Journal of Sol-Gel Science and Technology
https://doi.org/10.1007/s10971-022-05987-7

INVITED PAPER: INDUSTRIAL AND TECHNOLOGICAL APPLICATIONS OF SOL-GEL AND HYBRID MATERIALS

(M)other tongue: the optic and haptic scale for restAURAtion works made of silica aerogel

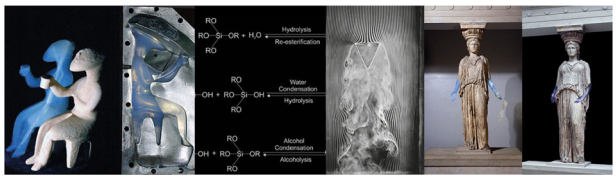
Ioannis Michaloudis[1] · Konstantina Papachristopoulou[2] · Farah El-Zein[3] · Szymon Pruciak[3] · Pagona-Noni Maravelaki[4] · Kazuyoshi Kanamori[5]

Received: 18 June 2022 / Accepted: 2 November 2022

Abstract

Silica aerogel is an attractive material for art as well as science and engineering. The characteristic transparency and low refractive index have made silica aerogel a novel material for visual arts under the name of *aer()sculptures*. Starting from one sculptural work by the first author, the artwork *(M)other*, is a novel concept proposing the use of silica aerogel in the "restAURAtion" of cultural heritage to replace classical plaster of Paris techniques. Restoring missing parts of a monument with a translucent material renders a new aesthetic quality. Light scattering disambiguates the missing arms of a Parthenon Caryatid, for example, an ethereal image adding to its historic value, which cannot be achieved by the plaster of Paris restoration technique.

Graphical abstract



Keywords Silica aerogel · Visual arts · Photography · Nanomaterials · Restoration · Heritage

Highlights

- Transparent silica aerogels have been used for visual arts by the first author and named as *Aer()sculptures*.
- The missing arms of a caryatid were restored by photo editing with transparent silica aerogels instead of plaster of Paris.
- The new aesthetic nature of restoration as a study case will be viewed in New Acropolis Museum.

✉ Ioannis Michaloudis
michalou@alum.mit.edu

✉ Kazuyoshi Kanamori
kanamori@kuchem.kyoto-u.ac.jp

[1] Institute of Nanoscience and Nanotechnology, National Centre for Scientific Research "Demokritos", Patr. Gregoriou E & 27 Neapoleos str. 1341, Aghia Paraskevi, Greece

[2] Photonic Nanotechnology Research Lab, Department of Matarial Sciences, University of Patras, Patras 26504, Greece

[3] Department of Design, Faculty of Arts and Humanities, American University of Cyprus, 52 Ammochostou Avenue, 6019 Larnaca, Cyprus

[4] School of Architecture, Technical University of Crete, Polytechnioupolis, Akrotiri, 73100 Chania, Crete, Greece

[5] Department of Chemistry, Graduate School of Science, Kyoto University, Kitashirakawa, Sakyo-ku, Kyoto 606-8502, Japan

Published online: 02 December 2022

1 Introduction

This paper is the continuation of an idea of the of the first author during his solo exhibition, *aer()sculptures*. The starting point for our paper will be the artwork *(M)other*, one of the MICHALOU(di)S's *aer()sculptures* (Fig. 1), presenting the complex of a two-person Cycladic figurine; on the shoulders of a female marble figurine, we see the engraved arm of a second missing figurine, an idol lost forever. The first author replaced the lost part of the Cycladic figurines' ensemble with an *aer()sculpture* made from silica aerogel, an ethereal nanomaterial composed of 99% nothing and 1% vitreous (Fig. 2). With an art and science academic team here (a visual artist, a material scientist, a photographer/interior designer, an architect, and a chemist) we are developing this same concept for sculptures where lost pieces of the marble could be replaced by the bluish fragments of sky. In order to propose prompt discussions on the scales and distances between the viewer and the heritage artifact, a visual but also tactile vocabulary has to be proposed, thus the subtitle of this paper is inspired from the title of an educational talk/presentation of the first and fourth authors at the 2nd Biennale of Larnaca on 13th of October, 2021 with the title "Synergies of Art, Science and Technology". In this paper, we will show how and why the concept of *aer()sculpture* restAURAtion was developed. The nanomaterial silica aerogel could replace the "plaster of Paris" used as a moulding material for casting copies of sculptures to restore the missing parts of ancient sculptures. Our hypothesis – better, our proposed concept – is a

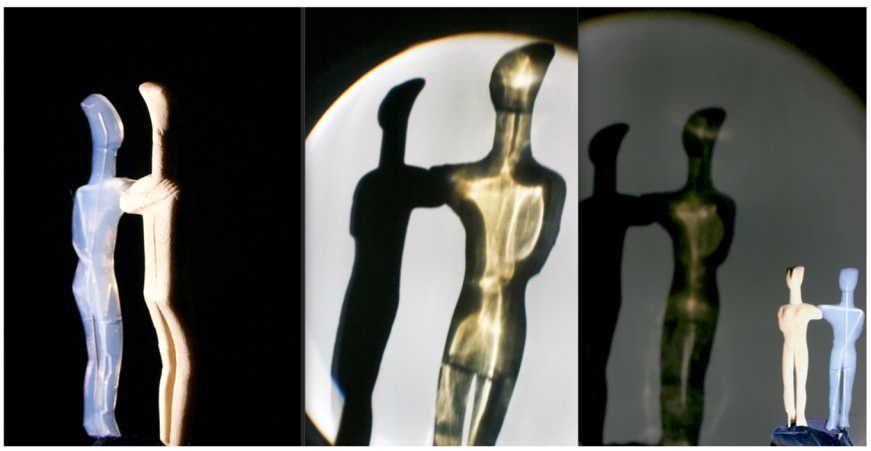


Fig. 1 *(M)other*, art installation in situ, silica aerogel, marble, LED light, projection screen, Museum of Cycladic Art, October 2006, Athens, Greece. Translucent silica aerogel permits the passage of light, thus producing a golden hue shadow, compared to the dark shadow coming from the marble. Partly adopted from ref [3], copyright © 2011, Springer Science Business Media, LLC

