. and *Trichoderma* spp. on flax [23, 19]. In addition to the incidence of bacteria such as *Cytophaga* spp., *Microspora* spp., *Myxococcoides* spp., *Sorangium* spp., *Sporocytophaga* spp. or *Vibrio* spp. [19].

Biocides include the use of Octenidine, nitrates with ammonium chlorides, or silver ions [19]. Although the best option is inhibition, either passive, by climatic control, or active, by applying a superficial wax layer.

6.1.4. Modified cellulose

With cellulose as a base, it is possible to substitute certain groups within the sugar macromolecule. Thus, cellulose is synthesised and used to produce fabrics (like rayon), films or sheets (cellophane) -cellulose nitrate and acetate, in which the -OH group is replaced by acetates and nitrates respectively- as well as cellulose ethers which, due to their characteristic viscosity, are used as adhesives or thickeners in paints. In these cases, carboxymethyl, hydroxypropyl and methyl groups, etc. are added [24].

The configuration of long cellulosic chains for synthesis increases the susceptibility to attack by organisms: the loss in viscosity of gelled cellulose ethers is an emblematic example. Bacteria, fungi and actinomycetes produce the necessary enzyme cellulase for cellulose breakdown. Bacteria include the genera *Bacillus, Cellulomonas, Clostridium, Cytophaga, Pseudomonas, Sporocytophaga, Micromonospora, Nocardia, Streptomyces* or *Streptosporangium* [25]. In terms of fungal attack, the aerobic genera *Aspergillus, Cladosporium, Penicillium* (extremely common in cellulosic environments) and *Chaetomium* are mostly observed, as well as the genera *Neurospora, Coriolus, Pleurotus, Schizophyllum, Fusarium* or *Trichoderma*; and anaerobic genera *Neocallimastix, Piromyces, Caecomyces, Orpinomyces* and *Anaeromyces* [26,27].

Antifungal agent ethyl parahydroxybenzoate can be used to eliminate cellulose degrading fungal species [28].

6.2. POLYMERS

A polymer is a macromolecule, usually organic, following the union of several monomers, which are molecules of low molecular weight [29]. This union is produced through polymerisation, resulting in a less chemically active substance with a higher molecular weight [30]. The service of polymers in works of art is evidenced by the presence of various plastics, either as components of the piece, as art objects or for support. Also in the form of synthetic resins such as polyvinyl acetate, polyvinyl alcohol, epoxy or alkyd resins, phenol/formaldehyde polymers or cellulose nitrate in the form of adhesives or as a component in paints and film-forming substances [31,32].

Natural or synthetic rubber, latex and silicone are also polymers, which through water absorption and oxidation mechanisms become biosusceptible. Butadiene's vulnerability to degrading genus *Nocardia* is an example [12]. The degree of crystallisation, branching and polymer morphology (molecular weight) determine the susceptibility to enzymatic degradation, establishing an inverse relationship between the melting temperature (Tm) and the rate of biodeterioration.

The presence of additives, fillers, or impurities, especially plasticisers (adipates and sebacates based) used as a nutrient source, increase the susceptibility to microbiodeterioration [12]. Some of the biocides used on plastics are known as *Trilan, Cymid*, salicylanilide and organic-arsenic compounds and organotins [33]. It should be noted that the addition of hydrogen peroxide, sulphuric and nitric acid can oxidise the polymer surface, and surfactants such as Tween 80® and sodium dodecyl sulphate increase their hydrophilicity, promoting biodegradation [34].

All mentioned plastics are organic polymers, with vinyl polymers composed of only carbon atoms and non-vinyl polymers composed of oxygen or nitrogen atoms in addition to base carbon atoms.

