THE FUTURO HOUSE IN LIMNI, CORFU

A Living Space

Eugenia Stamatopoulou, Maria Karoglou, Asterios Bakolas

ABSTRACT: The restoration of the Futuro house in Corfu is complicated by being both an art object and a living space. The glass-fiber reinforced polymer (GFRP) materials showed damage that could be related to ageing and exposure to the local, unfavorable environmental conditions (light, humidity and temperature). In order to establish the technical condition of the building, non-destructive techniques were used. Additionally, indoor air quality was tested. The research has shown that the most relevant causes of damage to GFRP materials are moisture, exposure to sunlight and thermal changes. The intervention strategies applied so far are not conclusive. Maintenance is always needed. Further investigations are deemed necessary to understand the properties and state of conservation of the materials at a micro scale.

KEYWORDS: Futuro, GFRP, Investigation, degradation, preservation

INTRODUCTION: The Finnish architect Matti Suuronen exhibited the first Futuro house in 1968, a portable plastic house in the shape of a flying saucer.[1] [2] An important design idea was the development of sandwich construction in which fiber-reinforced plastic was combined with polyurethane insulation for interior thermal control.

This paper presents an overall approach to study and document the condition of the Futuro house, as well as an evaluation of the stability of previous restorations, particularly related to the environmental factors affecting composite plastics materials.

The Futuro house that is presented here was produced by Polykem Ltd., under the Belgium/Benelux license for International Promoting Co, SA. Bruxelles, between 1968 and 1969.[3] In 1969, three Futuro houses were imported into Belgium; one of those was located near Brussels until 1999, when it was saved from demolition by the Belgian architect Philemon Van Langendonck.[4] The same Futuro house, was later shown (2007) in the exhibition titled, "Tomorrow Now - When Design Meets Science Fiction", at the Grand Duke Jean Museum of Modern Art (MUDAM), in Luxembourg.[5] After MUDAM, the Futuro house travelled to Paris to be included in Christie's Auction (27/11/2007), "*Arts Décoratifs du XXème siècle et Design*", as Lot 391. It passed to a new owner to be transported to Greece to be installed in a courtyard of a private house in Limni, on Corfu, where it is still standing.[6]

DESCRIPTION OF THE CONSTRUCTION AND CONDITION OF MATERIALS (2007-2019)

The Corfu Futuro house is a single space, ellipsoidal form, consisting of eight identical upper and eight lower segments. They are made from 4 mm thick, random chopped glass-fiber, reinforced unsaturated polyester panel skins and a thick core of polyurethane foam. Each panel is numbered separately (0B to 7B for the bottom segments and 0T to 7T for the upper ones). The position of the panels is numbered clockwise starting with the staircase/door panel (0B). The overall diameter of the house is 5.50 m with a net interior area of 24 m^2. The house is carried on a slender circular steel ring held on four triangular legs 1.48 m above the ground. The overall weight of the plastic building is 2,500 kg. The individual segments are bolted together through stabilizing ribs at the edges of the elements. The house is accessed through a trap door that fits flush with the exterior of the building.

Each segment consists of GFRP sandwich panels created by hand lay-up molding. The inner and outer surfaces of these panelswere covered over the years with several layers of gel coats. Actually, the outer surface of the panels

01 Wooden reinforcement of the lower elements of the building, covered with the characteristic purple and grayish topcoat. © E. Stamatopoulou, 2008

02 View of the interior depicting element 4T. The arrows point the newly reshaped openings. © E. Stamatopoulou, 2008

is covered with a gray gel coat whereas the inner surface is coated with a purple primer and a graying top coat. In several areas with losses of the gel, underlying red color which results from the mold level where a red resin was used for the mold making, is also visible.

The lower panels are internally reinforced with wood and steel to strengthen the construction [FIGURE 01]. Additionally, the building has twenty oval windows of doubled Perspex (PMMA) sheets.[7]

The condition of the house was first examined and documented in 2007 by a team of engineers from KU Leuven in the course of research on composite materials.[8] During this investigation, the authors reported mechanical damage such as fractures, cracks and micro-cracks, as well as areas of delamination and flaking of the gel coat throughout the exterior surface. Larger cracks have been related to the brittleness of the GFRP in combination with local stress concentrations, especially on the holes for the bolted joints. This is probably due to excessive pressure applied during assembly of the panels. Micro-cracks and delamination of the coat gel were highest in the upper panels, particularly those oriented to the south. Clearly, the condition of the gel coat was related to the environmental factors (UV-radiation, heat and humidity), where the house had been located for several years.

