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محور (الابداع في عمليات التصميم)

Research title

Interaction between Building-integrated photovoltaic (BIPV) and Fractal geometry in the context of Environmental Design

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Introduction

Solar energy is one of the most important sustainable source of energy in our times, it is almost the only available solutionin the context of current and future wars to control energy sources, especially oil as the most importantone. But unfortunately oil is decreasing day by day, while sun is the sustainable source of energy till the end of life on earth. This is why scientific entities and research in developed countries~~is~~ are going toward developing ~~of~~ different efforts to utilize renewable energy sources, especially solar energy.

Right now, solar energy only accounts for a tiny portion of the World's total electricity generation, because it is more expensive than alternatives like cheap but highly polluting coal. Solar power is about five times as expensive as what people pay for the current that comes out of the outlets.
In order to have a hope of replacing fossil fuels, scientists need to develop materials that can be easily mass-produced and convert enough sunlight to electricity to be worth the investment.
This paper examines how the environmental designer could help in this field. Architects and environmental designers have worked together to create architectural solutions in the field of Building-integrated photovoltaic (BIPV); these designs were interested in technical and operational aspects, without full regard to aesthetic or decorative ones, with the common trend of simplification through the available geometric shapes from photovoltaic (PV), which caused similarity, and a lack of concern for spatial identity.

My research will collect and review previous practices carried out by environmental designers, artists and architects who tried to develop aesthetic solutions for the use of photovoltaic (PV) as one of the environmental design supplements. This will be followed by introducing fractal geometry as one of an effective way to fill spaces with geometrical motifs into a mathematical order to create a wide range of patterns to develop new orders for photovoltaic (PV) designs on surfaces, to create decorative patterns moving through building surfaces or any other environmental design element.

Statement of the problem

Solar energy is one of the most important sources of energy in future, and therefore many form of application need to be developed at different scales for a variety of urban and cultural contexts. To date, BIPV and other applications of PV in the urban environment have mainly been focused on maximizing efficiency of energy output, with less regard for aesthetics and context. There is a need to reach the optimal balance between aesthetics and power efficiency of final products.

Objective

Creating design solutions by using BIPV through aesthetic and decorative aspects, and developing various simple shapes of photovoltaic (PV) units to be used as repeated motifs into different orders, to create decorative patterns moving through building surfaces or any other environmental design element.

Hypothesis

The use of Fractal geometrical shapes would improve the design of photovoltaic integration n with building facades.

Delimitations

Works and designs created since the beginning of the millennium up to now in the most experienced countries in using of BIPV (Germany, Spain, Turkey, USA and some East Asian states).

Methodology

Inductive method

Keywords

Building-integrated photovoltaic (BIPV)**/** Building-applied photovoltaic (BAPV) - Renewable energy - Solar energy - Environmental Design- Environmental Design elements – Fractal geometry- Motif – Pattern- Repetition

Theoretical framework:

Solar power

The sun—that power plant in the sky—bathes Earth in ample energy to fulfill all the world's power needs many times over, It doesn't give off carbon dioxide emissions, It won't run out, And it's free, it is energy from the sun.

"Solar" is the Latin word for "sun" and it's a powerful source of energy. It is considered as a serious source of energy for many years because of the vast amounts of energy that is made freely available. It is considered 'Renewable Energy because

- The technology used to convert the sun's power into electricity does not produce smoke (carbon dioxide and other air pollutants).
- Tapping the sun's energy does not usually destroy the environment..

So how on Earth can people turn this bounty of sunbeams into useful electricity?

Solar Energy

The sun's light (and all light) contains energy. Usually, when light hits an object the energy turns into heat, like the warmth we feel while sitting in the sun. But

when light hits certain materials the energy turns into an electrical current instead, which we can then harness for power.
Old-school solar technology uses large crystals made out of silicon, which produces an electrical current when struck by light.. The silicon turns a good portion of light energy into electricity, but it is expensive because big crystals are hard to grow.
Newer materials use smaller, cheaper crystals, such as copper-indium-gallium-selenide, that can be shaped into flexible films. This "thin-film" is not as good as silicon at turning light into electricity.
Right now, solar energy only accounts for a tiny portion of the World's total electricity generation, because it is more expensive than alternatives like cheap but highly polluting coal. Solar power is about five times as expensive as what people pay for the current that comes out of the outlets.
In order to have a hope of replacing fossil fuels, scientists need to develop materials that can be easily mass-produced and convert enough sunlight to electricity to be worth the investment.

What is a solar cell?
Solar cells are devices that convert light energy directly into electrical energy. In these cells, there are semiconductors (silicon alloys and other materials). Larger arrays of solar cells are used to power road signs, and even larger arrays are used to power satellites in orbit around Earth. Solar cells are also called **photovoltaic cells** or **PV devices**. It is differ from **Solar panels** which do not generate electricity directly. Instead they heat up water directly. They are often located on the roofs of buildings where they can receive the most sunlight.[1]

How Do Solar Cells Work?

