A Critical Analysis of the Potential of Photovoltaic (PV) Modules as Design Elements. a Case of Selected Kampala Hotels, Uganda

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Abstract- Traditionally, Photovoltaic (PV) modules have been perceived as technical devices other than design elements, often integrated onto building envelopes in more often than not as a non-aesthetical component thereby appearing as afterthoughts. This in the end compromises a building's design aesthetics while in pursue of green and clean energy. Furthermore in Uganda, the energy costs of operating facilities especially large building portfolios such as hotels, shopping malls and arcades are consistently rising due to the high rate of growth of demand for electricity. Despite the high influx of PV systems in Uganda, PVs are not being utilized beyond their accustomed norm of generating electricity energy. The study therefore investigates the potential use of PV modules as building design elements with specific reference to selected in the Capital City of Uganda, Kampala. The research gives a theoretical understanding of the different ways in which PV modules can be applied to enhance a building's design aesthetics as well as the major factors that affect their integration as design elements. A total of four case studies and field surveys furnished the research with useful and consistent analyzable results. The study reveals that the architectural integration of PV modules is feasible and that the site contexts, marketability and design character of the hotels allow for PV integration as design elements and can be used to offset the short term economic disadvantages of this technology.

Index Terms- Photovoltaic, Modules, design elements, Uganda

I. Introduction

Photovoltaic or PV can be defined as that pertaining to the generation of electricity when radiant energy falls on the boundary between dissimilar substances, two different semiconductors. (Merriam-Webster 2013) whereas Module are the PV cells combined to form modules, which give the system the flexibility to be expanded or reduced to suit any given application. (Basnet 2012) The concept of using photovoltaic modules to generate electricity has existed for quite a long time. Apart from their accustomed norm of providing electrical power, these devices can also be used as building and landscape design features such as roof covers, facade finishes, glass panels or sun screening devices. In other words, PV modules pose great potential to the built environment due to their dual functionality.
Claas Helmke (2001, p.1) points out the three categories of building integrated PV modules based on their physical properties and application. He further defines these categories in terms of generations, with the first generation of building integrated photovoltaic systems consisting of PV modules mounted onto private or commercial buildings using custom-made substructures and fixtures, these being the most commonly applied systems in Uganda. Second generation PV systems are characterized by PV modules that replace parts of the building envelope while the third generation systems are classified by flexible photovoltaic laminates (Helmke 2001, p.3).

The use of PV modules is increasingly becoming popular within Uganda's built environment but there is no significant evidence to show that they have been fully utilized to complement building design aesthetics. Regional practice strongly depicts the installation of photovoltaic panels onto flat and inclined roof systems. This is more common in areas near the equatorial region where the sun's position is usually high all-round the year (Basnet2012, p.16). Whereas there have been a number of studies on photovoltaics in architectural design, there has not been any study to assess their potential use as building design elements in Kampala.

II. Objectives

The prime goal of this research is to analyze the potential use of PV modules as building design elements with specific reference to selected Kampala hotels. The specific objectives included; to identify the factors affecting the use of PV modules as design elements; to reveal ways of how PV modules can be used to articulate building aesthetics; to discuss the benefits of the architectural integration of PV modules; to assess the challenges of using PV modules as design elements within Kampala hotels and finally to propose ways in which the challenges can be overcome.

III. Methodology

The research adopted the following data collection techniques: Direct Observation: Field visits to selected hotels premises within Kampala. To document the architectural character of hotel buildings using photography and sketches as tools of capturing and analyzing information.; Literature review: On how PV modules have been used to enhance building design aesthetics, factors determining their use and any other information that may prove useful to the study. These included books, reports, thesis, online articles and journals.

Interviews and Questionnaires: These were used to collect information in form of expert and personal opinions from target populations comprising of practicing architects, PV expatriates, hotel administration and the general public. The specified population groups majorly consist of stakeholders responsible for the implementation of PV modules as design elements.

IV. Literature review

PV modules as design elements

The use of PV modules to articulate building facade aesthetics is a modern movement that lies within the field of architectural engineering.

According to Anne G. Hestnes (1999), PV systems when integrated in a building, become part of the general building design and also often become general building elements. This therefore implies that there may be a cost reduction factor when used to execute a function of a building component that they would have otherwise been superimposed on.