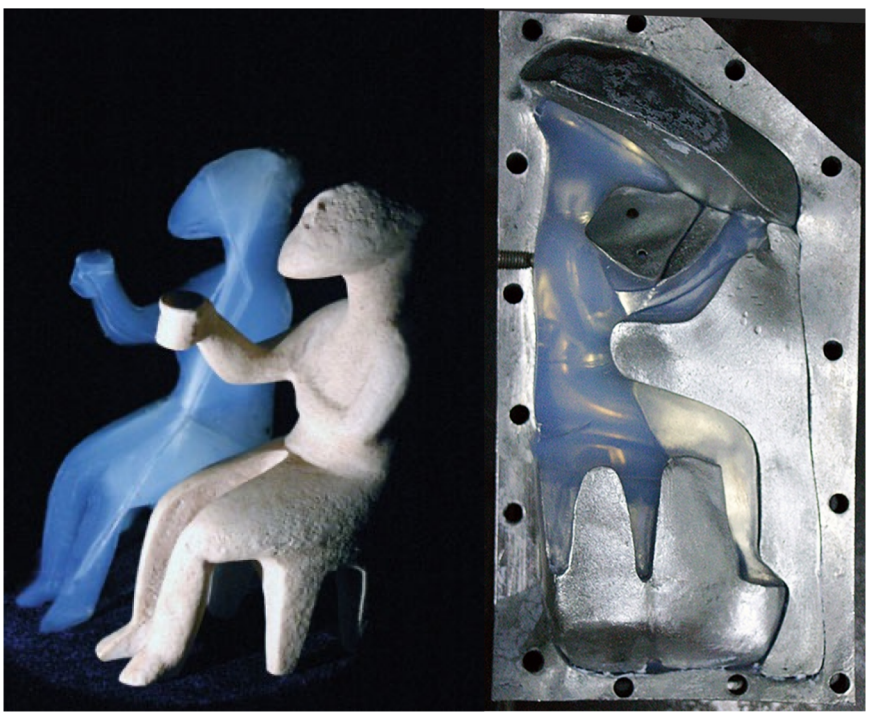


Fig. 2 *The cup-bearer*. (Left) The silica aerogel sculpture is 17 cm tall and weighs 20 g, but the marble sculpture of the same dimensions weighs 350 g. Photograph and copyright: MICHALOUS, 10/2006. (Right) A six-parts metalic mold is used to cast the complicated *cup-bearer* silica aerogel sculpture. Partly adopted from ref [3], copyright © 2011, Springer Science Business Media, LLC

parenthesis in the historic analysis of the monument adding an explanatory note on the statue's meaning and role as a piece of cultural heritage. The transparent, heavenly-looking silica aerogel material could suggest – and not impose – to the viewer a "see-through" missing part of the statue (according to the archaeological research findings, through with an ambiguity necessary to feed the minds). Our work concludes with a proposal of the case study of restoring the statue of the "Lost Caryatid" in the New Acropolis Museum in Athens Greece.

2 Conventional plaster of Paris vs. silica aerogel

2.1 Plaster of Paris

Plaster of Paris is the so-called quick-setting gypsum consisting of a fine white powder (calcium sulfate hemihydrate $CaSO_4 \cdot 0.5H_2O$), also known as modelling plaster in fine arts, which hardens when moistened and allowed to dry. The term plaster of Paris derives from of its preparation from the abundant gypsum found near Paris. It is prepared by calcining calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) or mineral gypsum at 120–180 °C.

The term plaster commonly refers to a variety of composite materials used for interior applications such as finishing of the wall, with important examples according to their chemical composition being lime plaster and gypsum plaster. Lime plaster originates from the calcination of calcium carbonate at 700–900 °C. Hydration and carbonation follow to yield secondary calcium carbonate. The gypsum plaster derives from rehydration of the calcium sulfate hemihydrate to yield again gypsum in the final dried solid material. The solidity of the hardened mass depends on the amount of water used, which determines the shape of the crystals. Excess water results in structures with high porosity with the presence of pores and voids. The setting process is accompanied by generation of heat (*ca*. 3900 cal/mol) and a slight increase in volume due to thermal expansion. It is usually used at the relative density of 0.5–0.7 (theoretical density 2.35 g/cm^3), with the pore diameter 50–200 μm. The microstructure consists of an aggregation of interlocking needle-shaped gypsum crystals. These physical properties result in the white, opaque appearance with well-defined interfaces coming from the high refractive index, which is in contrast to the silica aerogels [1].

The advantages of plaster of Paris, such as the minimum shrinkage and cracking upon drying and good workability, make it as an excellent medium for casting molds [2]. However, important drawbacks must be considered: (a) the need for sealing the pores to prevent moisture and dust ingress by applying a coating; (b) the low resistance to water action and the consequent possibility of leaching from the surface if non-water proofing additives were used; and (c) the need for hardening of the plaster by adding specific components, often altering the aesthetical appearance. Therefore, it becomes imperative that additives to be embedded in order to retard the setting time, especially in ornamental indoors plasterwork placed on ceilings and cornices, as well as to reduce porosity, water absorption and solubility and increase the hardness.

2.2 Aerogels and *Aer()sculptures*

Aerogels are the lightest solid materials ever created in human history [3]. These highly porous solid materials can be described as "solid foams" made of a sparse solid skeletal matrix, typically inorganic oxide/hydroxide, filled with air [4–6]. They exhibit porosity greater than 95 %, and up to the record value of 99.8 %, and a huge specific surface area of ~500–1500 m^2/g. Consequently, they are ultralight solids (Fig. 2) having density typically in the range of 2.0–200 mg/cm^3, and when degassed, their ultra-porous matrix density measures as low as ~0.7 mg/cm^3. To compare, the density of, for example, vitreous silica (SiO_2), forming the respective silica porous skeleton, is ~ 2.20 g/cm^3 and that of dry air ~1.2 mg/cm^3. Consequently, impressive unique physical properties are drawn from the solid ultra-porous and usually inert nature of aerogels.

Aerogels were first reported by the American scientist Samuel Stephens Kistler in 1931. He formed a wet gel and replaced the pore liquid solvent with air under supercritical drying conditions. Exceeding the critical point temperature, T_c, of the solvent mixture, the transition from liquid to gas allowed the material to dry via the supercritical state in the body of the gel. Technology today applies sol-gel synthesis of glasses and ceramics. The method produces a variety of inorganic porous networks from precursors of silicon, metallic, organic, and hybrid alkoxide monomers. Although the method was discovered in the late 18th century and studied extensively in the early 1930's, much attention was paid more recently with the development of monolithic gels [7]. Homogeneous ultralight aerogel solid materials were thus formed from inorganic oxides encompassing the desired properties, such as optical transparency, chemical resistance, in addition to the provision of specialized compositions.

Aerogels are classified into three categories, inorganic, organic and their hybrids. Structures are found in the form of monoliths, granules, or films, and are characterized by their specific porous configuration. Each category encompasses several types of aerogels, depending on the precursor reagents used for fabrication and as additives. The unique characteristic structure depends on the synthetic conditions