UV-radiation and heat are both particular factors that can dramatically damage the condition of the GFRP's gel coat. Also, the rain and frost-thaw cycles in Belgium may create a fatigue load on the core due to moisture infiltration that results not only in crack growth, but also in gradual deterioration of the underlying glass laminate.

In 2008, after the acquisition of the Futuro House by the present owner, urgent and necessary repairs to stabilize the construction were undertaken at a French marine workshop specializing in the repair of GFRP.[9] The restoration consisted of the consolidation and reinforcement of cracked and broken parts of the edges and surface of the panels. Furthermore, restoration was focused on the repair and stabilization of mechanical damage at the midline of the house. Finally, some of the grooves holding the window seals had deteriorated, which allowed water to leak into the house. Therefore, it was also decided to re-form the openings and to secure the seals with mastic [FIGURE 02].

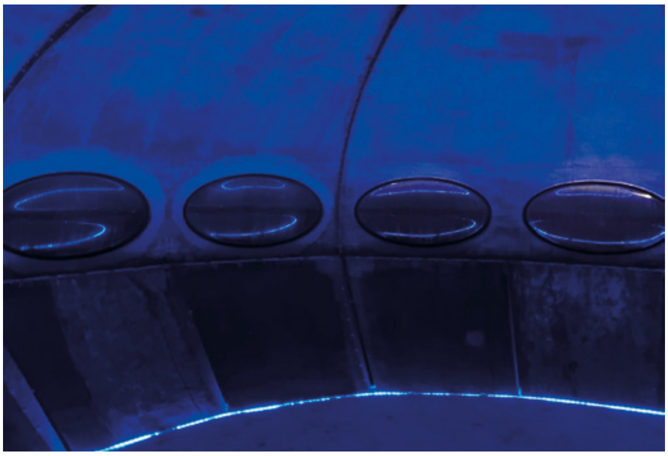
Internally, the upper panels of the house were partially covered with a grayish top coat, and the lower segments were upholstered with carpet [FIGURE 03].

In order to keep the overall aspect of the Futuro House intact, it was decided to retain the interior upholstery and coating as a historical reference of the materials used. Additionally, no intervention was made on the outer surface at the level of the gel coat.

After the 2008 restoration the Futuro house was transported to Limni in Corfu and installed permanently in its current location where it is surrounded by high trees and vegetation. The Futuro was meant to be used by the family as a space for relaxation and was kept unfurnished. A white carpet was laid, and blue-tinted hidden lighting was installed to create a calm and peaceful atmosphere in the inner space [FIGURE 04].[10]

Temperatures in Corfu vary during the seasons and between night and day, which can contribute to the deterioration of the materials. In order to protect the building, it was decided soon after installation in 2009 to treat the outer surface with a new clear coating, and to partially retouch some of the areas that were flaking and losing material. A restoration project was planned with the aid of a group of specialist boat painters in Greece.[11] Loose material was stripped in order to consolidate voids and cracks, then fiberglass reinforced resin was applied. Finally, a primer was applied for retouching the areas with a two-part gray epoxy. The entire surface was protected with a final varnish.[12]

03 Interior of the Futuro house, 2007. Arrows show the layer of top coat with a grayish color on top of purple primer and the presence of a synthetic carpet at the lower part of the segment. © E. Stamatopoulou, 2008



04 Interior of the Futuro house at night with the blue light installation. © E. Stamatopoulou, 2008

05 a-b Condition of the top coat in the interior of the Futuro house in 2007 (a) and in 2010 (b). © E. Stamatopoulou, 2010.