The short description: Silicon is mounted beneath non-reflective glass to produce photovoltaic (PV) panels that collect photons from the sun and convert them into DC electrical power. That DC power then flows into an inverter, which transforms it into basic AC (alternating current) electrical power.[1]

Photovoltaic (PV)
Photovoltaic (PV) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect.

1http://cleantechnica.com/2011/09/30/solar-basics-how-do-solar-panels-work/

The term "photovoltaic" comes from the Greek φῶς (phōs) meaning "light", and from "volt", the unit of electro-motive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery (electrochemical cell). The term "photo-voltaic" has been in use in English since 1849[2]

A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power... The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years. They were first mass-produced in the year 2000, when German environmentalists including Euro solar succeeded in obtaining government support for the 100,000 roofs program.

Driven by advances in technology and increases in manufacturing scale and sophistication, the cost of Photovoltaic has declined steadily since the first solar cells were manufactured, and the levelised cost of electricity from PV is competitive with conventional electricity sources in an expanding list of geographic regions.

Solar PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. More than 100 countries use solar PV. Installations may be ground-mounted , or built into the roof or walls of a building Fig.(1) .[3]

Figure (1)

2 Smee, Alfred (1849). London: Longman, Brown, Green, and Longmans. p. 15. Found in

3 Photovoltaic System Pricing Trends – Historical, Recent, and Near-Term Projections, 2014 Edition" (PDF). NREL. 22 September 2014. p. 4. Archived from the original on 29 March 2015.

How do Photovoltaic Work?

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.[4]

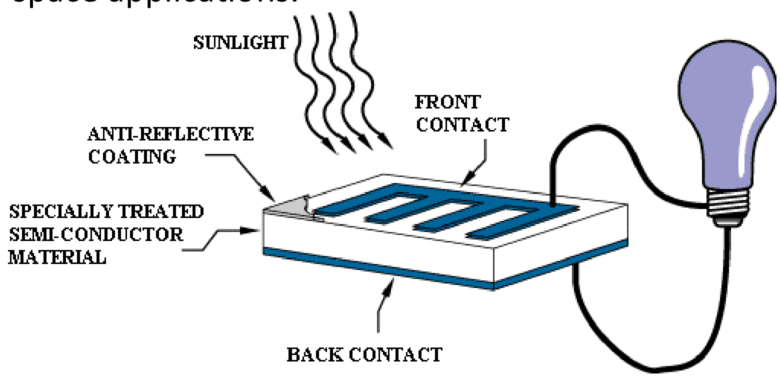

Figure (2)

The diagram above Fig.2 illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

[4]http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

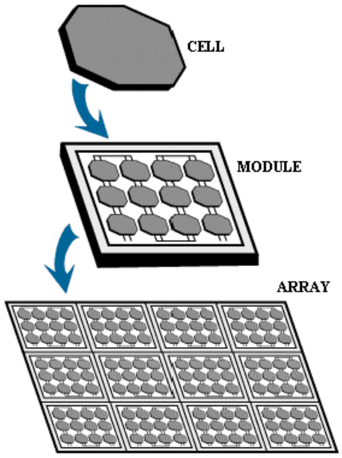

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Figure (3) Multiple modules can be wired together to form an array (like fratal way of repetition). In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.[5]

Standard products and BIPV forms

- Standard thickness (Fig. 4)
- Standard color category (Fig. 5)
- Standard sizes (Fig. 6)
- Degree of transparency (Fig. 7)

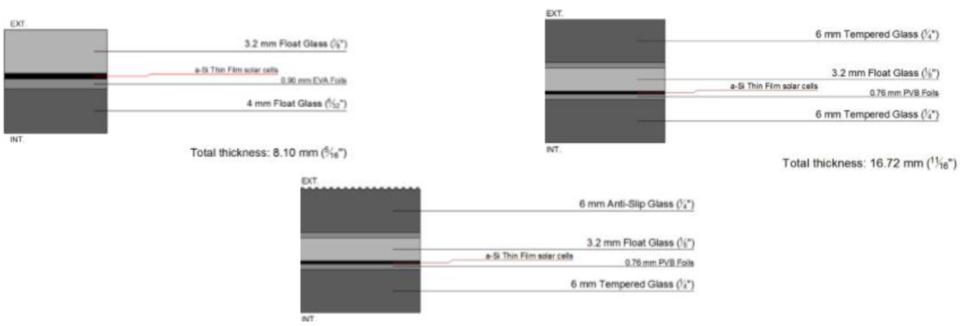
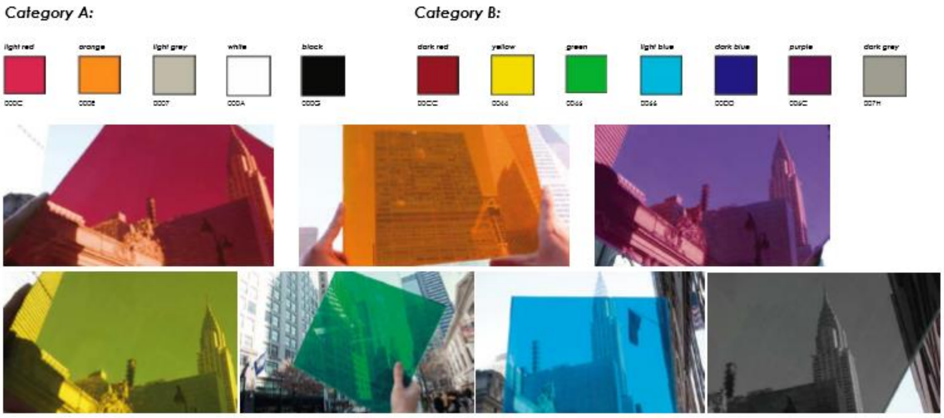


