# Fuzzy Model for Integration of Solar Systems into Nearly Zero-Energy Buildings

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*Abstract*—**The general aspiration for a larger living space over time along with the population growth prediction has significant implications on future energy needs, underlining the urgency for improving energy performance of buildings. In the European Union (EU), building sector accounts for approximately 40% of global energy consumption and for 36% of $CO_2$ emissions. Taking into account that around 75% of the total stock in the EU is energy inefficient, this part of building sector represents a great potential for energy saving and reduction of $CO_2$ emissions. Especially, this refers to the buildings built in the period from 1950 to 1970, due to the utilization of low-cost construction technologies. In order to achieve nearly-zero energy level, various energy efficiency measures and building-integrated renewable technologies need to be implemented.Solar thermal systems and photovoltaic (PV) systems may play a crucial role since they can provide electricity, heating, and cooling of the buildings as well as hot water supply. Towards this end, the main objective of this paper is to propose a model for optimizing PV integration through retrofitting of multi-family housing based on fuzzy sets type-2. Building retrofitting is being considered as one of the main strategies to contribute to the reduction of building energy consumption and greenhouse gas emissions. The proposed model employs fuzzy VIKOR method based on type-2 fuzzy sets to create an effective decision-making platform for selection of the optimal solution. Fuzzy set theory provides the possibility of addressing complex problems when it is not possible to gather a complete data set or/and when data accuracy is uncertain. The variables involved can have both quantitative and qualitative form contributing also to the flexibility of the model. The model developed in this study can help both the investors and the contractors in decision-making process regarding the integration of PV system through retrofitting of the multi-family residential buildings.**

*Index Terms*—**Building integrated photovoltaic system (BIPV), Nearly Zero-Energy Building (nZEB), fuzzy VIKOR method, fuzzy sets type-2.**

## I. Introduction

According to the Energy Performance of Buildings Directive (EPBD), a nearly zero energy building (nZEB) is a building with very high energy performance where the "nearly zero" or very low amount of energy required should be largely covered by renewable sources produced on-site or nearby [1], [2]. The European Union (EU) Renewable Energy Directive 20/20/20 targets emphasizes not only a 20% increase in energy efficiency and 20% reduction of $CO_2$, but also increase of participation of renewable energy sources in energy production to 20% [3]. According to EPBD, from 2020, all new buildings in EU countries need to be nZEB while the deadline set for public buildings is December 31, 2018 [2]. The International Energy Agency (IEA) defines a nZEB as a building with large photovoltaic (PV) cells and a photo-voltage system [4] highlighting the role of PV systems.

Building integrated photovoltaic (BIPV) systems have an important role in the electricity supply of buildings since they have been proved to be feasible renewable energy generation technology. In addition to BIPV, building integrated photovoltaic/thermal systems (BIPV/T) have the additional important potential of supplying both electrical and thermal loads. A comprehensive review of the research on the BIPV and BIPV/T systems in terms of energy generation amount, nominal power, efficiency, type and performance assessment approaches is provided in [5]. A detailed review and evaluation of solar thermal facades in terms of the standard collector types and their components, as well as the evaluation of novel solar thermal systems available on the market using standard methods (based on experimentally determined parameters ISO 9806) is provided in [6]. Comparison of the BIPV and BIPV/T technology regarding the function, cost and aesthetics is presented in [7] while recent advancement in BIPV product technologies for rooftops, facades and windows along with their properties is described in [8].

Building sector has an important role in the global environmental scenario as it accounts for 40% of total energy consumption, 55% of electricity consumption [9], more than 40% of total materials consumption worldwide and over one-third of greenhouse gases emissions [10]. After the building sector, transportation is the second highest sector consuming almost 32% of total energy, while industrial and agricultural sectors consume 26% and 2% of energy, respectively [11]. The building sector continues to grow across the world due to population growth, economic and infrastructure development. Energy retrofitting of existing buildings is one of the greatest challenges in urban sustainability today since the existing buildings represent the vast majority of the European building stock, approximately 75%, predominantly characterized by very poor energy performances and therefore requiring energy improvements [12]. By applying state-of-the-art technologies, a reported 30% to 80% of energy consumption in buildings can be reduced [13]. Therefore, rather than the construction of new buildings, retrofitting and renovation of the existing buildings is Europe's largest resource for energy and greenhouse gases emissions savings.

