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A multifunctional ETFE module for sustainable façade lighting: Design, manufacturing and monitoring

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ABSTRACT

This paper summarizes initial activities developed under the ETFE-MFM project, an European EU-FP7 funded initiative focused on the design, manufacturing and testing of a smart solution for current façade multifunctional requirements in the building sector; as energy harvesting, glazing, thermal isolation and lighting. The system is based on Ethylene Tetrafluoroethylene (ETFE), a polymeric material with increasing interest in textile architecture. The aim of this work is to provide a standardized ETFE module acting as a flexible LED display harvested by photovoltaics.

In this way, LED strips, organic solar cells and flexible electronics have been embedded in an ETFE structure and a lamination process has been developed using Ethyl Vinyl Acetate (EVA) as interlayer material. This process has been optimized in order to provide good optical and mechanical performance without affecting the functionality of the components. The resulting ETFE membrane has been framed leading to a 1.5 × 1.5 m^2 prototype that it has been vertically installed in a building roof for monitoring and testing from Nov. 1st, 2016 to Sept. 30th, 2017. As main result, it can be said that the module had an average production of 43.45Wh per day with maximum values between 80 Wh and 90 Wh. Taking into account that monitored energy consumption for video displaying is 35.32 W, this yields to an average self-standing mode of 74 min. Up to our knowledge, this constitutes a new approach to design and manufacture a textile architecture module with these features.

1. Introduction

Buildings are the largest energy consumers in the world economy, accounting for over one-third of final energy use and approximately 30% of global carbon emissions [1]. These figures do not take into account the energy and carbon emissions required for the production of building materials or for logistics and building construction. In this sense, the Energy Performance Building Directive (EPDB) Recast promotes energy efficiency (EE) and integration of renewable energy sources (RES) in buildings in the European Union (EU). This directive is based on the evidence that buildings have significant untapped potential for cost effective energy savings, and its compliance would mean that in 2020 the EU will consume 11% less total energy [2]. Consequently, the construction industry must adopt eco-friendly practices and materials that reduce their environmental impact. In the case of photovoltaic (PV) energy, the adoption of building integrated photovoltaic (BIPV) technology as energy source on buildings is helping to spread out the incorporation of distributed RES. In BIPV systems, several factors are interacting at the same time, such as i) PV energy generation, ii) structural function and architectural design, iii) thermal behaviour and iv) light transmittance of the PV modules and the cost. Consequently, BIPV technologies are strategic and necessary components for the efficient utilization of RES and EE, especially in urban areas and different approaches have been developed in recent years on conventional materials, being glass-based BIPV the most representative solution.

In parallel, polymeric materials have emerged as an important trend in modern architecture as building skins and envelopes. Fluoropolymer membranes made of high performance ethylene tetrafluoroethylene (ETFE) are increasing its use in transparent and highly translucent roofs and/or facades as a substitute for glass due to its special properties, such as flexibility, lightweight (providing the use of long span structures by avoiding overweight), self-

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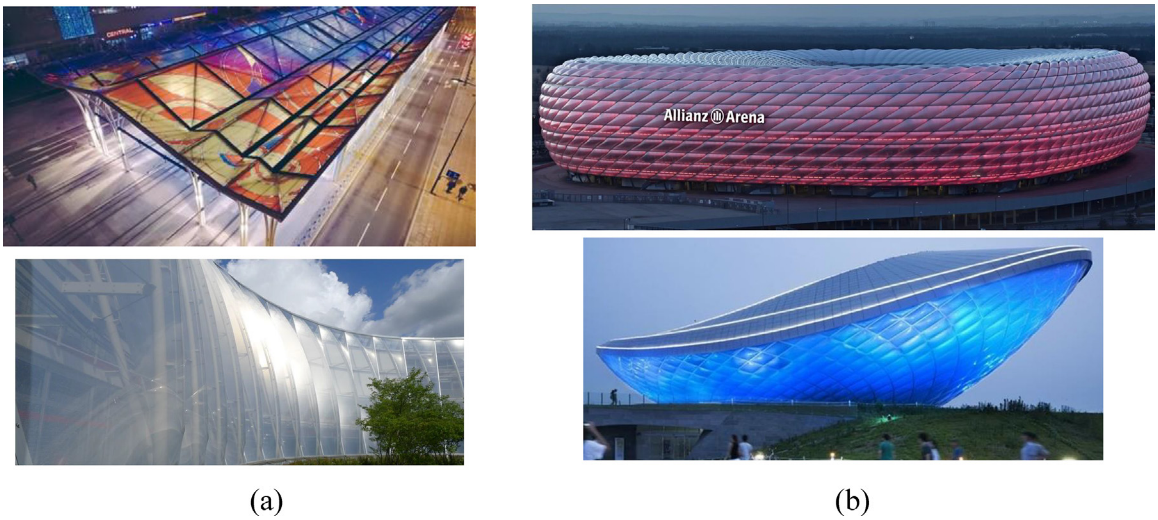

