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Aesthetic perception of photovoltaic integration within new proposals for ecological architecture

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ABSTRACT

Architecture has become an important field of research on the mitigation of climate change. The literature contains a number of environmental studies of buildings and energy efficiency improvements analysis. Important advances have also been made by integrating renewable energies within the building envelope. In architecture, however, it must be remembered that the formal aspect is as important as the functional one, and therefore rating the aesthetic perception of these new technologies is very interesting to better integrate more sustainable technologies in the city. This work focuses on the real opinion of the citizens about the aesthetic impact resulting from the use of photovoltaic systems in buildings. A survey was conducted using the Self-Assessment Manikin (SAM) to evaluate the feelings through two classic dimensions of affect: hedonic valence (pleasant-unpleasant) and arousal (activation or emotional intensity). Overall, results (error range of 5%) show that all the prototypes were rated positively and with a medium level of arousal, although the integrated systems obtained higher values in both dimensions of affect. The degree of appreciation of the installation by the observer has proved to be a powerful factor. On a socio-demographic level, respondents' age was observed as an influential factor in these subjective evaluations.

1. Introduction

Architecture, as a discipline, has undergone very significant changes in recent years. Apart from aesthetic factors or the innovative and challenging architectural designs frequently offered by the world's most renowned architects, the construction of buildings has become an important field of research investigating ways to mitigate climate change. Terms such as bioclimatic design, sustainable construction, energy efficiency and environment-friendly or natural materials are associated with the latest advances in an architecture that strives to adapt increasingly better to a more sustainable global development.

The literature contains studies which include environmental assessment as a means to help architects in their search for materials and construction solutions that guarantee the development of buildings that generate a lower environmental impact. The Life Cycle Assessment (LCA) methodology has been used in a number of studies as a tool that allows the calculation of environmental impacts and, therefore, the comparison of different aspects ranging from specific materials to whole buildings, including the entire construction process, the use phase and even the end of life of the building (Azzouz, Borchers, Moreira, & Mavrogianni, 2017; Bastos, Batterman, & Freire, 2014; Bonomo, Frontini, De Berardinis, & Donsante, 2017; Buyle, Braet, & Audenaert, 2013; Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014; Ghattas, Gregory, Olivetti, & Greene, 2013; Hemmerle & Hemmerle, 2016; Ortiz, Bonnet, Bruno, & Castells, 2009; Ramesh, Prakash, & Shukla, 2010; Sagani, Mihelis, & Dedoussis, 2017; Werner & Richter, 2007; Zabalza Bribián, Aranda Usón, & Scarpellini, 2009; Zabalza Bribián, Valero Capilla, & Aranda Usón, 2011). Many studies have shown that the greatest environmental impacts are produced during the use phase of the building, as this is the one with the greatest energy consumption (Azzouz et al., 2017; Ghattas et al., 2013; Peuportier, 2001; Ramesh et al., 2010), mainly due to the use of heating and air conditioning, household appliances and lighting. It therefore follows that a significant part of the research conducted focuses on reducing the impacts during this phase.

One possible way to lower the impact is to directly reduce the energy consumption of the building, which depends on a number of factors such as the construction solutions, the climatic conditions of the area where it is located and the type of installations the building is equipped with. A second way, however, consists in using renewable energy sources. This has led to a significant increase in the use of photovoltaic energy over the last 20 years, both in Spain and in Europe

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Fig. 1. The Eco-House prototype exhibited at SDE 2012. BIPV systems are used in the façade and BAPV on the roof.

as a whole. Initially, this technology was implemented in the form of "solar farms" integrated within rural areas, which occasionally modified a landscape that had remained practically unaltered for years except for the introduction of extensive agriculture (Torres-Sibille, Cloquell-Ballester, Cloquell-Ballester, & Artacho Ramírez, 2009). Yet, the requirements set out in increasingly more sustainable European and worldwide policies have gradually led to the presence of these facilities within the urban landscape, mainly in the form of systems for capturing solar power, which today generate a significant part of the European energy supply. The European Union has launched a plan to create an Energy Union to ensure a safe, affordable supply while also respecting the climate. The goals of this plan require that 20% of the energy must be obtained from renewable sources by 2020 and 27% by 2030. The advances being made in this sense are considered to be positive, as the quota of renewable energy rose from 8.5% in 2005 to 14.1% in 2012, according to figures from the European Commission. The scope of these goals nevertheless requires an active commitment by both the industrial and the residential sectors as regards the use of renewable energies.

