CONTEMPORARY TENDENCIES OF DESIGNING BUILDING PHOTOVOLTAICS WITH INTEGRATION TO THE ARCHITECTURAL DESIGN

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Abstract. *Solar energy was recognized as one of the most important renewable energy technologies in many countries in the recent years. The renewable technologies achieved an important awareness among architectural engineers, who see the concept of integration of photovoltaic system as a new opportunity for integration in the architectural design. Analysis of urban disposition of the solar radiation in the cities is becoming an important factor in conceptualizing the intersecting systems as a basis for architectural study in the organization and orientation of buildings for optimizing the solar potential. In the beginning of the development of the photovoltaic systems, as a solar power generating renewable technologies, they were analyzed only by electrical energy engineers, which created only standard products with limited design possibilities in terms of patterns, dimensions, texture and colors, so integrated approach with architectural engineers is important sustainable factor for the optimization and sustainability of the architectural design. The recent development of the solar renewable technologies and the PV systems, created a new possibilities for them to be reviewed as architectural elements in the architectural design process by many important international architectural studios. Architects must think of new concepts of integration of the photovotaic systems as architectural elements by creating pixeled photovoltaic module, patterns in monocrystaline cells, as well as using different visible materials, patters, textures and color in the thin film modules of the photovoltaic cells in the composition of the architectural design. This scientific paper will explore the architectural possibilities in the architectural design of building integrated photovoltaics in terms of the functional, constructive and aesthetics formal aspects of using building-integrated photovoltaics in architectural design. Building integrated photovoltaics modules should respond to the technical aspects of the energy production, as well as, be integrated as architectural elements according to the function and the building envelope: adaptive fasade, double fasade, PV shading cladding systems in the architectural buildings.*

Keywords: *Architectural Design, Building Integrated Photovoltaics, Solar Renewable Technology.*

1 SOLAR RENEWABLE ENERGY GENERATED BY PHOTOVOLTAIC MODULES

Photovoltaics as integrated element in Architectural design create a new concept of integrated approach with design consultations with the architectural engineers. They are important sustainable factor for the optimization and sustainability of the architectural design. In the beginning of the development of the photovoltaic systems, as a solar power generating renewable technologies, they were analyzed only by electrical energy engineers, which created only standard products with limited design possibilities in terms of patterns, dimensions, texture and colors.

Solar renewable technologies PV systems, create new possibilities for important International architectural studios to be reviewed as architectural elements in the architectural design process.

Photovoltaic systems can be applied in architectural building in two ways: applied in the existing system as building applied photovoltaics or building integrated photovoltaics when the architects plan to substitute and integrate building element: roof, fasade, shading element, parapet. The architect can also choose the typology, size, color and transparency of the photovoltaic modules. Building integrated photovoltaics have more architectural function to the building, than only energy production.

The economic benefit of installing building integrated photovoltaics is that it will be profitable and it will reduce the distribution and transmission losses in the electricity network. These systems have technical and aesthetic aspects that contribute to creating energy-conscious architecture and urban environment.

Building Integrated photovoltaics modules should correspond to the technical aspects of the energy production, and be integrated as architectural elements according to the function of the building envelope: adaptive fasade, double fasade, PV shading cladding systems in the architectural buildings.

Building Integrated Photovoltaics are defined as photovoltaic modules that have double function: energy and architectural aesthetic function, in order to replace the standard structural elements in the buildings. In this case, there is production of electricity on one side, and on the other side from the architectural aspect there is replacing of the traditional building materials with photovoltaic modules which bring significant savings by replacing building material.

2 PHOTOVOLTAIC PANELS AS ELEMENTS IN THE BUILDING INTEGRATED PHOTOVOLTAICS

Photovoltaic cells are the main integration element in the photovoltaic panels. They have semiconductor materials, that have better efficiency according to their different structures. Silicon is the most used pure semiconductor material for the production of photovoltaic cells in a form of monocrystalline, polycrystalline and amorphous silicon.

There are different types of photovoltaic sells: first generation monocrystalline silicon, second generation amorphous silicon, polycrystalline silicon, cadmium-telluride, copper indium gallium selenide, third generation nanocrystalline solar cells, photoelectrochemical cells, graetzel cells, polymer solar cells, solar cells synthesized in coating and fourth generation hybrid - inorganic solar cells with a polymer matrix

Photovoltaic cells that have the most efficiency are using dark blue anti-reflective material coating. Comparing to them the thin-film modules have lower efficiency, but they are cheaper and require less material in the production. The thin-film modules can be used in industrial buildings and buildings with large areas.