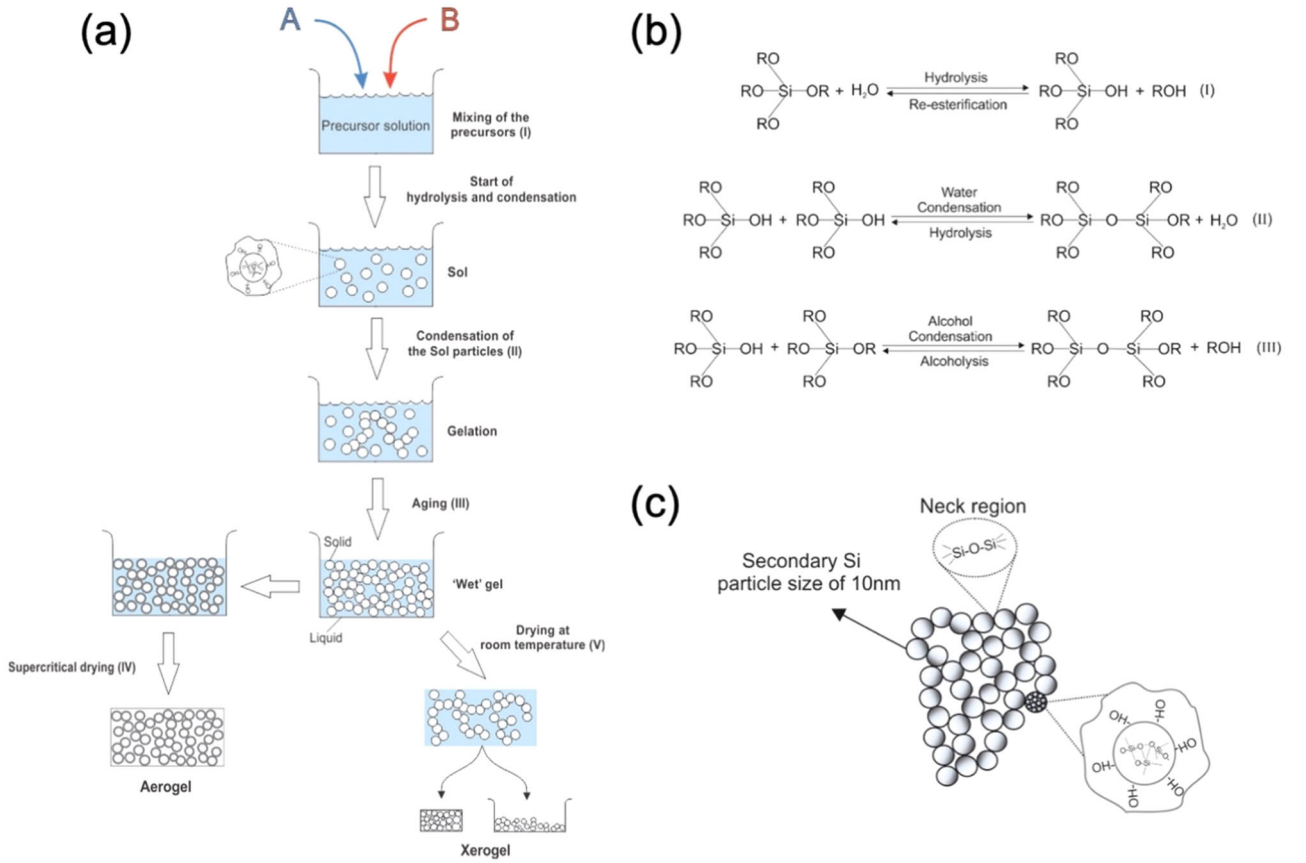


Fig. 3 **a** Flow diagram illustrating the typical fabrication process comprising (I) sol-gel composition, (II) condensation and gelation, (III) aging and wet gel production, (IV) supercritical drying for aerogel production, or, alternatively, (V) ambient pressure drying for xerogel production. **b** Chemical reactions forming the aerogel material and **c** schematic of its typical nanostructure

and materials used for manufacture. The solvent used in the sol-gel process plays a decisive role. Its importance is not only limited to the homogenization of the precursors in the initial stages of synthesis, but it also influences greatly the polarization and viscosity; in effect, it determines the formation dynamics, the final size and shape of the nanoparticles and, consequently, the skeleton network as a whole. Aerogel physical properties and behavior depend on the type, shape, and size of skeletons and pores, which are affected by the skeleton formation. Distinct cases have three-dimensional (3D) open pores connected by channels, forming air inclusions, respectively providing, or not, communication between the cavities within the material and the external environment.

Silica aerogels are the most popular and well-studied materials. Their silica skeletons can be formed by branched molecular networks. Their thermal conductivity is extremely low, $k \sim 0.01$ W/(m K) at 300 K, their subsonic speed of sound, $v \sim 90$–130 m/s, and their low refractive index, $n \sim 1.01$–1.24, properties of which make these materials very attractive for a variety of applications. It is important to note that all the above are combined with high transparency with some Rayleigh or Mie light scattering, respectively, for small and larger skeletal size and imperfections. Aerogels exhibit, in general, relatively low mechanical strength, having a modulus of elasticity < 1 MPa, thus requiring special handling techniques, even though they are quite mechanically stable under static stress.

Sol-gel processing involves the development of inorganic networks through the formation of a colloidal suspension of the sol–silica matrix and the formation of a gel, which is a porous network in a continuous liquid-phase. Figure 3 presents the typical fabrication process using precursor molecules such as alkoxides or salts of a metallic or metalloid element. Metal alkoxides are the most popular because they react easily with water. The most used alkoxides are alkoxysilanes, such as tetramethoxysilane (TMOS) and tetraethoxysilane (TEOS). However, other alkoxides, such as those of aluminum, titanium, and boron, are also used in the sol-gel process, often mixed with TMOS or TEOS. Gel preparation is the first step of aerogel synthesis, as presented in Stage I of Fig. 3. In a typical case, initially, the two primary solutions A and B are prepared. Solution A is a mixture of alkoxysilane and alcohol, while solution B is added as a mixture of water and catalyst. Upon reactions, the mixture leads to the sol, which is the colloidal

Fig. 4 Light scattering in MICHALOU(di)S's *aer() sculpture*, replica of a Protocycladic idol. Silica aerogel sculpture is in light transmission (left) and light back-scattering (right) modes. Adopted from ref [3], copyright © 2011, Springer Science Business Media, LLC

dispersion to be converted into a gel. Fabrication of solid porous materials is performed by gel casting techniques followed by postprocessing. Widely applied materials forming methods are the casting /molding, extrusion, foil manufacturing, fiber manufacturing or spinning, as well as dip coating and spin coating on flat substrates. Variations of these methods and/or their combinations lead to a plurality of manufacturing modes, which are industrially relevant and appropriate for inorganic and organic materials.

Under properly tuned drying conditions, no collapse of the solid skeleton occurs and thus monolithic aerogel objects can be cast with the help of simple or complicated molds (Fig. 2). Examples presented in Figs. 4, 5 are replicas of ancient Cycladic figurine, with characteristic hues due to the Rayleigh and Mie scattering phenomena by its solid skeletons [8]. Advances in the field are related to the production of fused silica nanostructures [9] by controlled sintering of micro-casted/micro-patterned artificially designed and natural bio-architectured master patterns. Further to these original developments, significant interest was generated in the late 1970s and 1980s when monolithic inorganic gels formed at low temperature turned into glass without the need for high-temperature fusion.

This paper involves the transformation of the restoration material in art by applying new science and technology and the metamorphoses of various masks or facets of art: sometimes as a sculpture then as an interactive installation, or finally, as a photography. A form is considered "attractive" when it begins to push its limits – the moment its inner tension approaches the state of its catastrophe, its exhaustion. In other words, a shape is only fascinating when it testifies to an exceeded limit. The concern that "limits" this paper will therefore be the spatio-temporal framework, where a form of expression exceeds its properties, changes shape and becomes formless, fluidic, elastic, etc. In other words, our hypothesis is; the metamorphosis of materials is the nodal point on which a form of artistic expression tilts towards another artistic form, more elastic; from its scarcity to its plethora, the material – and the nanomaterial – is a point both open and closed: a (c)over point.

We can say so that MICHALOU(di)S is a classic sculptor when he prepares the models and the moulds for his *aer()sculptures*… However, MICHALOU(di)S as an artist does not, in fact, produce "three-dimensional" shapes because, by working with a plastic/elastic material like the silica aerogel, he works with the memory of space and that of time. Based on Henri Poincarré, his artworks are spaces in-between dimensions asking for all senses to participate in the reading and contemplation of these works.

