

The use of architectural treatments for optimal utilization of solar energy

Dr. Amr A. Zeina

Department of Architectural Engineering, Faculty of Engineering, Horus University, New Damietta, Egypt

Abstract:

Recent technological development in the manufacture of photovoltaic solar cells, the use of modern materials such as silicon, and the discovery of nano-cells have led to an increase in their efficiency in generating electrical and thermal energy, as well as in their ease of use. Which allows its exploitation in the architectural formation of the building, especially the facades, where the traditional exploitation of solar cells is to place them on the roofs of buildings in a horizontal manner, which wastes the exploitation of roofs in serving users.

Where the research dealt with the definition of sustainability and its principles, then the study of solar cells and their types as one of the applications of benefiting from solar energy in generating clean energy according to the principles of sustainability in order to preserve the environment, then studying the role of architects in achieving the principles of sustainability by providing clean energy through the optimal exploitation of solar energy in power generation Clean through architectural treatments, studying and analyzing some international and Arab architectural examples in which the optimal utilization of solar cells was made through architectural treatments such as facades and how they added the aesthetic shape of the building and maintaining the sustainability of the surrounding environment, then access to the results and discussion and finally the conclusion and recommendations that encourage architects to How to exploit solar cells through architectural treatments on a large scale.

Keywords:

Sustainability- Solar energy - Architectural treatments.

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Introduction

The effects of the increasing global human demand for energy, to the use of environmentally polluting species such as fossil fuels and others, so alternatives were searched to provide the required energy from alternative environmentally friendly sources such as photovoltaic cells by exploiting solar energy to generate the necessary electrical energy without endangering the delicate balance of the ecosystem(de Lemos Martins et al., 2019).

In the past, an increase in carbon emissions was seen as a sign of economic progress and expansion. Emissions were estimated at 93 million tons in 1860, but by 1900 they increased to 525 million tons and by 1950 to 1.62 billion tons. The amount of carbon in the atmosphere was by the end of the year. In 1994, it increased by 4 billion tons over the previous year(Gunarathna et al., 2023).

Therefore, the United Nations has been keen to encourage the exploitation of clean energy to achieve the concept of sustainability and protect our planet from extinction, as photovoltaic units collect solar energy to produce clean and sustainable electricity using solar energy, and researchers hope to increase the efficiency of solar power plants to make optimal use of solar energy to generate the required energy (Gunarathna et al., 2023).

Photovoltaic panels are characterized by their flexibility and simplicity of installation, and are one of the most well-established renewable energy

sources, and will have a significant impact on the transition towards a greater share of renewable energy in the global energy sector(Kabir et al., 2018).

The technological costs used in manufacturing solar panels are still relatively high, but with the continuous development of manufacturing technology, it will lead to a decrease in the standard cost of energy that can reach 36%, which may attract more investors and enhance the share of solar photovoltaic energy in the energy sector in the world(Yang et al., 2014).

It is possible to encourage and develop the exploitation of solar energy through the conclusion of technology sharing agreements in the manufacture of solar cells between countries of the world in order to achieve the principles of sustainability(Almaz, 2018).

The architectural sector must play a major role in encouraging and implementing a strategy to achieve the principles of sustainability through the exploitation of clean energy sources, especially solar energy(Yang et al., 2014).

Research problem:

The limited exploitation of solar cells by architects in buildings to produce environmentally friendly energy by installing them on the roofs of buildings where the extension is horizontal, especially since they need large areas, which wastes the exploitation of roofs of buildings for the activities of users and

becomes neglected places, and therefore the exploitation is not ideal, nor Solar panel cells are exploited by architects as architectural treatments that give the building an aesthetic and functional appearance.

Research objectives:

Using architectural treatments and architectural formation to take advantage of modern technological development by enhancing the efficiency of solar cell production of renewable energy.

Research Methodology:

To achieve this goal, the research followed the deductive approach to identify some important concepts of research such as sustainability and its principles, as well as solar energy and technological development in the production of photovoltaic cells for optimal utilization of solar energy in the generation of electricity or thermal energy through the literature that dealt with these topics and the role of architects in achieving the principles of sustainability through The exploitation of solar cells in the treatments and the architectural formation of the building to become environmentally friendly, then the inductive approach to study and analyze some international and Arab examples of architectural projects that applied the principles of sustainability through the exploitation of solar energy on a large scale through architectural treatments in generating clean energy that does not affect the environment.

1- Sustainability:

Sustainability was defined in 1987 AD by the Portland Commission (the World Commission for Development and the Environment (WCED)) as "the path of human progress that meets the needs and requirements of current generations without prejudice to the ability of future generations to meet their needs"(unhabitat, 2021), meaning that every generation must meet its current needs without incurring debts. It can pay it without prejudice to the needs of future generations, and according to this definition, the principles of justice between one generation, justice between current and future generations, and preserving the integrity of the environment are the main guides for sustainable development(Almaz and Farahat, 2023).