06 The Futuro house installed in Limni, Corfu, in its current condition. © E. Stamatopoulou, 2019

07 Detail of the deterioration of the exterior top coat in 2019 that had been applied during the restoration of the Futuro house in 2009. © E. Stamatopoulou, 2019

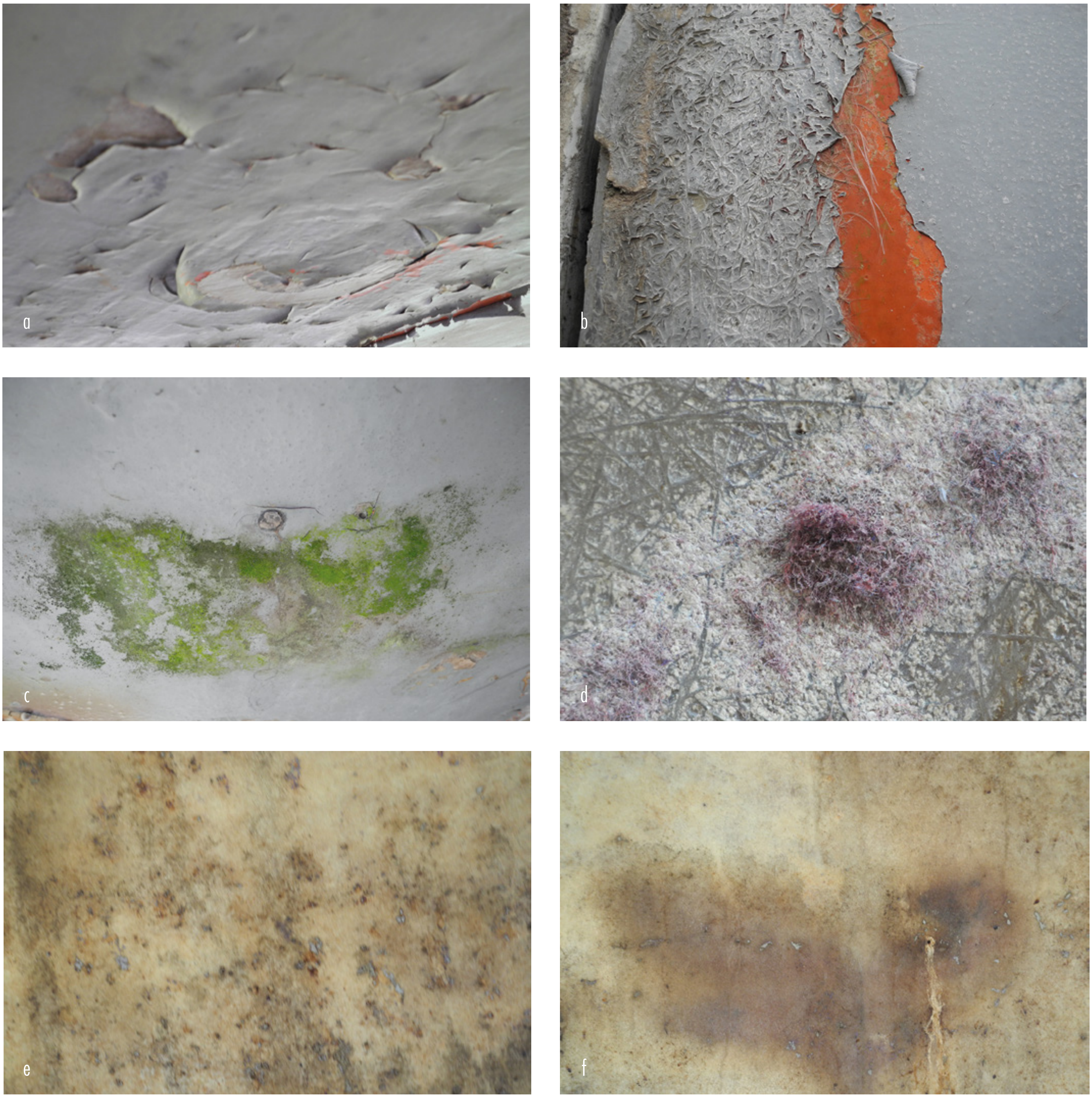
A year later in 2010, severe damage (extensive flaking) to the internal primer and top coat was noted [FIGURE 05]. Also, the carpet was moist and emitting a foul smell.

This could have been related to the increased impermeability of the outer surface after restoration which hindered the dispersal of internal moisture. As a result, condensation under the primer and top coat may have caused it to swell and flake, which was then exacerbated by seasonal temperature variations. Later in 2010, both the cracked and flaking internal primer and top coat were entirely removed.