Types of photovoltaic modules that are most frequently used in building photovoltaics are: mono-crystalline, poly-crystalline and thin-film modules, which have different level of light absorption, energy efficiency, manufacturing technology and cost of production. Mono-crystalline modules are highly efficient, as blue black polygons that have efficiency in good light of 15%-20%. Polycristalline are mostly used solar panels, even though they are less efficient. Thin film modules are more flexible and they can be produced in different colors, textures and shapes, as well as that the fact that the material for their production is lower, they are cheaper compared to other types of photovoltaics. Hybrid photovoltaics combine photovoltaic sells with the solar thermal collector, which removes heat and captures the energy.

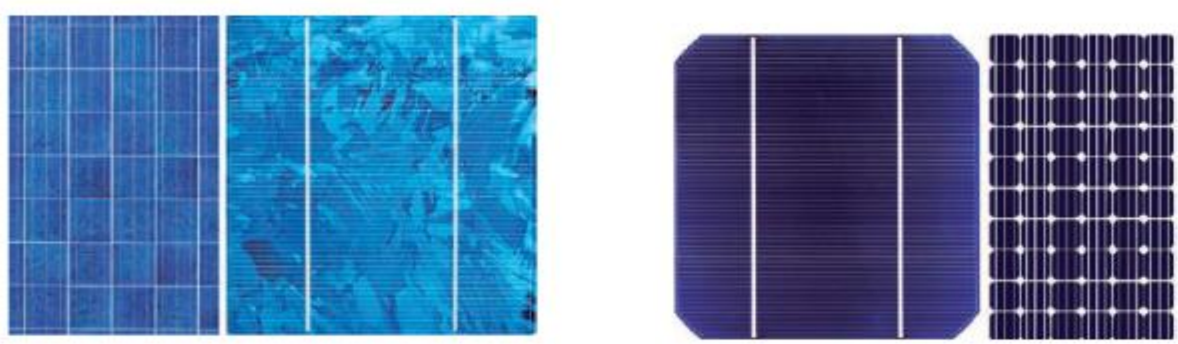

Figure 1. Types of Crystalline PV Cells (Architectural Design Element)

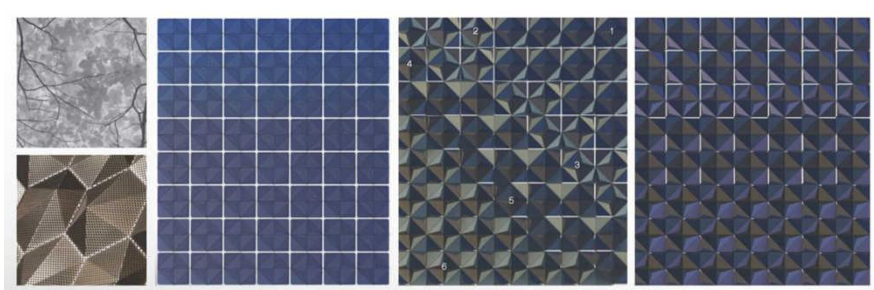

Figure 2. Photovoltaic Panels Patterns with specific architectural design

Figure 3. Architectural Design Element - Photovoltaic Panels Patterns with Photo-printing can be achieved with specific architectural design for the building

Structure of the cells is very important factor in the design of the building integrated photovoltaics. They are available in a different shapes, sizes and models from insulated glass structure to sound iso-glass. The cell has possibility to have natural light enter the building according to the distribution and arrangement of the photovoltaic cells. The arrangement of the photovoltaic cells will contribute to the aesthetic of the architectural design, and will also depend on the density of the cell position in terms of energy production (denser cells will have higher energy production). These types of modules are recommendable in architectural buildings that require high level of integrity and architectural aesthetic design result. Very important factor in the design of the building integrated photovoltaics is the choice of color in the architectural design. Also, important aspect to consider in terms of choosing the color, is that the lighter color of the photovoltaic cells provides lower efficiency in energy production.