1-1 dimensions of sustainability:

According to the United Nations definition of shelter UN-Habitat, it is a dynamic process (effective and changing), with multiple dimensions, and requires the concerted efforts of all workers in the field of urban development (the state, the private sector, non-governmental organizations and users), and at

all levels (central and local) in order to achieve urban development For current generations without prejudice to the needs of future generations within a stable institutional, political, economic and social framework capable of empowering the actors of that development(Zeina and Mohamed, 2021).

In the definition of the United Nations Human Settlements Program, UNCHS, the city that achieves sustainable urban development is the city that achieves economic and social development side by side with urban development, so that such development takes into account the avoidance of negative impacts on the surrounding environment resulting from that development(Zeina, 2022).

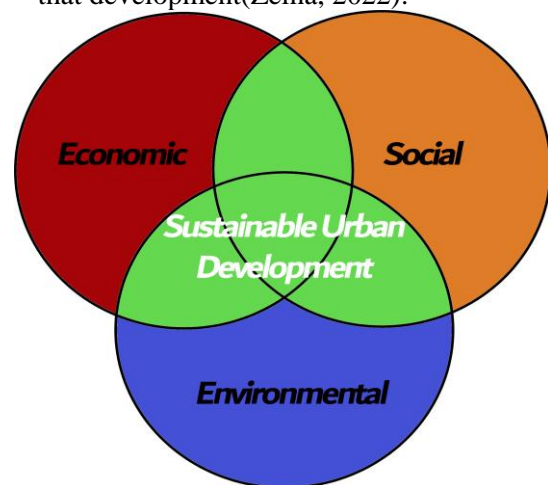


Figure 1 shows the dimensions of sustainable urban development. Source: (UN-Habitat, 2012)

1-2 Sustainable Development Goals:

A unifying framework for peace and prosperity for people and the planet, both now and in the future, is provided by the 2030 Agenda for Sustainable Development, which was accepted by all United Nations Member States in 2015. The 17 Sustainable Development Goals (SDGs), which are an urgent call to action for all nations—developed and developing—in a global partnership, are at the Centre of it. They understand that combating poverty and other forms of deprivation requires policies that enhance health and education, lessen inequality, promote economic growth, combat climate change, and fight to protect our seas and forests(Hák et al., 2016).

The 17 sustainable development goals (SDGs) to transform our world:

GOAL 1: No Poverty

GOAL 2: Zero Hunger

GOAL 3: Good Health and Well-being

GOAL 4: Quality Education

GOAL 5: Gender Equality

GOAL 6: Clean Water and Sanitation

GOAL 7: Affordable and Clean Energy
 GOAL 8: Decent Work and Economic Growth
 GOAL 9: Industry, Innovation and Infrastructure
 GOAL 10: Reduced Inequality
 GOAL 11: Sustainable Cities and Communities
 GOAL 12: Responsible Consumption and

Production
 GOAL 13: Climate Action
 GOAL 14: Life Below Water
 GOAL 15: Life on Land
 GOAL 16: Peace and Justice Strong Institutions
 GOAL 17: Partnerships to achieve the Goal



Figure 2: shows the Sustainable Development Goals.

Source: (Hák et al., 2016)

We see that the Sustainable Development Goals No. 7 and 11 put a strong emphasis on clean energy and sustainable cities, therefore we must increase the usage of renewable energies like solar energy and create systems to capitalize on it, particularly applications of artificial intelligence(Hák et al., 2016).

2- Solar Energy:

Solar energy is one of the renewable energy sources that have been the subject of study and policy due to the growing threat of climate change and global warming.

2-1 Definition of Solar Energy:

Using the sun's heat and light to generate electricity and solar thermal energy is one of the most significant renewable energy sources. The technology needed to collect solar energy at the necessary scale are the biggest difficulty in transforming it into various forms. Every day, the sun provides over 173,000 terawatts of energy to the globe, 10,000 times more energy than is used worldwide(Dickinson, 2018).

Photovoltaic (PV) cells made their debut in 1958 when they were launched into outer space onboard the Vanguard Satellite. The PV cells proved so reliable that they have been an

intricate part of powering our telecommunications industry ever since(Kabir et al., 2018).

The fact that silicon, one of the most prevalent materials on Earth, serves as the fundamental building component of solar cells is just one of the numerous advantages of making solar cells. Moreover, the primary component of beach sand is silicon(Bagher et al., 2015).

The massive rise in the global economy, which is a reflection of both population growth and increased wealth, is taking place on a planet that isn't much bigger now than it was when humanity first evolved some 4 million years ago(Bagher et al., 2015).

The employment of active or passive solar techniques is one of the two main ways to transform solar energy. Using concentrated solar power, which directs sunlight to a specific region using mirrors or lenses, photovoltaic systems (solar panels and other associated components), and solar water heating are all necessary components of active solar approaches. Buildings must be oriented towards the sun and have enough ventilation in passive systems(Kabir et al., 2018).

2-2 Strategies of solar energy utilization:

Many innovative strategies, including the

following, have been employed to increase the effectiveness of solar energy utilization(Gunarathna et al., 2023):

Concentrator photovoltaics: By using lenses and curved mirrors to focus light onto photovoltaic surfaces, these systems combine the advantages of photovoltaic systems and concentrated solar power. Moreover, they employ solar trackers, which guarantee the center point of the cell when the angle of the sun varies(Bagher et al., 2015).