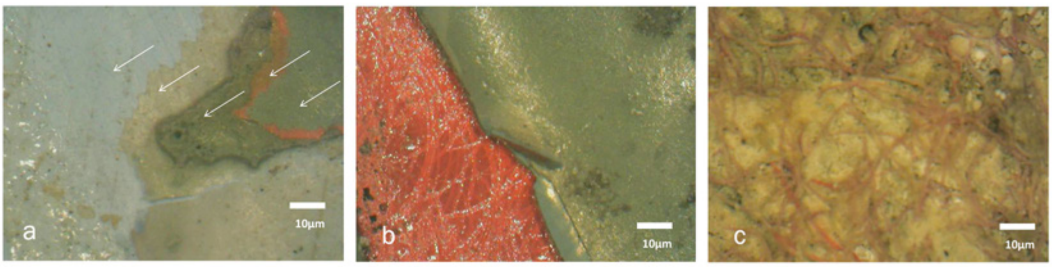
Today the condition of the Futuro House is poor and plans for restoration need to be reviewed. A recent inspection, made in summer 2019, revealed extensive areas of new flaking, cracks, blisters and material loss on the exterior top coat [FIGURE 06, FIGURE 07].

NON-DESTRUCTIVE INVESTIGATION TECHNIQUES

In order to understand causes of deterioration, it was decided in 2019 to implement systematic investigations of the structure using non-invasive techniques.



08 a-f Macro – photographs of the inner and outer surface of the Futuro house showing, (a) exfoliation of the outer coating, (b) areas with previous restoration, (c) growth of mold on the outer bottom region, (d) growth of reddish mold in the inner surface, (e) inner areas with surface irregularities, (f) inner area with extended change of color from yellowish to brown. © E. Stamatopoulou, 2019

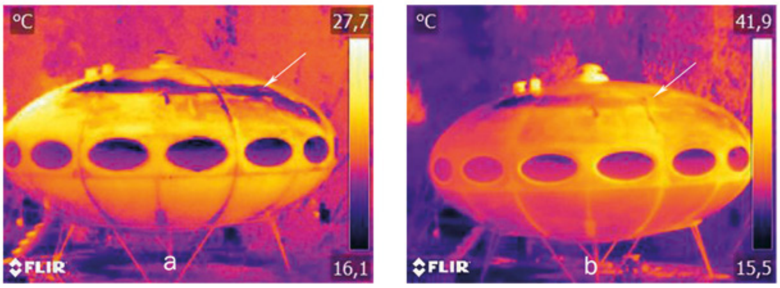


09 a-c Documentation of the outer and inner surface of the Futuro house using a portable digital microscope with x50 magnification. (a) The arrows mark the various layers on the outer surface, (b) region with exfoliation of the grey gel coat leaving visible the original inner core of red resin, (c) inner surface of the GFRP material depicting the random disposition of the glass fibers. © E. Stamatopoulou, 2019

The photographic documentation illustrated a range of defects such as exfoliation and cracks, as well as areas of previous restoration. [FIGURE 08].

Additional examination of selected areas with the use of the portable digital microscope (I-Scope, Moritex), revealed the surface characteristics of the panel core as well as various layers of coatings on the outer surface [FIGURE 09].

Finally, the structure was examined using infrared thermography (FLIR, B200) to detect damaged areas.[13] The thermographs taken were processed using the



10 a-b The arrows point the area where measured temperature at 10 a.m. is 18 °C (a) when at 6 p.m. is 30 °C (b). © M. Karoglou, 2019

ThermaCAM QuickReport 1.1. software. The examination of the structure revealed an uneven distribution of temperature during the day [FIGURE 10].

These temperature fluctuations may severely affect the stability of the composite material by causing local cracks, humidity condensation and exfoliation and delamination of the various layers.[14] In the case of GFRP, the coefficient of thermal conductivity of the polymer is greater than that of the fibers. This means that the behavior of the constituent parts of the composite material differ, resulting in residual tensions.[15]

Additionally, atmospheric humidity and surface moisture are considered to be one of the most important causes of long-term degradation of polymeric composites. For the structure, water solutions affect the composite by decreasing the glass transition temperature, stiffness and strength of the composite, and increasing its volume.[16] Osmosis, defined as "*the migration of hygroscopic solutes within a laminate owing to moisture ingress, which ultimately results in blistering of the gelcoat*" is very characteristic of GFRP, causing extensive areas of blistering, cracking and final loss of the protective gel coat.[17]

EXAMINATION OF INDOOR AIR QUALITY OF THE FUTURO HOUSE

During the summer of 2015, the owner of the Futuro house reported an irritating odour inside the house. Concerned about the quality of the air, he requested an analysis that was carried out by a specialist company.[18] Tests were done for excessive aldehyde emissions, using a passive system for collecting the volatile organic compounds (VOCs) according to ISO/FDIS 16000-4:2004.[19] The samples were then analyzed using HPLC (High Performance Liquid Chromatography). The results showed the presence of various aldehydes with higher concentrations on acetaldehyde (9.1 $\mu g/m^3$), formaldehyde (82.2 $\mu g/m^3$) and isovarelaldehyde (10.8 $\mu g/m^3$).

