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Hybrid materials in design. Collaboration with nature as a creative practice (passage of research)

Hybrid materials

Hybrid materials are composites that have the characteristics of two different components or even acquire and create new properties[4]. Many natural hybrid materials consist of two different components – organic[5] and inorganic compounds[6]. In such cases, the inorganic part provides the mechanical strength and overall structure of natural objects, while the organic part connects them. In this article, it is important for me to find out the true meanings of the classification of natural materials and to briefly overview the history of the development of hybrid materials. The previous phase of the study described personal experiences during a trip to Guatemala and the first relationship with new plastiglomerate rocks, which geologically partially confirm the existence of a new Anthropocene period and are a perfect example of a combination of hybrid materials – a symbol of synthetic civilization – plastic and the natural world of nature, however, in this article, when talking about hybrid materials, I will limit myself to natural materials only. The decision to narrow down the overview was determined by my work and experience in this particular area of materials.

The growth of hybrid living materials in both the academic science community and industry is driven by the need for new knowledge and the personal curiosity of scientists. Contemporary artists experimenting with various biomaterials or bacterial cultivation technologies are no exception. The main periods in the field of natural sciences related to the genesis of hybrid materials are prebiotic chemistry[7], the first hybrid materials, the production process of *sol-gel* materials[8] and modern hybrid materials[9]. With the development of hybrid materials in the natural sciences, a bioart revolution has emerged in parallel in the art world, revealing how society interacts with science without avoiding the use of even living tissue parts in its practices[10].

The first hybrid materials

The first hybrid materials were used in an early period, as is evidenced by the frescoes of prehistoric caves. As it is still known, the oldest painting was found in 2017 on the island of *Sulawesi*, Indonesia, a full-scale painting of a wild boar created about 45,500 years ago, using the first man-made hybrid material – dark red ocher dye[11]. Such dye was produced by mixing two components with different properties – iron oxide (inorganic compound) and water (organic compound rich in carbon bonds or even microorganisms). Archaeological research presented in a 5-part mini-series created by U.S. broadcaster PBS proves that such hybrid materials have also been used in tribal rituals, burial processes, or even used in daily life to mark and distinguish which members of the tribe are hunters and which are pickers and so on.[12] Other so-called earth pigments are also found in the caves that date back. Shades of this type are extracted from minerals, iron ore, charcoal, burnt bones or white lime[13], and mixed with water they alter the physical properties of the materials (for example, a liquid substance is formed from loose powder), thus creating new ways to use pigments.

The Guardian, *World's oldest known cave painting' found in Indonesia,* 2021 m. [interactive]: https://www.theguardian.com/science/2021/jan/13/worlds-oldest-known-cave-painting-found-in-indonesia

Marco Almbauer - Own work, *Hellocker-Pigment*, 2015 m. [interactive]: https://upload.wikimedia.org/wikipedia/commons/b/b3/Hellocker-_Pigment.JPG

Evidence of the first use of hybrid materials is also being found in Europe, such as wall paintings of the *Lascaux*cave in France, created almost 17,000 years ago[14]. Here, each component played a specific role: the rust powder was a pigment that created a brownish-orange

shade, and aluminosilicate clays were used as the dye base. Later the inorganic components were combined with organic binders (animal bone marrow, fat, urine, saliva, blood, etc.) which were mixed to form hybrid clays. Other examples of this type of clay have been used around the world and have been used from cosmetics to prehistoric medicine[15]. Preparations of hybrids of natural origin for cleaning or treating skin infections are still used today (face masks, mud baths, etc.).