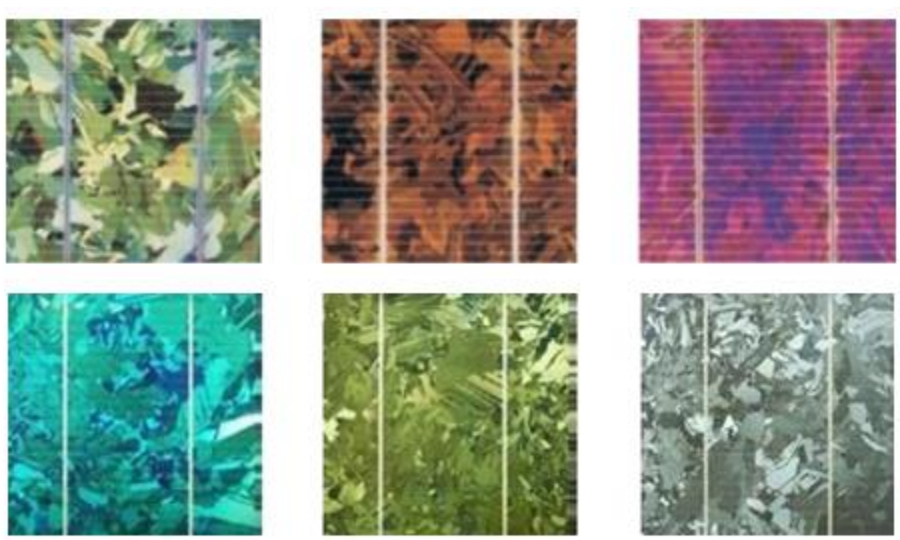

Figure 4. Color varieties in the photovoltaic cells in Solar Innova modules, Source: Solar Innova modules

Integration of photovoltaics can be done in the following building areas: roofs as ideal places for building photovoltaic integration that provide large unused surface, skylights and roofs with glass structure which can create diffuse lighting and can combine photovoltaic installation, fasades which can add the integration of the building photovoltaics in different ways such as glass curtain, ventilated fasade, and other elements such as shading devices that provide shading and aesthetics in the architectural design.

It is very important to have into consideration the fact that the integration of the building photovoltaics should comply to the principle to enable production of electricity and natural light in the building. Also the customized photovoltaic cells, can create interesting light effects in the corridors or interior design in the building as a light and shadow effect.

Even in a situation with a partial shading in the photovoltaic modules, the photovoltaic system is greatly affected in terms of the energy production. In the system of integrated building photovoltaics, special attention should be added in terms of providing adequate ventilation, and this can be solved with a planned ventilated space and space for ventilation between the module. Also, ventilation should be provided for the inverters for optimal usage of the photovoltaic system.

The Photovoltaic system needs to be monitored by the energy technology institutes, which will determine if there is a malfunction in some of the modules which will reduce the overall energy production, identify the irregularities and replace the malfunction of the module. Electrical engineering should provide all technical energy calculations. Also, very important factor is to determine the shades in the photovoltaic system, because they have very important effect in the reduction of the production of electricity.

The Project which will include integrated photovoltaics should analyze both aspects: the production of electricity and the architectural design from the beginning of the architectural project. The project should presented different scenarios with different type of modules in terms of their energy efficiency, architectural aesthetics design and economic aspects of the photovoltaic modules, in order the investor of the project to decide which system will be chosen in a calculations of long-term effects and benefits as a best solution in terms of production of electricity or designing the photovoltaic cells.

The Photovoltaic systems can be also created by adding battery storage units, which can store the accumulated electricity. Integrated building photovoltaics system should also analyze and take into consideration the optimal orientation and angle, as well as the load and stability of the construction of the building. One of the interesting principle of using building integrated photovoltaic systems is that they can be part of circular recycling, and this process can be done in thin film and silicon modules in terms of the materials glass, aluminium and semiconductor materials that they are using, which will reduce their production costs and have positive impact on environment. This principle should be further explored as a possibility by architects and electrical engineers.