Figure (4)

[5]http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/



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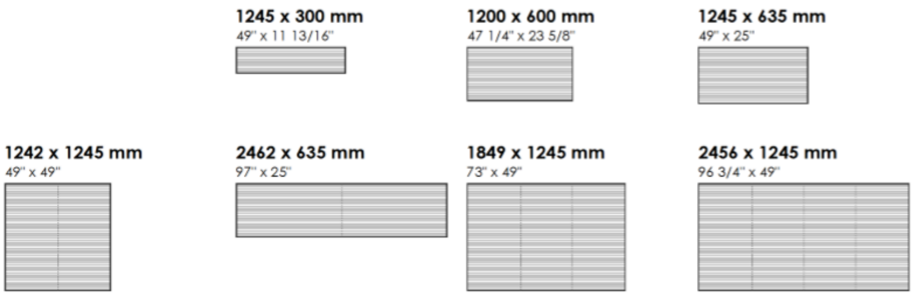


Figure (6)

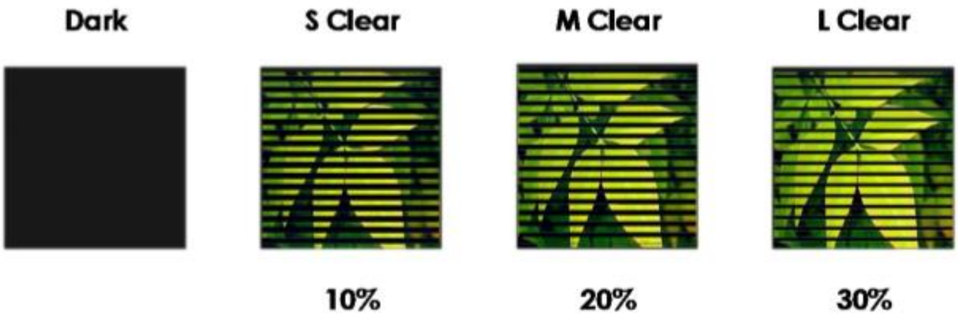
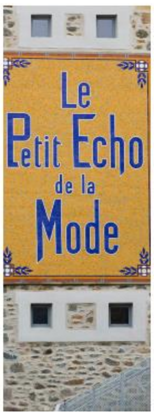


Figure (7)

BAPV Building-applied photovoltaics

The term building –applied Photovoltaic (BAPV) is used to refer to Photovoltaic that are a retrofit – integrated into the building after construction is complete. Most building-integrated installations are actually BAPV. Some manufacturers and builders differentiate new construction BIPV from BAPV.

Figure (8) BI(pv)Panels integrated into the curtain wall instead of conventional glass spandrel panels on the 37th through the 43rd floor.



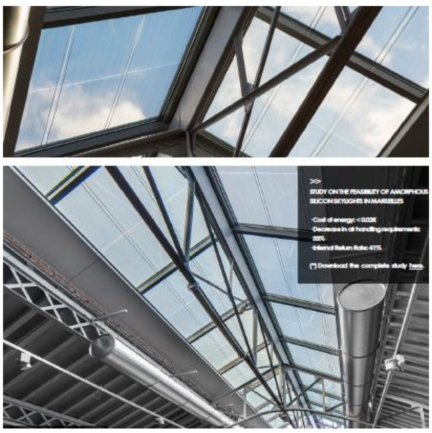


Figure (9) Photovoltic Transparent tiles shaped into skylight has taken place in the refurbishment of the historic building Le Petit Echo de la Mode In Brittany (France), a major project was established to develop the design, construction and maintenance of energy facilities.

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BIPV Building-integrated photovoltaics

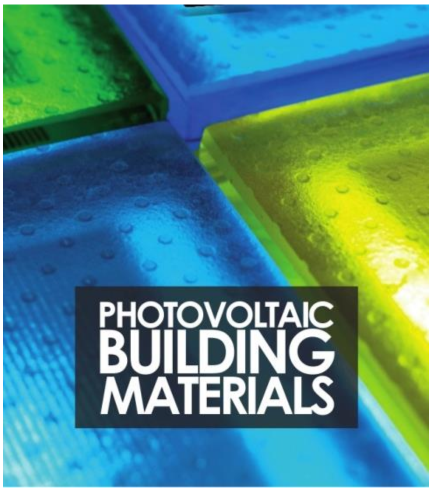

Figure (10)

Photovoltaic transparent floor tiles

Building integration of solar panels is one of the most important applications of solar panels. The field of BIPV is changing the way the new buildings are constructed all over the world. Integration of solar panels in the building means truly making the solar panel a component of the building such as a window, roof, door or even the wall.