Similarly, in the United States (US) as well, buildings consume 40% of primary energy and more than 70% of electricity [14]. The US Department of Energy in collaboration with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is taking concrete actions towards making the nZEBs the market-viable standard by 2030. They define nZEBs as buildings that produce as much energy as they use [14]. In

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order to fulfill this target, the starting reference are the US high performing buildings. The Energy Independence and Security Act of 2007 defines a high performance building as a building that integrates and optimizes on a life-cycle basis all major high performance attributes: energy conservation, environment, safety, cost-benefit, productivity, sustainability, functionality, durability, accessibility and operational considerations [15]. The high performance building can therefore be considered as a prototype of the nZEB. Furthermore, ASHRAE has developed Standard 189.1P for high-performance green buildings and a certification program to facilitate their design. In addition, High Performance Buildings Database has also been developed by the US Department of Energy in collaboration with the National Renewable Energy Laboratory as a shared resource for the building industry [16], [17].

However, most new renewable energy sources are installed in the developing countries. In China, which is the single largest developer of renewable power and heat over the past eight years, the installation of renewable energy sources is growing rapidly [4]. By 2040, 60% of total energy consumption is planned to be provided through renewable sources. An average solar PV project in China is already less expensive than both the new and existing gas-fired power plants, and it is projected to be less expensive than the new coal-fired plants and onshore wind plants by 2030 [4].

Although the continuous growth and improvement of PV technology have decreased its price allowing some countries in the EU to reach a parity with the price of electricity produced by conventional power plants [4], [5], several other factors continue to limit their wide application. Among the most important factors are the following: i) lack of knowledge among building professionals regarding different technologies, ii) an overall reluctance to use "new" technologies, iii) the constraints that arise from functional and aesthetic factors related to the integration of solar systems, iv) the lack of efficient tools to support the design process [3].

## II. Description of the Methodology

Integration of active solar systems into building envelope has several advantages: a) it eliminates the need for use of land, b) BIPV and BIPV/T can replace elements of the building envelope (roof covering or façade cladding), c) it enables the consumption of energy at the production site, d) BIPV and BIPV/T are ecologically sound, e) the building appearance can be improved if the integration is architecturally adequately applied on the building envelope, etc. Solar panels can be applied both on new buildings and in retrofitting or reconstruction of the existing buildings, although the application on new buildings when the implementation of a solar system is planned from initial phase of the project planning has more impact on energy production and economic savings as well as on functional and aesthetic improvement of the building.

Since solar thermal collectors and photovoltaic panels are multifunctional elements, their integration into buildings is a complex process that takes into account a number of different, often conflicting criteria, and usually requires a holistic multidisciplinary approach. In order to obtain high-quality solar system integration solutions, it is necessary to consider all relevant aspects (functional and aesthetic, energy, economic, and ecological aspects) across all integration stages: starting from the initial idea until the installation, maintenance and monitoring of the system [18]. Due to the complexity of the problem, the solar system integration solution is usually a compromise between the functional and aesthetic, energy, and economic aspects [19], [20]. Therefore, a multi-criteria decision- making method – VIKOR based on fuzzy sets type-2 is employed in order to select the optimal variant solution in regard to the given set of criteria.

Since human thinking and knowledge can be expressed in a more natural way through fuzzy sets, the fuzzy models are therefore simplified [21]. Fuzzy set theory reflects the human reasoning in interpreting approximate information and uncertainty during the decision making process. It was specially designed for mathematical representation of uncertainty and imprecision [21]. In the following paragraphs, some basic definitions of fuzzy sets type-2 are given.

