Abstract — Building Integrated Photovoltaics provides a unique way of harnessing solar energy and transforming buildings from energy consumers to energy producers. Global interest in BIPV has expanded within education and commercial sectors with an increase in research publications and market share per annum. According to the market analysts, an estimated yearly growth rate of 18.7% and a total of 5.4 GW will be produced and installed across the globe between 2013 and 2019. Although the BIPV technology has been in the public domain for the last three decades, its adoption has been hindered in specific regions by several issues within professional and public domains. These barriers are fueled by lack of knowledge, cost issues, biased perception and inherent technological limitations. Literature references assert that proper education is a significant way of addressing adoption barriers. This study aims to develop a conceptual educative-communication model for presenting BIPV proposals. The target is towards developing holistic research and market proposals which justify investigation and investment of resources. This approach was developed by harmonizing the widely agreed pillars of sustainability with a hierarchical description of BIPV and its unique advantages. Further research has been identified, for evaluation and testing of this approach in various contexts to validate its practicality in real-life scenarios. The significant contribution lies in the development of the approach to advance the discussion and adoption of BIPV.

Index Terms— Building Integrated Photovoltaic (BIPV), Barriers, Sustainability, Multi-functionality, Proposal

I. INTRODUCTION

BIPV refers to the use of photovoltaic devices to replace conventional building materials in components of the building envelope, such as the roof, skylights or facades [1]. The building envelope is conventionally made up of roofing, walls, glazing, cladding and fenestrations; and other structures like shading devices, parapets, and balconies. Each of these components provides opportunities for integrating PV in the building and by extension, for façade customization [2-6]. Specifically, the main BIPV applications extracted from literature [3,4,7,8] include roof, skylight, atrium, curtain walls, glazing, external/shading devices and other advanced systems which include double skin facades.

BIPV technology represents the opportunity for a triple advantage in architectural design. It harnesses solar energy, addresses some limitations of utility-scale PV and converts the building from an energy consumer to energy producer as a multi-functional component. In harnessing solar energy, it utilizes renewable energy from the sun which provides more energy in one hour than the all the people on earth require for a whole year [9,10]. It also provides decentralized on-site energy right next to the point of use, thus reducing transmission and conversion losses, as well as ancillary costs limitations with utility-scale PV [11-17]. Also, it serves as a multifunctional energy-producing building component used for roofing, cladding, glazing or shading [1-3].

The global BIPV market witnessed a 35% growth between 2014 and 2015 from an estimated 1.5 GW to 2.3 GW [18]. However, the contribution of BIPV to the energy capacity added by Solar PV in 2016 was 1% -being about 3.4GW of the total from Solar PV —about 303GW [18-20]. Thus, though BIPV technology has multiple benefits and has been in public domain for the last three decades, its adoption rate in the built environment is limited. Six major BIPV adoption barrier categories were identified in the literature relating to education, product, economy, database, industry, and management [21-32]. Identified from the literature include several strategies which address these barriers; with education being the most crucial [33]. This paper aims to develop an educative-communication model for research and market proposals which justify investigation and investment of resources in BIPV.

II. OVERVIEW OF BIPV

This section covers BIPV classification and application, its materiality and multi-functionality and specifics on adoption barriers. Several modes of classifying BIPV exist in literature as a result of the interdisciplinary nature of the technology. Some of these classifications are standardized and well-known whereas some others are emerging; there are also industry-
specific and technical classifications. These various forms of classifications relate to:

- **Type of Photovoltaic technology**, e.g., monocrystalline, polycrystalline, amorphous, organic, dye-sensitized [34,35].
- **Type of BIPV product**, e.g., tiles, modules, glazing or foil [1,36]
- **Location in the building**, e.g., roof or façade [2,4]
- **Customization strategy**, e.g., Systematic Parametric Variation (SPV), Modification of Conventional Features (MCF), Enhanced Design Modularization (EDM) or Compositional Modification and Hybridization (CMH) [33]

These groupings, however, overlap as they are only industry or discussion-specific. In actual terms, they simply guide classifications for functional purposes. Fig. 1 below shows the various opportunities for BIPV in the building envelope; from the roof to the façade.