Fig. 1. Some of the most representative new architectonic ETFE buildings based on a) single layered structures: Lodz Tramstation (Lodz, Poland) (top) and Centre of Gerontology (Bad Tölz, Germany) (bottom), and b) cushion structures: Allianz Arena Stadium (Munich, Germany) (top) and Arc River Culture Pavillion (Daegu, South Korea) (bottom).

cleaning surface, thermal insulation, eco-friendly and high levels of stability [3–10]. As a result, ETFE can improve the environmental performance of a building and may reduce the overall environmental burden incurred from the construction process itself and during its lifetime [11–14]. In addition to these studies mainly oriented to the development of architecture based on conventional ETFE foils, it is also important to remark current trends focused on the enhancement of ETFE material by printing [15] or the development of new types of films [16].

In the last twenty years, ETFE structures have been installed using the ETFE either as a single layer membrane or as an air-filled cushion (see some examples in Fig. 1). In single layered structures (conventional tensile membrane fabrics), the ETFE press-stress forces define the curvature of the membrane form. In this case, both internal and external stresses work together to make the structure stable as shown on Fig. 1a). However, the dominant application of ETFE foils is focused on a cushion structure consisting of up to five layers of ETFE foil with inner air pressures between 250 Pa and 1000 Pa. In Fig. 1b, some examples of this architectonic concept are shown.

In the recent years, thin film solar cell (TFSC) PV technology has been studied as energy source for BIPV in ETFE architecture without the need of additional supporting structures. In this sense, several studies related to thermal performance of ETFE cushions with integrated PV elements have been published [17–20]. In all cases, flexible amorphous silicon (a-Si) PV modules were horizontally integrated on the surface of the middle-layer of a three-layered ETFE cushion (see some examples in Fig. 2). Following this approach, a singular building was presented by SolarNext AG, where flexible PV modules based on a-Si are embedded on the top layer of two-layered (5 m × 5 m) ETFE cushions (Fig. 2a). The same PV technology was used by Taiyo Europe GmbH for the development of a three-layered ETFE cushion with a-Si PV modules installed (not integrated) inside a pocket and fixed to the ETFE middle layer using mechanical fasteners (Fig. 2b). Both cases represent singular projects and, consequently, the building elements comprising ETFE cushions and PV elements cannot be standardized. It is also important to mention that current developments in organic photovoltaics has allowed to researchers from Politecnico Di Milano [21–23] to propose and develop the integration of this technology in ETFE membranes, what opens new possibilities for BIPV in textile architecture.

In spite of this tendency to BIPV, it is also noticeable the increasing number of buildings that integrates displays in their façades [24]. This new concept, which is based on the integration of many thousands of light emitting diodes (LEDs) on a large building, seems to be the new hot thing in architecture for decoration or advertising. The term “media façade” is often associated with over-dimensional screens and illuminated/animated advertisings. In this case, the façade itself is dematerialized and turned into one huge urban screen for sending messages. At the onset of dusk, the building moves into the background and serves only as a backdrop for the light show which then becomes the main attraction. Therefore, architecture tends to use media façades more and more as a stylistic feature. Textile architecture seems to follow this tendency and represents a paradigm of building enhancement appearance, as shown in Fig. 3a and b. In Fig. 3a, some examples of building elements comprising lighting devices based on LED technology for architectural facade lighting are shown for ETFE cushioned structures, being LED devices located just behind the cushions and letting the light go through the transparent ETFE foils. A similar approach has been developed by TEXLON® Flexipix [25] (Fig. 3b). This product provides a transparent media façade and ‘climatic’ envelope in a single product. The large-scale media display has been created by inserting high quality LED colour diodes on a transparent foil grid within the high-performance TEXLON® ETFE façade.

Nevertheless, the energy consumption required for adding this feature represents a high cost in the building management and it is limiting this upward trend. Saving energy is an omnipresent challenge, and façade lighting must therefore get to grips with ecological compatibility issues. The use of novel photovoltaic technologies has been proposed to achieve sustainable illuminated building skins, allowing a high degree of integration and without compromising building aesthetics. According to this concept, thin film PV technologies are considered the most promising renewable energy sources and has demonstrated its viability to achieve real BIPV [26].

In this sense, the integration of both technologies (PV and LED) in a single building element have been studied in last years. It is worth to mention the GREENPIX project [27] that comprises PVs and LED devices on a building façade element. It constitutes the largest colour LED display worldwide (using 2.292 colour RGB-LEDs to make a 2.200 m^2 display screen) and a PV system based on polycrystalline silicon solar cells laminated within the glass of