Photovoltaic cell systems are positioned across lakes, irrigation canals, and water reservoirs in floating solar energy applications. The benefit over systems that are put on land is that it increases energy conversion, conserves water lost to evaporation, and encourages land preservation(Dickinson, 2018).

Perovskite Solar Cell: This solar cell uses a substance with a perovskite structure as the energy-storing active layer, such as compounds made of methylammonium lead halides. Although not being as steady, they capture energy more effectively than conventional techniques(Dickinson, 2018).

2-3 The importance of using solar energy:

For the following reasons, solar energy is a

crucial renewable energy source(Kabir et al., 2018):

Solar energy harvesting is environmentally benign since it produces no significant greenhouse gas emissions.

It is sustainable – for the apparent reason that its source is the sun.

It is completely free, and anybody with the correct tools and information may use solar power to meet their requirements.

Economically advantageous - while having a high initial setup cost, the maintenance costs are rather cheap.

Many uses: Solar energy may be utilized to produce both thermal and electrical energy.

2-4 Economic Significance of Solar Energy:

The market for solar energy is anticipated to keep growing as long as the technology supporting its collection keeps developing. According to Prudence Research, the market was valued \$197.23 billion in 2021. According to the company's projections, at a CAGR of 7.2%, it would reach \$368.63 billion by 2030(de Lemos Martins et al., 2019).

Clearly, this can only be accomplished by continually improving the processes for converting solar electricity(Dickinson, 2018).

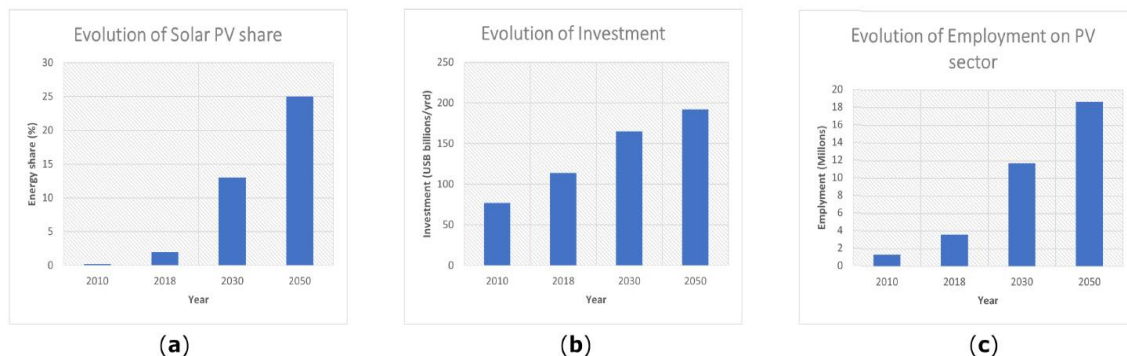


Figure 3 shows Evolution of the importance of PV sector. (a) Evolution of the energy share of PV systems; (b) evolution of the investment in PV energy; (c) evolution of employment in the PV sector. Source: (Dickinson, 2018)

2-5 Challenges in the Utilization of Solar Energy:

Solar energy has drawbacks despite its benefits. Variable supply - The availability of solar energy varies greatly depending on the time of year and the location. Low supply means that usage is also constrained(de Lemos Martins et al., 2019).

Energy conversion of photovoltaic cells has not yet reached its maximum efficiency, despite the continual advancements made in solar energy conversion(Hemsath and Bandhosseini, 2015).

Land space is needed for the installation of solar power systems, which might be difficult

in places with limited land(Hemsath and Bandhosseini, 2015).

Although there is no complete list of technological hurdles to solar energy conversion, these are some of the difficulties that need to be solved in the path of developing sustainable solar energy through the use of artificial intelligence applications(Dickinson, 2018).

2-6 Types of Solar Cells:

1st Generation Solar Cells.

2nd Generation Solar Panels

3rd Generation Solar Panels

Solar cells contain materials with semiconducting properties in which their

electrons become excited and turned into an electrical current when struck by sunlight. Solar cells come in a huge variety of forms, but the two most popular kinds are those constructed of crystalline silicon (both monocrystalline and polycrystalline) and those produced using a process known as thin film technology (Bagher et al., 2015).

2-6-1 1st Generation Solar Cells:

The most typical solar panel types utilized in conventional settings are those built of monocrystalline silicon or polycrystalline silicon (Bagher et al., 2015).

1- Monocrystalline Silicon Solar Cells:

The hue of monocrystalline solar cells, sometimes known as "single crystalline" cells, makes them simple to identify. The fact that they are said to be created from an extremely pure kind of silicon is what distinguishes them the most, though (Yüksek and Karadayi, 2017). Monocrystalline solar cells are created from "silicon ingots," which have a cylindrical shape for optimum performance. In essence, engineers created the silicon wafers that make up the monocrystalline panels by cutting four sides out of cylindrical ingots. So, unlike other types of solar cells, monocrystalline solar panels feature rounded corners rather than square ones (Yüksek and Karadayi, 2017).