6.2.1. Vinyl polymers

Polyethene, with short and occasionally branched chains, is not susceptible to biodeterioration in its pure form, however, the high- and low-density forms (HDPE and LDPE) can be targeted by the bacterial species *Pseudomonas* sp. and *Pseudomonas aeruginosa* [35]. Also, larvae of the coleopteran insect *Zophobas* can affect LDPE, and the fungus *Aspergillus flavus* both [36,37]. The polyethene glycol (PEG) variation can be metabolised by many Gram-negative bacteria because of oxidation of alcoholic groups and breakage of the ether bond [12]. The biodegradation capacity of the fungi *Aspergillus clavatus, fumigatus, Pleurotus ostreatus,* bacteria *Bacillus* sp. and actinomycete *Steptomyces* sp. is of note [38,39,40,41,42].

Polyvinyl chloride, **PVC,** supports fungal growth −species such as *Aspergillus flavus* and *Cochliobolus* sp. can appear [34,43]. Bacteria can also attack the plasticised polymer by *Streptomyces rubrieticuli* that can be identified as a pink stain [12].

As for the high molecular weight polymer, **polypropylene**, it is worth mentioning the biodeterioration capacity of the bacteria *Stenotrophomonas panacihumi* and the fungi *Phanerochaete chrysosporium* and *Aspergillus niger* [44,45,46].

Both **polystyrene** and the acrylic polymer **PVA** (polyvinyl acetate) are susceptible to bioattack in their liquid form [12]. The former being vulnerable to degradation by *Pseudomonas aeruginosa, Bacillus megaterium, Streptococcus pyogenes Cephalosporium* sp., *Mucor* spp. and *Zophobas* [47,48,36]. And the latter being able to be degraded and used by the bacteria *Pseudomonas* sp. as a source of carbon and energy [49].

6.2.2. Non-vinyl polymers

The biodeterioration accessibility of **polyester** depends on the organic acid used for its formulation: adipates, sebacates and caproates are recognised as degradable, and there are numerous esterase and hydrolase producing organisms, the enzymes that degrade esters and hydrolyse their bonds, respectively [12,49].

Polyurethanes become susceptible to biodeterioration with their polyether content, which increases the possibility of hydrolysis. Protease, lipase and esterase enzymes from aerobic and anaerobic bacteria attack urethane bonds and polyester segments [12]. *Pseudomonas fluorescens, Pseudomonas chlororaphis* and *Comamonas acidovorans* have extracellular and thermostable polyester segment degrading enzymes. Bacteria of the genera *Bacillus, Pseudomonas* and *Micrococcus*, as well as the fungus *Aspergillus fumigatus*, can degrade polyurethane [50].

Finally, **polyamides** (constituents of films and fibres such as nylon), although very resistant, can be degraded by hydrolase enzymes present in *Flavobacterium* and *Pseudomonas* and colonised by chromogenic fungi without affecting their stability [51,12].

6.3. SYNTHETIC PAINT

Paints are composed of a binder (vinyl acetate, vinyl chloride, acrylate, styrene latex, etc.), pigments (usually mineral) and a solvent, either hydrocarbon or aqueous, they also usually contain surfactants, viscosity regulators (usually cellulose ethers, with biostability risks of their own) and organic inert fillers.

The first bacterial autotrophic colonisation on inorganic layers or elements, and the consequent segregation of acids alter pigments, decomposing them and favouring the appearance of fungi, which produce whitish veils, chromatic changes and stains, and enzymatic activity, capable of damaging the chemical composition of the substrate [9]. Components such as latex, present in up to 40% of paint emulsions, contain nutritional elements for microorganisms, as well as possessing a pH of between 4.5 and 9 in liquid paint, which can be colonised by both Gram-negative and Gram-positive bacteria, especially the *Bacillus* genus. However, 75% of the microorganisms are *Pseudomonal* bacteria, which appear in response to the optimum pH of 8 - 9.5 of dried paint [12].

On paint layers, mostly fungi of the genus *Alternaria, Aspergillus* (especially *niger*, which produces melanin and consequently black spots; and *flavus* species) are found [31]. But also, from other genus like *Aureobasidium, Cladosporium, Nigrospora* and species such as *Aureobasidium pullulans, Chaetomium globosum, Epicoccum nigrum, Gliocladium virens* or *Penicillium citrinum, purpurogenum, pinophilum* and *variable* [19]. Paint binder sets up the order of susceptibility positioning acrylic, polyvinyl acetate, and alkyd from lowest to highest risk of biological attack [52].