### A. Fuzzy Set Theory

Fuzzy set theory was introduced by L. A. Zadeh [22] in order to address the vagueness and imprecision of human thought and language. A fuzzy set, also called type-1 fuzzy set (T1FS), represents a class of objects with continuum of membership grades [22]. It is characterized by a membership (characteristic) function assigning each object with a membership grade in the range between zero and one. L. A. Zadeh have also introduced fuzzy set type-2 (T2FS) as an extension of T1FS [23]. The T2FS can convey more degrees of uncertainty, thus providing more robust results [21],[24]-[27]. General T2FSs are not commonly used in real-life applications due to complexity of computational operations [21]. Instead, a special type of general T2FS, interval type-2 fuzzy set (IT2FS) is introduced, allowing considerable simplification of computation, while conveying higher degree of uncertainty than T1FS [24], thus providing more accurate and robust results [26], [27]. Therefore, IT2FSs are widely used in numerous applications [28]. A systematic review of multi-criteria decision-making methods based on IT2FS is presented in [28], and specifically for the industrial applications of IT2FS and systems in [26]. Additionally, Castillo and Melin [29], [30] reviewed the design and optimization of IT2FS controllers and IT2FS optimization based on the bio-inspired methods.

The type-2 fuzzy sets are defined as follows [21], [31]-[33]:

$$\tilde{\tilde{A}} = \left\{ \begin{matrix} \left((x,u),\mu_{\tilde{\tilde{A}}}(x,u)\right), \forall x \in X, \\ \forall u \in J_x \in [0,1], 0 \le \mu_{\tilde{\tilde{A}}}(x,u) \le 1 \end{matrix} \right\} \tag{1}$$

where $J_x$ denotes an interval in [0, 1]. Interval type-2 fuzzy set with the trapezoidal form of membership function is graphically represented in Fig. 1. The upper and the lower membership functions of a trapezoidal fuzzy set are type-1 membership functions, Fig. 1, and are defined as follows:

$$\tilde{\tilde{A}}_1 = (\tilde{A}_1^U, \tilde{A}_1^L) = \left( \begin{matrix} a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(A_1^U), H_2(A_1^U), \\ (a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(A_1^L), H_2(A_1^L)) \end{matrix} \right) \tag{2}$$

where $\tilde{A}_i^U$ and $\tilde{A}_i^L$ are type-1 fuzzy sets, $a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U$ ; $a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L$ are the reference points of the trapezoidal fuzzy set $\tilde{\tilde{A}}_i$; $H_j(\tilde{A}_i^U)$ denotes the membership value of the element $a_{i(j+1)}^U$ in the upper trapezoidal membership function $\tilde{A}_i^U; 1 \le j \le 2$ ; $H_j(\tilde{A}_i^L)$ denotes membership value of the element $a_{i(j+1)}^L$ in the lower trapezoidal membership function $\tilde{A}_i^L; 1 \le j \le 2$, $H_j(\tilde{A}_i^L), H_1(\tilde{A}_i^U) \in [0,1]$, $H_2(\tilde{A}_i^U) \in [0,1]$, $H_1(\tilde{A}_i^L) \in [0,1]$, $H_2(\tilde{A}_i^L) \in [0,1]$ and $1 \le i \le n$.

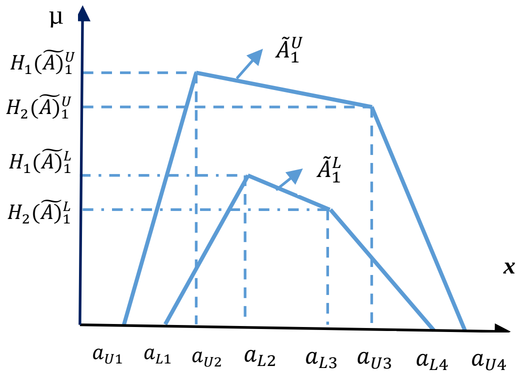


Fig. 1. Graphical representation of trapezoidal INT2FS.