Building integrated photovoltaics refers to the concept of integrating photovoltaic elements into the building envelope, establishing a symbiotic relationship between the architectural design, functional properties and economic regenerative energy conversion (Zeeuw 2011, p.6).

From the above, it can be noted that major factors surrounding this concept are, to improve building aesthetics thus marketability of the project, a concept that integrates sustainability, social and economic issues.

PV technology has advanced with time becoming more efficient as well as taking on various forms in order to capture various architectural styles. Building integrated photovoltaic systems can be categorized into three generations, basing on Claas Helmke (2001). The generations are categorized based on the physical properties and the modes of integration of the photovoltaics.

The first generation of building integrated photovoltaic systems was the genesis of the architectural integration of PV modules. With these systems the photovoltaic generator is mounted onto an existing roof using substructures and fixtures (Helmke 2001, p.2). However, due to the mode of integration their impact on the facade appearance is questionable in terms of workmanship. They focused more on function than aesthetics.

Flexible photovoltaic laminates are categorized under the third generation of building integrated photovoltaic systems. Their flexible character enables them to take up the form of the building component onto which they are secured (Helmke 2001, p.3). With this, new fields of application can realized due to the flexible and lightweight character of the photovoltaic laminates especially with curving building envelopes.

The above discussions reveal that there has been a transition in building integrated photovoltaic systems, each portraying a specific character and function, prompting one to ask whether Kampala's architecture is in position to comfortably embrace this transition and to what extent, with specific reference to hotel designs.

PV Module Integration Methods

In the thesis titled *Architectural Integration of Photovoltaic and Solar Thermal Collector Systems into buildings*, Arjun Basnet (2012, p.24) states that PV module integration methods can be classified into two categories, superimposed and integrated systems. The author further defines a superimposed system as where the PV system is attached over the existing building envelope while an integrated system is where the PV system forms a part of the building envelope. A system where photovoltaics form parts of the building envelope may appear as a more unified body compared to that where the photovoltaic modules are superimposed.

Types of PV Module Integration

There are three basic ways of integrating PVs in buildings, Roof-based systems, Facade systems,

Sunshades and sunscreens, based on Randall Thomas' (2001, p.23) book on *Photovoltaics and Architecture.* Depending on which part of the building they are to be integrated, the properties of the PV modules and character of the specific area of integration have to be identified.

Roof integrated PV systems involve integrating PV modules on flat roofs, inclined roofs, curved roofs and skylights. Roof based systems may be easier to integrate PVs aesthetically and functionally than a wall (Randall 2001, p.27). These could then be considered as a potential starting point for exploring design though the use of photovoltaics in Uganda.

PVs laid horizontally on the flat roofs are normally not visible from the ground and hence the significance of aesthetic part of integration can be less (Basnet 2012, p.28). This type of integration basically focuses on energy production rather than design aesthetics due to restricted views. Not much design articulations can be achieved unless the roof is looked at from a higher viewing platform.

Transparent and semi-transparent PV roof panels can be used in glass covered areas such as atriums; part glazing and part-opaque PVs (Randall 2001, p.27) transmit enough diffused sunlight to achieve a pleasant lighting level in the atrium.

Facade integrated PV systems involve integrating PV modules as cladding elements in opaque parts of the facade, transparent PV facade in almost the same way as a standard glazed facade, on inclined walls and PV modules as sunshades. Randall (2001, p.28) suggests that a facade could even consist of a combination of glazed areas for vision and opaque PV panels or have PV modules with opaque areas and transparent ones for curtain walling systems. This indicates that opaque PV modules can be superimposed onto a structural wall or fitted into the frame of a curtain walling system to create a wall plane that achieves a desired facade aesthetic.

Sun shades can take the form of a fixed or moveable system and can be installed either vertically or horizontally on the facade of a building, as posited by Basnet (2012, p.39). These can be a good option for preventing the penetration of direct sun rays into the interiors most especially on the east and west facing facades. Installation costs, skills and technology could be a factor to consider when selecting either system.