![Figure 1: BIPV in the building envelope Source: Ref. [37]](image)

Table 1 shows various representative examples of BIPV façade integration. The importance of these examples is to show the design adaptability and opportunities with BIPV. It also presents a guide for enhancing an understanding of its materiality and multi-functionality. The latter part of the paper explained various concepts for the development of the educative-communication model.

### A. BIPV Barriers

From the findings of several studies stated earlier, six broad categories of barriers have been identified. Each of these barriers embodies a unique set of challenges to BIPV adoption; a further explanation of each barrier category is presented as listed below.

1. **Educational barriers**
   - Lack of sufficient technical knowledge by architect [22]
   - Few certified BIPV contractors available [24]
   - Poor public understanding and cost perceptions of BIPV [25]

2. **Product barriers**
   - Lack of products suitable for quality building integration [22].
   - Need to improve overall aesthetics and allow for customization of appearance [22].
3) **Economic barriers**
- High Price of BIPV systems, Expected Pay Back Time (EPBT) and Maintenance costs for modules [23].
- Lack of governmental incentives [22].
- Low government support and developer’s reluctance [24].

4) **Database barriers**
- Lack of information on best practice examples/demonstration examples [23].
- Need to increase the number of demonstration projects [25].
- Practical demonstrations to educate the public regarding energy use and environmental issues [32].

5) **Industry barriers**
- Need for professional collaborations between all stakeholders [26].
- Lack of mutual understanding and knowledge concerning everyday practice [30].
- Additionally, the building industry is described as being very inert and as lacking sufficient innovative drive [30].

6) **Management barriers**
- The BIPV ecosystem is not yet mature; business models have to be developed [21].
- Lack of adequate Business models [21].
- Capacities of the system are too high for the affordability of local target adopters [26].
- Insufficient and inappropriate management [26].

To further explain the degree of interaction between facilitating and restraining factors, a condensed list of BIPV barriers from literature over the last five years was weighted alongside suggested strategies and presented as a force field analysis [33]. Figure 2 below of the analysis shows that education, product, and economic barriers were most crucial and educational strategies most significant. Building on this, it is expected that an educative-communication model will assist to advance BIPV adoption. As such, further discussions on this concept and development of the model are the focus of the rest of this paper.

**Source:** Ref. [33]

### B. BIPV Communication

Several strategic models have been developed to communicate the importance of BIPV adoption. Examples of this include the IEA Task 41-SubTask C three-stage approach from client to design team to design-communication tools [38], the EU-based use of “an ambitious demonstration project portfolio” [39] and an AIQ-model to initiate and to focus discussions on preferences for architectural integration of energy-producing solar shading [40]. This research adds to existing literature a communication model for initial proposal presentations on BIPV adoption to justify market investments and research investigations.

### III. MODEL DEVELOPMENT

#### A. Pillars of Sustainability

The mainstream theory for sustainability has become the idea of three pillars (3Ps) namely: economic, social and environmental sustainability [41]. The pillars of sustainability follow the concept that every sustainable approach or idea must provide benefits regarding the cost, social impact, and ecological impact or carbon footprint. The three pillars are interwoven and have been explained using different terms to highlight the importance of the sustainability and the three major players (people, planet, and profits). Adopted by the General Assembly of the 2002 and 2005 World Summit on Sustainable Development, these three components—economic development, social development and environmental protection—are presented as interdependent and mutually reinforcing pillars [42, 43]. Today, these pillars are expressed and discussed extensively across various governmental, professional and commercial circles; influencing concepts like the triple bottom line in sustainable urbanism and other aspects of the sustainable built environment. They respectively relate to continued support for a defined level of economic production, the ability of a social system to maintain resident well-being, and ability to ensure and maintain a responsible use of renewable resources and curb non-renewable resource depletion.

Concerning environmental sustainability, the framework must promote the overall well-being of people. For the social sustainability, the concept must maintain equity while economic sustainability ensures the framework is innovative and efficient. Based on the definitions of the pillars, it is...
important to state that any framework or model must meet the requirements highlighted in the definitions. For this paper, the study agrees that for BIPV, the framework for research and market proposals must satisfy the crucial requirements for the pillars of sustainability. Also, the integration of the pillars for development of a framework must provide a truly sustainable design or development that will make the world a better place.