Another example of early hybrid materials is clay mineral-based wool bleaching and fabric washing materials used in ancient Cyprus and Rome about 7,000 years ago. Archaeological evidence has been found that clay and sand were combined with urine in Rome to organically improve detergent properties. The Romans even made a commercial system to collect urine waste from public urinals and sell it as a detergent[16]. As a modern hybrid of clay and urine materials – the waste-free and ring-design-based building material developed by Suzanne Lambert, a scientist at the University of Cape Town, which is produced by solidifying sand with human urine at room temperature – can be mentioned. The process used is called *Microbial Carbonate Precipitation* and is equated to the formation of seashell material[17]. Sand and human urine, which is rich in bacteria that produce the enzyme urease, are poured into a brick form. Urease causes a chemical reaction – it breaks down in the urine and produces calcium carbonate, known as the main component of cement, which hardens the bricks.

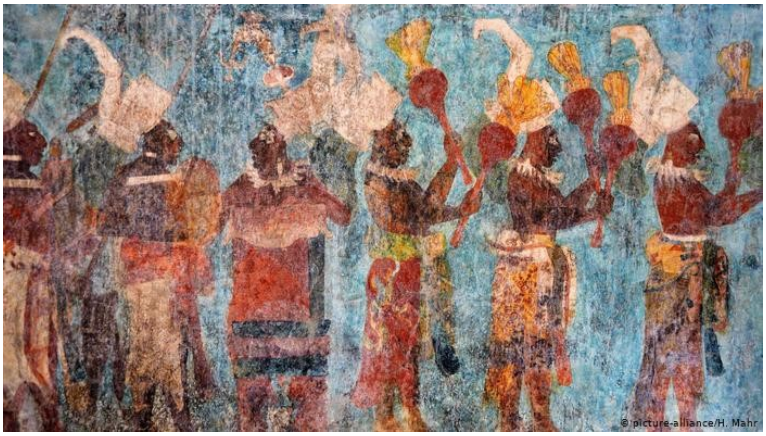
The Great Wall of China, *Dr.Zhang said the use of sticky rice was one of the greatest technical innovations of the time*, [interactive]: *https://harinhk.wordpress.com/2016/02/22/examine-your-interests-towards-china-through-this-post/*

One more example of the first hybrid materials is found in ancient China, during the Ming Dynasty (1368 - 1644). According to Chinese scientists, the secret of the strength and durability of the Great Wall of China lies in the sticky rice that was used in the hybrid mortar along with another

standard mortar ingredient – lime. In ancient China, the hydraulic mortar was not available, possibly due to a lack of volcanic ash in the area, but the sticky rice composite had higher strength and water resistance than lime mortar[18] and also prevented the growth of weeds.

During the studies of modern chemical science amylopectin – a type of polysaccharide found in rice and other starchy food products that are responsible for the strength and durability of sticky rice mortar – has been identified[19].

Inorganic solid materials, such as clay minerals, were also used in ancient times as bases for hybrid materials to preserve and conserve the characteristics of organic materials. Thus, around the year 800, using *attapulgite* and trying to preserve the specific properties of indigo pigment, the people of ancient Mayan civilization developed a nanocomposite hybrid material[20]. The obtained composite is an extremely stable pigment, resistant to UV radiation and temperature above 200 °C.



DW, *Oldest and biggest Mayan monument discovered*, 2020 m. [interactive]: https://www.dw.com/en/oldest-andbiggest-mayan-monument-discovered/a-53697662

Nila Colori, *Pigment Maya Blue - Type 1,* [interactive]: https://nilacolori.com/prodotto/pigment-maya-blue-type-1/?lang=en

This dark blue material was used during the ceremonies and was associated with the deities of the rain – the Mayans painted the sacrifices for the gods in the hope of rain. Mayan blue was also used to decorate pottery or create frescoes in temples. Surprisingly, it has remained too intact and unchanged for centuries even in the warm and humid tropical climate of Central America. Mayan blue was created in Yucatan, Central Mexico, and Guatemala (from personal experience

during a trip to Guatemala, I can see that Mayan blue is still the dominant color in the country, used extensively not only in old frescoes but also in conventional wall decoration or modern street art).

The technique of Mayan blue production continued in Spain, from where, later, in the colonial 19th century, it came to the Cuban region and began to be called Havana blue[21]. Today, Mayan blue is described as a nanohybrid material, and ancient Mayan technological experience has been used in the modern chemical industry to ensure pigment durability in hybrid polymer-clay nanocomposites and *geopolymers*.

