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BIPV Design guideline Based On Kneller's Design model Steps

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Abstract

One of the most critical issues in today's world is environmental problems (such as increasing global warming, air pollution, ecosystem destruction, etc.) caused by human activities. The adverse effects of these activities have appeared in various fields. The building construction industry is one of these practical aspects that must be noticed with the aim of its environmental damage reduction. Substitution of renewable energies instead of fossil sources for building energy supply is one of the solutions. For example, solar energy can help reduce pollution produced by buildings in different ways. Photovoltaic cells use the sun's energy to generate electricity. For their successful performance in the building, various parameters should be considered in the design process. PV cells in the building can be used in two types: BAPV(building-applied photovoltaics) or BIPV(building-integrated photovoltaics). In the BIPV type, due to the replacement of PV modules as some part of the building skin, a more accurate and detailed design is needed compared to the BAPVs. Therefore, this article's purpose is to provide a design guide for BIPVs that presents step-by-step considerations for architects. Based on previous studies and BIPV guidelines, the essential parameters and design considerations were classified adapted to Kneller's design model, which includes five stages of First Insight, preparation, incubation, illumination, and verification. Finally, the interaction of some of these parameters was discussed, and the parameters classified in each stage were summarized in a table.

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1. Introduction

The impact of energy consumption on the environment has continuously increased [1]. There are various solutions to environmental issues. The PV device is one of the most promising renewable energy technologies, converting solar energy into environment-friendly electrical energy using solar radiation. Replacing fossil fuel-generated power with secure, clean, and suitable PV-generated power can mitigate issues like climatic changes [2].

Building energy consumption reduction and power generation from renewable sources in the buildings; zero energy buildings (ZEB) or net-zero energy buildings have been discussed in construction issues nowadays [2]. Buildings that generate energy using renewable energy sources reduce overall greenhouse gas emissions [3]. PV in building works as an onsite green power generation, reducing transmission losses, and improving the building’s overall performance [2].

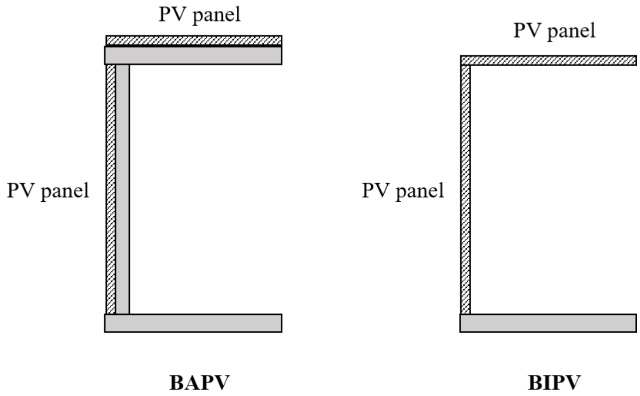
In order to achieve the most suitable product, different elements should be considered in the BIPV design phase [4]. These considerations must include primary energy, economic investment, total costs, labor [1], the building's use, PV location and orientation, electrical loads, safety codes, utility issues [3], daylight received amount, ventilation, privacy protection, color, appearance, size, wind and snow load , resistance and maintenance, weight, materials used, etc. [4]. The integrating BIPV complexity in the planning process requires specialized knowledge to provide conditions to meet the homeowner and architect expectations [5]. Due to the lack of a specific design model for BIPV for architects who want to work in this field, this article aims to provide a guideline based on Kneller’s 5-step design model that is agreed upon by some architects like Lawson [6]. After a concise definition of PV and BIPV, Kneller’s design process stages were briefly mentioned, and then important effective parameters on BIPV design were investigated and classified in each step of Kneller’s model design.

2. Literature review

1-2- Utilization of PV in buildings

There are two frequent techniques to use PV in a building, including Building integration (BI) and building attached/applied (BA) [7]. BAPVs are an addition to an existing or new building [2], while Building Integrated Photovoltaic(BIPV) is the integration of photovoltaic into the roof and facade of the building envelope (Fig. 1). The Solar BIPV modules serve the dual function of energy generation and building skin replacing building envelope materials [3].