3 PHOTOVOLTAIC INTEGRATION PANELS AS ARCHITECTURAL DESIGN ELEMENT (FORMAL AESTHETIC ASPECTS IN ARCHITECTURAL DESIGN BY POSITIONING INTEGRATION OF PV PANELS)

Photovoltaic panels as architectural design element should incorporate the formal aesthetic aspects in the architectural design with the concept of integration of photovoltaic panels according to the International Energy Agency (IEA) as: added technical element, added technical element with double function, free-standing structure, part of surface composition, complete fasade or roof structure or form optimized for solar energy.

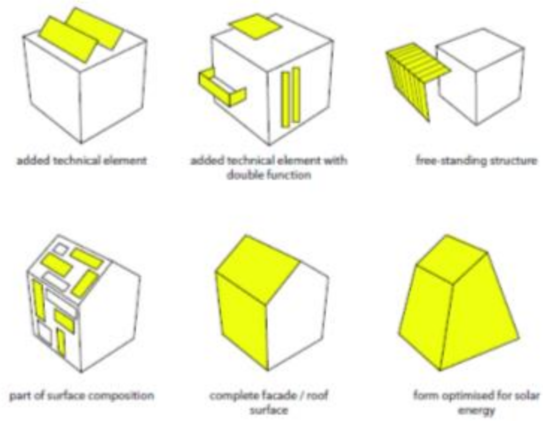

Figure 5. Architectural Design Element- PV Panels, Formal Aesthetic aspects in Architectural Design for positioning and integration of PV panels, Source: Illustration from IEA analysis of positioning and integration of PV Panels, Solar Energy and Architecture, http;//task41.iea-shc.org

The levels of integration of building photovoltaics which can be implemented are: basic, medium and advanced. Basic level requires formal flexibility of the modules, and typically includes retrofit projects. Medium level of integration includes the non-active elements with added function, such as cladding and shading elements. Advanced level of integration provides a complete roof or fasade system that is usually custom-made and includes all interface elements in the photovoltaic systems.

Figure 6. Rooftop with Photovoltaic Panels at the University für Bödenkultur, Vienna, Austria 2016

Roofs are also important architectural element in the application of building integrated photovoltaics. They have great variety of photovoltaics according to color, size, shape and transparency. The photovoltaics can be implemented on the roof with existing structure, or they can be implemented in a photovoltaic roofs which contribute to their efficiency and environmental aspects.

Figure 7. Roof with Photovoltaic Integrated Panels that follow the shape and angle of the roof system

Fasades and skylights provide new aesthetic possibilities to the building. The new innovative technological development leads to integrating building photovoltaics on the building envelope surface.

Building integrated photovoltaics can be implemented in modern architecture as ventilated curtail wall. This system has load-bearing fixing system connected to the building envelope, so the distance between the wall creates space which ventilates the solar modules and creates good insulation layer. Fasades can be designed using different materials with integration to the photovoltaic modules. Ventilated fasades are usually part in the architectural design when there is a need for energy efficient renovation fasade.

Figure 8. Ventilated Fasade as an integrative Photovoltaic Architectural Element

The integration of building photovoltaics into the fasades is achieved in many different solutions, because the fasade is very important architectural design element that is first observed when a visitor approaches the building.

Figure 9. Fasade with integrated PV Panels as Architectural Element

The fasades which use integrated building photovoltaics are multifunctional, on one side they provide production of electricity, create thermal and noise insulation to the building, and on the other side they represent innovation with aesthetic character to the building where the panels become the integral part of the building fasade.

Integrated photovoltaics with the architectural design incorporate the functionality, construction, but also the aesthetics of solar renewable technology. Architects can design fully the shape of the building in accordance to the optimal energy production, The famous architectural slogan from the architect Luis Sullivan "Form Follows Function" is shifting into a new contemporary concept for all architects "Form Follows Energy", which can be seen as a principle in the Energy Base Building in Vienna.