Visual aesthetics of PV designs

On the whole, PV systems that are architecturally pleasing within the context of the building, good material and colour composition, that adapt well to overall modularity, the visual aspect of the grid which is in harmony with the building and creates a satisfactory composition will result in good integration and renders high architectural quality (Roberts and Guariento 2009, P.12).

Factors influencing the use of PV modules as design elements

A study conducted by Craig Jackson and Sara J Wilkinson (2003, p.404) titled *An Evaluation of the Viability of Photovoltaics in Residential Schemes Managed by UK Registered Social Landlords* showed that 57% of the respondents felt that despite the cost factor, photovoltaics were both innovative and exciting and an energy source of the future. The findings suggest that design aesthetics can be a factor considered by a project client to offset the economic disadvantages associated with the use of PV systems. The use of PV modules as architectural design elements could therefore be looked at as a benefit when assessing the viability of their integration. This is due to the fact that visual appearance does increase the marketability of a project as such new technologies could always be used as an opportunity to create a niche market by staying one step ahead of the competition (Jackson et al 2003, p.406). Design aesthetics could therefore be established as a factor when assessing the potential use of PV modules as building design elements.

Cost is a major propriety in relation to other factors when it comes to the architectural integration of PV modules. Initial capital and maintenance cost of PV installations are categorized under cost in this discussion. A major attraction of building integrated PVs is that the cost of the elements they replace can be offset against the PV cost (Randall 2001, p.33) for example the use of integrated PV systems as cladding elements in opaque parts of the facade, transparent PV facade in almost the same way as a standard glazed façade or PVs as sunshades.

In general, costs of PV systems are higher than those of conventional cladding systems that they set out to replace. However, compromises are at times may made for the architectural aesthetics. Jackson et al (2003, p.407) study hypothesized that in order for residential social landlords to view photovoltaics as a truly viable option, costs would need to fall. The above discussion deduces cost as a determining factor to the integration of PV designs but with social issues having the potential of offsetting their economic disadvantages.

More often than not, designers view solar design as a limitation rather than an opportunity. Many architects and clients feel that solar architecture implies rigid design limitations regarding orientation, placement of windows, sloping roof elements, sun spaces and so on (Kiss Cathcart Anders Architects 1993, p.6). But for the implementation of any idea, project clients and those responsible for the implementation must be informed of the project's potential out comes.

The size of the development program that the Registered Social Landlords in the UK managed or expected to execute had a link to the use of photovoltaics on their schemes (Jackson's et al 2003, pp.401-402). The survey revealed that the larger Registered Social Landlords had more scope to utilize new technologies and products such as photovoltaics due to their ability to have more access to research funding and undertake demonstration projects.

Randall (2001, p.28) mentions that, inclined photovoltaics can be integrated on a vertical wall to create a glazing or rain screen cladding system, but goes ahead to caution that complexity for such construction cladding increases. This reveals that architectural engineering with specific reference to the integration of PV modules calls for an understanding of design and construction techniques. Low skills and technology may therefore limit the level of PV design articulation.

V. Analysis of the Findings

The scope of the research was limited to hotel developments situated within the Kampala central business district. Kampala's central business district could possibly be termed as one of the busiest areas in Uganda and for that reason the research sought to analyze hotel developments prone to a large client base. The research had also aimed for a representative sample size of approximately eight hotels preferably those built in recent time and bearing a large capacity. However, the research was limited to four hotels as a result of the ongoing terror alerts within the country. The inability to gain in-depth data has to be recognized.

Protea hotel is located at the Kololo terrace, flunked by Acacia avenue, upper Kololo terrace and Elgon terrace road on the west, north and south respectively. Furthermore, the terrain slopes along the upper Kololo terrace and Elgon terrace road with Acacia avenue at the lowest point.

Grand imperial hotel premise is located in the heart of Kampala's central business district, on Speke road, Nakasero hill. The hotel is flunked by Shimoni road on the south, Speke road on the north-east and The Square 2 on the north-west. Situated on its western side with a height of approximately 50 meters is the East African development bank, the only adjacent landmark building that has a shading effect on the hotel's building envelope.

Metropole hotel is located on Windsor road, Kololo hill. The site is flunked by tarmac roads on the north and west facades, coupled with a row of trees along its boundary walls. The hotel building mass is orientation in such a way that the longest facades are facing the east and west direction.