Monocrystalline solar cells are not only the most space-efficient, but they also produce the most electricity. This makes sense since fewer

cells would be required for every unit of electrical output. Monocrystalline solar arrays are therefore the most compact in terms of size and generating intensity.

The fact that monocrystalline cells persist the longest of all the cell types is another benefit. For these kinds of PV systems, several manufacturers provide warranties ranging from 10 to 25 years (Bagher et al., 2015).

2- Polycrystalline Solar Cells:

The first solar cells to be presented to the market were polycrystalline solar cells, commonly referred to as polysilicon and multibillion cells, in 1981. The cutting procedure utilized for monocrystalline cells does not apply to polycrystalline cells. Instead, the silicon is heated and then poured into a square mound, giving polycrystalline its square form. As a result, they are significantly cheaper since the production technique almost eliminates silicon waste (Bagher et al., 2015).

Yet polycrystalline is less effective than its sibling, monocrystalline. In general, polycrystalline solar PV systems have an efficiency of 13–16%; once more, this is due to the material's lesser purity. This fact also makes polycrystalline less space-efficient. The fact that polycrystalline has a lower heat tolerance than monocrystalline, which means they don't operate as well in high temperatures, is another disadvantage (Yüksek and Karadayi, 2017).

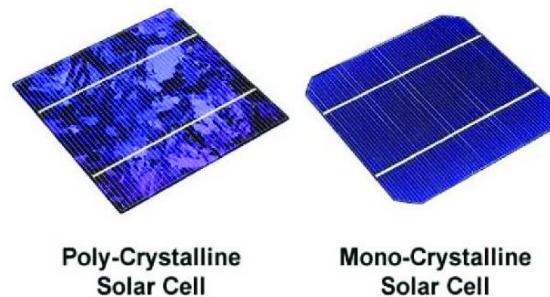


Figure 4: shows Monocrystalline Silicon vs Polycrystalline Solar Cells Source: (Bagher et al., 2015)

2-6-2 2nd Generation Solar Cells:

These cells, which are various kinds of thin film solar cells, are mostly utilized in photovoltaic power plants, which are built into buildings or smaller solar power systems (Bagher et al., 2015).

1- Thin Film Solar Cells:

The thin film solar cell is another emerging form of solar cell, growing at a pace of over 60% between 2002 and 2007. Around 5% of all cells sold in 2011 were produced by the thin film solar cell sector (Bagher et al., 2015).

Choose thin-film if you're seeking for a less priced choice. A substrate is covered with one or more photovoltaic films made of silicon,

cadmium, or copper to create thin-film solar panels. Due to economies of scale and the fact that less material is required for manufacture, these solar panel types are the simplest to construct and cost less than alternatives.

They are also more resistant to high temperatures and flexible, which creates several options for different applications. They are often inappropriate for residential installations since they take up a lot of space. They also have the smallest guarantees due to their lower lifespan than mono- and polycrystalline solar panel types. Nonetheless, in cases where there is a lot of space available, they might be a useful alternative when selecting among the many solar

panel kinds(Bagher et al., 2015).

2- Amorphous Silicon Solar Cell (A-Si):

Have you ever used a pocket calculator that is fueled by the sun? Yes? Then you have undoubtedly seen solar panels of this kind before. Of the several varieties of solar panels, the amorphous silicon solar cell is the one that is primarily employed in such pocket calculators. The greatest thin film technology is used in this kind of solar panel, which has three layers in

total(Bagher et al., 2015).

In this scenario, the thickness is 1 micrometer, just to give you a quick idea of what "thin" implies (one millionth of a meter). These cells have an efficiency rate of just 7%, which is lower than crystalline silicon cells, which have an efficiency rate of about 18%. Nevertheless, the A-Si-Cells have the benefit of being more affordable(Bagher et al., 2015).



Figure 5: shows Amorphous Silicon Solar Cell (A-Si) Source: (Bagher et al., 2015)

2-6-3 3rd Generation Solar Cells:

Several thin film technologies are used in third generation solar panels, however the majority of them are still in the research or development stages. Some of them employ organic materials to create power, while others use inorganic elements (CdTe for instance)(Bagher et al., 2015).

1- Biohybrid Solar Cell:

One sort of solar panel that is still in the development stage is the biohybrid solar cell. A seasoned group at Vanderbilt University made the discovery. Using photosystem 1 to mimic the natural process of photosynthesis is the

premise behind the new technology. The American Journal of Optics and Photonics has further information about the biohybrid solar cell if you're interested in learning more about how it functions in depth. It provides greater information on how these cells function. Many of the components used in this cell are identical to those used in conventional systems, but the combination of photosystem 1's numerous layers makes the conversion of chemical energy to electrical energy far more efficient (up to 1000 times more efficient than 1st generation types of solar panels)(Bagher et al., 2015).



