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Architectural Implications in the Building Integration of Photovoltaic and Solar Thermal systems – Introduction of a taxonomy and evaluation methodology

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Abstract: *This paper examines the architectural implications for the integration of photovoltaic and solar thermal systems in new construction or extensive renovation of existing building shells. The study is based on a documentation of the current literature and a taxonomy of current and proposed applications based on conformance to a variety of building typologies. Additionally to the literature review, the paper delves on the investigation, assessment and categorization of existing applications, through case studies, analyzing the type and the function of each case, in order to identify the best practices for the different applications.The ultimate aim of this effort is to critically present the breadth of typologies of the plethora of alternatives available for building integrated photovoltaic and solar-thermal panels in ways that maximize their potential for solar gains for the purpose of addressing the power and thermal requirements of a given structure as well as its design.*

Keywords: Active Solar Systems, BIPV, BISTS, Building Envelope, Façade Design

1. Introduction

The energy problem is at the forefront of current discussions. After the first oil crisis in the early seventies, the use of renewable sources, especially solar energy integrated with architectural design, is an important parameter in reducing a building's carbon footprint [1]. Also, as the stock of fossil fuels is depleted, countries like Cyprus look to exploit local climatic conditions – extended sunlight periods – to lessen reliance of the current building stock on the national grid which relies on fossil fuel combustion. Indeed, solar energy is viewed as one of the main alternative sources of energy to deal with fossil fuel dependancy [2], especially as the operational costs of buildings account for 40% of energy use in the EU context. The increasing use of renewable energy sources means that building integrated solar thermal systems (STSs) and photovoltaics (PVs) have a key role in the provision of electricity, domestic hot water and in the heating and cooling of buildings [3].

2. Methodology of Investigation

The proposed methodology relies on literature review and precedent analysis to formulate a classification and taxonomy of various existing applications of the above mentioned systems. The fourty-two case studies selected and featuring both BIPV and BISTS, provide a sample for a taxonomy that delves on the investigation, assessment and categorization of existing system applications. In each case, system functions are examined in order to identify the specifications of the various applications and juxtapose them in a table format according to new buildings and extensive renovations. PVs and STSs are dealt in parallel to provide a holistic approach to an evaluation of the architectural implications building integration.

3. Literature Review

In the literature, the debate on renovation of existing buildings is dominant, with the field of building integrated technologies moving in that direction – the integration of solar panels to existing buildings in order to produce energy required for the building's operation without occupying any land. In the ongoing discussion, PVs are seen to be generally of benign environmental impact making use of one of the most viable renewable energy technologies by replacing existing building cladding materials [4].

Consequently, it is important to define the geometry and performance of BISTS and BIPV and to examine their applicability to new or existing building shells. Identified systems may fall into the following groups: *BIPV foil products*, *BIPV tile products*, *BIPV module products* and *solar cell glazing products* [5]. The STSs available for integration in the market are: the *Glazed Flat Plate Hydraulic Collectors*, the *Unglazed Flat Plate Hydraulic Collectors*, the *Unglazed Plastic Hydraulic Collectors*, the *Unglazed Flat Plate Air Collectors*, the *Vacuum Tube Hydraulic Collectors* and the *Concentrating Hydraulic Collectors* [6]. These technologies take the solar irradiation and convert it into solar thermal energy -for air or water heating- in the case of BISTS [7] and electricity in the case of BIPV.

Moreover, to be considered as **building integrated** these systems should be a functional part of a building's structure or should be architecturally integrated into its design [8]. The same rules, apply on the BISTS as well, having in mind that the basic solar thermal panel has the same geometry. The two usual **positioning locations** for a PV or an STS system are the roof and facade, with all other locations being known as building components [9, 10]. Another important aspect of these systems is the **flexibility** in the application of these systems to allow a multitude of building integrated options, e.g. BIPV foil products which are lightweight, flexible and can be curved, as well as being easy to install given prevailing weight constraints for roofs [5]. **Transparency** of the modules also offers the designer a range of possibilities to combine the production of electricity with interesting lighting effects [11]. **Weather proofing** is another consideration in the integration of PVs and STSs acting as the shell of the building as rainscreens or roofs. In this case the system modules act as an outer screen for the building, protecting an inner leaf from the deleterious effects of heavy wetting, solar radiation and the effects of thermal expansion and contraction [11]. It is also important to consider the effect of **noise reduction** as the system panels in double-skin facades or vertical flat surfaces make a positive contribution in this aspect [12, 13]. Also, by **shading** a façade system panels provide a passive way to limit excessive solar gains and the good opportunities of the combination of system modules into shading devices, gives both reduced cooling loads and utilization of solar energy which are a palpable expression of the conservation of energy [11]. Further, designers may vary the **color and texture** of an STS absorber without affecting to a large extent its performance (7-18% in similar climatic regions with Cyprus) [14] or in the case of the PVs more colors can be obtained by the variation of the thickness of the anti-reflection coating, although by doing this, the efficiency will decrease by 15–30% depending on the color, due to the increase of the overall reflection [11]. The parameters outlined above may be incorporated in **pre-fabricated** and **customized units** and PV and STS modules -especially the flat-ones- may be used as "filling" panels, integrated into **curtain wall** systems or **double facade** systems either in the vision area or in the spandrel area of the facade [11].