To protect pictorial layers the use of inert gases such as helium, argon or nitrogen is usually proposed for biological eradication, as well as the application of chemical biocides such as Biotin®, New-Des® and Nipagin® [23].

7. THE CONFLICT OF PREVENTION COMPATIBILITY

With contemporary artistic confection, materiality acquires evaluative importance when approaching an artwork's reading and interpretation, so substitution of original material is not always an option. An additional characteristic of this confection is the disinterest in a harmonious coexistence between materials in the same artistic object as a premise. Accordingly, in terms of the conservation of a piece of art, the construction of the art object itself must be positioned as the first conservation challenge. Compositional elements often do not respond to a harmonious coexistence: either due to the erroneous application of film-forming substances or additives, unsuccessful combinations, or a methodology that is far removed from its original intended use and application.

This interference and material interaction can promote microbiological appearance, due to the damage produced on the original material, or enzymatic inter-material interactions. Therefore, evaluation of material contact and the consequences of a conservative plan that does not consider the dangers it may pose is defined as indispensable, before even establishing basic prevention and control limits.

Rubbers or wool could become sources of sulphur compounds that affect the integrity of metals such as silver or gold, fabrics such as felt or fixing adhesives, all common materials in contemporary works. It is also possible to encounter combinations of materials such as processed woods (that can contain adhesives, varnishes, sealants, or antifungal and rot-proofing substances that can potentially secret organic acids such as formic and acetic acid) with metals like copper, zinc, lead; or with polyvinyl acetates, polyurethanes, and silicones; as well as alternatives to wood such as plywood or chipboard with paper. Some plastics are sources of chlorites, which affect the composition of polyvinyl chloride, polyvinylidene chloride, copper, aluminium, zinc, or iron. As well as nitrogen oxides: pollutants from plastics that damage cellulose nitrate or copper and iron [53].

It is worth mentioning that, for example, the presence of copper in a composition can increase the activity of laccase, a bacterial enzyme found in, for example, the actinomycete *Rhodococcus* which, with its copper-catalysing activity, contributes to the biodegradation and biodeterioration of polyethene [54].

All the reactions described above either damage the composition of the materials concerned and promote the deformation of the initial shape of the material itself so that biological attack increases in possibility; or they are preparatory biodeterioration mechanisms, whereby the biodeterioration action has already started.

On the other hand, treatment decisions are also affected by the origin, response, behaviour, and compositional characteristics of all various materials: a certain treatment may be the answer for the baseline material but produce damage on the surface adhered materials and vice versa. And not only is there a relevant compositional discrepancy in terms of choice of preservative treatments, but their maintenance and the physical conditions of the environment can become both a positive and damaging agent on the same piece, varying the outcome of the affected material.

An extermination treatment such as anoxia or gas substitution by modified atmosphere may be useless if the specific identity of the organism to be eliminated is unknown, especially in the case of bacteria. Thus, a nitrogen-modified atmosphere only affects aerobic species, without inhibiting anaerobic activity. Similarly, anoxia will not affect anaerobic organisms. These treatments may exterminate certain species, while promoting the growth of others, with different nutritional needs, so recognising their behaviour in advance will ensure the correct decision [55].

Likewise, for the maintenance of the piece, control of the RH of the environment is paramount. On artworks of multi-material interference, the discrepancy between RH comfort ranges arises. Minerals, cellulose, metals, proteic elements, etc. have different degrees of material properties protection (Fig. 8), so identifying the specific needs of each material is the first step in assessing a suitable RH and temperature levels, sometimes requiring environmental insulation for a specific area. This decision, as D. Erhardt and M. Mecklenburg point out will depend, beyond the appropriate range for each material, on choosing as a priority mechanical damage prevention (achievable with a higher RH) or chemical degradation prevention (with lower RH) [56].