B. BIPV Triple Advantage and Hierarchy of Form

A descriptive understanding of BIPV viz-a-viz, a structural breakdown of its constituents, has been suggested [44]. Reference is made to the elemental and compositional dimensions; the former relates to specifics such as the cell technology, cells shape, module design, and arrangement. The latter refers to the building function and type of product. The descriptive model provides a holistic understanding of BIPV is here proposed to encompass the hierarchy of BIPV origins and form.

To state succinctly, the hierarchical composition of BIPV relates to it first as a building component, next as type of PV technology; then as a strategy which harnesses solar energy to generate electricity. Solar energy is itself a renewable source of energy which assists to reduce the use of non-renewables and stem the rate of global environmental pollution. The idea portrays a wider perspective of what BIPV represents and may help to appreciate its relevance to society and facilitate its adoption. Fig. 3 shows a diagrammatic illustration of the BIPV-PV-Solar-Renewable chain.

![Figure 3: BIPV Hierarchy of Form](source: Authors)

C. Unified BIPV-3P Matrix

The final stage of the model development is an integrated matrix which presents a juxtaposition of the BIPV hierarchy of form and the 3Pillars of sustainability. The concept leads to a comparison of the four (4) components of the BIPV-PV-Solar-Renewable chain with the Environmental-Economic-Social Pillars. In this comparison, BIPV technology/proposal/project is discussed at each level of its hierarchy based on associated environmental, social or economic benefits. Added to the model is the design dimension to simulate the intrinsic architectural orientation of BIPV. Fig. 4 below shows the color-coded matrix, and the discussion section summarizes the practicality of the matrix in operation.

Each cell in the matrix corresponds to the required information at each level of the BIPV Hierarchy based on its 3P benefits. The grid format selected assists in a structured and systematic approach to present the facts required to justify the project/proposal objectives and benefits.

IV. DISCUSSION

The developed matrix is divided into a set of rows and columns to communicate the proposal/project idea. The information contained by detailing the 3P section of BIPV hierarchy 1 to 3 (i.e., Renewable, Solar and Photovoltaic aspects) is similar for all projects (Cells 1 to 12). However, discussing it in context can be different and potentially presents better relevance and aids understanding. For example, based on regional policies, Renewable Energy (BIPV Hierarchy 1) has economic benefits (Cell 2). As such, this information will differ for projects in separate geographical locations and consequently impact the contents of the matrix. BIPV Hierarchy 4 (cell 13-16) is the core of the proposal, and the 3P outline should be discussed at two levels; firstly the benefits of BIPV as an energy source and secondly, as a building component.

To aid better understanding the Matrix, the crucial information required for communicating a BIPV project proposal for the sixteen cells has been outlined below. The list of suggested contents is aligned with the 3P columns on the Matrix. However, this is a guide not an exhaustive list to justify the proposal. Similar questions should be developed to facilitate contextual and holistic potentials based on unique characteristics of the proposal.

![Figure 4: BIPV-3P Matrix](source: Authors)
A. Cells 1 to 12 relating to BIPV Hierarchy 1 to 3

Cell 1: Environmental benefits of Renewables
- State cumulative percentage/amount in tons of reduction of carbon emissions in the region
- State accrued benefits in wildlife conservation and human preservation (or related interest to sponsor)

Cell 2: Economic benefits of Renewables
- State fuel and maintenance cost savings compared with non-renewable energy sources
- State marketability of free natural resources

Cell 3: Social benefits of Renewables
- State the potential reduction in the Social Cost of Carbon associated with similar energy output from a fossil fuel power plant
- State accrued benefits of replacing fossil energy sources, and other points such as international recognition and accountability

Cell 4: Design benefits of Renewables
- Highlight adopting buildings as a free-standing support medium for Building Integrated Renewables
- State potential visual impact on energy awareness on the residents in the region

Cell 5: Environmental benefits of Solar Energy
- State cumulative percentage/amount in tons of reduction in carbon emissions in the region
- State reduction in pollution (e.g., noise) during use compared to fossil fuel energy generation