BIPV are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades.[6] The photovoltaic panel is integrated into the building fabric- such as glazing - rather than a 'tack-on' addition replacing conventional building cladding materials but with the added benefit of producing renewable electricity.

This applications for buildings began appearing in the 1970s. Aluminum-framed photovoltaic modules were connected to, or mounted on, buildings that were usually in remote areas without access to an electric power grid. In the 1980s photovoltaic module add-ons to roofs began being demonstrated. These PV systems were usually installed on utility-grid-connected buildings in areas with centralized power stations. In the 1990s BIPV construction products specially designed to be integrated into a building envelope became commercially available.[7] By 2011 scientists suggest that there may be significant technical challenges to overcome before the installed cost of BIPV is competitive with photovoltaic panels.[5] However, there is a growing consensus that through

6Strong, Steven (June 9, 2010). "Building Integrated Photovoltaic (BIPV)". wbdg.org. Whole Building Design Guide. Retrieved 2011-07-26

7 Eiffert, Patrina; Kiss, Gregory J. (2000). Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Source Book for Architect. p. 59. ISBN 978-1-4289-1804-7.

their widespread commercialization, BIPV systems will become the backbone of the zero energy building (ZEB) European target for 2020.[8]

Continuum of residential solar system designs showing increasing integration (from left to right) with building architecture and material

Least integrated
(Open rack-mounted PV)

More integrated
(Close roof rack-mounted PV)

Fully integrated
(Direct-mounted BIPV, multifunctional)

Figure (11)

BIPV Forms

Building-Integrated Photovoltaic modules are available in several forms:

Facades can be installed on existing buildings, giving old buildings a whole new look. These modules are mounted on the facade of the building, over the existing structure, which can increase the appeal of the building and its resale value.[9]

Flat roofs is The most widely installed to date is an amorphous thin film solar cell integrated to a flexible polymer module which has been attached to the roofing membrane using an adhesive sheet between the solar module backsheet and the roofing membrane.[clarification needed]

Pitched roofs

- Modules shaped like multiple roof tiles.
- Solar shingles are modules designed to look and act like regular shingles, while incorporating a flexible thin film cell.

8"Investigation of building integrated Photovoltaic potential in achieving the zero energy building target". AngelikiKylili, Paris A. Fokaides,.Indoor and Built Environment.Retrieved 30 October 2014.
9Henemann, Andreas (2008-11-29). "BIPV: Built- in Solar Energy". Renewable Energy Focus (Science Direct) 9 (6): 14, 16–19. doi:10.1016/S1471-0846(08)70179-3.

- It extends normal roof life by protecting insulation and membranes from ultraviolet rays and water degradation. It does this by eliminating condensation because the dew point is kept above the roofing membrane.[10]
- **Glazing**(Semi) transparent modules can be used to replace a number of architectural elements commonly made with glass or similar materials, such as windows and skylights.

Figure (12)

Figure (13)

Environmental Design

Environmental design is the process of addressing surrounding environmental parameters when devising plans, programs, policies, buildings, or products, it refer to the applied arts and sciences dealing with creating the human-designed environment. These fields include architecture, geography, urban planning, landscape architecture, and interior design. Environmental Design is a human-centered discipline that focuses on the total spatial experience—from the first moment of encounter to the last moment of interaction Environmental design can also encompass interdisciplinary areas such as historical preservation and lighting design, Designers consciously working within this more recent framework of philosophy and practice seek a blending of nature and technology, regarding ecology as the basis for design

10Eiffert, Patrina (2000). Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Source Book for Architect(PDF). pp. 60–61.

Eenvironmental design involves professionals in the fields of urban planning, landscape architecture and architecture. These professionals focus on environmentally conscious techniques and materials. They study the relationship between man-made structures and the surrounding environment to develop infrastructure, including commercial buildings and homes by taking into account functional, economic and ecological needs.

An environmental designer working as a planner provides analysis and develops community-growth strategies with an eye toward long-term needs.

Environmental design refers to the physical surroundings that provide the setting for human activity, ranging in scale from buildings and parks, green space to neighborhoods, the local community, as well as supporting infrastructure, such as roads and expressways. Environmental design is defined as the physical and constructed environment in which people live, work, and recreate on a day-to-day basis by the general public. This encompasses streets and parks, together with public infrastructure and privately owned places. In addition, environmental design is concerned with the way these places are experienced and used, as well as other aesthetic elements that contribute to the quality of community environments. Environmental design practitioners develop long- and short-term plans and designs to use land and natural resources for the growth and regeneration of urban, suburban, and rural communities, while helping local officials make decisions concerning development, preservation, physical, and environmental issues. Environmental design promotes the best use of a community's land and physical resources for residential, commercial, institutional, and recreational purposes.