8. BEYOND DETECTION AND CURATIVE MEASURES: PROPOSED STRATEGIC MODEL OF ACTION FOR BIODETERIORATION PREVENTION IN ART COLLECTIONS

8.1. GENERAL PREVENTIVE CONSIDERATIONS

In section 5.1.2, water, temperature, light, and atmospheric composition are mentioned as decisive factors for the development of organisms. The control of these factors determines the bioemergence and consequent degradation of artistic material.

Monitoring the occurring factor of water, concentrates on the observation of relative humidity levels and the water activity (a_w) of the specific material. Generally, the **relative humidity** control recommendation stops at the range of 50-55% [57] but depending on the materials used and the type of collection, the 25-75% RH [58] expansion is considered; however, this value should always be adapted to the lowest possible level: the drier the environment is, the less favourable it becomes for biological settlement.

The most important premise in monitoring and determining RH levels is to ensure that there are no abrupt changes or that the values do not border on the extremes of the recommended range. The a_w values of each object vary depending on the surrounding air, so it is precisely the effect of RH on the aqueous activity of each material that determines its biodeterioration compatibility.

Temperature, in conjunction with relative humidity, will determine the environment for potentially harmful organisms. This value is usually maintained within the range of 16-20° Celsius, never exceeding this temperature in exhibition spaces. For the storage of works of art, it is advisable, given the possibility, to consider the additional decrease in temperature, which ensures the reduction of biological growth. It is important to consider not only the biological deterioration caused by elevated temperature, but also the general risk of the object's material composition, such as dimensional changes, softening of plastic elements and increased attraction of ambient particles [59]. The critical consideration, however, is the immutability of both RH and temperature and their combination, as well as adequate ventilation, especially in exhibition spaces, to prevent condensation [8].

In terms of **lighting**, the wide range of choices must be considered, as well as the material exposure time limitation. Light degradation can be a determining factor in terms of the damage caused, thus inviting biological attack. Its absence can favour the proliferation of insect or fungal species or make the photosynthetic development of others impossible. As a standard value, 50 lux is set as an acceptable intensity for direct illumination of artwork, although there are instances where an increase to 150 lux contributes to a more faithful interpretation of the image [57]. Typically, the most prominent recommendations describe the reduction of lighting time, control of the receiving radiation, the use of UV filters, the reduction of red and infrared spectrum emissions and the use of screens or curtains to block direct incidence [8]. Of