Cell 6: Economic benefits of Solar Energy
- State energy security benefits and independence; and advantages of a constant source of fuel
- State flexibility and adaptability for basic household use and advanced technological applications

Cell 7: Social benefits of Solar Energy
- State potential to advance global energy reduction targets and advocacy/image recognition
- State potential for labor employment and other corporate social responsibilities

Cell 8: Design benefits of Solar Energy
- State passive opportunities such as daylighting, along with sustainability benefits
- State active opportunities such as photovoltaics, along with sustainability benefits

Cell 9: Environmental benefits of Photovoltaics
- State cumulative percentage/amount in tons of reduction of carbon emissions in the region
- State advantages of a constant source of fuel relating to the reduced recurrent need for fuel harvesting

Cell 10: Economic benefits of Photovoltaics
- State comparative long-term cost benefits compared with other energy sources relating to maintenance
- State savings in cost of fuel compared to other energy sources

Cell 11: Social benefits of Photovoltaics
- State investment as a form of social responsibility towards a global sustainable future
- State labor employment, advocacy, and support for the industry

Cell 12: Design benefits of Photovoltaics
- State opportunities as a building integrated or building applied system
- State technological growth as a sign of the global shift towards harmony with the architectural design

B. Cells 13a-16a relating to BIPV Hierarchy 4; focusing on BIPV as an Energy Source

- Cell 13a: Environmental Benefits
  - State how much the proposal reduces CO2 emission
  - State how much land is saved compared to utility-scale PV based on expected power output
  - State the number of trees saved by using BIPV in the project based on similar expected power output from a utility-scale PV plant

- Cell 14a: Economic Benefits
  - State the amount of savings in labor cost
  - State the amount of savings in infrastructure cost compared to utility-scale PV based on expected power output
  - State the cost savings in land purchase compared to a utility-scale project of the same expected power output

- Cell 15a: Social Benefits
  - State the visibility of the project to the public
  - State opportunities for educating the public [45]

- Cell 16a: Design Benefits
  - State the amount of energy produced
  - State the amount of energy saved compared to use of non-renewable sources
  - State the benefits of energy control enjoyed by the intended owners
C. Cell 13b-16b relating to BIPV Hierarchy 4; focusing on BIPV as a Building Component

- **Cell 13b: Environmental Benefits**
  - State the savings in embodied energy
  - State the environmental impact advantage compared with replaced building materials

- **Cell 14b: Economic Benefits**
  - State labor cost savings
  - State aggregated cost savings compared with alternative materials e.g. bricks or blockwork; mortar, painting; and separate costs for glazing and associated costs.
  - At an advanced level, carry out a comparative full life cycle analysis with other material alternatives

- **Cell 15b: Social Benefits**
  - State potential visual impact and energy awareness education on/for the residents in the region
  - State potential to serve as contemporary green building icon

- **Cell 16b: Design Benefits**
  - Discuss the aesthetic potential of the project compared with other surrounding modern buildings
  - State multi-functional uses of the BIPV installation: does it provide daylighting or view or shading along with energy

For each of these, information is to be provided which is specific to the project proposal, with the background facts on the 3P benefits on renewable, solar and PV hierarchies. This matrix is flexible and can be presented as is, or modified based on specifics of the proposal. Although all the cells need not be filled, a general introduction of the BIPV hierarchy following the suggested chain can assist to develop a strong presentation to justify market/financial investments and research investigation.

V. CONCLUSION

This paper has presented the conceptual development of an educative-communication model for BIPV market and research proposals. A holistic understanding of project proposals, facilitated by proper communication of the project goals and benefits can potentially facilitate acceptance. To evaluate the developed model the authors propose two approaches for further studies. Firstly, the use of a survey to investigate an understanding and impact of the model based on respondent’s perception of BIPV. Secondly, the use of the model may be applied to discuss a proposal for a BIPV demonstration project. Conclusively, this paper elaborates the need and strategies for proper communication of innovative ideas to encourage adoption and a global sustainable future.

**REFERENCES**


[42] Assembly UG. World summit outcome. UN Doc No A/60/L. 2005 Sep 20;1