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Overcoming technical barriers and risks in the application of building integrated photovoltaics (BIPV): hardware and software strategies

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ABSTRACT

Building Integrated Photovoltaics (BIPV) is a smart energy production system that incorporates solar PV panels as part of the roof, windows, facades and shading devices. BIPV products development has been ongoing for the past 30 years, but their practical applications have been slow in comparison to conventional rack-mounted solar PV. One of the main reasons is that the technical barriers, which span from design phase through to commissioning and maintenance phases, have not been understood by stakeholders. The aim of this research is to identify the technical barriers and risks associated with the application of BIPV from building design through to operation stages, together with proposing possible solutions. Where a solution could not be proposed, recommendations for future research and development are made. A four-step research approach is employed, which includes examination of previous publications and collection of feedback from the industry professionals. The research highlighted the importance to apply advanced simulation tools and energy performance monitoring platforms in practice, and encourage stakeholder collaborations in the whole supply chain. This paper contributes to the BIPV area by providing structured knowledge from systematic and longitudinal perspective in relation to the technical barriers and risks, to help professionals understand and improve their knowledge. This paper also makes a unique contribution to the research arena by providing a conceptual model of the associated barriers and risks from life-cycle perspective together with proposing five directions for future research.

1. Introduction and research aims

The potential for solar energy to make a significant contribution to global electricity demand has been widely recognised. Numerous models have been developed which illustrate how the global economy can grow whilst CO_2 emissions can be reduced. Solar photovoltaics (SPV) is seen as a major contributor to solar energy supply. The SPV manufacturing industry is one of the world's fastest growing industries with total annual revenue over AUD $50 billion in 2009 [1]. SPV's application in buildings is potentially huge, with claims being made that SPV will ultimately be able to supply all of the energy required by residential and non-residential buildings [2].

The PV electricity production in buildings has increased by a factor of 40 from 52 MW in 1995 to 2000 MW in 2010 [3]. It is widely expected that in the near future the PV industry will, to a large extent, focus on the built environment given that, for instance, in Australia, commercial and residential buildings contributed 23% of all of Australia's greenhouse gas emissions [4].

By employing a Building Integrated Photovoltaics (BIPV) approach, the application of photovoltaic technology in the form of solar panels has allowed buildings to be transformed from energy users into energy producers [5]. BIPV is a smart energy production system that incorporates SPVs as part of the roof, windows, facades and shading devices [6]. A BIPV module is an integral part of a building's functionality. PV modules are defined as being building-integrated, if the PV modules form a building component which provides a function as defined in the European CPD 89/106/EEC [7]. Building functions in the context of BIPV are one or more of the following [7]:

- mechanical rigidity and structural integrity
- primary weather impact protection including rain, snow, wind, hail
- energy economy, such as shading, daylighting, thermal insulation
- fire protection
- noise protection

BIPV products development has been ongoing for the past 30 years, but their practical applications have been slow in comparison to conventional rack-mounted solar PV. For example, in Australia, the PV industry is involved mainly focused on PV systems installation rather than PV systems design, improvement and manufacturing. Currently the most widely promoted PV products in Australia are rooftop solar PV systems, which are used to generate electricity from rack-mounted PV panels on a roof, whereas BIPV products have not yet reached large-scale application. One of the main reasons is that the technical

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barriers, which span from design phase through to commissioning and maintenance phases, have not been understood by stakeholders [14]. There is still a long way to go with many challenges ahead before BIPV become a viable and favourable option for those wanting to adopt sustainable living initiatives [10]. The lack of technical knowledge from relevant professionals or stakeholders is a hurdle for BIPV adoption [13].

The integration of BIPV into buildings requires architectural, structural and aesthetic considerations. Unlike traditional solar panel systems, BIPV does not require a stand-alone structure, resulting in potential cost savings and providing an added incentive in the adoption of BIPV [5]. Other incentives that influence the use of BIPV are; photovoltaic systems provide a reliable solution for electricity supply in buildings at places with or without electrical grid [6]; no additional land area is needed as BIPV replaces traditional building materials and electricity is generated at this point of use, therefore transmission and distribution losses are avoided [6]. Ultimately the application of BIPV leads to lower utility and maintenance costs [9,63].

A BIPV system needs to satisfy the client's needs regarding its durability and reliability, currently none of these can be assured due to the fact that the technical risks are still problematic [12]. Issues such as water penetration, islanding and heat transfer due to poor design integration considerations and difficult maintenance procedures have all contributed to the low uptake rates of BIPV systems. Governments and other stakeholders in the building supply chain need to understand not only the benefits of BIPV systems, but the technical issues, and move towards developing unified building regulations and accredited training programs, to encourage an increase in BIPV application rates. The study of technical barriers and risks can also allow future research to be aimed at specific issues and developing solutions. A review of previous publications has found that none of the papers provided a holistic view from a lifecycle perspective regarding the technical barriers and risks of BIPV, and yet this is the first important issue which needs to be solved if BIPV is to be widely applied.