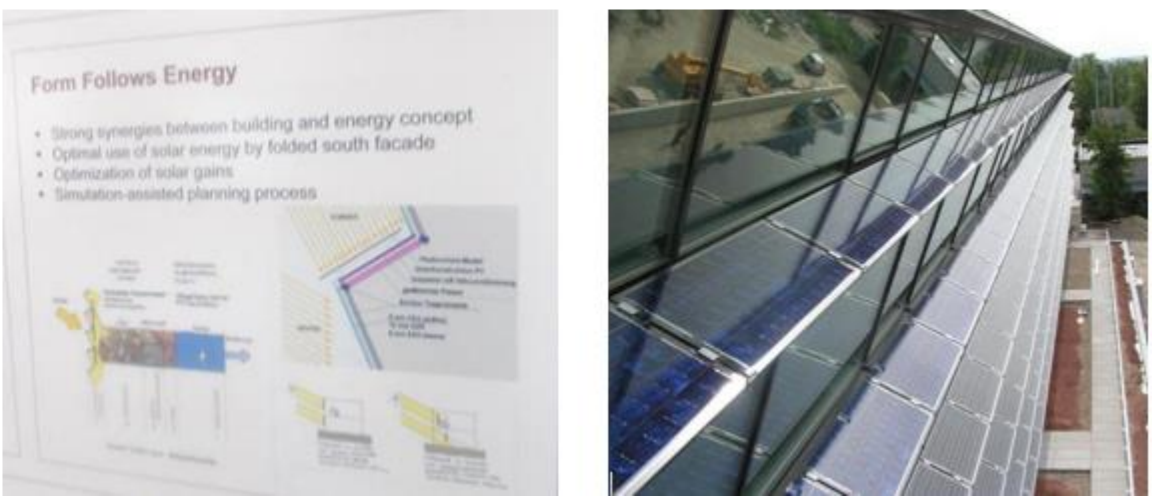

Figure 10. Energy Base Building, Austrian Institute of Technology, Vienna, Austria 2016

The architects have methodology to combine the morphological different shapes, colors and patterns in the building integrated photovoltaics, by approaching the design with customized photovoltaic cells with modern sophisticated renewable design using the photovoltaic technology.

Figure 11. Integrated Building Photovoltaics with different colors, textures and patterns

One of the new innovations in terms of photovoltaics technology is the photovoltaic solar transparent glass, as an innovative high-tech building material which can integrate the solar photovoltaic sell easily in the glass structure while producing energy and have transparent appearance that bring natural light in the building. This system is applicable in architectural design of buildings with different functions, but it is especially recommended in office buildings and buildings with business premises. Main characteristics in the morphological integration of the solar technology that define integration are: the medium for energy production, form of the module, size of the module field, the materials of the module and texture (mono-crystalline silicon), absorption of solar energy, color, size and shape of the modules and type of jointing the modules.

Laminated glass is recommendable and applicable in a cladding glass fasade where the parapet is designed in a safe laminated glass that holds together when it is broken. It is also used in an areas where precautions of high wind resilience is needed. It gives high sound insulation and blocking of most of the UV light. The thickness depends on the regulations. The float glass is a transparent glass that offers high light possibilities and low UV radiation protection. It can be customized in different design pattern according to the needs of the architectural style and the transparency.

Skylights are ideal place for positioning integrated building photovoltaics, because they have slight incline angle, and the photovoltaic panels can create effects of light and shadows providing light in the interior space. Photovoltaic systems in this type of construction are semi-transparent because they allow light inside the building. They provide thermal, solar and sun protection, and selective natural light as semi-transparent photovoltaics, as well as great visual elegant effects in the buildings.

Figure 12. Semi-transparent fasade in Office buildings providing sun-light for the workers in the office building

Shading architectural elements as integrated building photovoltaics are effective and alternative element to generate electricity, which replace traditional elements for shading systems, filter the UV radiation, help raise awareness of the citizens for energy production, integrate renewable energy in urban areas, capitalize from the unused urban structures and create rational economic profitable usage. In this architectural element both aspects are combined: energy production and functional formal aspect of shading.

Figure 13. Shading Systems and Skylight Systems in the Architectural Design of Buildings

Figure 14. Shading Architectural Elements with Photovoltaic Panels

Important possible position of the implementation of integrated building photovoltaics are parking areas, which can contribute directly in charging batteries from the electric cars. The design is typically based on integration of parking modules for two cars with integrated photovoltaics with an incline of 8 degrees for rainfall system. It is very important to design the photovoltaic area with maximum possible energy production, and protection of weather influences: wind, snow and rain weather conditions.

Figure 15. Parking Structures with Photovoltaic Panels that provide shading systems and also functional changing of electro-mobiles

Integrated building photovoltaics can be also implemented in the balcony as an architectural element. This system is particularly recommended when the balcony is highly exposed to sun radiation for optimization of the energy production and to improve its visual elegant appearance. In this situation of the integrated building photovoltaics, it is used multi-layer safety glass with unlimited design possibilities typically in apartment buildings. The photovoltaic modules can be transparent and semi-transparent photovoltaic colored monocrystalline or polycrystalline cells.