3 $(art)^{sci}$

> *"Science! true daughter of Old Time thou art! Who alterest all things with thy peering eyes. Why preyest thou thust upon the poet's heart, Vulture, whose wings are dull realities […]"*
>
> Poe, E. A., Sonnet – To Science

The relationship between Art and Science has endured for hundreds of years. As a neuroscientist Dr. Matt Johnson points out on the relationship: "*Both science and*

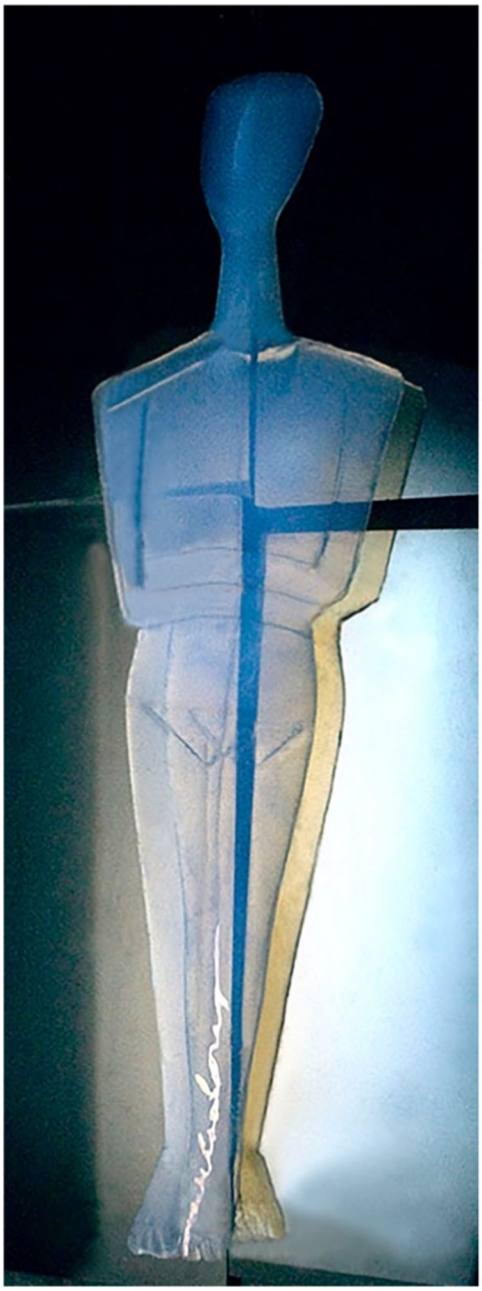


Fig. 5 *Modigliani* is a unique Protocycladic idol "translated' -thus our title- by MICHALOU(di)S from marble to silica aerogel. The diaphanous body of silica permits us to observe the metallic signature of the artist incorporated into the sculpture, $40 \times 20 \times 4$ cm, Athens, Greece, 2006. The orange and blue natural colors of the sculpture can be observed thanks to the Rayleigh scattering and four glossy black plastic panes

art are fundamentally concerned with the exploration and discovery of the unknown." Photography's relationship with both art and science is in its nature more difficult. Thousands of years of observations of natural phenomena of the physical world resulted in what we call *Camera Obscura* [10].

As in Fig. 6, *Camera Obscura* phenomenon comes from an observation that rays of light travel in straight lines and change when they are reflected and partly absorbed by an object, retaining information about the color and brightness of the surface of that object. Lighted objects reflect rays of light in all directions. A small enough opening, a pinhole, a *poros* [11], a barrier admits only the rays that travel directly from different points in the scene on the other side, and these rays form an image of that scene where they reach a surface opposite from the opening (Standage, 1773: 67). This unique device used for thousands of years by both scientists (*e.g.*, studies of the movements of the sun) and artists (*e.g.*, *Camera Obscura* used for perspective studies for sketches by artists like Vermeer in Fig. 7, or Canaletto) eventually married the chemical investigations, which started already in the 12th century [12], and thus photography was born. In its early days, despite the enthusiastic reception by the Fine Art community, verbalized famously by the French painter Paul Delaroche, who upon seeing the first daguerreotype image around 1840, declared "*From today, painting is dead*" (Newhall, 1973:17). Photography was perceived as a subservient.

Persistent work of photographers such as Edward Steichen and Alfred Stieglitz as well as the use of photography in a Pictorialist movement allowed this specific medium to be considered as Art on its own. This proposition was later cemented by the German philosopher, cultural critic and essayist Walter Benjamin in his cultural criticism essay "The Work of Art in the Age of Mechanical Reproduction", where he proposes and explains that mechanical reproduction devalues the *aura* (uniqueness) of an *objet d'art* and that in the age of mechanical reproduction and the absence of traditional and ritualistic value, the production of art would be inherently based upon the praxis of politics and ultimately permitting greater accuracy in reproducing a work of art.

Simultaneously, the relationship between photography and science was growing and interchangeably the first was informing the latter and vice versa. French scientist Étienne-Jules Marey in 1882 created his chronophotographic gun by using pictures from it he studied horses (and many other animals), birds, microscopic creatures and most importantly human locomotion. His work was significant not only in art and design with the studies of the smoke (Fig. 8) but also in the development of cardiology, physical instrumentation, aviation and cinematography. Thanks to his massive contribution to super-fast imaging technology few decades later, a young scientist at Massachusetts Institute of Technology, Harold Eugene "Doc" Edgerton, used stroboscopic equipment, in particular, multiple studio electronic flash units, to produce strikingly beautiful photographs, many of which appeared in Life Magazine and for which he was awarded a medal by the Royal Photographic Society. Prints

Fig. 6 Illustration of the camera obscura principle from James Ayscough's *A short account of the eye and nature of vision* (1755 fourth edition)

Fig. 7 Philip Steadman's exact reconstruction of "The Music Lesson" by Vermeer uses a plate camera with the lens in the precise position in space that Philip Steadman had determined previously as being the viewpoint of the painting and the use of Camera Obscura for the rendering for the painting

of the Edgerton's scientific work are sold in Fine Art Galleries around the world to this day.

Ever since, the relationship between art – including photography – and science was only getting stronger and has been evolving rapidly over the past 25 years, since NASA had released the first art-based payload of Lowry Burgess into outer space in 1989. Since this moment, Space Art has begun to flourish with such artists as Burgess and Joe Davies who seek to explore the relationships between space, science and art. In 2001 the first author, MICHALOU(di)S shifted his practice to Sky Art with the project *(Nephele)*^{3}*: the Cubic Cloud* generated at MIT and presented at the 2002 Sky Art Conference [13]. Through the use of the "immaterial" silica aerogel and its aesthetics that personify our sky, MICHALOU(di)S has become centered in Space Art. In the following chapters, we will show how the nanoporous silica aerogel replaces a material absence by a nanomaterial's supposition, similarly to the process of photographic retouching.

4 Presence in absence

The vast majority of society associates photographic retouching with advancement of digital photography, especially with the flagship software of Adobe Photoshop. While the phrase "to photoshop" was adopted among internet commenters just years after the software's release on February 19th, 1990, it did not become widespread until stories about edited propaganda and touched-up celebrities began to regularly fill the news feeds almost two decades later. Seeing usage raised in the late years of the first decade of the new millennium, Merriam-Webster decided to add "photoshop" to its dictionary in 2008, with a definition: "… to *alter (a digital image) with Photoshop software or other image-editing software especially in a way that distorts reality (as for deliberately deceptive purposes)*. (Merriam-Webster: 2008).

However, the history of retouching is as old as the history of photography itself. In 1839 Louis-Jacques-Mandé Daguerre, having succeeded with experiments in what we now know as photography, famously declared "I have seized the light – I have arrested its flight!" Subsequently Daguerre registered his ground breaking invention calling the process *Daguerreotype* (Fig. 9) with the French Academy of Sciences and the Académie des Beaux Arts on 7 January of that year. The images presented to both academies were enthusiastically praised as nearly miraculous, and news of the daguerreotype quickly spread. On 19 August 1839, the French Government presented the invention as a gift from France "free to the world", and complete working instructions were published.