### B. Fuzzy VICOR Method Based on IT2FS

S. Opricović [34]-[36], introduced VIKOR method, a multi-criteria decision making (MCDM) method suitable to solve decision-making problems involving non-commensurable and conflicting criteria. The method ranks alternatives and selects a "compromise solution" based on the Lp metric - a measure of "closeness" to the "ideal solution", and provides maximum "overall utility" of the majority of criteria and minimum "regret" of each individual criterion [35]. In this context, the"compromise solution" means a feasible solution which is closest to the ideal solution while "compromise" denotes an agreement established by mutual concessions [36]. As many other MCDM techniques, the VIKOR technique is also fuzzified by incorporating interval type-2 fuzzy sets (IT2FSs) [37]. A review of the application of VIKOR and its fuzzy extension has been presented in [38]. This paper incorporates the extended VIKOR method with IT2FSs (trapezoidal fuzzy sets) to select the BIPV optimal variant. The model assumes $m$ criteria $\{C_1, C_2,..., C_m\}$, $n$ alternatives ($n$ different variants of BIPVs) designated as $\{A_1, A_2, ..., A_n\}$, and $l$ experts $\{E_1, E_2,..., E_l\}$. The value of the criterion function $i$ for the alternative $A_j$ is denoted with $f_{ij}$. The application IT2FS VIKOR method is described in the following section.

## III. A Fuzzy Model Based on IT2FS VIKOR Method

This paper proposes a model based on IT2FS VIKOR method as a decision-making platform for the BIPVs. Graphical representation of the proposed model is given in Fig. 2. It includes the following six phases: the 1st Phase: Concept development, formulation of objectives and criteria identification; the 2nd Phase: Position selection of PV panels on the building envelope, the 3rd Phase: Design of BIPV Variants; the 4th Phase: Optimization of BIPV Variants; the 5th Phase: Ranking of the BIPV Variants and Selection of the optimal one by applying IT2FS VIKOR method; the 6th Phase: Construction and Installation of the BIPV Optimal Variant; and the 7th Phase: Operation, monitoring and maintenance of the installed BIPV Optimal Variant.

In the first phase, relevant set of criteria and design requirements are identified in order to generate possible solutions (i.e., set of alternatives). Thereafter, in the second and the third phase, the solar panels position selection and generation of the design variants with regard to the requirements and adopted set of criteria are performed. In the third phase, Fig. 3, the optimization process for variants design in relation to the adopted set of criteria is carried out. The importance of criteria weights is then determined and variants performance evaluation in regard to the defined set of criteria is accomplished under the interval type-2 fuzzy sets environment. Thereupon, the IT2FS VIKOR method is applied to calculate the variants ranking and select the optimal solution as follows:

*Step 1*: The average IT2FS performance values of alternatives are calculated using (9), i.e.,

$$C_c = \left(\tilde{\tilde{c}}_{ij}^k\right)_{mxn} = \begin{bmatrix} \tilde{\tilde{c}}_{11}^k & \tilde{\tilde{c}}_{12}^k & \cdots & \tilde{\tilde{c}}_{1m}^k \\ \tilde{\tilde{c}}_{21}^k & \tilde{\tilde{c}}_{22}^k & \cdots & \tilde{\tilde{c}}_{2m}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{c}}_{n1}^k & \tilde{\tilde{c}}_{n2}^k & \vdots & \tilde{\tilde{c}}_{nm}^k \end{bmatrix} \quad (9)$$

where $\tilde{\tilde{c}}_{ij}^k = \left(\frac{\tilde{\tilde{c}}_{ij}^k + \tilde{\tilde{c}}_{ij}^k + \cdots + \tilde{\tilde{c}}_{ij}^k}{l}\right), \tilde{\tilde{c}}_{ij}^k$ is an IT2FS, $1 \le i \le m, 1 \le j \le n, 1 \le k \le l$, and $l$ denotes the number of experts. Table 1 presents linguistic variables and corresponding IT2FS used in this paper

*Step 2*: The weighted type-2 fuzzy decision matrix is calculated as follows:

$$\tilde{\tilde{V}} = [\tilde{\tilde{v}}_{ij}]_{mxn}, \quad (10)$$

where

$$\tilde{\tilde{v}}_{ij} = \tilde{\tilde{w}}_{ij} \otimes \tilde{\tilde{c}}_{ij} = \begin{pmatrix} (f_{i1}^U, f_{i2}^U, f_{i3}^U, f_{i4}^U,); H_1(\tilde{F}_i^U), H_2(\tilde{F}_i^U), \\ (f_{i1}^L, f_{i2}^L, f_{i3}^L, f_{i4}^L,); H_1(\tilde{F}_i^L), H_2(\tilde{F}_i^L) \end{pmatrix} \quad (11)$$