During the second period, which lasts from 1600 to 1940, the synthesis chemistry of silicates, silicon and general materials was the most developed, the first rubber and industrial silicone were created from organic polymers. The third period from 1940 to the end of 1970 is characterized by the development of mixed organic and inorganic materials – clay, zeolites[22], other polymers are mixed with additional components to give the materials different properties. This type of material is classified as synthetic hybrids, so I will not expand too much in this historic period.

The fourth period of hybrid materials, from the beginning of the 1980s to the present day, is characterized by new "soft chemistry" methods, which lead to the development of colloids[23], gels, cellular ceramics and other materials. These methods make it possible to combine materials of organic biological origin with minerals in a broad sense and to develop new hybrid materials that meet today's technological needs.

Modern hybrid materials

Hybrids containing organic and inorganic constituents are increasingly popular as very strong and promising modern materials. The additional characteristics provided create the perfect synergy of the properties of the desired material and the final product. The diversity of results and the abundance of new properties offer very broad perspectives for the application of materials and encourage the involvement of different research communities[24], it is a strong catalyst for innovations. Further, I will single out a couple of the clearest (without trying to delve too much

into the separate science of biotechnology) and the most relevant components for my research used in the development of modern hybrids – one example from the field of organic-chemical hybrid materials, another – organic-biological.

Hydrogels are one of the fastest-growing components of organic-chemical hybrids in biotechnology and materials science. It is a network of hydrophilic polymer[25] chains composed of cross-polymers that create large water gaps. Hydrogels may consist of networks of intermediate hydrophilic polymers, such as collagen[26], alginate[27], elastin[28], fibrin[29], etc. Other chemical and physical methods can also be used to form them. Hydrogels are very versatile – the three-dimensional microenvironment of their structures ensures the transfer of nutrients, gases and active biomolecules, in especially important tissue engineering and regenerative medicine, into the material. Hydrogel stiffness affects cell behavior and can be used as a multi-cell culture platform to imitate living tissue[30]. Aerogels formed from hydrogels are one of the lightest solids known to a human today: combining a polymer with a solvent a gel material is formed from which the liquids removed are replaced by gas to maintain the same solid network of material but radically change its weight[31] [32]. Innovative 3D *bio-inks* are also produced from hydrogels used in the creation of functioning human organs, various ointments for the treatment of wounds or scars.

Thermaxx Jackets, *Aerogel Insulation Blankets By Thermaxx Jackets,* 2019 m. [interactive]: https://www.thermaxxjackets.com/aerogel-insulation-blankets/

Cells, bacteria and microorganisms, which consist of organic molecules, are used to form organic-biological hybrid materials. Organic molecules found in the plant, mammalian and bacterial cells are considered to be the main building blocks of biology and microbiology. Unicellular organisms allow us to get essential information on the main processes of cell biology required for the study of other multicellular organisms – worms, insects and other small creatures or even living human tissues, which allow us to understand even more complex vital processes in the human body[33].

The choice of the main components in the creation of hybrid materials depends on their properties to supplement or add functionality to the materials related to specific physical, chemical or biological properties. In the case of my art project, I do not seek to create the specific benefits of functionality by "improving" already existing properties of materials, but by creating hybrid materials I experiment between chemistry and biology and explore under what conditions – staged by the designer – materials naturally acquire and create new properties.