Figure 1: BAPV and BIPV difference



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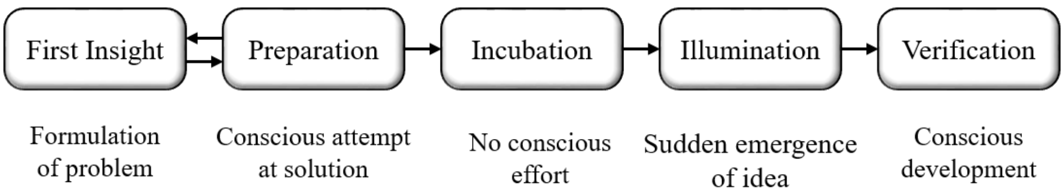
2-2- Design Process

There are various design process models. Kneller's model (1965) is one of them that identifies five stages of the creative design process, including first insight, preparation, incubation, illumination, and verification [8]. These steps can be seen in the Figure below (Fig. 2).

Figure 2: Kneller's design model



[6]

3. BIPV Suggested Design Process Based On Kneller's Design model

Any realistic design protocol shows that events are parts of some bigger goal, and they are carried out together in order to move the project forward in some way [9]. Since the BIPV system replacement is more critical than BAPV [7], in this part, the various parameters that influence the purpose achievement of a BIPV design project are discussed under the Kneller design model category.

1-3- First Insight (problem Formulation)

At this step, the architect needs to be aware of the existing problem. Thus the problem situation has been formulated, and it needs to prepare a scheme to solve the problem [8].

1-1-3- BAPV or BIPV

The building attached/applied photovoltaic (BAPV) indicates when PV systems are attached to a building without replacing its traditional envelopes. Building integrated photovoltaic (BIPV) replaces traditional building envelope and acts as windows, walls, and roofs. Both BAPV and BIPV work as an onsite green power generation, reducing transmission losses, and improving the building's overall performance [2]. Suitable photovoltaic arrays should be used according to photovoltaic technologies, architectural forms, costs, and other building site situations [10].

2-1-3- Building function type (activity time)

Design development depends on matching the time of demand and the time of supply pattern. Energy consumption varies with both the type and the individual building, so a design team should conduct a preliminary specific analysis for the building. A wide range of building types, from offices to hotels to industrial buildings, can use PVs. Offices have good PV potential because of their year-round electricity requirement and peak demand between 9 am and 5 pm. Alternatively for schools, there is much less electricity consumption in the summer during the school holidays. The daily load variability is notable too. Houses are active seven days a week, but their energy demand is different day and night. Commercial and industrial buildings provide significant conditions for PVs due to their large roof areas [11].

3-1-3- Coordination between PVs and passive solar systems

An interdisciplinary approach is crucial for the development of a nearly zero energy building (NZEB), which is based on the combination of solar passive design strategies (such as cross-ventilation and solar protection) and an active strategy like building Integrated Photovoltaic/Thermal system (BIPV/T). Alternatively, in another example, the adaptation of a double façade and BIPV system should be considered. If an existing building is supposed to use a BAPV system, That building's envelope data, the mechanical and the electrical systems must be recorded [12].

4-1-3- Site climate

In order to choose the appropriate solar technology to generate energy from solar radiation, the location climate condition needs to be investigated [13]. For example, the minimum and maximum temperature, precipitation, and solar radiation [12].

The received sun radiation is one of the most crucial climatic factors. The global horizontal irradiance indicates the total irradiation delivered from the sky to a horizontal surface on earth. It is not affected by any geometric or technical limitation, but the geographical potential is a portion of the BIPV theoretical potential that can be exploited as input for BIPV systems [14]. The variation range of Solar electricity generation depends on the sun's position and weather conditions change [15]. The BIPV geographical potential for a city represents the total solar incident radiation on the city building skins [14]. For instance, India is blessed with high solar radiation, which receives 6 billion GWh equivalent energy potential annually, thus making PV technology suitable for this country [2] or Southeast Asia's climate that supports PV systems [16].

5-1-3- Annual energy consumption (load pattern)

The approximate load pattern of the project should be considered to choose the most optimal PV type. For instance, a 4-person household's electricity requirement can be supplied by a five kWp system with an annual yield varying between 3,500 and 5,000 kWh [17].