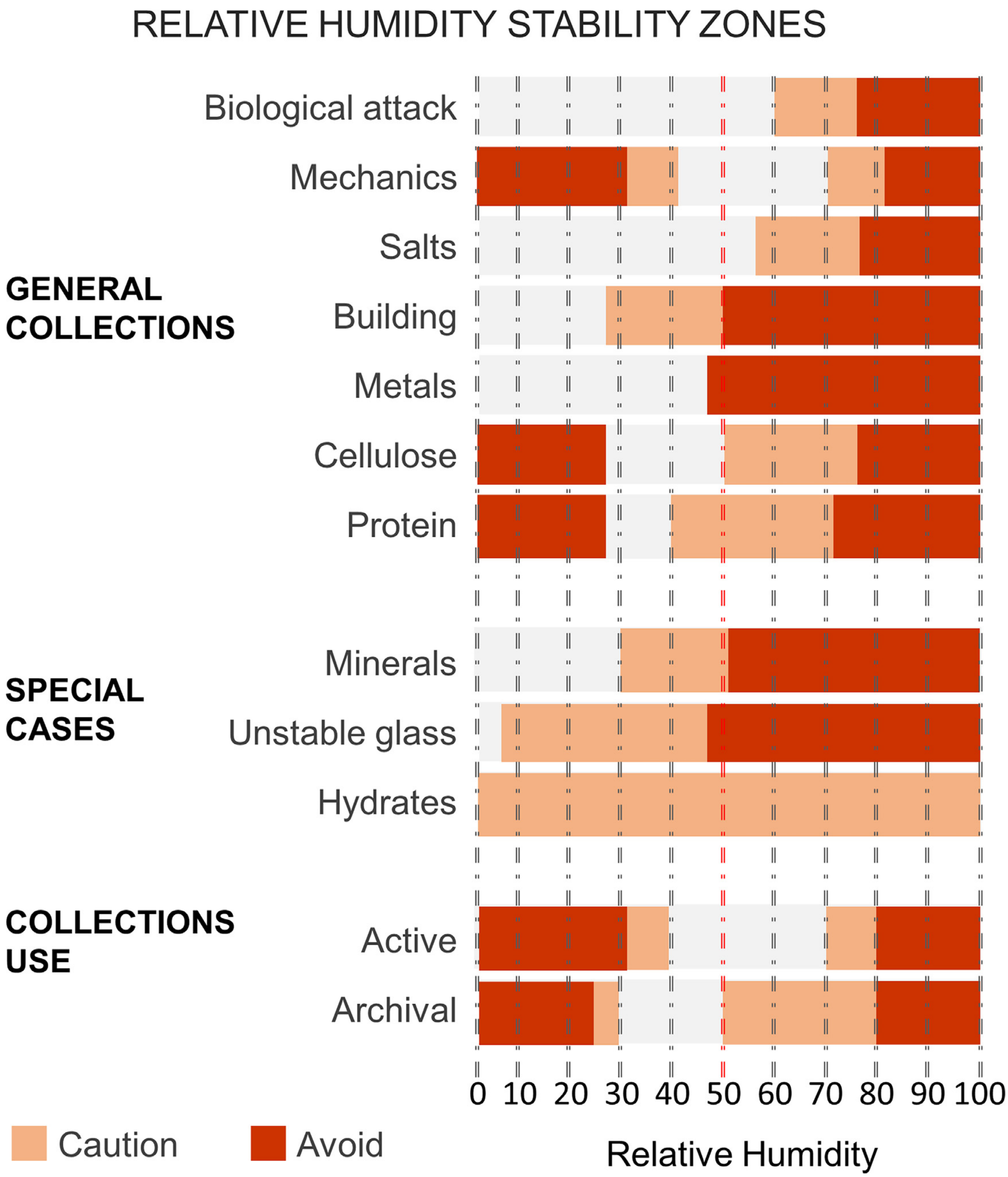

Figure 8. Comfort zones variation of RH in a diverse range of materials as described by D. Erhardt and M. Mecklenburg [59]

course, the constant control of radioactive emission and light intensity is essential, trying, with the appropriate climate, to keep the containment room as dark as possible for as long as possible.

Finally, **environmental particulate**, as well as general pollution, must be limited as much as possible, given its decisive role in the introduction of the life cycle on surfaces, as well as the biotic transport that the atmosphere itself harbours. To control this factor, the filtering of air present in the storage and exhibition space, as well as the recirculation of filtered air, should be emphasised [60]. If necessary, an extraction system should be implemented. It is also interesting to consider protective storage, which inhibits direct contact with the environment using inert materials that are compatible with the object and do not attract environmental dust.

The presence of biological particulates in the environment must be controlled with regular ventilation, and specific filters can be implemented to not allow organisms to access the space. There are also life development predicting methods via specialised data logger installation, which considers environmental conditions to report the possibility of biological occurrence. Accordingly, a fungal logger recognizes the fungal growth rate and the characteristics of the environment to estimate the stage of growth and dispersal [61].

Finally, serving as general recommendations, practices such as isolation of new items, a standardised quarantine period, and periodic review of the conditions of the archive, exhibition or specific room are highlighted. Likewise, the maintenance and surveillance of the air filters of the air conditioning systems is indispensable, due to the possibility of fungal settlement in this area [62]. Undoubtedly, the regulated cleaning of the space is decisive and obligatory for the correct maintenance and preventive conservation.