Figure 6: shows Biohybrid Solar Cell Source: (Bagher et al., 2015)

2- Cadmium Telluride Solar Cell (CdTe):

This photovoltaic technology employs cadmium telluride, which allows the manufacturing of solar cells at a comparatively low cost and hence a quicker payback period, among the variety of other types of solar panels (less than a year). This solar energy technology uses the least quantity of water during production compared to

the others. Your carbon footprint will be as little as feasible using CdTe solar cells because of the quick energy payback period. The fact that Cadmium Telluride is poisonous if consumed or breathed is the sole drawback of utilizing it. This is one of the biggest obstacles to be overcome, especially in Europe, where many people are quite hesitant to use the technology that

underlies this kind of solar panel (Bagher et al., 2015).

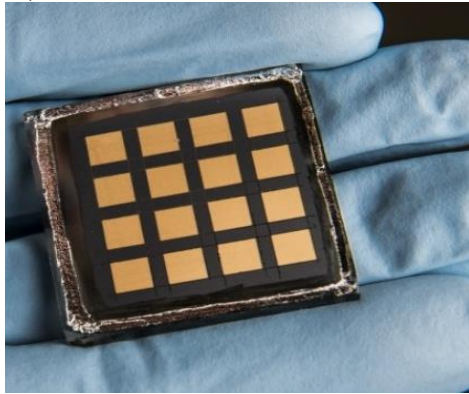


Figure 7: shows Cadmium Telluride Solar Cell (CdTe) Source: (Bagher et al., 2015)

3- Concentrated PV Cell (CVP and HCVP):

Concentrated photovoltaic cells produce electricity in the same way as traditional solar systems. These multi-junction solar panel types have the greatest efficiency rate of all existing photovoltaic systems, up to 41% (Kabir et al., 2018).

Such CVP cells get their name from the features that make them more effective than other kinds of solar panels: curved mirror surfaces, lenses,

and occasionally even cooling systems are utilized to concentrate sunlight and boost efficiency (Kabir et al., 2018).

As a result, CVP cells, which have a high performance and efficiency rate of up to 41%, have evolved into one of the most effective solar panels. What is still true is that CVP solar panels can only be as effective if they are facing the sun at the ideal angle. The solar panel's solar tracker is in charge of tracking the sun in order to achieve such high efficiency rates (Sanna et al., 2014).



Figure 8: shows Concentrated PV Cell (CVP and HCVP) Source: (Bagher et al., 2015)

Table 1: shows Advantages and Disadvantages of Solar Cell types Source: (Sanna et al., 2014)

Solar Cell Type	Efficiency Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-Si)	~20%	High efficiency rate; optimized for commercial use; high life-time value	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-Si)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

3- The role of architects and building designers in achieving sustainability:

Including PV in building projects, to a large extent, depends on the architects' and designers' knowledge of this technology (as a building material), its aesthetic qualities, construction detailing, weathering, durability, limitations on solar access, performance, products, warranties, and cost. The architect is particularly curious in how solar panels (PV) might be incorporated into an ethical design strategy that considers both the energy equation and the general aesthetics of the structure. Architects should talk to customers about these possibilities and should be knowledgeable about the economics of PV Building Integration (BIPV), including value-

added advantages, avoiding greenhouse gas emissions, connecting to the grid or storage, dependability, and system failure risks. While it's critical that architects are aware of all these concerns, their demands for technical information may not be very high (Wang et al., 2014).

The aesthetic, construction, durability, weathering, and sun access limits are likely to receive more attention, especially during the early idea stage. The function of PV modules in the structure is referred to as functional integration (Sanna et al., 2014).

We can thus discuss multifunctionality or double function requirements. When a photovoltaic module is a part of a building, it is

referred to as being building integrated. In the context of BIPV, the building's functions might involve one or more of the following(Sanna et al., 2014):

- mechanical stiffness and structural integrity;
- thermal and solar protection, such as shading/daylighting;
- weather protection from rain, snow, wind, hail, and UV radiation;

On the other hand, aesthetic integration relates to the design and look of the building and is more challenging to define specifically. The potential of PV to establish the architectural language of a structure must be understood in relation to the integration of aesthetics (morphological and figurative). In current architecture the image is one of the primary criteria of recognizability of buildings and a new unique route of innovation is more and more tied to "Solar Architecture"(Wang et al., 2014). Any aesthetic definition, however, can assist architects and building owners in defining relevant references while being unable to definitively and objectively describe what is attractive in terms of integration(Kanters et al., 2014).

- The placement and size of the modules must be consistent with the overall architectural design of the structure.
- The visible material, surface texture, and color of the PV module should match those of the other building skin materials, colors, and textures with which it interacts.
- The module's size and form must be suitable with the grid used to organize the building's components as well as the varying sizes of the other façade elements.
- Jointing types must be carefully taken into account when selecting the product since they highlight the modular grid of the system differently in relation to the building.

3-1 PV integration by building elements (roof, façades and openings):

On the roof PV can be integrated by(Tian et al., 2018):

- Replacing a portion of the existing roof with PV cells that are directly installed on the tiles or modules that have the same dimension and form as the current building elements. Tile materials can be used to cover all or only a portion of the roof. They are often grouped in modules, have the same look and feel as typical roof tiles, and may replace some conventional roof tiles, making it simple to adapt roofs. The cell type and tile form vary; certain tile products may mimic curved

ceramic tiles; the curved surface area prevents these goods from being as space-efficient but may make them more aesthetically appealing(Kabir et al., 2018).