6-1-3- On-greed or stand-alone or hybrid system

BIPV systems can either be connected to the utility grid, or be designed as stand-alone systems. Therefore, a utility-interactive solar photovoltaic system or an off-grid photovoltaic system should be chosen in the design process [3]. The grid-connected type benefits the utility grid as a storage component in the BIPV system to improve stability and reliability. The second type employs batteries for extra power storage and stable power supply for fluctuating power generation. A supplementary generator is usually necessary for extreme weather conditions [18]. The hybrid PV system is the third way. They are combined with other systems for energy conversion. This system's advantage is that if one of the plants breaks down, the continued electricity supply is still ensured. The plants complement each other to provide a constant supply of electricity during the day or year [19].

2-3- Preparation (Conscious effort at solution)

In the second stage, the architect starts to seek a problem solution and there is a time-consuming round-trip process between this stage and the first [8].

1-2-3- Upstream policy standards and criteria

There are various upstream codes like state energy codes, residential energy codes, commercial codes, etc. Local codes vary by state and municipality. For instance, zoning ordinances relative to solar access laws in the United States [20]. Nevertheless the absence of BIPV standards is an issue in some areas [18]. PV system standards are available, but there are no specific standards for BIPV/BAPV systems. For instance, noise protection standards by integrating PV in buildings are not mentioned in the building codes. Alternatively, health and safety codes regarding fire, electricity shortcuts, and wire failures that should be considered [7]. Many building codes are necessary to adapt to electro-technical codes due to the complex symbiosis of engineers in a BIPV project [5]. For example, installation barriers, such as the cabling and connection fixings failure, can create a problem after PV integration into the building. Only one standard, EN 50583, has recently been initiated for BIPV [7]. Also, the lack of government support is one of the policy obstacles to BIPV use [18]. Warranties are a solution to increase the employer's willingness to use PVs. For example, some major PV manufacturers offer power production warranties for as long as 10, 20, and 25 years [20].

2-2-3- Symbiosis of the architect and other stakeholders

The complete integration of PV demands a complex interlocking of all stakeholders, including those responsible for products, marketing, planners, developers, architects, and installers. So a PV product for the particular building project should be selected in collaboration with all of them [5].

3-2-3- Optimal location on building envelope

There is a wide variety of possible applications for the integration of PV systems in and on buildings [19], including roof integration or mounting, façade integration or attachments, windows, sunshade, rain-screen integrations, atrium/skylights, claddings, railings, etc. [18].

Façade: BIPV has recently become a renewable energy generation component in building design in façades [16]. Curtain façades, rear-ventilated façades, and double façades are some types of facades adaptive to the BIPV system. In urban settings, façades represent a significant part of the area available for BIPV. High-rise buildings have a higher ratio of facade area to roof area [19]. Façade BIPV is usually designed to resist wind loads, snow loads, and impose loads: barrier loading, impact loading due to cleaning and maintenance, bomb blast effect, and seismic effects [21].

Roof: In terms of roof type connection, the PV panels lay flat on the roof, or are integrated with the roof. In the first type, no effect is made on the roof profile, and they may consist of attached PV sheets material to the roof [21]. In the second case, PV can substitute the roof system’s external layer as cladding, or the entire technological part as skylights [15]. Flat or sloping roofs are another classification of roofs [22].

Shading: Using photovoltaic integrated shading devices significantly improved the overall energy efficiency [16]. The optimal inclination for the most energy production is the same angle that provides the most shade [17]. The synergy of shading and energy consumption, and electricity generation reduces the total costs of such installations [4]. Some examples of this type include solar protection fins and louvers, sun protection panels and canopies, sliding shutters, etc. [19]. These PV shades should not impose any additional load on the building structure. PV shading systems may also use one-way trackers to tilt the PV array for maximum power while providing a variable degree of shading [4].