Environmental Designer should have the skills to understand, analyze, and solve problems with a view toward community planning, physical development, and the design of sustainable environments. Environmental design utilizes knowledge from the social sciences and applied arts to plan and develop community environments that affect, and are affected by, human behavior.[11]

Environmental Design elements:

In relation to the definition of the environmental design and the environmental designer duties **Environmental Design elements can be defined as**; building surfaces (roof, walls) gates and windows, street and urban furniture, landscape architecture ,it can be every community environment detail.

Uses of the BIPV in the vision of environmental design:

Figure (14)

Figure (14) *New constraction solution Photovoltaic Blustrade,in Napoly,Italy ,Silicon with semi transparency 30% with a total instaled power output of 11 KWP, This balustrade generate 11.000 KWh per year .*

Fig. (15) Photovoltaic Door and windows

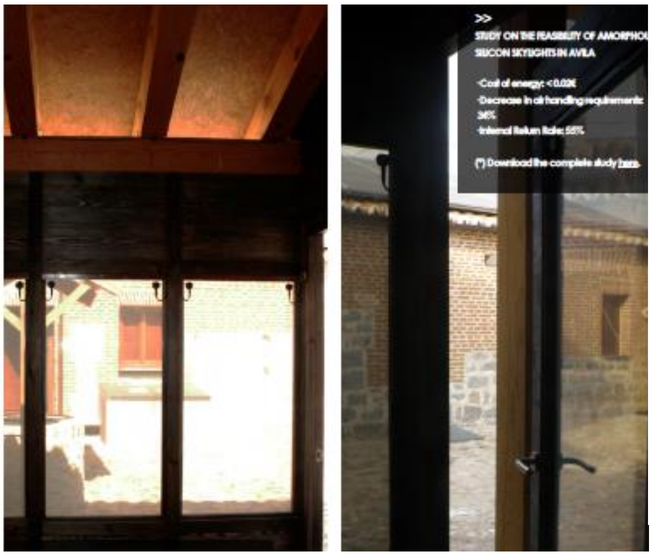

Fig.(16) Photovoltaic floor til

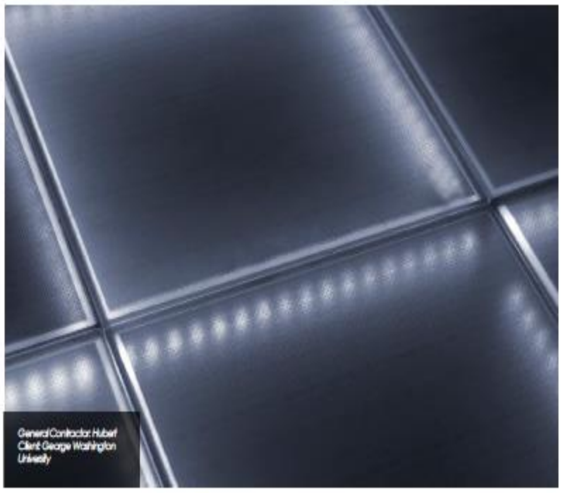

Figure (17)

Onyx Solar designed and developed the ventilated photovoltaic façade for the Pfizer-University of Granada-Junta de Andalucía (GENyO in Spanish).
The facade combines three types of glass and, with a total active area of 5,627 Sq Ft, produces a peak power of 19,300 W, generates about 32,000 kWh of energy per year and also prevents the emission of 21 tons of CO2 emissions into the atmosphere

Figure (18)

Bursagaz Building –Turkey, the design originality superimposed a mosaic double skin onto the façade. The glass, featuring crystalline silicon, with 20% transparency, allowing homogeneous light into the building and reducing the need of artificial lighting.

Figure (19)

Urban furniture with photovoltaic tile

Figure (20)

Photovoltaic Façade – ISCE Building-Spain

Figure (21)

Photovoltaic on the rooftop – Apple store- San Francisco-

Fig.(22) Photovoltaic Backyard wall Located in private residence located in Spain, tiles with satin – finish anti glare glass which maintains its photovoltaic properties and the same time diffuses the passage of the light, providing privacy and comfort for users.