TABLE I: Linguistic Terms for Variant Evaluation [31]

| Linguistic terms | Interval Type-2 Fuzzy Sets (IT2FSs) |
|---|---|
| Very Low | ((0;0;0;0.1;1;1),(0;0;0;0.05;0.9;0.9)) |
| Low | ((0;0.1;0.1;0.3.1;1;1),(0.05;0.1;0.1;0.2;0.9;0.9)) |
| Medium low | ((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9)) |
| Medium | ((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9)) |
| Medium high | ((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9)) |
| High | ((0.7;0.9;0.9;1;1;1),(0.8;0.9;0.9;0.95;0.9;0.9)) |
| Very high | ((0.9;1;1;1;1;1), ( 0.95;1;1;1;0.9;0.9)) |

*Step 3:* Positive ideal solution ($P^{e}*$,$P^{v}*$) and negative ideal solution ($N^{e-}$) for upper and lower reference points of the interval type-2 fuzzy numbers are calculated by using (12)-(14) as follows [39]:

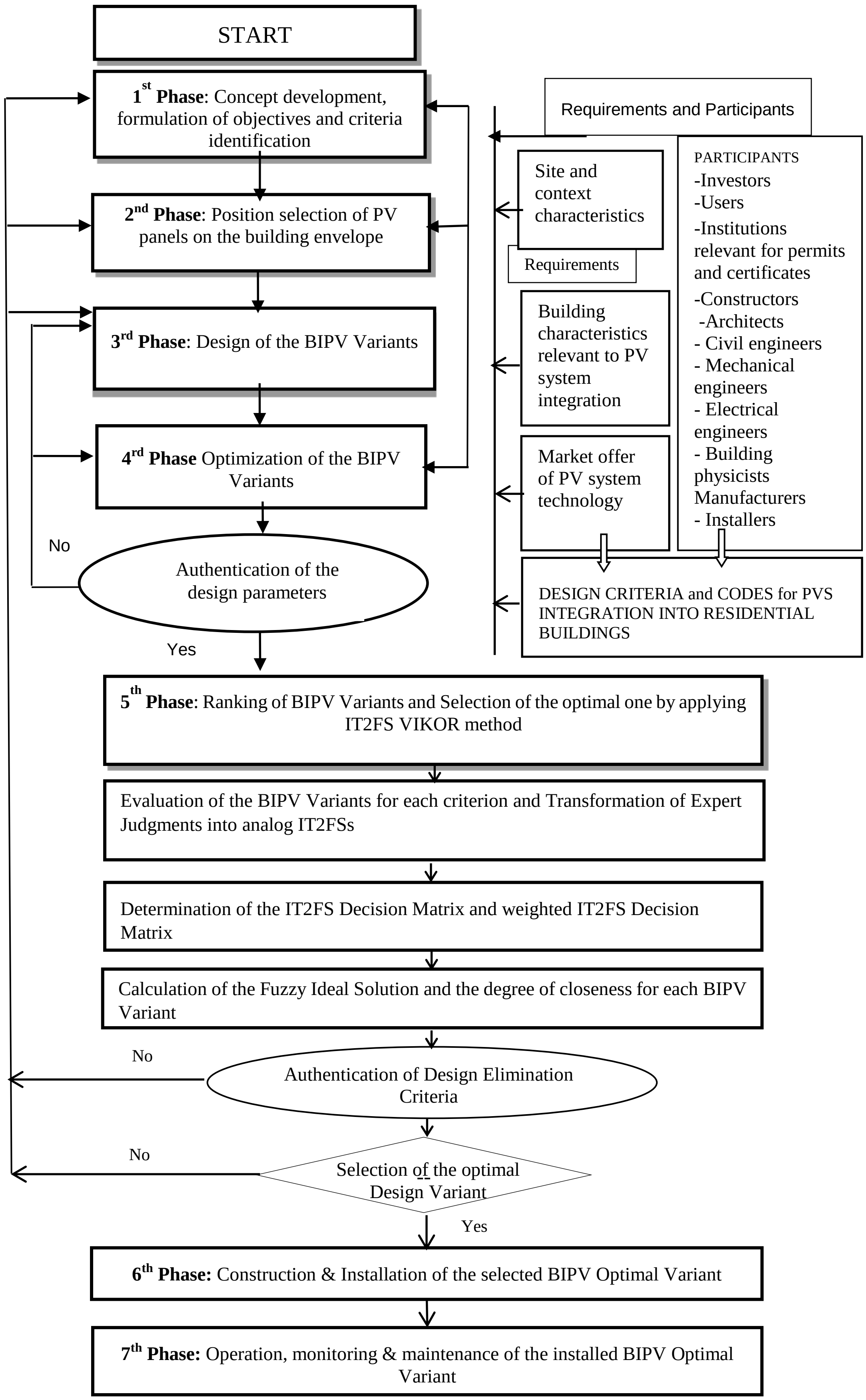


Fig. 2. Graphical representation of the fuzzy model for BIPV system in retrofitting of residential buildings.