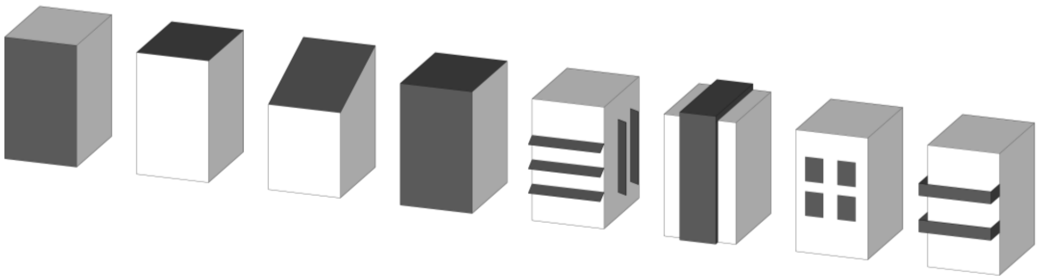
Skylight and Atrium: PV can also be used in other types of house glazing, such as skylights [16]. These elements provide both electricity and light to the building and can enhance indoor thermal comfort [20]. They can produce light hallway walks and floors and present architectural designs of light and shadow [4] because BIPV is a glass element that provides different degrees of shading [20].

Window: PV cells can be used in windows [16]. For example, semitransparent windows and privacy protection panels are some types to use [19].

Balcony: Parapet areas usually use safety glass-glass semi-transparent modules. Balcony fronts can either be two-layers or single glass with laminated PV. The generated heat at the PV back can create thermal comfort in cold weather and benefit from natural ventilation by opening in summer [15].

Figure 3 depicts various types of PV positions in the BIPV system.

Figure 3: BIPV position options



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4-2-3- Optimal orientation

The module’s orientation in the azimuthal (compass) direction and the BIPV module’s angle are decisive for the annual yield and the time pattern of solar power generation [23]. Installation site latitude determines the optimum angle. The greater the distance from the equator, the steeper the optimal installation tilt. For example, in Germany, south-facing surfaces with an angle of 35° to the horizontal receive the maximum possible solar radiation [19]. However installation in the optimum tilt is not always possible due to some design limitations. Some solutions can help with this, for instance, setting the BIPV system at several different angles, or when PV modules are operated at low irradiance levels, modules can have more angle relative to the building skin (roof or facade) [23].

5-2-3- Technical Components

BIPV systems equipment components have to be carefully selected and specified [3]. A complete BIPV system includes the BIPV modules, a charge controller, power conversion equipment(an inverter to convert the DC to AC power), backup power supplies, appropriate support, and mounting hardware, AC and DC wiring and cables, safety disconnects, DC load-break switch [3][19]. PV modules can be connected in parallel or series to form an array. The type of connections between the PV modules determines the cabling system, the system stability, and the necessary cable dimensions [19]. The inverter must be chosen based on utility requirements [3].

6-2-3- Building form and aesthetic

Some architects describe PV as an aesthetic problem that complicates the planning process and limits their creative possibilities. The future value of BIPV potentials will probably make them adaptable to this technology [5]. Considering aesthetic requirements depends on the compatibility with the existing surrounding area [24]. To create the visual appeal of BIPV modules, the cells can be visible elements and be used as fundamental elements of patterns. Alternatively they can be invisible by coloring the module uniformly in the cell color or by using a colored or light-scattering front cover (often with efficiency reduction) [23].

7-2-3- Structure

The impact of structural loads on PV arrays and PV attachments, such as dead load, wind load, earthquake (seismic) load, live load, rain load, and snow loads, is critical in the planning and developing a PV system. The entire PV array mounting system and all components must be designed to support the maximum expected load combinations. The PV attachment method can significantly affect the loads that are being applied to the structure and how it is being handled [21].

8-2-3 PV size or area

The systems should be sized to meet the goals of the owner, typically defined by budget or space constraints [3]. BIPV unit sizes vary from type to type. Although a smaller unit size is more desirable for its flexibility in the design, it leads to a more significant number of smaller components, increased labor costs, more electrical connections, and more operation and maintenance challenges. On the other hand, a greater unit size solution will create more limitations for the architects but includes less system complexity, fewer labor costs, and fewer operation and maintenance expenses [14]. For instance, knowing the required area ratio of PV materials in a photovoltaic skylight glass is effected on the design process [16].