Sheraton hotel is located on Kintu road at the heart of Kampala's central business district. The site is flunked by Kintu road, Speke road and Nile Avenue on the north, west and south respectively. With a storey height of 13 floors, the hotel building imposes high visual dominance on the surrounding context. Furthermore, the hilly terrain does not have a significant impact on the visual quality of the hotel building as a result of its grand height.

The architectural integration of PV modules is context dependant. Aspects such as shadowing from adjacent trees and buildings, terrain and dust intensity may have a positive or negative impact on PV designs. The character of the building features determines the type, method and properties of PV integration.

The performance of PV modules decreases with shadowing hence designs for building integrated PVs need to consider this to maintain high performance (Randall 2001, p.11). One would expect that, shadowing of the hotel buildings in the Kampala central business district would majorly arise from their adjacent buildings. This may have been true for Grand Imperial hotel however the study revealed that the major source of shadowing of hotel buildings was caused by trees thou in a mild state.

Out of the four hotels that were visited, only one of them was flunked by two roads. The rest had three roads abutting their premises. The study shows that the roads created an offset distance between the hotels and adjacent buildings consequently rendering the facades free of shadowing. Height as an advantage allowed for views of Sheraton hotel from streets far beyond the hotel premises on streets such as Sezibwa and Pilkington road. In other words, it can be argued that the height of the hotel buildings coupled with the sloping terrain offer unobstructed views of the hotel facades.

The study also reveals that, despite the hotels being located on hill slopes, the flat roofs could not be seen from the ground regardless of the viewing point. Therefore, the significance of PV design aesthetics can be less or not there at all as reported in the research by Basnet (2012, p.28). On the contrary, the pitched roofs could be viewed from both within and off the hotel premises especially from the upper parts of the sites.

In summary one can say that, the vast application of pitched roofs on hotel building designs with specific reference to clay tile roof coverings pose great potential for the architectural integration of PVs on inclined roofs and integrated PV tiles.

It is apparent that some of the hotel buildings possessed 'blank' facades that facing the east and west as observed on Sheraton and Metropole hotel. Furthermore, air conditioning systems secured on the facades of Protea and Metropole hotel had a discreet effect on the surface area although Metropole hotel managed to mitigate this effect by securing them within recessions in the facade.

VI. Conclusion

Research reveals that PV module integration methods can be classified into two categories, superimposed and integrated systems. There are also three basic ways of integrating PVs in buildings, roof-based systems, facade systems, sunshades and sunscreens.

A comparative study of the four hotels reveals the suitability for the architectural integration of PV inclined roofs, vertical facade and sunshade systems, partially to the vivid views of the hotel building envelopes from adjacent streetscapes that flunk Sheraton, Protea, Metropole and Grand Imperial hotel on the upper slopes of Nakasero and Kololo hill where they are situated. They enjoy high visual qualities without compromising security on the hotel premises. Furthermore, the vast application of visible installation free terracotta tile pitched roofs on three hotels as opposed to the invisible installation packed flat roofs poses great potential for PV integration on inclined roofs, as a combined roof element or mounted above the roof coverings.

It is evident that the vast applications of inclined, curved and straight transparent glazing members in public spaces create opportune areas for the integration of semitransparent PV glazing known to possess a high solar radiation absorption rate. However, these integrated systems require a high level of skill and PV technologies that are currently unavailable in Uganda. The research therefore proposes that architects work closely with PV expatriates and other engineers through design consultations to be in position to design and construct buildings that incorporate such technology.

The research data confirmed that PV modules on the local market cannot effectively satisfy requirements that must be addressed by PV designs namely size, colour, cost, transparency and weather-tightness. For that reason, special orders have to be made for any hotel design that seeks to incorporate PV modules as design elements. However, PV technology will have to be affordable in capital terms before they can be seen as both a design and power production option. Cost reduction will occur if PV modules are manufactured locally, as pointed out in the research survey, where plans of establishing PV module assembly plants in Entebbe and Mbale exist. In addition, training of solar PV technicians to be in position to install complex integrated systems will result in a reduction of construction costs, as the cost of the PV modules are offset against that of the substituted elements.

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