8.2. THE ARTWORK'S INTRINSIC CONSIDERATIONS

For a correct qualitative assessment and decision making on the intervention of a specific piece concerning biodeterioration, first, and to establish an adequate model of consideration, the damage must be detected and located, along with its typology and the study of its incidence, severity and attacking organism. Once the state of the damage has been determined, the situation must be assessed, establishing the need for treatment and the quantitative impact on the artwork. Determining the cause of the biological occurrence is an important information-gathering step and the first step in the development of an effective prevention protocol; the cause could be single or multiple, it may be a deceptive clue or present itself as an unsolvable problem in the given environment, or it may be an unnoticed prior attack whose organisms have already disappeared. All these possibilities guide the construction of the consideration system.

Eliminating biological residue without altering the original medium must be conducted before deciding to use a biocide. Before deciding if a particular biocide should be used, the first consideration lies in the effectiveness of the hypothetical treatment, evaluating its potential negative consequences on the object/material itself, the operator, the environment, and subsequent maintenance. Before contact with the original piece, the impact of previous interventions (if they exist) should be estimated and any previously added preservative materials or structural, physical treatments should be considered as well. Once the best method harbours sufficient compatibility with the artwork's situation, a biodeterioration prevention plan should be established, allowing the adjustment of preventive conservation measures after the intervention. It is also necessary, knowing the material composition of the pieces and the type of contamination present, to carry out tests in the laboratory and ensure effectiveness. It will improve the elective perspective and will result in an adequate, meditated route of action in favour of the artistic material, thus giving way to reflect on the maintenance of the piece, and the establishment of a routine of periodic care/revisions, the nature of these treatments and the frequency of their application.

8.3. THE ARTWORK'S EXTRINSIC CONSIDERATIONS

The space in which the artwork inhabits determines the survival of its materials to biodeterioration, so, in addition to assessing the activity related to the work, it is essential to complete the inspection for the conservation of the work with the assessment of the containing space.

Firstly, the conditions and characteristics of the building must be analysed; then the conditions and characteristics of the environment and interior spaces, such as storage rooms, adjoining or nearby spaces; and finally, the analysis of the conditions, characteristics, and state of the collections themselves. This hierarchical observation will allow the monitoring and cleaning division of the corresponding architectural elements. Specialised and concentrated attention is required in the following categories: the cleanliness of general spaces, compliance with standards and inspections, routine cleaning and vacuuming, and the correct distribution and replacement of traps; the cleanliness of the objects and pieces themselves, as well as the spaces under or behind the exhibition furniture; and the security and maintenance of the building itself and its protection [63].

Finally, and with this inspection completed, the implementation of standardised analytical management is required, which translates into the introduction of the specific programme IPM, Integrated Pest Management, a strategy of action for pest control, which makes it necessary to recognise the priorities and adapt them, in pursuance of enabling valid protocols, as well as future expansion [64]. IPM aims to establish systems and protocols to block the emergence of pests; and if possible, to prevent their introduction; and if detected, to identify them; and then to critically assess the problem of emergence, which requires a systematic inspection established from the outset, and which will house the orderly recording of results and history of treatment and movements. Consistency of data collection is essential to determine trends within the space and to be able to target the detected biointroduction problem, as well as to identify specific at-risk parts of the site and room. Finally, this strategy itself should be periodically reviewed and subjected to utility assessments and changes if necessary.

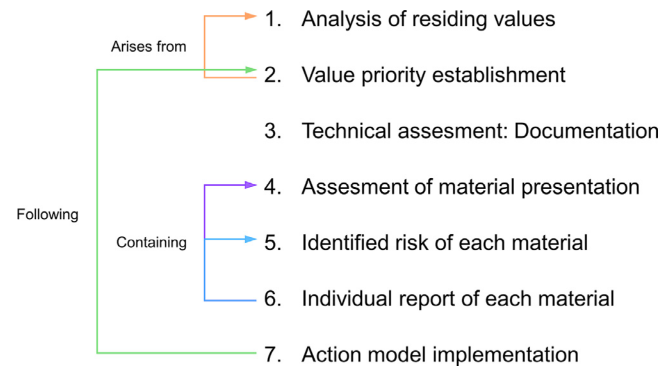

Figure 9. Action model for multi-material contemporary art works in relation to biodeterioration