Figure 16. Integrated Photovoltaics applied as an architectural element on the Balcony

Integrated building photovoltaics can be also used as architectural element in the acoustic barriers. Photovoltaic solar barriers are very effective in reducing the noise pollution in highways and railways with very high frequencies, with combination of producing energy production. They also have grid-tie economic benefits because they are usually large scale photovoltaic systems that don’t need additional land space.

Ground panels with integrated building photovoltaics floor can create sustainable architecture with created unique urban spaces that can generate free electricity, which can have different visual effects of customization with colors and textures. The floor with photovoltaic cells is walkable, have anti-slip structure and supports load efficiency similar to other structural solutions. Sidewalk can also be integrated with photovoltaic floor, that combines the sustainability and architectural function using different colors and textures. The photovoltaic floor is very attractive and can be integrated in any architectural project.

4 INTERNATIONAL ARCHITECTURAL DESIGN STUDIOS INTEGRATE BUILDING PHOTOVOLTAICS IN ARCHITECTURAL DESIGN PROCESS

Architectural Design from famous International Architectural Design Studios such as Zaha Hadid Architects, incorporated custom designed photovoltaic integrated panels that contribute to the design feature as well as to the production of electricity for the sustainable design project: Beijing Daxing International Airport, Zaha Hadid Architects includes photovoltaic power generator.

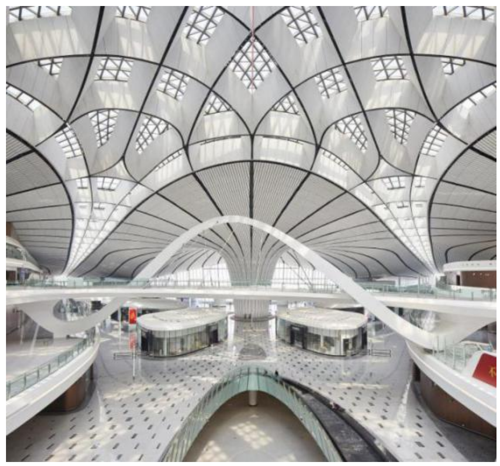

Figure 17. Architectural Design with PV Panels, Beijing Daxing International Airport, Zaha Hadid Architects includes photovoltaic power generator

Figure 18. Architectural Design with PV Panels, Kapsarc, Saudi Arabia, Zaha Hadid Architects

5 ARCHITECTURAL DESIGN STUDIOS INTEGRATE BUILDING PHOTOVOLTAICS IN ARCHITECTURAL DESIGN, DEPARTMENT OF ARCHITECTURE, FACULTY OF ENGINEERING

Architectural Project worked during the architectural design studios in the course Sustainable Architecture at the Faculty of Engineering, Department of Architecture at International Balkan University had several sustainable project objectives: to improve the architectural functioning of the building with implementation of renewable technologies: solar panels, photovoltaic panels, geothermal pumps, green roof system, to improve the connection and between public buildings: municipality building by promoting the use of renewable technologies.

Figure 19. Diploma Architectural Project, Student: Ozcan Kana, Mentor: Assoc. Prof. Dr Viktorija Mangaroska

Figure 20. Diploma Architectural Project, Student: Kubra Hodo Mentor: Assoc. Prof. Dr Viktorija Mangaroska

6 QUALITY STANDARDS IN IMPLEMENTATION OF BUILDING PHOTOVOLTAICS THAT NEED TO BE CONSIDERED IN ARCHITECTURAL DESIGN PROCESS

Integrated building photovoltaics are becoming more important in the field of contemporary sustainable architecture that use new way of application of renewable solar energy. They incorporate the functionality, construction, but also the aesthetics of the renewable technology. The integrated building photovoltaics can be positioned on the building: roof, wall cladding, sun cladding and shadings, additional architectural element - balconies, parapets, and any other architectural element.