9-2-3- Materials Technology

PV technologies include first-generation (opaque silicon type), second-generation (transparent or semitransparent thin film), and third (emerging types)[3][1][2]. There is another technology that is a combination of first-generation materials and second. It is made of an amorphous silicon matrix containing tiny silicon crystals to shift the spectral absorption band toward the longer wavelengths [1]. the first generations are employed for BIPV and BAPV applications, whereas the second and third generations are primarily considered for BIPV applications [2]. Third-generation type PV cells are suitable for BIPV application due to their transparency [7].

The materials chosen for each layer must fit specific requirements based on a suitable repartition of sunlight spectral interval and their mechanical and electrical properties. Strong absorption coefficients, high minority carrier lifetimes, and high mobilities should be considered for PV materials choice [1].

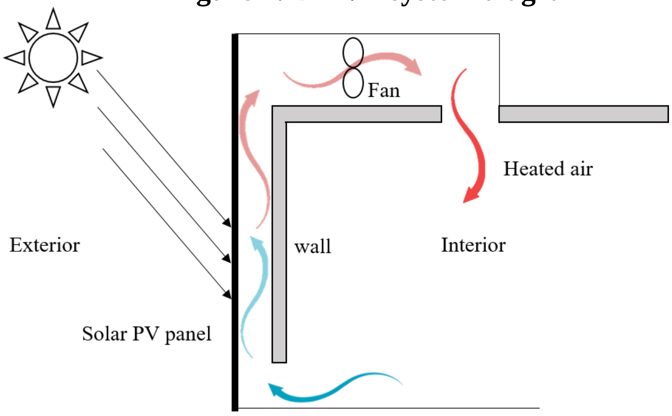
10-2-3- System Weight

BIPV systems can be employed during building refurbishment even though the building may not have been designed to support the additional weight. This may lead to the collapse of buildings. Some new technologies, such as thin-film cells, can solve this issue, albeit with lower efficiency than heavier BIPV systems [14].

11-2-3- With or without ventilation

It would be proper to increase the rear ventilation dimensions to keep the module temperature as low as possible. In the façades with no rear ventilation, temperature reduces PV yield [19]. In some applications, a fan and an air duct are employed in the system to draw the heated air into the room to reduce the winter heating load and reducing the PV temperature. Such systems are called BIPVT systems and benefit from solar energy both electrically and thermally [24] (see Fig. 4). Addition of water and air can serve the seasonal energy demand. Air mode will provide hot air in winter, and water will supply the building hot water for the rest of the year [7]. Also, the ventilated façade or double skin can reduce the weather condition’s effect on the internal structure [24].

Figure 4: BIPVT system diagram



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12-2-3- Multi-functions PV

In addition to generating electricity, PVs can have various functions, and it is an opportunity to improve the design by considering them. For example, privacy screening and sun protection, daylight receive, energy conversion and shielding(e.g., as a repeater antenna), aesthetical added value, heating, thermal insulation and energy saving, harmful weather condition protection, burglary protection, safety, residual structural support, acoustic benefits, etc. [19][1][4][24].

3-3- Incubation (Unconscious attempt at solution)

This stage usually requires no conscious effort because it depends on imagination or inspiration. An architect’s experience can affect this period duration [8]. For instance, the building type features, best material, cost, sustainability, and other vital parameters mentioned in the previous steps combine in the architect’s mind unconsciously. The architect thinks about different alternatives and mentally investigates them regarding various parameters. For example, the best roof for a flat application is probably a fully adhered thermoplastic olefin or polyolefin (TPO) membrane roof that is an excellent choice for commercial applications and is cost-effective and more environmentally friendly than some other options too [22].

4-3- Illumination (Sudden idea emergence)

‘Illumination’ can be considered together with ‘incubation’ step. It is not sure how, why, and when the human mind suddenly comes up with an idea. However, some argue that in this period, architects maintain a continuous screening process of all the data that has been absorbed during the previous intensive periods [8].