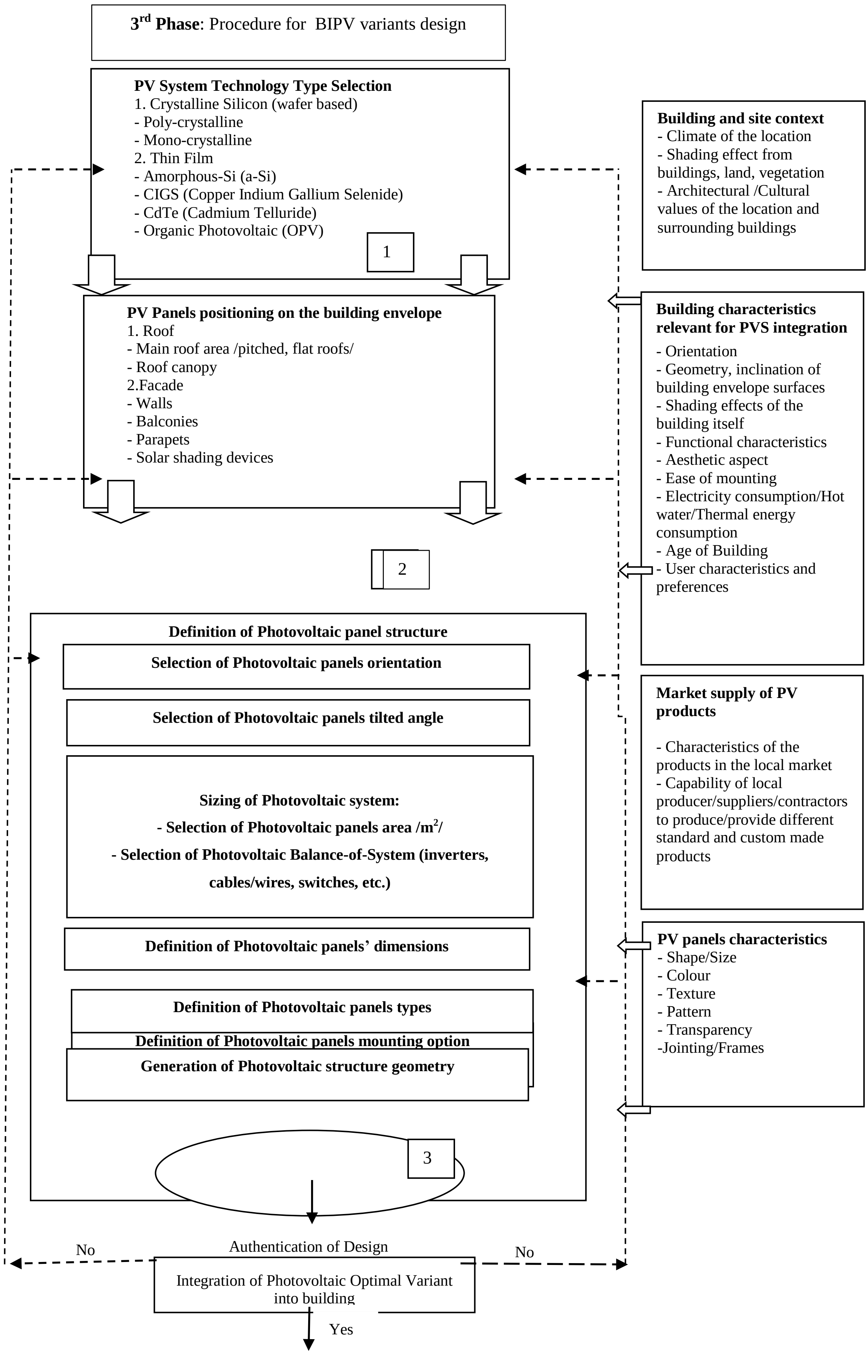


Fig. 3. Design of BIPV Variants

$$P^{c*} = \{\tilde{\tilde{c}}_{ij}^{*}, \tilde{\tilde{c}}_{ij}^{*}, \dots, \tilde{\tilde{c}}_{ij}^{*}\} = \{\max_i \tilde{\tilde{c}}_{ij} \mid i \in Benefit\} \quad (12)$$

$$P^{c*} = \begin{pmatrix} \left(c_{i1}^{U*}, c_{i2}^{U*}, c_{i3}^{U*}, c_{i4}^{U*}; maxH_1(\tilde{C}_i^U), maxH_2(\tilde{C}_i^U)\right) \\ (c_{i1}^{L*}, c_{i2}^{L*}, c_{i3}^{L*}, c_{i4}^{L*}); maxH_1(\tilde{C}_i^L), maxH_2(\tilde{C}_i^L) \end{pmatrix}$$

$$P^{v*} = \{\tilde{\tilde{v}}_{ij}^{*}, \tilde{\tilde{v}}_{ij}^{*}, \dots, \tilde{\tilde{v}}_{ij}^{*}\} = \{\max_i \tilde{\tilde{v}}_{ij} \mid i \in Benefit\} \quad (13)$$

$$P^{v*} = \begin{pmatrix} \left(f_{i1}^{U*}, f_{i2}^{U*}, f_{i3}^{U*}, f_{i4}^{U*}; maxH_1(\tilde{F}_i^U), maxH_2(\tilde{F}_i^U)\right) \\ (f_{i1}^{L*}, f_{i2}^{L*}, f_{i3}^{L*}, f_{i4}^{L*}); maxH_1(\tilde{F}_i^L), maxH_2(\tilde{F}_i^L) \end{pmatrix}$$