3. Comparative assessment and Critical Evaluation of Building Integrated Systems.

3.1. Best Practices

In order to cover all the possible applications regarding building integrated PV and ST systems, 42 case studies were examined. In these case studies, 7 types of different technologies are applied on new or existing buildings. Some technologies are more "popular" while others are seen in a limited number of examples. Various types are listed below:

3.1.1. BIPV and BISTS in New Buildings.

In this case, building integrated solar thermal systems and photovoltaics are fully integrated into the shell and form an integral part of the building design concept (Figure 1).

Figure 1: Views of integrated systems in 4 newly constructed buildings [Available online from www.bio-tecture.net, www.fondazionerenzopiano.org, www.jetsongreen.com, www.archdaily.com (accessed 25 May 2014)]

3.1.2. BIPV and BISTS in Existing Buildings.

Similarly, there are examples of applications in renovated buildings which form part of the building envelope, while improving the building's energy performance (Figure 2).

Figure 2: Views of integrated systems of 4 renovated buildings [Available online from www.projects.pilkington.com, www.solarwall.com, www.ecda.co.uk (accessed 25 May 2014)]

3.2. Comparison in the application of BIPV and BISTS in new and existing buildings.

The organization of the table below (Table 1) is based on the differentiation of these two categories, which thereafter, are organized according to the system technologies mentioned

			Applicability on New Buildings							Applicability on Existing buildings						
			BIPV				BISTS			BIPV				BISTS		
			Modules	Solar Cell Glazing	Foil	Tiles	Unglazed Flat Plate Air Collectors	Unglazed Flat Plate Hydraulic Collectors	Vacuum tube hydraulic collectors	Modules	Solar Cell Glazing	Foil	Tiles	Unglazed Flat Plate Air Collectors	Unglazed Flat Plate Hydraulic Collectors	Vacuum tube hydraulic collectors
System	Application	Air Heating					16							16		
		Water Heating						4	1						4	1
		Electricity Production	5	13	1	2				5	12	1	2			
Architectural	Application	Replacement of a building component	3	12		2		4		3	12		2		3	
		On Façade	3	9			16	2	1	3	8			16	1	1
		On Roof	4	4	1	2		1	1	4	4	1	2			1
		On Building Component		1				2			1				2	
		Flexibility														
		Ease on application														
	Building Physics	Transparency														
		Thermal Insulation		2							2					
		Weather proofing	5	11		2		2		5	11		2		1	
		Noise Reduction	3	3			16	1		3	2			16	1	
		Shading	2	12				3	1	2	11				3	1
		Structural														
	Integration	Visible Collector Profile	5	5				1		5	5				1	
		Surface Colour Texture		1		1	16	1			1		1	16		
	Construction	Pre - Fabricated Units	5	8		2		1		5	8		2		1	
		Customised Design		5	1		16	3	1		4	1		16	2	1
		Curtain Wall	2	3						2	3					
		Double Envelope Structure		3			16	1			2			16	1	

Scale: 1 … 16 | Low … High

Table 1 - Comparative table between the application of BIPV and BISTS in new and existing buildings.

above. Subsequently, each system is examined according to its architectural integration merits, such as a system's integration on the building shell, e.g. on the roof, in a façade or as part of another building integrated component. Then, issues of system flexibility are covered both in terms of unit geometry and mounting ease – rated from low to high – both of which affect the viability of a system's integration on new or existing buildings.

Subsequent categories include architectural aspects, beginning with "transparency", which is rated again from low to high and addresses the extent to which system panels allow for effective insolation from the outside and visibility from the inside of a building façade. Thermal insulation is also examined, which addresses the "weather proofing" performance of the system panels constituting the building shell, which indicates the technologies that can provide protection from the weather to the building and also illustrate contributions with regards to noise protection and façade shading. There follows an estimate with regards to the shell structural system contribution inherent in the panel assembly, as a result of its integration in the building façade. Two further issues are examined: the extent to which the "collector profile is visible" after building integration; and the variations in "surface color or texture" beyond the base case. Next, the comparative table looks at issues of pre-fabrication and the customization potential of the systems examined in order to fulfill individual case study specifications; and lastly it indicates whether the system examined forms part of a curtain wall or double-skin facade.