- Constructing a totally transparent or shading roof using transparent or semi-transparent PV panels. There is a wide range of shapes, including flat, slanted, and circular.
- installing lightweight, flexible foil solutions that make installation simple and adhere to the weight restrictions for roofs. To keep the foil flexible and preserve efficiency at high temperatures for usage on non-ventilated roof solutions, PV cells are frequently constructed from thin-film cells. Due to thin-film cells' high solar cell resistances and low efficiency, PV foil products have a low fill factor. Yet, flexible methods make it feasible to significantly alter the product's degree of inclination(Wang et al., 2014).
- Constructing a totally transparent or shading roof using transparent or semi-transparent PV panels. There is a wide range of shapes, including flat, slanted, and circular.
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Yet, flexible methods make it feasible to significantly alter the product's degree of inclination.

In BIPV practice, mono-crystalline roofing materials are typically employed in cold areas while poly-crystalline roofing materials are typically used in hot Mediterranean regions, especially on tiles. As tiles are often relatively tiny, technology efficiency must be improved(Wang et al., 2014).

PV may be applied in a variety of ways as an outside façade on external vertical walls(Tian et al., 2018):

An exterior finish or film that is completely blended into the wall. In this situation, the PV surface must be resistant to mechanical and thermal forces;

- Vented Façades: Double façade structures known as PV-ventilated façades offer the benefit of utilizing outside air to cool PV modules.

Building integrated photovoltaic façade ventilation is advantageous from an electrical

and thermal standpoint.

The PV panel's back air flow reduces module temperatures, enhancing electrical performance. Reduced wall or glazing temperatures behind the module are another benefit of ventilated PV façades, which also means summer cooling needs are reduced.

A regulated airflow behind the PV façade also opens up the possibility of using the warm air for winter preheating.

drapery walls Curtain wall systems are a well-established technology utilized in several projects such as city center workplaces.

The most popular system is mullion/transom stick. Normal double glazing is used for vision regions, whereas opaque glass or insulated metal panels are used for non-visual sections. Being double-glazed components that have been factory constructed, PV modules are simple to include. The module would normally have an overall thickness of less than 30mm and could have an exterior panel made of laminated glass-PV-resin-glass and an inside pane made of glass with a sealed air gap in between. There are several design possibilities (Bagher et al., 2015).

For instance, a façade might include both opaque PV panels and glazed view portions, or it could include PV modules with both transparent and opaque parts.

4- Case Studies:

4-1 Sheik Zayad Learning Center at Al Ain Zoo

Location: Al Ain - Abu Dhabi

Use: Public (Learning center)

Project: iC consulenten Ziviltechniker GesmbH

Power: 150 kw

The Sheik Zayad Learning Center is the first government sustainable building to achieve the highest possible grade of sustainability. It is dedicated to the most stringent sustainability criteria set by Abu Dhabi Urban Planning

Council (UPC) (Sanna et al., 2014).

The project's design process brought together an interdisciplinary team of building and landscape architects, structural, electrical and mechanical engineers, museum interpretive designers, and sustainability consultants to work collaboratively and iteratively, in pursuit of high-performance improvements. This procedure resulted in a solitary, thoroughly sustainable solution.

Due to the use of the greatest household lighting and ventilation technology now available, the building may realistically be operated on a "energy self-sufficient basis". Some of them consist of:

- Building orientation and massing: The internal courtyard's location and perforated shape inside the structure encourage air passage through and around the courtyard.
- Natural soil serves as insulation: Most of the structure is underground, which reduces the temperature differential between the inside and outside.
- Day lighting: The structure is positioned to let in as much natural light as possible. High-quality natural light is provided by recessed apertures and indirect skylights, which reduce excessive solar heat input. Windows with small openings let in natural light while preventing heat transfer.
- Shading: The building's main entrance is shaded by a huge cantilevered overhang. Throughout the summer, retractable fabric shade devices will be employed to cover the courtyard and outdoor areas.
- Photovoltaic energy: The building's whole roof is covered with photovoltaic collectors, which produce 150 kW. In this manner, the structure generates over 95% of the necessary primary power.



Figure 9: shows Desert learning center, Al Ain - Abu Dhabi

Source: www.designboom.com

4-2 Museu de la Ciència i de la Tècnica de Catalunya (MNACTEC)

Location: Terrassa, Catalunya

Use: Museum

Contractors:

Museu Nacional de la Ciència i de la Tècnica de

Catalunya, ES

Laboratoire Analyse et Architecture des Systèmes du CNRS, FR

Teulades i Façanes Multifuncionals SA (TFM), ES

BP Solarex, UK

Power: 38,7 kwp

As a technological and architectural cover for the separating wall of the apartment building next to the center, the museum chose a photovoltaic colored façade. 527 solar modules linked to the main grid were mounted on a steel frame that was placed above the wall. The colored photovoltaic façade is attached to what seems to be a curtain wall so that it functions as a system that generates power while also preventing the separating wall from scorching in the summer and cooling down too quickly in the winter (Sanna et al., 2014).