and

$$N^{c-} = \{\tilde{\tilde{c}}_{ij}^{-}, \tilde{\tilde{c}}_{ij}^{-}, \dots, \tilde{\tilde{c}}_{ij}^{-}\} = \{\min_j \tilde{\tilde{c}}_{ij} \mid i \in Benefit\}, \quad (14)$$

$$N^{c-} = \begin{pmatrix} \left(c_{i1}^{U-}, c_{i2}^{U-}, c_{i3}^{U-}, c_{i4}^{U-}; minH_1(\tilde{C}_i^U), minH_2(\tilde{C}_i^U)\right) \\ (c_{i1}^{L-}, c_{i2}^{L-}, c_{i3}^{L-}, c_{i4}^{L-}); minH_1(\tilde{C}_i^L), minH_2(\tilde{C}_i^L) \end{pmatrix}$$

Thereupon, the average ($S_j$) and the worst ($R_j$) group scores for each integrated BIPV variant are calculated as follows:

$$S_{j=} \sum_{i=1}^{m} \frac{1}{2}\left(S_{ij}^U + S_{ij}^L\right), \forall j = 1,2,\dots,n. \quad (15)$$

$$R_{j=} \max_i \left(\frac{1}{2}\left(S_{ij}^U + S_{ij}^L\right)\right), \forall j = 1,2,\dots,n. \quad (16)$$

where $S_{ij}^U$ and $S_{ij}^L$ is calculated as follows:

$$S_{ij}^U = \sum_{i=1}^{m} \frac{\sqrt{\frac{1}{4}\sum_{k=1}^{4}\left[\left(f_{i1}^{U*}-f_{i4}^{U}\right)^2+\left(f_{i2}^{U*}-f_{i3}^{U}\right)^2+\left(f_{i3}^{U*}-f_{i2}^{U}\right)^2+\left(f_{i4}^{U*}-f_{i1}^{U}\right)^2\right]}}{\sqrt{\frac{1}{4}\sum_{k=1}^{4}\left[\left(c_{i1}^{U*}-c_{i4}^{U}\right)^2+\left(c_{i2}^{U*}-c_{i3}^{U}\right)^2+\left(c_{i3}^{U*}-c_{i2}^{U}\right)^2+\left(c_{i4}^{U*}-c_{i1}^{U}\right)^2\right]}}, \quad (17)$$

$$S_{ij}^{L=} = \sum_{i=1}^{m} \frac{\sqrt{\frac{1}{4}\sum_{k=1}^{4}\left[\left(f_{i1}^{L*}-f_{i4}^{L}\right)^2+\left(f_{i2}^{L*}-f_{i3}^{L}\right)^2+\left(f_{i3}^{L*}-f_{i2}^{L}\right)^2+\left(f_{i4}^{L*}-f_{i1}^{L}\right)^2\right]}}{\sqrt{\frac{1}{4}\sum_{k=1}^{4}\left[\left(c_{i1}^{L*}-c_{i4}^{L}\right)^2+\left(c_{i2}^{L*}-c_{i3}^{L}\right)^2+\left(c_{i3}^{L*}-c_{i2}^{L}\right)^2+\left(c_{i4}^{L*}-c_{i1}^{L}\right)^2\right]}}, \quad (18)$$

for $\forall j = 1,2,\dots,n$.

*Step 4*: The $Q_j$ is calculated by using $S_j$ and $R_j$ as follows:

$$Q_j = v\frac{(S_j - S^*)}{(S^- - S^*)} + (1-v)\frac{(R_j - R^*)}{(R^- R^*)} \quad (19)$$

where $S^* = min_j S_j$, $S^- = max_j S_j$, $R^* = min_j R_j$, $R^- = max_j R_j$, and $v \in [0,1]$ represents the decision-making strategy weight of the "maximum group utility". Then the smallest $Q_j$ is determined as a compromise solution if the following two conditions are acceptable.

*Condition 1*: The acceptable advantage measure is defined as follows:

$$Q_{H_2} - Q_{H_1} \geq DQ, where\ DQ = 1/(n-1) \quad (20)$$

*Condition 2*: Acceptable stability in decision-making: $Q_{H1}$ alternative must also be the best ranked regarding the S and/or R measures. Both the acceptable advantage measure and the stability measure are determined in order to test the suitability of derived solution.

## IV. Conclusion

Recent technology advances as well as decreasing prices place solar systems as highly reliable sustainable technology with great potential for building integration. This paper proposes a fuzzy model for optimizing building integrated photovoltaic system in retrofitting of multi-family residential buildings, by incorporating VIKOR method based on interval type-2 fuzzy sets for multi-criteria decision-making process. In order to design all Pareto-optimal solutions the following relevant factors are considered: a) site characteristics (solar irradiance, shape and size of the land, topographic parameters, etc.); b) building characteristics (geometry, inclination of building envelope surfaces, functional characteristics, etc., Fig. 3.); c) solar systems characteristics (shape and size, color, texture, transparency, etc., Fig. 3.); d) user requirements and criteria relevant for the integration of the solar systems into residential buildings. In the proposed model, all necessary calculations and simulations for positioning of the solar panels on the building envelope as well as generation of BIPV variant solutions along with their individual optimization processes in regard to the set of established criteria are defined, and graphically presented in Fig. 2. Selection of the optimal BIPV variant in regard to the defined set of criteria: functional, energy, economic, aesthetic and ecological, is performed by applying VIKOR method in fuzzy type-2 environment in order to better incorporate uncertainties regarding the climatic conditions, user preferences, building and site characteristics.

Future advancement of the proposed model could be achieved by forming an appropriate computer software for calculation and simulation of all relevant energy, functional and other important parameters, and connecting them with appropriate "smart" tools in situ, installed for monitoring and gathering real-time data. In that way, all needed information regarding the energy load, maintenance, operation, users and other important parameters concerning the state of the art of the BIPV system can be obtained in real time, thus forming an useful "smart" system for planning, design, construction, operation and maintenance of the BIPV system.

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