In order to prevent significant sensory irritation in the general population from formaldehyde exposure, the World Health Organization recommends an air quality guideline value of 100 $\mu g/m^3$ as a 30-minute average. This guideline value represents an exposure level at which there is a negligible risk of upper respiratory tract cancer in humans.[20]

The presence of aldehydes in the interior of the Futuro house is associated with the thermal ageing and weathering of the polymers. Thermal degradation refers to the chemical and physical processes in polymers that occur at elevated temperatures, and photo-oxidation that occurs due to radiation (especially UV's) absorption. Both degradation types involve the reaction of free radicals from the polymer with oxygen to form peroxide radicals (PO), that in relation with other climatic quantities such as heat and moisture may generate hydro peroxides (POOH). These hydro peroxides can dissociate further to produce a series of decomposition products including aldehydes and ketones.[21]

The concentration of formaldehyde detected in the Futuro house was lower than the acceptable exposure levels and non-risky for the habitants. Nevertheless, it was advised to use a system to regularly renew the indoor air. For this reason, a ventilation and air-conditioning system to provide fresh air was installed on the ceiling of the house and the temperature for the interior was set at 18°C annually [FIGURE 11].

RESTORATION AND PRESERVATION DECISION-MAKING

The owner considers his Futuro house in Limni to be an artwork and a living space, which should be a consideration in the restoration and preservation of the structure. Consequently, it is imperative to preserve as much as possible of any original material from 1968/69, but also to safeguard and stabilize the construction over the time.

The environmental conditions of the location need to be taken into account in planning the conservation. The defects of the material are mostly related to environmental conditions, repairs and additions of new materials. Failures may consist of cumulative damage to the matrix, interfacial separation with the fibers, and chemical attack of the fibers, or a combination of two or more of these processes. The consequential effects may be loss of stiffness and mechanical integrity of the composite material.

In order to determine the conservation for this Futuro house, other laboratory tests are necessary to:

1 Provide information about the mechanical characteristics and stability of the composite material and determine the nanomechanical properties of polyester matrix composite using nano-identification.
2 Provide information about the composition and deterioration of the polymer, by means of Fourier Infrared Spectroscopy (FTIR), Raman Spectroscopy (μ-Raman), as well as Differential Scanning Calorimetry (DSC) to estimate the cross-linking degree of the polymer and Scanning Electron Microscopy (SEM) to help to identify the type of polymer and to localize the failure.

The results will be evaluated and used as a base for the establishment of an overall restoration and conservation plan that will include the application of materials in the inner and outer surfaces of the house, address issues of moisture permeability and protect the original coatings in the years to come.

CONCLUSION

Research has shown that, in this case, the most relevant causes of damage to GFRP materials are moisture, exposure to sunlight and thermal changes. The interventions applied so far are not conclusive. Maintenance is always needed. Further investigations are deemed necessary to understand the properties and the condition of the materials at a micro scale.

11 Interior of the Futuro house. The arrow indicates the position of the air-conditioning. © E. Stamatopoulou, 2015

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7 Sixteen of these windows are located on the bottom part of the top segments (two windows in each panel, slightly curved. The exterior windows are 96x50 cm and the interior sheets are 93x48 cm). Four double sheet windows are located in the upper part of segment 2B: these are sized at 91x48 cm (outer sheet) and 90x45 cm (inner sheet). The windows are secured with silicone rubber seals. Internally, the floor is covered with eight 18 mm plywood sheets.

8 idem 3.

9 The restoration was conducted by Roman Touly at the A.C.C.F. Chantier Naval, at Pont-l'Abbé, France between February and June 2008.

10 Statement given by the present owner in October 2019.

11 The name of the local company is *Mitakidis-Michailos* and are professional boat painters (official site: http://mitakidis-michailos.com/en/)

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