There are two different kinds of modules: blue high-performance standard monocrystalline cells and translucent, magenta, and golden monocrystalline cells that let in over 10% of solar energy.

Despite the fact that the blue modules convert sunlight into electricity more efficiently than the other two colors, the aesthetic criterion was chosen to take precedence over some functionality because this façade is located in a busy and conspicuous area of Rambla d'Egara,

one of the main streets in Terrassa. The PV installation has a capacity of 39.7 kwp and occupies an area of 300 m². It generates roughly 40,000 kWh each year, providing 15% of the museum's power needs, and has come to symbolize both the institution and the city of Terrassa.



Figure 10: shows Museu de la Ciència i de la Tècnica de Catalunya (mNACTEC), Terrassa

Source: commons.wikimedia.org

4-2 Apple's Spaceship HQ

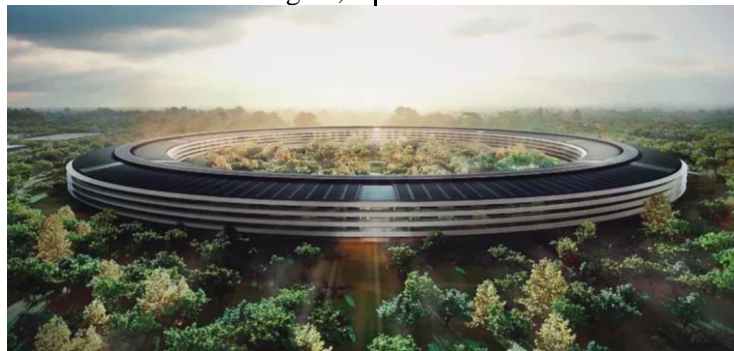


Figure 11: shows Apple's new 'spaceship' HQ in Cupertino Source: www.nytimes.com

Apple's new 'spaceship' HQ in Cupertino is expected to be one of the greenest office campuses in the world.

With solar energy prices dropping to record lows and advancements in design soaring, more architects and developers are turning to solar for

its costs savings and aesthetic appeal. As we'll see over the next two years, some of the largest building projects in the world are integrating photovoltaics from the rooftop down to the facade. Below are just a handful we can't wait to see completed (Ranabhat et al., 2016).



Figure 12: shows Apple's new 'spaceship' HQ in Cupertino Source: www.nytimes.com

Apple's gorgeous new \$5 billion headquarters in Cupertino, California, dubbed the "Spaceship," will not only contain the largest pieces of structural glass ever made, but also one of the

largest solar arrays for a corporate building in the world. The technology giant is taking advantage of its copious rooftop surface area to install thousands of solar panels with an

estimated output of 16 megawatts of power. The campus will also feature 4 megawatts of biogas fuel cells and source additional renewable energy from a nearby 130-megawatt solar installation from First Solar.

In addition to renewables, Apple is also adding 2,500 new and indigenous trees (bringing the total to over 7,000), groundbreaking sustainable design elements, and miles of biking and jogging trails. In total, the 175-acre campus will be 80 percent green space.

"We're building a new headquarters that will, I think, be the greenest building on the planet," Apple CEO Tim Cook said. "It'll be a center for innovation, and it's something clearly our employees want and we want."

Apple's new HQ campus is expected to be completed later this year.

4-3 Melbourne's off-grid skyscraper

A new 60-story apartment building slated for Melbourne's skyline is aiming to offer future residents a completely off-grid experience. To achieve this, Peddle Thorp Architects have designed a building with a facade wrapped in

solar cells and complemented with roof-mounted wind turbines, sustainable design and a massive battery storage system. Called Sol Invictus ("invincible sun"), the building will be oriented to give its curved exterior the ability to capture as much of the sun's east-to-west movement as possible (Ranabhat et al., 2016).

"This concept would see the technology shaping a fundamental part of the architecture," architect Peter Brook from Peddle Thorp told Curbed. "Many designers engineer buildings to reduce their exposure to the sun. In this case, we're doing the opposite."

According to Brook, leveraging solar panels in the facade as opposed to the roof allowed the designers to expand the square footage available for renewable power from 4,305 square feet to 37,673 square feet. While that number will offset roughly 50 percent of the building's energy needs, the designers are hopeful that gains in efficiency and other improvements will move that number closer to 100 percent when the project is completed in the next three or four years.