For example, in a research on a building in Cyprus, it was concluded that the use of BIPV/T as an auxiliary system can reduce the energy consumption of the heating systems in winter [12]. One of the parameters of the first step (first insight) that influenced this idea was the weather. Cyprus has high solar radiation for almost eight months of the year [12]. In another example in China, due to the inconvenient installation and maintenance processes of photovoltaics, a new BIPV structure design scheme and the use of prefabricated photovoltaic modules were proposed as two solutions to solve that problem (based on the maintenance issue identification in the first design step and structural data on Preparation step) [10]. In another instance, land unavailability due to India’s population growth and rapid urbanization is a known problem for solar plants, so solar rooftops can be a probable solution. An example in India shows that the BIPV window system can be a suitable way for the Indian context to reduce the building’s HVAC load(problem finding based on the first and second steps) [2].

5-3-Verification (Conscious development)

In the final stage, the concept will be evaluated, tested, and elaborated. If it seems that the idea has any defect, the process can be reformulated, and a new investigation period has begun [8].

The BIPV should be selected according to actual needs. A combination type may not be functionally, economically, and technologically appropriate, although it can be architecturally attractive [10].

Today simulation is one of the most widely accepted tools in system analysis, research, and development [25]. For instance, the energy consumption, natural light, or ventilation level of an existing building and a proposed building can be analyzed and compared through 3D modeling simulation [12]. There is a wide range of simulation software for simulation, economic evaluation, photovoltaic industry related, analysis and planning, monitoring and control, solar radiation map, etc. Also, online simulation software can be used. This software is designed with different goals, and the demanded simulation software for manufacturing depends on the purpose of their use. For example, if one wants to design grid-connected PV system, then there will be specific simulation software for the corresponding task [25]. In Table 1, a software categorization is investigated.

Table 1: Suitable software for PV system

Tools Fields	Software
Simulation	INSEL, TRNSYS [25]
Economic evaluation	HOMER, Solar Advisor Model(SAM), RETScreen, SOLinvest, EnergyPeriscope
Photovoltaic	APOS photovoltaic StatLab, Organic Photovoltaics Analysis Platform, PV Cost Simulation Tool [25]
Analysis and planning	PVPlanner, Archelios, String Design Tool, PVSOL, BlueSol, PV F-CHART, Solmetric PV Designer, DDSCAD PV, Polysun, REA System Sizing Tool, PVSYST, Solar Pro, PV Professional, Solarius-PV, Matel Grid [25], DAYS program [16] EasyPV(structural load calculations) [21]
Monitoring and Control	Meteocontrols, SPYCE, pvspot, Autodesk ECOTECT Analysis, METEONORM, Shadow Analyser, Shadows, Amethyst ShadowFX, Sombrero, Panorama master, Horizon, GOSOL, Skelion [25]
Solar radiation maps	Focus Solar, SolarGIS, 3TIER, PVGIS [25]
online software	PV-Phil, SolarDesignTool, oTilt, PVwizard, Logiciel CalSol [25]

(retrieved from [25]**) (By the authors)**

1-5-3- Executable Install

Easy installation needs a simple structural and mounting system, for example, composed of aluminum staples, brackets, and profiles [24]. For instance, the type, quality, and warranty of the roof can determine the solar installation ease, or it is essential to install a roof that lasts at least as long as solar PV panels [22]. A team of trained BIPV installers is also required to mount suitably [5].

2-5-3- Energy efficiency

The energy-conscious design and energy efficiency measures must be considered to reduce the building power requirements. This will enhance comfort and save money while also enabling a BIPVs system to provide a more significant percentage contribution to the load supply[3]. For example, in a case study in Cyprus, PV openings reduced energy consumption by 50%, or in an example in Korea, using the BIPV model reduced the heating and cooling loads by 18.2% [16]. The BIPV efficiency levels vary depending on the technology, region climate, configuration, ventilation, alignment, tilt angle, etc. [14] [17]. The BIPV technical potential can be calculated by multiplying the BIPV panel efficiency by its geographical potential. The system output power can be calculated using the technical potential, technology, and efficiency data for the BIPV system [14].

1-2-5-3-PV life cycle and payback time

Ignoring total life-cycle costs and Focusing on a short refinancing period for BIPV systems leads to an incomplete vision for the employer [5]. For instance, within a research process, its payback time was estimated at 14.5 years by considering financial viability [12].