3.2.1. *Reijenga* Classification

In the context of the discussion above, it is also important to quote the work of Tjerk H. Reijenga [9], on the integration of PV systems in architecture and their subdivision into five categories: 1. applied invisibly; 2. added to the design; 3. adding to the architectural image; 4. determining architectural image; and 5. leading to new architectural concepts. However it must be said, that the challenge for architects, is the proper PV modules building integration, and it must be noted that the invisible apply of PV modules to a project does not necessarily mean that this project has lesser quality [9]. So based on the findings of the preceding heading, the 42 selected case studies may be reclassified and organized according to Reijenga's classification as follows in Table 2:

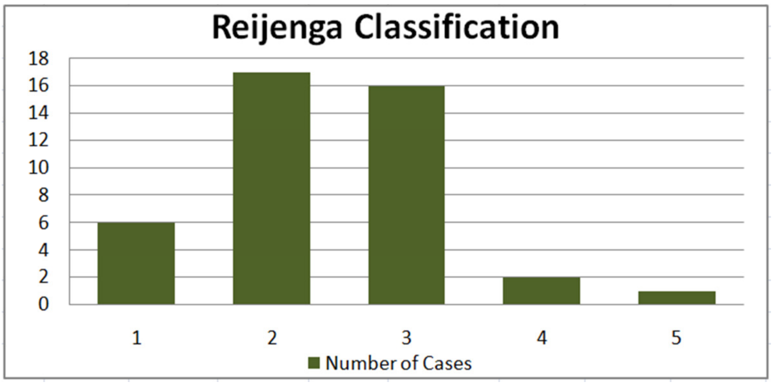

Table 2 - Dominant trends with regards to the integration of PV and STS in new and existing buildings.

4. Discussion – Conclusion

The results above indicate that building integration is equally possible in new and existing buildings. Also, the comparison reveals that the most popular method for integration is BISTS with the Unglazed Flat Plate Air Collectors, followed by BIPV technology of Solar Cell Glazing. Another important finding is that in a majority of the selected case studies, a number of compatible building façade components are readily interchangeable with solar panels indicating the relative ease of integration, while at the same time weather proofing, noise reduction and shading are also significant. An important characteristic of a properly integrated technology has also emerged, in the ability of the Unglazed Flat Plate Air Collectors to be colorized. In relation to the construction of an integrated system, apart from the Unglazed Flat Plate Air Collectors, construction methods available do not determine the popularity of appropriate integration. On the other hand, it is significant that technologies which can be applied easily are not popular. It is also remarkable that no technology offers high system panel transparency, both in their application to new or existing buildings. It is also shown that although foil is flexible and relatively easy to apply, it is not a popular application. Finally, it is clear that no technology yet makes significant contributions to a building's structure.

In both cases of existing and new buildings, the two technologies that offer themselves for building integration are the BIPV, Solar Cell Glazing and the BISTS, Unglazed Flat Plate Air Collectors. Although they are not the easiest to integrate within a building facade, they are widely used due to their superiority in many of the categories illustrated above. However, it is significant that in the case of Cyprus, where cooling loads are about six times larger than the heating loads [15] - probably also true of several other Mediterranean locales - the preffered technology is Solar Cell Glazing, due to the shading it offers, which can be used as part of a passive cooling strategy. Electricity generation may then be used as an energy source for cooling. Similarly BISTS contribute to the production of hot air or water. Finally, the utilization of the reijenga classification analysis indicates that according to that categorization method the prevailing entries were the panel systems: "Added to the design" and also "Adding to the architectural image". From this to occur, system panel designs need to be innovative in the way in which they allow for it to coexist symbiotically and be part of the architectural concept of each building.

4.1. Further Research

Given the results of this research, future work will be carried out in terms of prototyping of various assemblies of building integrated solar systems based on the parameters outlined above. The prototyping phase will be concurrent with a simulation phase that will attempt to examine the combination of parameters available to the design team, as well as the construction of scaled versions of building shell versions in order to conduct filed measurements and for simulation model verification purposes on the road to a holistic approach with regards to the examination of the architectural implications in the Building integration of photovoltaic and solar thermal systems in the case of Cyprus.

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