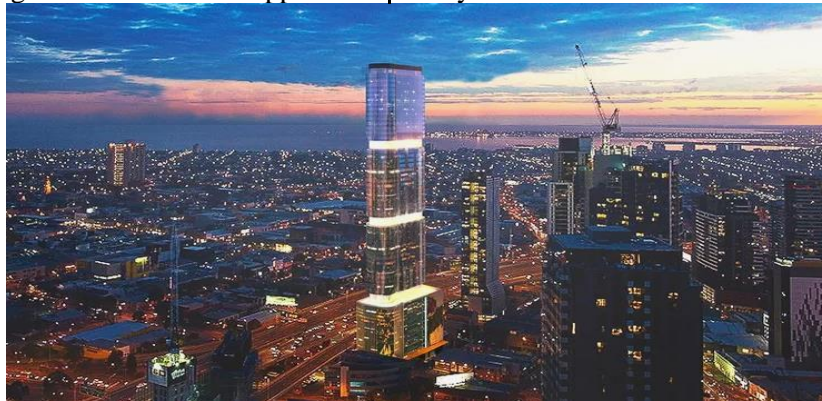


Figure 13: shows Melbourne's off-grid skyscraper Source: www.designboom.com

4-4 General Electric's 'solar veil' HQ

As a tribute to Boston's maritime heritage, GE's new sustainable headquarters overlooking the city's Fort Point Channel will include a dramatic solar veil. According to Boston Magazine, the veil will be "composed of solar slats that will let light through, but not before it bounces off their photovoltaic surfaces" (Yang et al., 2014).

In addition to repurposing two old brick

warehouses on the 2.4-acre site, GE also will install native plantings, rooftop gardens, and, as a sign of things to come, elevated ground floors and critical systems to account for future sea level rise. To encourage the use of mass transit, biking or walking to work, the site will feature only 30 parking spots for its expected 800 employees.



Figure 14: shows General Electric's 'solar veil' HQ Source: www.smartenergydecisions.com

After completion sometime in 2018, GE expects its HQ to be certified as one of the greenest buildings in the U.S.

4-5 Tesla's Gigafactory

Tesla's Gigafactory in Nevada, the future battery-production centerpiece of its electric car empire, is not only the world's largest building by physical area (with a factory footprint of 126 acres), but also a net-zero energy facility (Yang et al., 2014).

According to CleanTechnica, the company decided from the start not to build a natural gas pipeline to the factory as a way of "forcing it" to rely on renewables. The current plan involves not only covering the entire roof in solar panels,

but also installing arrays in the neighboring hillsides. If that doesn't fully meet the facility's demands, Tesla Motors CTO JB Straubel says they'll just have to figure something out.

"So, it's kind of been a fun activity and just, a lot of challenges that come up," he recently shared. "But in every single step of the process, we have been able to reinvent and come up with solutions."

In addition to solar, Tesla plans on capturing complementing clean energy from on-site geothermal and wind installations. The site is currently on track to become full operational by 2020.



Figure 15: shows Tesla's Gigafactory in Nevada Source: www.theverge.com/

4-6 Copenhagen International School



Figure 16: shows the Copenhagen International School in Denmark Source: novonordiskfonden.dk

Once it's completed in 2017, the Copenhagen International School in Denmark will feature the world's largest solar facade. The more than 12,000 colored solar panels, integrated directly into the building's structure and glass, will produce half the energy needs of the school (around 300 megawatt hours per year) (Yang et al., 2014).

In an effort to engage the 1,200 students with the facility's clean energy features, "solar studies" will be integrated into the curriculum. This will allow students to monitor energy production in real-time for use in classes like

physics and mathematics.

"We are proud that with the construction of the new school we can integrate innovative architecture into our teaching principles. The goal of the school is to enhance students' competences in an international environment so that they become responsible citizens of the world with a focus on sustainability," Brit van Ooijen, Chairman of the Board of Copenhagen International School, said in a release.

5- Results and Discussion:

The study clarified the role that solar cells play through technological development in their

manufacture and the multiplicity of their types according to the type of material they are manufactured for optimal utilization of solar energy in supporting sustainable architectural formation. At the theoretical and applied level, as illustrated by global examples, these results appeared as follows:

- The use of solar cells in the architectural formation helps in achieving the strategy of sustainable development and making the architectural formation environmentally friendly.
- The development of solar cell manufacturing technology, which led to a multiplicity of photovoltaic cells, the development of manufactured materials such as silicon, and an increase in their formation and functional efficiency.
- The possibility of using advanced solar cells in the architectural formation, especially in the facades, whether straight, refracted or curved, while preserving the design philosophy of the architect and the vocabulary used in the design.
- The exploitation of solar cells in the architectural formation gave an aesthetic character to the building, in addition to its basic function in generating energy.
- Through international examples, it became clear that the exploitation of solar cells in architectural formation has spread on a large scale, despite the lack of high solar radiation that is available in Arab countries throughout the year on large areas of their lands.
- The lack of experience of architects in the exploitation of solar cells in the architectural formation in Egypt, as well as the weakness of the economic aspect led to the delay in Egypt in the optimal utilization of solar energy

6- Conclusion and Recommendations:

- The research recommends a number of recommendations that must be taken into account, the most important of which are:
- Governments should have a role in spreading the culture of sustainability and shifting to the exploitation of renewable energy technologies, especially photovoltaic cells.
- The use of solar cells in sustainable architectural formation must be activated.
- Encouraging architects and increasing their awareness of the technological development in manufacturing solar cells and how to exploit them in sustainable architectural formation.
- Encouraging the exploitation of advanced solar cells in the architectural formation, not

only of new buildings, but also that can be adapted in existing buildings.

- Benefiting from global experiences in exploiting solar cells in architectural formation and working to develop and apply them locally in a way that suits our environmental and economic conditions.

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