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[4] Science Direct, *Hybrid Material*, 2019 [interactive], [accessed: 31 03 2021]: https://www.sciencedirect.com/topics/materials-science/hybrid-material

[5] **Organic compounds** are any chemical compounds having carbon-hydrogen bonds. Millions of organic compounds are known due to carbon's ability to catenate (form chains with other carbon atoms). The study of the properties, reactions, and syntheses of organic compounds involves a discipline called organic chemistry. The boundary between organic and inorganic compounds is not very precise. Source: Spencer L. Seager, Michael R. Slabaugh. Chemistry for Today: general, organic, and biochemistry. Thomson Brooks/Cole, 2004, p. 342

[6] **Inorganic compounds** – in chemistry, inorganic compounds are usually those that lack carbon-hydrogen bonds, but the difference is not clearly defined. Source: Some major textbooks on inorganic chemistry decline to define inorganic compounds: Holleman, A. F.; Wiberg, E. Inorganic Chemistry Academic Press: San Francisco, 2001.

[7] **Prebiotic chemistry** is a science of how organic compounds formed and began to organize the emergence of life on Earth millions of years ago. Generally speaking, this field explores the path from chemistry to biology and raises the question whether this was determined solely by happy coincidence or whether it was a consequence of the inevitable laws of nature. Source: [interactive], [accessed: 31 03 2021]: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4187135/).

[8] The sol-gel process, developed in the 1930s, is the production of solids from micro-molecules. The method is used for the production of metal oxides, especially silicon and titanium. The process is described as a wet-chemistry method used to produce both glass and ceramic materials. In this process, the sol (or solution) gradually develops into a gel material and forms a network consisting of liquid and solid material phases. The applicability of the gel materials obtained during the sol-gel process is very wide – from the lightest *aerogel* material in the world to the hardest ceramic materials. Source: Brinker, C.J., et al., *Sol-Gel Transition in Simple Silicates, J. Non-Crystalline Solids*, Vol.48, 1982, p .47

[9] Research Gate, *History of Organic - Inorganic Hybrid Materials: Prehistory, Art, Science, and Advanced Applications,* 2018 [interactive], [accessed: 31 03 2021]: https://www.researchgate.net/publication/324587776_History_of_Organic-Inorganic_Hybrid_Materials_Prehistory_Art_Science_and_Advanced_Applications

[10] Dazed Digital, *Exploring the Complexities of Bioart,* 2018 [interactive], [accessed: 31 03 2021]: https://www.dazeddigital.com/beauty/body/article/42109/1/exploring-complexities-bioart

[11] The Guardian, *World's oldest known cave painting' found in Indonesia,* 2021 [interactive], [accessed: 31 03 2021]: https://www.theguardian.com/science/2021/jan/13/worlds-oldest-known-cave-painting-found-in-indonesia

[12] PBS, *First Peoples 9TV program),* 2015

[13] Pigments through the Ages, *Prehistory*, [interactive], [accessed: 31 03 2021]: http://www.webexhibits.org/pigments/intro/early.html

[14] Royal Society of Chemistry, *Prehistoric Pigments,* [interactive], [accessed: 31 03 2021]: https://edu.rsc.org/resources/prehistoric-pigments/1540.article

[15] M. I. Carretero, *Applied Clay Science,* 2002, p. 21, 155.

[16] The Guardian, *World's oldest known cave painting' found in Indonesia,* 2021 [interactive], [accessed: 31 03 2021]: http://www.ehu.eus/sem/macla_pdf/macla9/macla9_15.pdf

[17] Giora Rytwo, Environmental Sciences Department, Tel Hal Academic College, Upper Galilee (Israel), *Clay Minerals as an Ancient Nanotechnology: Historical Uses of Clay Organic Interactions, and Future Possible Perspectives,* 2008 [interactive], [accessed: 31 03 2021]: https://www.news.uct.ac.za/article/-2018-10-24-world-first-bio-bricks-from-urine

[18] Science Daily, *Revealing the ancient Chinese secret of sticky rice mortar,* 2010 [interactive], [accessed: 31 03 2021]: https://www.sciencedaily.com/releases/2010/05/100530093704.htm

[19] The Guardian, *World's oldest known cave painting' found in Indonesia,* 2021 [interactive], [accessed: 31 03 2021]: https://link.springer.com/article/10.1007/s11431-008-0317-0

[20] Springer, FuWei Yang, BingJian Zhang, ChangChu Pan, YuYao Zeng, *Traditional mortar represented by sticky rice lime mortar - One of the great inventions in ancient China,* 2009 [interactive], [accessed: 31 03 2021]: P. Gomez-Romero, C. Sanchez, New Journal of Chemistry 2005, 29, 57.