Developments with other photographic techniques, such as William Henry Fox-Talbot's paper negative (Fig. 10),

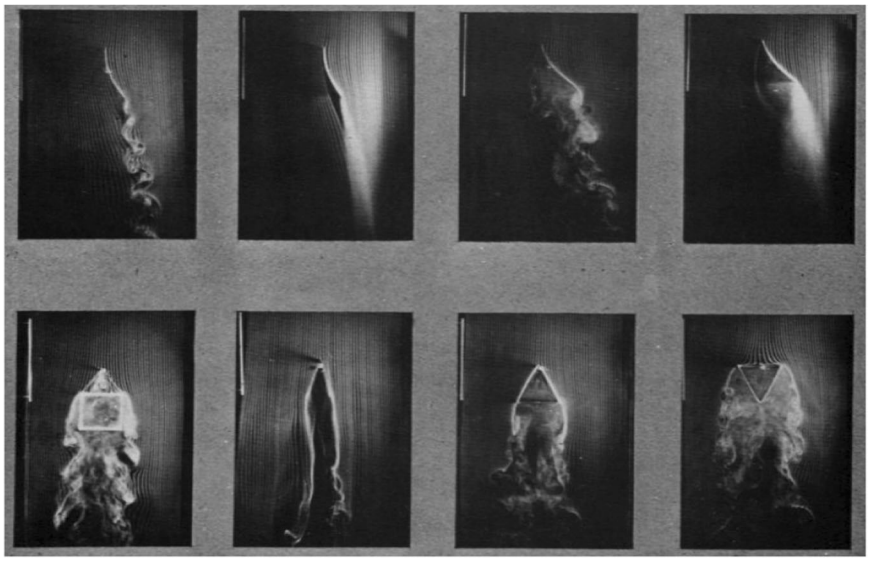


Fig. 8 ÉTIENNE-JULES MAREY, *Smoke photographs*. 1901

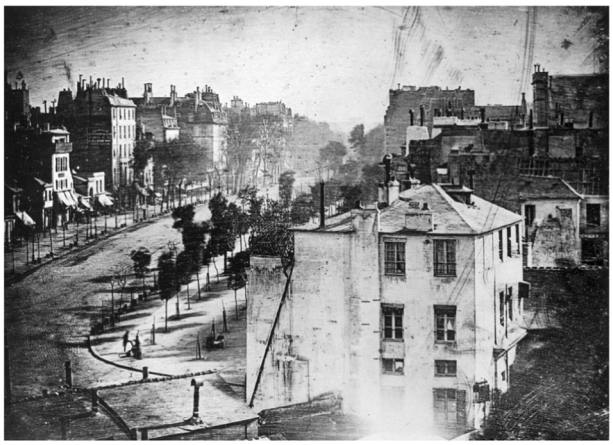


Fig. 9 Louis Jacques-Mandé Daguerre, *Boulevard du Temple*, Daguerreotype, 1838

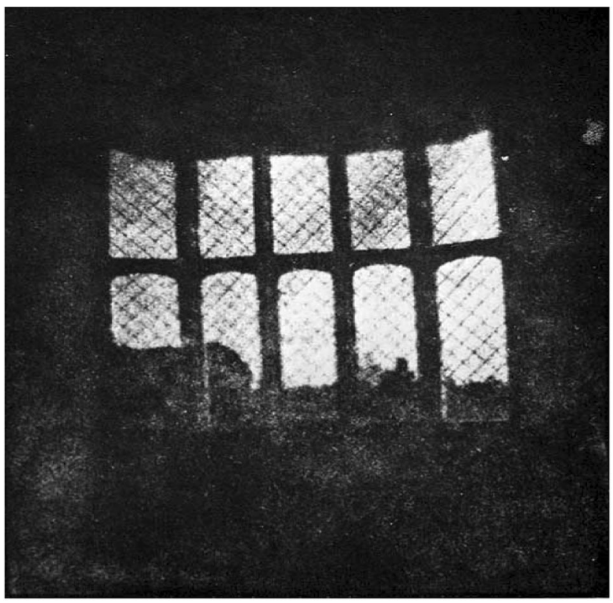


Fig. 10 William Henry Fox Talbot. Latticed window at Lacock Abbey, Calotype/Talbotype. 1835

pushed the photographic industry quickly in many new directions; the industry skyrocketed and invented many new techniques. Thus "photo-manipulation" became a new term for these strategies referring to a vast majority of techniques including film and negative manipulation, darkroom manipulation, chemical manipulation, and more. Even the term "Retouching" itself, was invented even prior to photography. It was a common term used by painters, meaning "reworking of a painting to enhance it". An early remaining example of photographic 'manipulation and retouching' is a composite photograph, where the head of Abraham Lincoln is superimposed on the background of an earlier print by A. H. Ritchie showing John C. Calhoun, 1852 (Fig. 11). This is of course an extreme example of using multiple images in the printing process. The vast majority of retouching involved simpler alterations and actions.

In 1888 Henry Reichenbach and George Eastman of the Eastman Company (later Eastman Kodak) developed a flexible film that was much easier to use and could be stored on rolls. This film featured a cellulose nitrate film base, called nitrocellulose celluloid or nitrate film. This film remained the main technique and since the 1930s practically the only method of recording photographs (and the moving image) for the entire industry and the general global public (Newhall, 1973: 153) up until the digital (r)evolution of early 2000.

The celluloid film was inserted into a camera and an image was recorded when the exposure took place. Once

Fig. 11 William Pate, *Calhoun John C. Abraham Lincoln*, mezzotint, 1865

the whole roll of film (the legendary 36 frames) was finished, it was then developed in a photographic darkroom where the latent image, developed using specific silver-based chemicals, would become a negative image. To achieve a positive image, a print on a photographic paper had to be produced, usually with the use of photographic darkroom enlarger. The most popular and mainstream film was 35 mm (across), so enlargements were practically always necessary. Photographic negatives on celluloid film, however, were very fragile – dust, scratches and grease from human fingers, as well as liquid stains from the process of development itself, often impacted on the look of final prints and that is where "retouching" was especially required. As tiny as dust and scratches could have appeared on the celluloid film itself, when enlarged onto photographic paper, they became a disturbance for the viewer.

Traditional analogue retouching is a manual task done with a brush on the print themselves with ink and water. Equipped with very fine brushes retouchers work with a minimal amount of ink and by "dotting" of the required areas they are matching the tonality of the surrounding to the area of work. The task for the retoucher is not to replace a missing or damaged part of the print with a replica of reality, but to push the attention of the viewer away from the area of the image which if not retouched would otherwise attract this attention. As the viewer of the photographic image is not aware of the "original" coming from the negative, there is no need (or even a possibility) to create such replica. Dust for example on a photographic negative lead to prints having bright white marks exactly on the same spot as the dust was sitting on the negative so the retouchers' task is to dot it finely. These areas of the photographic prints become literally spaces for projections of imaginations of the retoucher.

A similar approach to the absence is proposed in this paper for the use of the silica aerogel in conservation works in archeology of structures and sculptures. The proposed approach replaces the question of "What had been lost here" with the supposition of "Here is what it could be" and expands the role of imagination of both the contemporary artist/designer/retoucher as well as of the audience. Unfortunately, the history of conservation demonstrates plenty of examples of poor replacements with inappropriate materials such as plaster of Paris which cause for the audience the opposite, not only limiting the imagination but rejecting it completely.