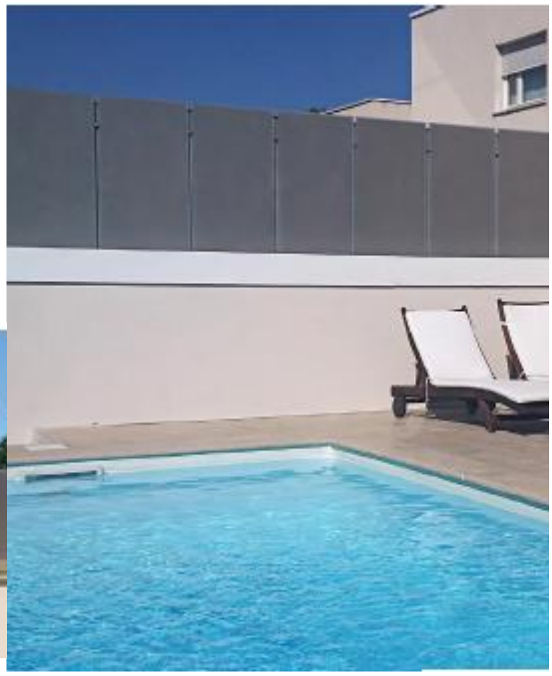

Figure (23) The Science pyramid, in Denver Botanic Garden, the designer has integrated hexagonal crystalline silicon photovoltaic glass modules with a custom-made design

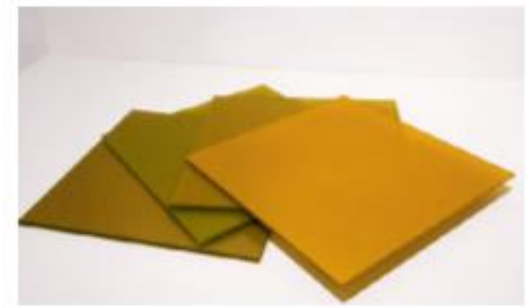

Figure (24) The Dubai Frame is an impressive rectangular picture-frame-shaped building, 150 meters tall and 105 meters wide, installed in Zabeel park in Dubai, it has been considered one of the world's new attraction 2015, and one of the most original skyscraper 1.200 m2 of amorphous silicon photovoltaic glass has been integrated in the façade, the total installed power output of 38 kwp. This multi-functional glass, provides the frame with undeniable aesthetic value due to its gold colour. A new generation of coloured semi-transparent photovoltaic glass has been developed for this project, encompassing wide spectrum of shades, and with the same efficiency as colourless photovoltaic glass.

Figure (25) Refurbishment of the Historic food market of Bajer (Spain).
Iinstallations of 175m2 photovoltaic skylight, with different degrees of transparency and colours form a mosaic inspired from Piet Mondrian, part of the power generated is sent to be stored in batteries, and the rest is sent to the grid for the building's own consumption.

Figure (26) Photovoltaic street furniture

Fractal geometry as an aesthetic solution (repeating system) for the photovoltaic tiles

Fractal Geometry

A **fractal** is a natural phenomenon or a mathematical set that exhibits a repeating pattern that displays at every scale. It is also known as**expanding symmetry** or **evolving symmetry** and if the replication is exactly the same at every scale, it is called a self-similar pattern.

Fractal geometry has been utilized by a number of mathematicians each creating his own formula or equation:

- A **Hilbert space-filling curve- fig.27** is a continuous fractal space-filling curve first described by the German mathematician David Hilbert in 1891, as a variant of the space-filling Peano curves .
- The **Sierpinski carpet –fig.28** is a plane fractal first described by WacławSierpiński in 1916. The carpet is one generalization of the Cantor set to two dimensions.The technique of subdividing a shape into smaller copies of itself, removing one or more copies, and continuing recursively can be extended to other shapes. For instance, subdividing an equilateral triangle into four equilateral triangles,

removing the middle triangle, and repeating leads to the Sierpinski triangle.

- The construction of the **Sierpinski carpet** fig. 29 begins with a square. The square is cut into 9 congruent sub squares in a 3-by-3 grid, and the central sub square is removed. The same procedure is then applied recursively to the remaining 8 sub squares, ad infinitum. It can be realized as the set of points in the unit square whose coordinates written in base three do not both have a digit '1' in the same position