The Photovoltaic modules should provide and ensure the highest quality standards in terms of quality, safety and design. The criteria for achieving high architectural quality of the building integrated photovoltaics are defined by the International Energy Agency (IEA) through its Program for Photovoltaic Energy. International Energy Agency Program as the following criteria: "natural integration of PV systems, PV systems that satisfy the architectural context of the building, quality materials and color composition, PV systems that fit well with the existing modular division, visual aspect of the network that is in harmony with the building and makes a good composition, PV systems appropriate for the context of the building and whose integration is well designed, the use of PV systems that challenged the innovative concept." (International Energy Agency Photovoltaic Power Systems Programme).

The standards of implementing building integrated photovoltaics in the building envelope, architects should specifically pay attention to create protection from wind, rain noise and intrusion, provide thermal insulation in cold winter and extreme summer heat, provide regulation for daylight, fresh air and passive solar gains. Special attention should be given in the architectural design of the integration of the photovoltaic modules in the opaque and transparent parts that should provide function of daylight and passive solar thermal gains and visual contact with the outside, and provide natural ventilation. Structural aspects that need to be considered when installing building integrated photovoltaics are to calculate the module load to the load bearing structure, to pay attention to avoid thermal bridges, to pay attention to provide fire protection and weather impacts, and create modules which will resist the wind loads and impacts.

Advantages on using integrated photovoltaics are: energy production, economic investment, reducing the carbon footprint and environmental protection, fasade elements that can have noise reduction and thermal insulation, and saving on the innovative building materials compared to traditional materials. Photovoltaics that are integral system to the building envelope provide clean energy to the building as a cost-effective methodology in the production of energy in architectural design. The produced energy can be used by the building directly without any transportation costs, or it can also be sold to the grid as a grid-tie system. Advantage of the integrated photovoltaics is that they are mostly suitable renewable energy source in cities and urban environment due to the quiet and clean production. Other advantages of the building photovoltaics are: innovation in contemporary and modern architectural design, customization of photovoltaic panels for specific architectural building, integration and aesthetics to the urban environment.

The modules and the photovoltaic solar sells in the integrated photovoltaics can be custom-made according the customer requirements, in terms of different architectural and visual appearance in shape, color, patterns. These building integrated photovoltaics can perform the same function in all areas of the building fasade, compared to standard photovoltaic modules that can be placed only on the flat roof structure in a specific angle.

7 CONCLUSION

Architectural possibilities using building integrated photovoltaics become functional, constructive and aesthetics formal aspects in the architectural design. Architects must think of new concepts of integration of the photovotaic systems as architectural elements by creating pixeled photovoltaic module, patterns in monocrystalline cells, as well as using different visible materials, patters, textures and color in the film modules of the photovoltaic cells in the composition of the architectural design.

Integrated photovoltaics in architectural design studios emerges from the concept of new innovative engineering methods in a stylistic form-based and optimization processes towards new modern contemporary and sustainable style in architecture.

It is becoming very important architectural engineers to have knowledge in the early architectural design phase for better integration of photovoltaics in terms of aesthetic, energetic, constructive and economic aspects in the architectural design of the buildings. Architects should particularly pay attention to the selection of the photovoltaic cells that will bring aesthetic value to the building, as well as the function of the integrated panels, such as thermal insulation, waterproof materials, fire protection, wind protection, acoustic insulation, daylight access, shading, color and transparency of the designed photovoltaics. The importance of use of renewable energy and the reduction of energy consumption, in terms of sustainable modern architecture becomes important factor in their early architectural design phase for many famous architectural studios around the world.

Engineering sustainable concept and paradigm start to shift, in a concept that incorporates contemporary design as a modulation of environments and ecologies in architectural sustainable parametric design of the 21st century. This concept of sustainable design in architecture which incorporated integrated photovoltaics that produce renewable electricity will lead into contemporary transformation of the design process of the next generations of architectural engineers of the 21st century.

Important characteristics that integrated photovoltaics with the architectural design of buildings bring are: improving the citizens' consciousness regarding sustainable renewable energy production, reducing the energy consumption and improving energy efficiency. The decision regarding building project with photovoltaic panels, is defined by several factors such as analysis of energy production, economic aspect and cost estimation, payback period, value and benefits on the energy production and the aesthetic of the building, environmental, social-economic and architectural long-term benefits of the building, photovoltaic cells in relation to their energy production, non-reflective surfaces, maintenance of the structures and possible replacement and recycling.

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