[21] Research Gate, *History of Organic - Inorganic Hybrid Materials: Prehistory, Art, Science, and Advanced Applications,* 2018 [interactive], [accessed: 31 03 2021]: https://www.researchgate.net/publication/324587776_History_of_Organic-Inorganic_Hybrid_Materials_Prehistory_Art_Science_and_Advanced_Applications

[22] **Zeolites** are minerals rich in aluminum and silicon compounds. They are used as a material with drying properties, water or air cleaners. Zeolites are also sold as dietary supplements to treat various ailments, and they can also remove heavy metals from the body. Source: [interactive], [accessed: 31 03 2021]: https://www.mskcc.org/cancer-care/integrative-medicine/herbs/zeolite.

[23] **Colloids** are mixtures of materials in which one substance of microscopic particles breaks down insoluble particles of another substance. Source: [interactive], [accessed: 31 03 2021]: https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/Solutions_and_Mixtures/Colloid

[24] Frontiers in Chemistry, *Hierarchy of Hybrid Materials - The Place of Inorganics-in-Organics in it, Their Composition and Applications,* 2019 [interactive], [accessed: 31 03 2021]: https://www.frontiersin.org/articles/10.3389/fchem.2019.00179/full

[25] **Hydrophilic polymers** are minerals rich in aluminum and silicon compounds. They are used as a material with drying properties, water or air cleaners. Zeolites are also sold as dietary supplements to treat various ailments, and they can also remove heavy metals from the body. Source: [interactive], [accessed: 31 03 2021]: https://www.mskcc.org/cancer-care/integrative-medicine/herbs/zeolite.

[26] **Collagen** is a protein in the form of a thread, one of the most important supporting materials for intercellular protein in connective tissues and the epithelial tissue's basement membrane. Form collagen fibers. Source: [interactive], [accessed: 31 03 2021]: https://www.jbc.org/article/S0021-9258(20)87534-6/fulltext

[27] **Alginate** is a naturally occurring anionic (atom or group of atoms with a negative charge) polymer commonly derived from brown seaweed. Source: [interactive], [accessed: 31 03 2021]: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3223967/

[28] **Elastin** is a connective tissue fibrillar protein that is included in tissues with elastic properties. These proteins form fibrils that can be stretched several times longer than their normal length, then they can twist again and return to their original position. Source: [interactive], [accessed: 31 03 2021]: https://www.ligos.lt/lt/terminai/elastinas/652/

[29] **Fibrin** is an insoluble, fibrillar protein important for blood clotting. Source: [interactive], [accessed: 31 03 2021]: https://www.ligos.lt/lt/terminai/fibrinas/786/

[30] Frontiers in Chemistry, *Hierarchy of Hybrid Materials - The Place of Inorganics-in-Organics in it, Their Composition and Applications*, 2019 [interactive], [accessed: 31 03 2021]: https://www.frontiersin.org/articles/10.3389/fchem.2019.00179/full

[31] Thermaxx Jackets, *Aerogel Insulation Blankets By Thermaxx Jackets,* 2019 [interactive], [accessed: 31 03 2021]: https://www.thermaxxjackets.com/aerogel-insulation-blankets/

[32] NASA, *Aerogels: Thinner, Lighter, Stronger,* 2011 [interactive], [accessed: 31 03 2021]: https://www.nasa.gov/topics/technology/features/aerogels.html

[33] Frontiers in Chemistry, *Hierarchy of Hybrid Materials - The Place of Inorganics-in-Organics in it, Their Composition and Applications*, 2019 [interactive], [accessed: 31 03 2021]: https://www.frontiersin.org/articles/10.3389/fchem.2019.00179/full