1.1. Research aims

Given the above mentioned background and literature review, the aim of this research is to identify the technical barriers and risks associated with the application of BIPV from building design through to operation stages, together with proposing possible hardware and software solutions. Where a solution could not be proposed, recommendations for future research and development are made. In this research, the term ‘technical barrier/risk’ is defined as a problem or difficulty which can potentially cause abnormal functioning of a BIPV system.

2. Research approach and process

Given the abovementioned research aims, a four-step research approach (Fig. 1) is employed, which includes examination of previous publications and collection of feedback from the industry professionals. The literature review process follows a similar style as used in previous studies by Xue et al. [15], Volk et al. [16], and Yi and Chan [17].

In Step 1, a comprehensive database search was conducted by using Science Direct, Scopus, and Ebsco Host searching engines, which are popular databases in energy, environment, building and construction fields. The complete search codes are listed as follows:

$$TITLE-ABS-KEY(building\ integrated\ photovoltaics)\ AND\ TITLE-ABS-KEY\ (tech^{*})$$

The Google Search Engine was also used to identify relevant public publications in addition to academic research papers. In order to reflect the current state-of-the-art BIPV products, only the past five years' public publications were reviewed.

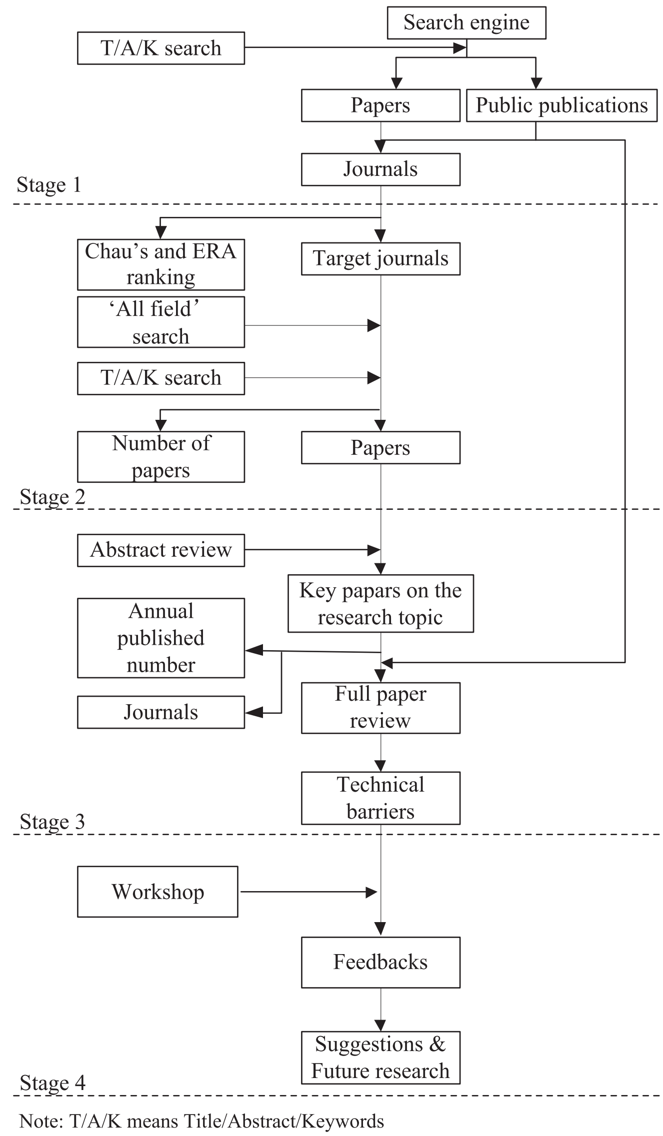

Figure 1. Research process.

In total, 224 academic papers were identified mainly published in journals such as Applied Mechanics and Materials, Energy and Buildings, Advanced Materials Research, Solar Energy, Renewable Energy, Renewable and Sustainable Energy Reviews, Solar Energy Materials and Solar Cells, Energy Procedia, Energy, and Building and Environment, and a small number of conference proceedings. Apart from the academic papers, 38 public publications such as industry reports and news articles were also identified to supplement the scholarly works.

In Step 2, in order to indicate the current research development of BIPV in construction projects, the search was extended to the top ranked construction journals by using the keyword ‘building integrated photovoltaic(s)’ in all fields as well as in title/abstract/keywords. The top-ranked construction journals that were searched are as suggested by the ERA (Excellence in Research for Australia) ranking, which included Automation in Construction, Building Research and Information, Construction Management and Economics, Engineering, Construction and Architectural Management, Journal of Construction, Engineering and Management, Journal of Management in Engineering, and International Journal of Project Management. These journals were not in the list of publication sources of the 224 academic papers. 91 papers that have referred to BIPV in the seven construction management journals were identified as summarised in Table 1; however, none of them have either