In different European countries, the building regulations demand an increasingly significant application of this kind of installations, which are starting to become common features in the urban landscape. An example of this is the Technical Building Code in Spain (Gobierno de España, 2013), which requires the installation of photovoltaic systems in industrial buildings and thermal systems in those for residential use. Hence, energy efficiency improvement systems – especially those capturing solar power –are today considered just another element of buildings.

A great deal of research has been conducted within the field of photovoltaic technology in recent decades, but its integration within urban environments has only been seen as an interesting proposition in the last 5–10 years. The earliest studies basically investigated the energy potential of the installations, focusing on the areas of the roofs of buildings and their capacity to house photovoltaic installations. The main aim of these studies was to optimise the installations from the point of view of energy efficiency. To do so, they analysed the different existing technologies and their suitability in different climates and urban settings. Examples of such work include the review conducted by Makrides and collaborators (Makrides, Zinsser, Schubert, & Georghiou, 2013; Makrides et al., 2010; Makrides, Zinsser, Phinikarides, Schubert, & Georghiou, 2012; Vivar, Fuentes, Norton, Makrides, & De Bustamante, 2014) or studies that analysed the conditions produced in shaded areas in the urban setting (D'Orazio, Di Perna, & Di Giuseppe, 2013; Loulas, Karteris, Pilavachi, & Papadopoulos, 2012).

One factor that is considered important in several studies is the repercussion of the economic cost of installing photovoltaic systems for the whole building (Bonomo et al., 2017; Hemmerle & Hemmerle, 2016; Sagani et al., 2017; Yang & Zou, 2016). And a recent study even states that, in order to decide whether to incorporate a PV system into the building, the main motivation is personal economic benefit ahead of the contribution to environmental protection (Fleiß, Hatzl, Seebauer, & Posch, 2017). It must be remembered, however, that the use of these systems in the building envelope falls within the field of architecture, and hence, not only the efficiency and cost of the installation are important but the aesthetic also plays a very important role. The acceptance of this new technology by citizens, as users of the city, is today a topic of growing interest that can be an invaluable aid in designing these installations in the future. The integration of photovoltaic technology in buildings has a great potential for application if it is addressed as of the design phase of the building (Johnston, 2007). Conversely, installing these systems at the end of the process involves a higher economic cost and results in an aesthetically less attractive building. The literature contains several studies that, without analysing the users' perception at the aesthetic level, do evaluate people's acceptance and even their willingness to use photovoltaic systems that are integrated within the envelope (Haw, Sopian, Sulaiman, Hafidz, & Yahya, 2009; Radmehr, Willis, & Kenechi, 2014). These studies conclude that, in order to raise people's awareness regarding the use of photovoltaic technology in buildings, it is necessary to find a way to apply them without upsetting the aesthetic of the façade. How the elements of the installation are introduced into the building envelope is therefore of great importance.

Depending on the way the photovoltaic technology installations used in the envelope are fitted they can be classified as BIPV (Building-integrated photovoltaics, which are totally integrated within the building envelope) or BAPV (Building-applied photovoltaics, which are mounted upon a metallic support structure on the roof of the building) (see Fig. 1).

In the case of BAPV, no special interest is given to the aesthetic integration of the system and priority is generally granted to its ability to capture solar radiation. The type of installation and its location (normally on the roof) are often decided at an advanced stage of the project or even after it has finished, being the resulting less aesthetically attractive and less closely linked to architectural design. The use of BIPV technology, in contrast, requires technical planners to consider the installation from the initial phase of the design of the building in order to achieve a good aesthetic integration within the building as a whole. The use of this technology is becoming more popular as the wide range of possibilities for integrating it become known to architects and builders (Henemann, 2008) and some researchers and architects are devoting part of their work to exhibiting the state-of-the-art of BIPV products (Cerón, Caamaño-Martín, & Neila, 2013; Petter Jelle, Breivik, & Drolsum Røkenes, 2012). As some authors conclude (Athienitis & Candanedo, 2010; Michael, Bougiatioti, & Oikonomou, 2010), if special innovative designs are used, in some cases such integration could require a higher initial economic investment, but other studies confirm the long-term economic advantages of using BIPV systems (Portolan dos Santos & Rüther, 2012). The development of this type of photovoltaic systems and their capacity for integration within architecture is an ongoing field of research, both for the scientific community and for the photovoltaic industrial sector.

But what perception does the user have of the presence of these installations in his or her surroundings? How can the industrial sector know whether its products are being accepted or not? Studies that take into account the users' opinion in order to be able to evaluate the