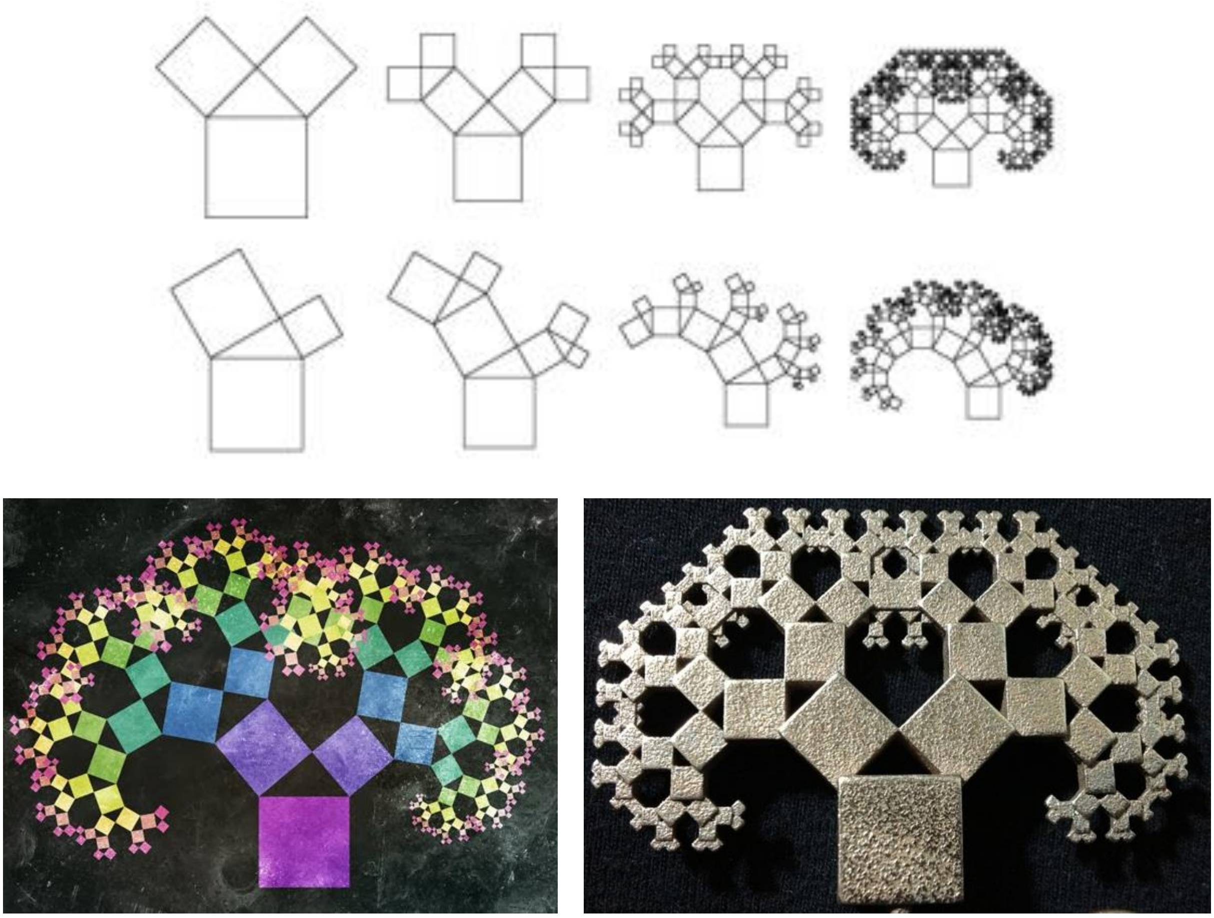

Figure (27)

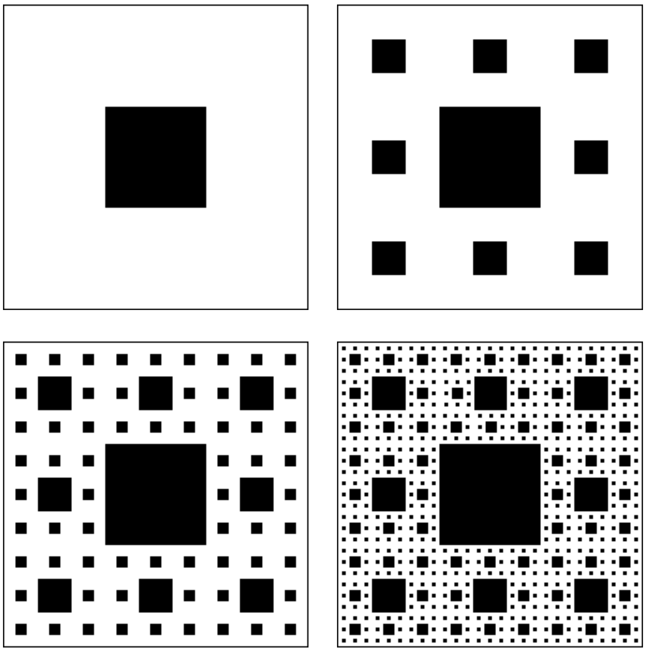

Figure (28)