3-5-3- Cost analysis

Environmental and economic issues can not be considered separately [1]. The most important issue with solar panels is cost [10]. So a well-thought PV business model is needed [5]. This indicator depends on various parameters, e.g., the technology, energy tariffs, system degradation rate, market price, annual production, and possible subsidies [14]. A notable point about BIPV's cost is that it should be viewed in terms of life-cycle cost and not just initial cost because the overall cost may be reduced by the avoided costs of the building materials replacement [3]. For example, in a renovation project, the total amount for the aluminum systems replacement, the painting of the thermally insulated façade, and the heating and cooling systems was calculated, while a considerable part of them would have also been done in a typical renovation [12].

4-5-3- Safety

Due to the regulatory specifications with attention to the safety and loading capacity of the materials used, the chosen type and method of fixing have a decisive impact on the design of the solar module. The structural and safety requirements for specific applications types can be met by using toughened glass or different thicknesses of glazing. E.g., stability and fitness of a walk-on glazing (caused by its higher damage risk by knocks) should be structurally analyzed. According to German regulations, only triple-laminated safety glass can be used for this application [19].

5-5-3- Shadow effect

Shading can significantly negatively affect the PV system's electricity yield. This is caused by shading by neighboring buildings, vegetation, shading of the building itself protruding parts, or dirt layers on the mounting system [23] [19]. A module surface orientation (based on the sun's position) can change the magnitude of the shadow effect [23]. Simulations of the daily and annual shadows path can determine the solar modules' optimal position and orientation. Shading effects can be reduced by adapting the module technology, the module design, and the several modules' electrical connection [19].

6-5-3- Temperature effect

An output reduction is expected as the PV modules heat up. The output loss amount depends on the PV cell technology type. This effect must be accounted [19]. Active or passive thermal regulation can reduce the elevated temperature effects. For example, a 10-15 cm gap between PV and the building façade can reduce the PV device temperature by ventilation.Also, high-speed wind can reduce PV temperature significantly [7].

7-5-3- Maintenance and replacement

Easy maintenance and replacement of photovoltaic components is a significant issue [10]. The system may be affected by some loads, such as snow, ice, and wind, which might could result in system deformation. This will lead to various failures, which might require repairs or replacement [14]. PV modules can provide rain-proofing, wind-proofing, wind load resistance, and aging resistance, etc. [19]. For instance, the hydrophobic self-cleaning coating is applicable for snow-covering PV, and hydrophobic and hydrophilic are suitable for anti-dirt [7]. One of the maintenance issues is the dust effect on PVs. For example, due to the abundance of dust in India, its negative impact on PV power generation reduction should be considered in the design [2].

4. Discussion

Design parameters interact with each other. Some of their relationships are mentioned.

Form and orientation: For example, architectural criteria in a BiPV design case may prevent the optimal positioning of modules from being used [19].

Material and orientation: Modules like thin film that perform well in weak and diffuse light can be used to proper effect in situations with suboptimal orientation [19].