5 RestAURAtion: plaster of Paris or silica aerogel?

> Since 2011, "…*one of the (first) author's projects in progress is the re-establishment of missing parts on classical sculptures, using silica aerogel. Transparent statues' members out of silica aerogel could offer to the viewer a celestial aspect on the "wounded" classical statues. And that because these members out of silica aerogel will be almost immaterial and absent. Thus, the new conserved statues' missing parts will not impose themselves as they do now the statues' missing parts made out of plaster and other opaque materials* …" (Aerogels Handbook, p. 798)

Historically, works of art had an "aura" – an appearance of magical or supernatural force arising from their uniqueness (similar to mana). The aura includes a sensory experience of distance between the reader and the work of art. Walter Benjamin defines the "aura" first in an earlier essay *A Short History of Photography* (Benjamin, 1930) as "*What is aura? A strange web of time and space: the unique appearance of distance, however close at hand*." This "aura", according to Benjamin, disappeared in the modern age because art became reproducible [14]. It is connected to the idea of authenticity. The unique presence of a work of art in time and space is what gives it an aura. If there is no original, it is never fully present anywhere. As authenticity cannot be reproduced, it disappears when everything is reproduced. According to Benjamin, even the original is depreciated, because it is no longer unique. With their

authenticity lost, the authority of the objects is also lost. The masses contribute to the loss of aura by seeking constantly to bring things closer. They create reproducible realities and hence destroy uniqueness.

Even though photography partially stripped the work of art of its aura according to Benjamin – the camera has enabled us to see the world that cannot be seen with the naked eye. Photography allowed us to stop the time. We can slow down and speed it up with photography or the moving image. This presents the way photography has emerged over time and our perception is transformed by our experiences with photography. Benjamin goes beyond a simple chronological account of developments in photographic chemistry, optics and practice and develops ideas of the cognitive and political potential of photography and introduces the concept of the "optical unconscious".

> " […] *we have some idea of what is involved in the act of walking (if only in general terms), we have no idea at all what happens during the fraction of a second when a person takes a step. Photography, with its devices of slow motion and enlargement, reveals the secret. It is through photography that we first discover the existence of this optical unconscious, just as we discover the instinctual unconscious through psychoanalysis*." (Benjamin, 1930).

6 The optic and haptic space of silica aerogel

If the universe is made up of stories not atoms, then the goal of our narration here is to collect intriguing meanings that are embedded in the Acropolis marbles and completing them by replacing the absent parts of the historic structures; restAURAting them with ultralight transparent structures of silica aerogel and thus giving them a future and allowing for a higher role of interaction with the public. These "Free-Dimensional" [15] forms allow a representation of the lost past, so that we can envision, imagine and realize through nano-matter, the passage via an elastic time-space entanglement. The idea is to connect architecture, art, history and space technology of the future together in one artwork, which extends from materiality of the matter to the immateriality of the spirit.

Capturing and embedding a piece of sky onto the Pentelic marble creates a link to the original context of the interaction and refractions of light and shadows. Science and art are parallel attempts to describe the world, and both may be part of a wider cultural landscape. Our free-dimensional forms allow restAURAtion and representation of cultural works, uniting the purpose of humanity as a whole and its moral awareness. Perceiving the renewed forms will further highlight the need to save historic artworks, which are an essential and integral part of human cultural and social systems and heritage. Furthermore, a multi-sensorial experience could be induced; engaging feelings, imagination, the history and explorations of such questions as (a) why these pieces are restored in such way; and (b) why with the use of the visible-to-the-naked-eye nanomaterial silica aerogel.

Silica as a computers' memory component, would offer – additionally – a "re-wombing" of the ancient artwork by giving them a rebirth in the digital era through stored data into the silica aerogel nano-network: we'll create a sculpture surrounded by its sky, a sky which has the ability to act as a data storage device having the possibility to display the 2500-years-old artworks' history in a holographic way [16]. Not only will the sculpture be physically intact but also a new kind of "life and soul" would be added, giving the viewers their own role on reflecting and depicting part of the story which then imprints a more impactful memory on them [17].

There are many theories about how and why particles seem to behave predictably. Starting from Einstein, who proved that time is relative and that time and space are inextricably interwoven, John Wheeler said in his book (1990) about existence: "*Time is nature's way to keep everything from happening all at once*." In order to enhance the memory of the sculpture, silica aerogel helps by preserving it and by linking its "stolen" story to the very present. By incorporating the reflections of the viewer through a critique of one's practice, one is dismantling and tackling this journey through a language of art practice. Both immersion and reflection will observe the resourceful development of creative process in order to arrive at a contemplation of history.

Heisenberg argued that science and art are parallel attempts to describe the world, and that both may be part of a wider cultural picture [18, 19]. The art of evolution is in constant flux, when one negates the expedition to explore how microcosmic experience fits into the macrocosmic narrative. By adding space (a piece of sky) to the Erechtheion caryatids – especially the one "misplaced" in the British Museum – one creates a unique – and probably utopian – methodology for the restoration of damaged sculptures in human history.

7 Resistance of (nano)materials

Why the transparency? Why adding a piece of sky/heavens to this statue? The diaphanous body and the light scattering quality of the silica aerogel (blue and orange natural colors of the nanomaterial) are the main aesthetic requirements applied to the ambiguous presence of the missing arms. We

Fig. 12 A moth attracted to silica aerogel's luminosity – a phenomenon known as *positive phototaxis* – is seen through the translucent nanomaterial; the moth is sitting on the right inner side of the *cup bearer* foot

Fig. 13 Restoration with aerogels of the sixth caryatid made by Pentelic marble is exhibited – up to now – in the British Museum, Museum number 1816,0610.128, © The Trustees of the British Museum, Asset number 85717001

wish to propose for the caryatid molded pieces of Attica's skies to form the missing arms of this sixth kidnapped caryatid. It is for the viewer to wonder and admire how the Attica's sky – an essential element around the caryatids, Erechtheion temple and Acropolis – returns back to the sculpted Pendelikon marble creating a synergy between the ethereality of silica aerogel and the materiality of the marble. How the cloudy sky from being the background of Erechtheion became the motionless missing arms of the missing caryatid? The aura of the authentic caryatid is merged here with the eerie nanostructured material and thus creating wondering smiles of resistance.

Silica aerogel is a material of nano-dimensions and has a translucent, diaphanous body (Fig. 12). This "mask of light" is like an exotic portable skyscape, like a *veduta* [20] representing an over-time-and-space dimensionality. The transparent nanomaterial becomes a link between the body of the sculpture and the space around it. It not only describes this space, but above all, it denies it. The "aerial transparencies" of MICHALOU(di)S are children's formulae, a game of "hide and seek", an expression of an uncertain view that evolves almost a "non-position".

In their original setting, the caryatids stood on the porch of the Erechtheion, with a sweeping southern view toward the Aegean Sea. They rested in contrapposto poses, three of them standing firmly on their right legs, demurely bending their left knees beneath diaphanous robes. The others stood in opposite pose. Together they held up a part of the temple's massive roof. The missing caryatid (Figs. 13–16, with the prologue of the catalogue in Fig. 17) is installed at the British Museum in London, which acquired it nearly two centuries ago after Lord Elgin, the British ambassador to the Ottoman Empire, had it sawed off the Erechtheion's porch, along with shiploads of adornments from the Parthenon to decorate his mansion in Scotland before selling the pieces to pay debts [21].