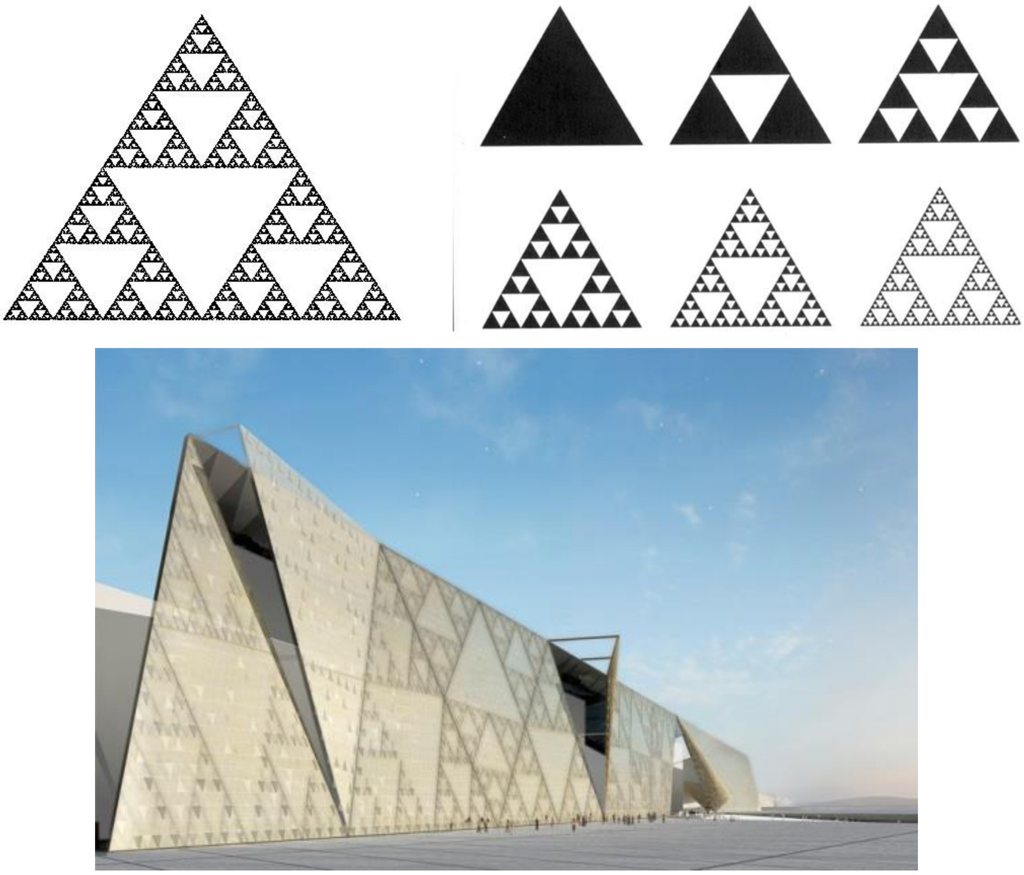

Figure (29) The New Egyotian Museum in Giza, Main Façade ,the whole project is under construction.

The architectural concept had been inspired from the Egyptian pyramids, and its triangular (2d) shapes, which lead designers to **Sierpinski** triangles as an atheistic solution for the Main Façade. Here, we can find how useful is using fractal geometry as a repetitive order to fill the façade space, and the ability of applying customized photovoltaic triangles shapes.

Results

- The study has found out that It's certainly feasible to create repeated patterns using fractal geometry applying (Photovoltaic) tiles on facades. This is already carried out in the Egyptian museum façade employing normal glass tiles. The same could have been replaced with Photovoltaic tiles generating energy that could be enough for illuminating a large area of museum.
- There are many possibilities to apply Photovoltaic tiles on different kinds of environmental design elements. Facades are only one of the options, designers created a very large variation of urban and echo furniture designs. These certainly can be replicated in many ways and many design fields. Glass products everywhere may be a reasonable solution.

- Examining the capacity of cutting **standard (PV tiles)** into tailored shapes, has resulted in stunning shapes that carry a trivial look but at the other hand this may increase the cost one way or another. Designers are advised to create new standard shapes that would augment the capabilities of using the fractal geometrical shapes easier and faster providing more exquisite applications. .
- The architectural concept used in the Egyptian museum facade that was inspired by Egyptian pyramids, similar to a larger extent to **Sierpinski** triangles as a solution for the design of Façade. Using fractal geometry can use a repetitive order to fill the façade space, with an ability to apply a customized photovoltaic triangles shapes . This would lead to to a superior variation in utilizing shapes in a number of different modules that would enrich the design and the way it can be utilized.

- Fractal geometry offer us different equations that can help in organizing the photovoltaic tiles on a surface. Hilbert space-filling curve. Is a graphical representation of the resulting equation can be utilized to customized BIPV shapes. The same applies to The Sierpinski carpet that is used in the sweeping the Cantor set into design of two dimensions. The way this is carried out is by converting the shape into a smaller subdivision replicates, eliminating certain predetermined copies. The process is continued recursive ly extending to other shapes. The process starts with a square that is cut off into sub squares in a grid, removing the central sub square.

- To get the most acceptable level of aesthetics in the generated designes, impeding factors such as the need for largest capacity of power generation, applicability which is the major restriction, the desire to minimize cost. If minimized and also if contradiction between all these three elements is overcome Fractal geometrical shapes could be obtained easily as an aesthetic solution to create repetitive motifs and patterns on surfaces.

Conclusion:

- The study has found out that It's certainly feasible to create repeated patterns using fractal geometry applying (Photovoltaic) tiles on facades.
- a very large variation of urban and echo furniture designs is feasible in many design fields; architectural glass, cladding, installations and sculpture., .
- The increased cost of cutting standard shapes into smaller or different ones may be overcome by the creation of new standard shapes with a little help from some gifted designers experienced in fractal design..
- **Sierpinski** triangles and many other fractal geometrical shapes can be a valuable solution to many of the problems faced in the field of facade design and many other areas.

- If solved the restricting elements can be minimized to a large extent by the elimination of contradiction between all these elements overcome.

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