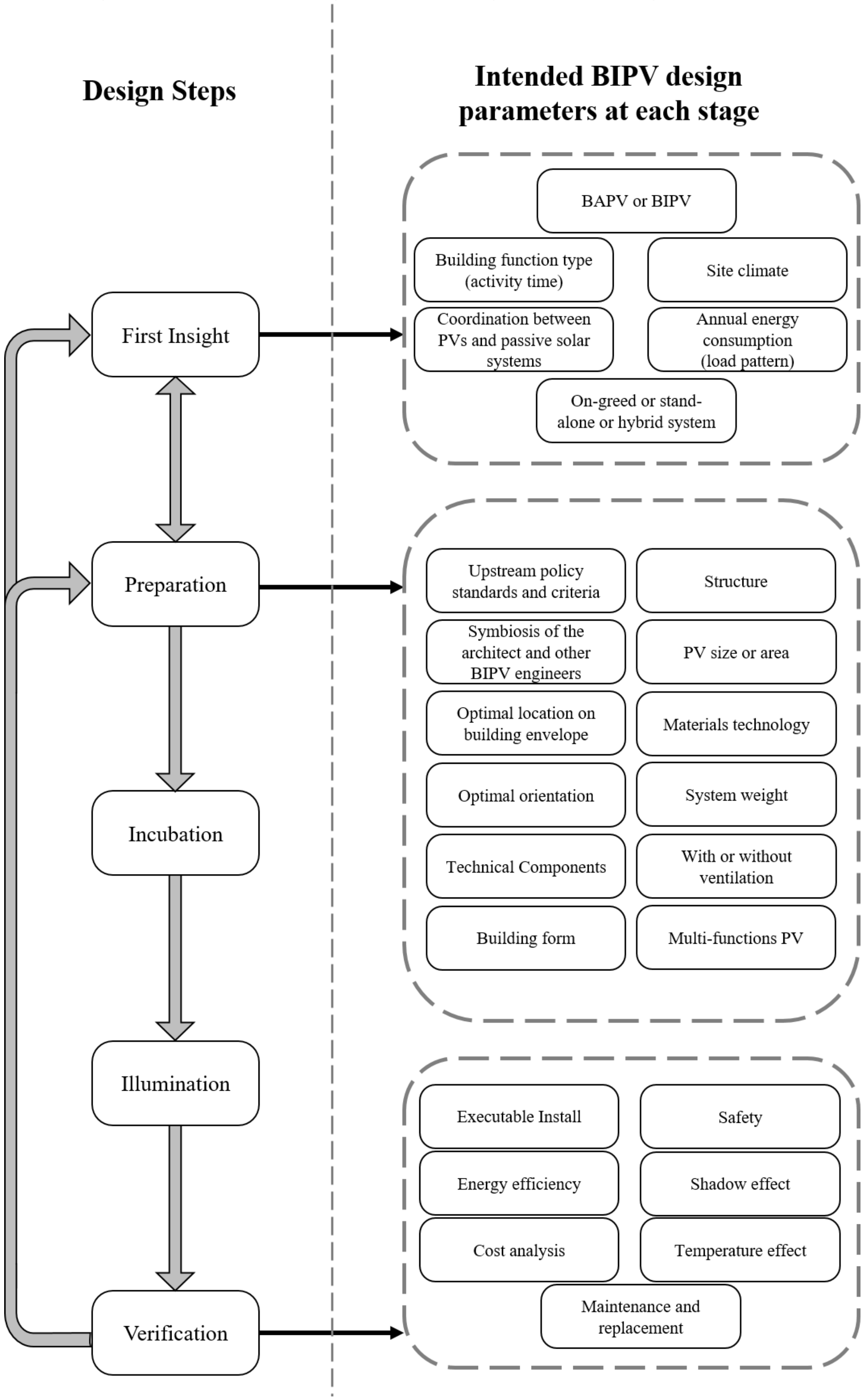
Aesthetic and cost: Costs usually affect the chosen form geometry. Standardized PV elements should be high, and the number of customized components with divergent geometry, such as triangles and other polygon surfaces, must be minimized [5].

Cost and PV location type: For instance, the roof type installed when a building is built can affect installation costs [22].

5. Acknowledgments

The use of clean and renewable energies such as the sun in providing all or part of the building's energy needs (such as heating, cooling, electricity, etc.) can reduce environmental pollution, less use of fossil fuels, the ozone layer less destruction, etc. The photovoltaic cell is a technology that generates electricity by using sunlight, and they can be used in two types in the building, BAPV, and BIPV. For the correct design of anything, it is necessary to know the factors affecting its performance and the interaction of those components. Due to the BIPV type complex design (photovoltaic cell as a part of the building skin), their step-by-step design is presented in this article. Kneller’s 5 step design model was used for this classification as a model accepted by architects like Lawson. These steps include First Insight, preparation, incubation, illumination, and verification. After knowing and collecting parameters affecting the design, construction process, installation, exploitation, and maintenance of BIPVs, all of them were categorized in Kneller’s design steps, and the interaction of some of these parameters with each other was discussed so architects can benefit from this guideline to design utilizing considering essential parameters. In Figure 5, the categories of parameters mentioned in each stage are presented. It is suggested that these parameters’ interaction with each other should be investigated and analyzed more accurately in future articles.

Figure 5: The BIPV design parameters graph according to Kneller's model



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