To visualize how the caryatid would look with silica aerogel, photographic retouching was applied. First, a female

Fig. 14 Back of the restored sixth caryatid, British Museum, Museum number 1816,0610.128, © The Trustees of the British Museum, Asset number 259232001

Fig. 15 The restored sixth caryatid from Erecheion, British Museum, Museum number 1816,0610.128, © The Trustees of the British Museum, Asset number 34504001

model was photographed digitally in a position as close as possible to one of the caryatids. The image of the hands only was then extracted and layered on top of the image of the caryatid followed by an overlap of a photograph of aerogel silica. An outline of the hands was made and overlapped with image of silica aerogel. The image of the hands was deleted and only an outline remained, effectively swapping the image of the hands of the model for (now) hands made of aerogel silica. The image like this is very flat as lighting conditions do not match, therefore with the use of dodge and burn functions, artificial shadows and highlights were applied to the silica aerogel hands to recreate the lighting conditions in the room where the caryatid was originally photographed using as indicators shadows and highlights on the statue and using skin structure of the hands of the model to recreate 3D light behavior (Fig. 18).

The natural daylight is the optimum way to illuminate these artworks. The atria could have light tunnels to allow daylight to access and light the ancient artworks. During night, our study case will need artificial lighting, from cold white LED lamps, preferably powered through solar energy [22]. Because of the light, the mirror and the diaphanous screen, the historical and the legendary of time, blend together and give birth to an amphi-temporal *Chronos*.

By weaving a direct link between the natural day light from the Athenian sky and the Acropolis' sculptures bathing in the Greek sun, we channel the natural warm sun to the inside. This natural light of Attica, which has long been regarded as an important factor in appreciating the Parthenon and the sculptures that originally adorned the exterior

of the fifth century BC temple once again envelopes and warms the ancient marble surface while creating amber shadows coming from caryatid's arms in silica aerogel.

Fig. 16 "…the missing caryatid is glaring in its absence from the platform (top), a subversive display of resistance that is reflected one floor up in the museum, where large swaths of the Acropolis frieze owned by the British Museum are represented as chalky plaster copies of the originals", "Acropolis Maidens Glow Anew" [21]. During our case study exhibition the *Caryatid restAURAted* will be displayed on the platform aside her sisters (bottom)

8 Omnipresent regenerating illusion

Inspiration arising from projections of eclipsing realities and infinitely nuanced transactions between what is "in the world" and what is "in our minds" have their own dynamics and energy. Illusion is not only to be relinquished; it is also to be maintained and transformed (Phillips 1988; Bertolini et al. 2001).

Aristotle believed the best way to transfer emotion from one person to another is through storytelling, as the audience feels connected to the generated ideation. Expanding on this notion, a visit for the viewer is engaging one's sensual logics to a time-travel experience: No metaphysical distinction between the past and the future remains, the distinction has no normative importance (the sculpture still exists with its lost parts), but a form of traveling back in time to experience some particular period or "meet" a notable person from the past occurs.

Illusion carries energy, as it were, of the mind's reach into the world, investing it with meaning; feeling and engagement in their broader senses. Space-time compression in a sphere of light via an attachment; in which Falzon calls "a product of interrelations"; experienced by the visitors, changes and directs the gaze towards the Acropolis nearby.

The encounter with reality is best understood as an integrative, blended transaction between the actual objects of the external world, and subjective experiences, which are themselves blends of our pasts and what is offered in the present. We are always making an imaginative connection with the world around us as we make contact with it; both inanimate objects and other people come to experience meaning of a unidirectional projection. Illusion is flexible and bidirectional transactional linkage stands as the third principle of mental functioning. It bridges primary process (Freud 1911) with internal process by projecting it outward. An array of imaginative and social transactions twisted these different, but

Fig. 17 This "textImage" is the catalogue's prologue for the solo exhibition of MICHALOU(di)S in the Museum of Cycladic Art, written in 2006 by Prof. Nicholas Stampolidis, the current director of the New Acropolis Museum

It is in this material that Ioannis Michaloudis has modelled his figures, inspired by eleven sculptures in the Museum of Cycladic Art, bringing the form of the beginning of the well-known Cycladic marble figurines into the language of expression of our space-electronic age, in a characteristic espousal of art and science, of the kind that our "advanced" age seeks. The material Ioannis Michaloudis uses for the ethereal replicas of Cycladic figurines and which was developed essentially for space flights, is privileged to capture something of the heavenly vault, both of its bluish tint and its misty texture. Thus, with the help of laser lighting and depending on the angle from which they are seen, these dreamy creations of poros texture take on a hue, something like the teardrop of a flame. Moreover, the positioning of the aer( )sculpture Cycladic figurines, whose shadows are projected on translucent screens placed in a circle in the exhibition, is such that, as they rotate, they give the sense of the slow motion of planets. Silica aerogel figurines - planets - which invite you to travel with them to other worlds in space; remote in reality, nearby with the power of the imagination.

Professor Nicholas Chr. Stampolidis
Director of the Museum of Cycladic Art

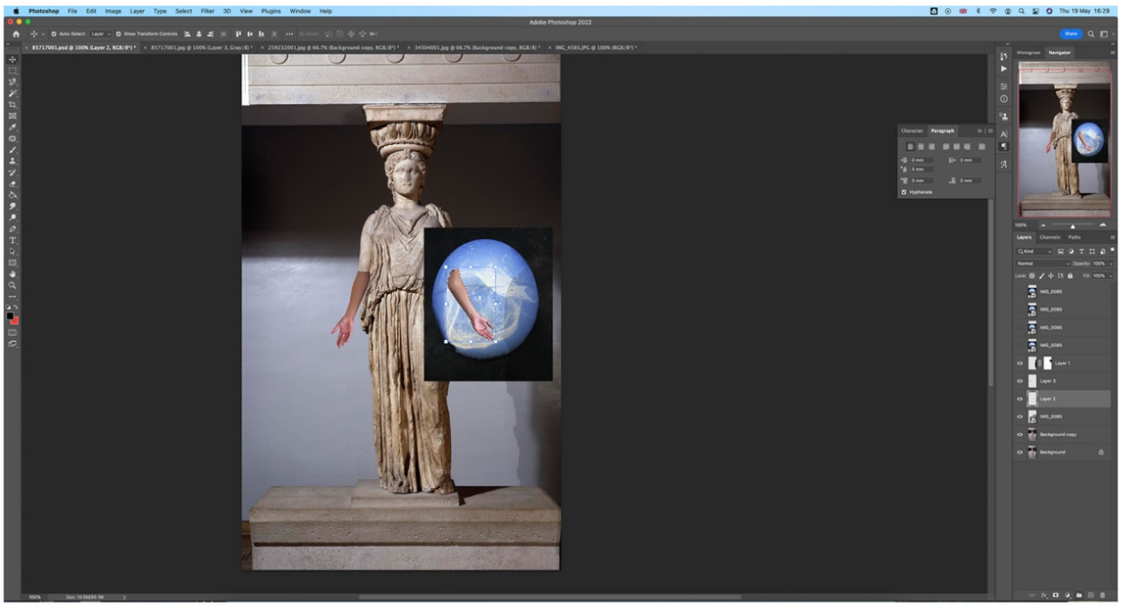


Fig. 18 By "photo-manipulating" the image of the missing arms of the caryatid we achieve a first visualisation of our *Caryatid resAURAtion* study case project, proposed for the New Acropolis Museum

interwoven phenomena, as the multiplicity of experiences. (Winnicott, 1951: 240).