8.4. STRATEGIC MODEL PROPOSAL ADAPTED TO CONTEMPORARY POLY-MATERIAL WORKS

The considered identification of the conservation goals of the work and its intrinsic and extrinsic characteristics serves to construct a path towards informed and appropriate decision making. However, the specification of the use of contemporary materials requires differentiation of action, focusing on the constituent materials and the effect of their presence and interaction together. For this purpose, a decision-making model has been developed for contemporary works composed of various materials, susceptible or already biodeteriorated (Fig. 9).

The first reflection lies in understanding the symbolic value of the piece to be treated. The analysis of resident, artistic values is essential, not only to act against biodeterioration but for any intervention or treatment around contemporary works in general. Thus, values of materiality, authenticity, historicity, aesthetics, investment, or iconicity must be identified (and ranked), and their presence on the component materials must be determined. This is the only way to assimilate an accurate vision of the artistic symbolism and to establish an informed reading of the piece. With the values identified, it is necessary to set the priority value(s), a determination that directs the consideration and perspective of the work (Fig. 9 points 1 and 2).

Next, the condition, characteristics, composition, and position in the artwork of each material must be assessed. For this, documenting and measuring factors such as placement, intervals between materials, and the relationship between that placement and the materials themselves are essential steps (Fig. 9 point 3). With this initial breakdown of materials, evaluation of the state of conservation, the artistic treatment and the presentation of materials can proceed. From this point on, it will be possible to identify each material's risks separately and/or in relation to other components along with evaluating whether there are materials that would be a contamination factor for the rest.

As a subsequent step, we propose the creation of appendices or individual files with the characteristics of the work and possible effects according to the unique circumstances of the piece, space, and usual location (if it is in storage, exhibition; if it has been or is often transferred; deteriorated or not; recent or cumulative deterioration, etc.). These sheets provide information on the composition of each individual material in detail; its state of conservation; its position in the art piece; its interaction with the other materials and the relationship of balance that exists; whether it poses a possible risk to the correct conservation of other materials; the biological typology capable of deteriorating the material; as well as a detailed history of restorative treatments and/or the application of biocides. Finally, special preventive conservation considerations should be contemplated, either to prolong the life of the material in general or concerning previous biocide treatments or products (Fig. 9 points 4,5,6).

Lastly, when it is time to act on the artwork, all the information gathered during the decision-making process is used to establish a safe intervention trajectory. With the material aspect under control and the knowledge of the technical behaviour of the whole, the priority values already established are considered to achieve a sustainable balance of all materials (Fig 9 Point 7).

9. CONCLUSION AND FUTURE PERSPECTIVES

The premise of contemporary preventive conservation presents complex decision-making routes and concerns relating to values often neglected in traditional artistic interventions.

The possibility of biological impact does not decrease regardless of contemporary materials incorporation in art pieces. This notion was explored in this review through the careful consideration of commonly preferred materials in mixed media confections and the study of their biodeterioration possibilities in the context of indoor storage or art collection environments. The focus on material composition and biodeterioration phenomenology allow the preventive conservation professional to foresee physical alteration outcomes and grasp the depth of biodegradation possibilities specific to collection care. Implementing an action model proved to be necessary since on modern materials, biodeterioration agents like fungi or bacteria are most prevalent, and their extermination could demand a treatment suitable for certain elements of the artwork but damage other parts of it for example the surface, base layers, addons, etc.

Through the information gathered, the approach to preventive conservation in the case of poly-material artworks affected by biodeterioration was organised, on top of establishing awareness of the vulnerability of numerous and diverse materials (that are not usually conceptualised as possible victims of biological attack). With this review of material incidence, a biodeterioration risk assessment was conducted, achieving familiarisation with the most common species. The great biological variety observed on works of art is thus established, solidifying the importance of prior study and taxonomic identification of the attacking species to eventually act on heritage content, and make the correct decision according to the existing biological typology in the future.

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