In classical antiquity, it was thought that the best way to achieve the best form was to compile a composite, piecing together the best fragments from living examples to create an ideal figure, perfectly proportioned and beautifully balanced, the product of ratios and reason. Ultimately, idealized nude became a symbol of both physical and moral excellence. In the tradition of Plato and Empedocles before him, Aristotle argued that there were four fundamental elements, namely, fire, air, water and earth. In his system, there was no such thing as void space. All space was filled with some combination of these elements.

In Aristotle's cosmology, each of the four elements had a weight. Earth was the heaviest, water less so, and air and fire were the lightest. According to him, the lighter substances moved away from the center of the universe and the heavier elements settled into the center. While these elements attempted to sort themselves out and to achieve order, most experiences involved mixed entities. While we have seen earth, fire, air and water, everything else in the world in this system was understood as a mixture of these elements. In this perspective, transition and change in our world resulted from the mixing of the elements.

In Aristotle's time there simply were not extensive collections of observational evidence. Things that looked like they were moving in the heavens, like comets, were not problematic in this model because they could be explained as occurring in the terrestrial realm. This model of the heavens came with an underlying explanation. The celestial spheres were governed by a set of movers responsible for the motion of the wandering stars. Each of these wandering stars was thought to have an "unmoved mover", the entity that makes it move through the heavens. For many of the Greeks, this mover could be understood as the god corresponding to any given entity in the heavens. Time can somehow be reduced to discussion about temporal relations among things and events. The opposing view, normally referred to as "absolutism with respect to time", has been defended by Plato, Newton, and others. Within this view, time is like an empty container into which things and events may be placed; but it is a container that is independent of what is placed in it by relationism of space and time having consequences.

The material – marble, plaster of Paris, or silica aerogel – is directly related to time and space. It has a body and this body is measured daily against these two adversaries. Time and space are there to defeat the resistance of the material. This research and this writing has attempted, therefore, to place the material - more precisely the transformation, the metamorphosis of the materials - at its center. Textile or text, habit or habitat are primarily materials that become immaterialities willing to compete with time and space. They will be formed and transformed by them – through human intervention. Through several trans/formations: the cry in logos, the earth in porcelain, the vine in wine, the matter in spirit.

9 Summary

In summary, collaborations between art and science have realized the novel silica aerogel-based sculptures in

visual arts. In addition, we have shown here through productive collaborations that the meeting of an artist with silica aerogels materialized unprecedented technique and expressions in the "restAURAtion" of heritage. By updating the ancient with the ultra-new, we connect history and future via time travel, thereby showing the value of these artworks and demonstrating the optical features of space-age nanomaterials. Furthermore, interaction offers unexpected experiences and reflections on the matter and materiality of artworks, whilst engaged with a multi-sensory experience of Attica light upon marble and sky. Moreover, the viewer will not only be staring and interacting with the restored artworks alone, but rather linking them all in a sequence as a constellation of stars.

Acknowledgements The authors would wish to thank Marianna Mourad and Dr. Maria Skordi for their helps in translations.

Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

References

1. Vekinis G, Ashby MF, Beaumont PWR (1993) Plaster of Paris as a model material for brittle porous solids. J Mater Sci 28:3221–3227
2. Risdonne V, Hubbard C, López Borges, Theodorakopoulos C (2022) Materials and techniques for the coating of nineteenth-century plaster casts: a review of historical sources. Stud Conserv 67:186–208
3. Aegerter MA, Leventis N, Koebel MM (2011) (Eds.) Aerogels Handbook, Springer: Berlin/Heidelberg, Germany
4. Hüsing N, Schubert U (1998) Aerogels–airy materials: chemistry, structure, and properties. Angew Chem Int Ed 37:22–45
5. Pierre AC, Pajonk GM (2002) Chemistry of aerogels and their applications. Chem Rev 102:4243–4265
6. Shimizu T, Kanamori K, Nakanishi K (2017) Silicone-based organic-inorganic hybrid aerogels and xerogels. Chem Eur J 23:5176–5187
7. Woignier T, Phallippou J, Prassas M (1990) Glasses from aerogels Part 1: The synthesis of monolithic silica aerogels. J Mater Sci 25:3111–3117
8. Michaloudis I, Dann B (2017) Aer()sculpture: inventing skies and micro-clouds into diaphanous sculptures made of the space technology nanomaterial silica aerogel. J Sol-Gel Sci Technol 84:535–542
9. Papachristopoulou K, Vainos NA (2020) Systolic nanofabrication of super-resolved photonics and biomimetics. Nanomaterials 10:2418
10. There are theories that occurrences of camera obscura effects inspired paleolithic cave paintings. One of the earliest known written records of a pinhole camera for camera obscura effect is found in the Chinese text called Mozi, dated to the 4th century BCE. Greek mathematicians Aristotle and Euclid independently described a camera obscura in the 5th and 4th centuries BCE. (Campbell, 2005:114)
11. *Poros* in Greek is a "small hall" and the origin of the word *nanoporous*. In Plato's *Symposium* 178, *Poros* (Porous), is the personified spirit (daimon) of expedience and contrivance, husband of *Penia* (Poverty) and the father of *Eros* (Love)
12. Albertus Magnus (1193–1280) discovered silver nitrate which darkens when exposed to light. This fact was crucial for the eventual development of a photographic image as salts of silver were the principal agents for the permanent record of the latent image (Davidson, 2015)
13. Michaloudis I, '(Nephele)^3 Sculpting of clouds', Sky Art Conference 2002 Proceedings, MIT Press, 2004, ISBN 0-9766549-0-3, pp. 96–99, and http://act.mit.edu/cavs/person/ffed1221-4f28-4568-be83-ab21a3e7becf
14. Reproduction vs reproducibility was a subject of debate for many years due to poor translation of the original as "The Work of Art in the Age of Mechanical Reproduction" rather than as intended in German original reproducibility "Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit"
15. Michaloudis I (2011) «Aer()sculpture: A Free-Dimensional Space Art», In Aegerter MA, Leventis N, Koebel MM, Aerogels Handbook, Springer, Chapter 35, 791–810
16. Michaloudis I, Kanamori K, Pappa I, Kehagias N (2022) U(rano) topia: spectral skies and rainbow holograms for silica aerogel artworks. J Sol-Gel Sci Technol. accepted for publication (https://doi.org/10.1007/s10971-021-05676-x)
17. Michaloudis I, Hance I, Tarbett-Buckley C, Koskina K (2016) "COSMuseum project: Memories and Souvenirs from planet Earth" Proceedings of 67th International Astronautical Conference, p. 18 (Guadalajara, Mexico, Sep. 2016)
18. Heisenberg, W (1958) Physics and Philosophy. Harper & Row New York, p.109
19. Zawojski, P (2018) Cyberkultura. University of Silesia Press, p. 52
20. In history of Art *veduta* is invented when art wants to escape from within art and from religious representation. So we will have the "window", this veduta, inside the painting but which opens to the outside. This find is quite simply the invention of the western landscape", cf. Alain Roger, Art et anticipation, Paris: Carré, Collection "Arts & esthetics", 1997, p. 20
21. "Acropolis Maidens Glow Anew" (https://www.nytimes.com/2014/07/08/arts/design/caryatid-statues-restored-are-stars-at-athens-museum.html)
22. The light designer Eleftheria Deko and her company already illuminated Acropolis monument that received the LIT Lighting Design Award of the year 2021 are willing to collaborate with us for the correct lighting design of our study case *Caryatid restAURAtion*