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BIPV in Construction:

the translation of products and systems into design and construction

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Authors: Dr Philippa Boyd, School of the Built Environment, University of Reading

Chris Coonick, BRE National Solar Centre and Adam Longfield, BRE National Solar Centre

Editor: Cathy Crawley, BRE

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Preface

Building integrated photovoltaics (BIPV) provide an opportunity to integrate renewable energy generation seamlessly into buildings, delivering multiple functions from a single building material. The architectural solar market is expanding. The global market for BIPV is expected to grow by 12.2% from 2016-2021[1]. BIPV technologies are being specified in refurbishment projects for buildings of special architectural or historic interest and exemplar low carbon new construction projects, typically public buildings and housing.

However, BIPV technologies pose hidden challenges for construction professionals. The technical challenges of BIPV systems are well understood[2] but the challenges of integrating these technologies into building projects is seldom considered. In contrast to building applied photovoltaic systems (BAPV – i.e. rooftop installations), this technology is integrated within the building structure, rather than as a bolt-on addition. This requires project managers to; anticipate interfaces between the technology and the building, understand how the specification of an integrated technology might be problematic within standardised construction project management, and adapt normal procedures to accommodate the requirements of the technology.

Often the incorporation of BIPV technologies is described through idealised project management processes, but with little understanding of the "real world" of construction projects. This publication provides guidance for construction professionals and stakeholders, particularly those involved with commercial building projects. The aim is to deliver practical advice to avoid the potential issues that might affect the integration of BIPV technology into building projects and effect the overall performance of the technology and building.

Introduction

Building on BRE's publication on BIPV challenges and opportunities[3], this guide uses research from three commercial building projects delivered under design and build contracts[4] and information provided by UK BIPV industry, to explain the implications of project management demands and conventions on the integration of the technology. Guidance includes the definition of friction interfaces between the technology and the other building elements, understanding the conflicting priorities of construction project management conventions and being aware of potential issues that influence the performance gap between design predictions and installed performance.

Following on from an introduction into the current options for BIPV, this publication looks at the division of roles and responsibilities for BIPV project delivery. Key considerations are identified for synergistic approaches to achieve systems that are optimised for both architectural and electrical performance and which can be easily maintained and function as a part of the building envelope long term. Solar technology suppliers and the construction sector have often operated as disparate industries but need to be brought together for the purposes of improving products, reducing system costs and increasing confidence in the application of BIPV, leading to wider acceptance of the technology and increased low carbon electricity generation.

Full integration of a multifunctional building system demands early engagement from the construction supply chain to ensure successful cost effective delivery. BIPV is one such system that has provided a number of challenges to construction management and build programmes. This has resulted in a technology that architects are often reluctant to specify and in which Clients are nervous to invest[5]. This publication looks at the incorporation of BIPV from the construction project perspective and aims to give insights to both construction professionals and technology developers so that BIPV integration into commercial buildings is better understood.

1 Building-Integrated Photovoltaics (BIPV): Technologies and Global Markets (E Vickstrom, 2017)
2 An Intro to Building-Integrated Photovoltaics Pt. 2: Challenges (T Lowder, NREL, 2012)
3 IP11/12 Building-Integrated Photovoltaic Systems – Challenges and opportunities for manufacturers and specifiers (S Pester, IHS BRE Press, 2012)
4 From Bicycles to Buildings: A Scot Analysis of Project Level Adoption of BIPV (P Boyd, University of Reading, 2016)
5 Building integrated photovoltaics (BIPV): costs, benefits, risks, barriers and improvement strategy (R Yang & P Zou, International Journal of Construction Management Vol 16 2016 Issue 1)

Introduction to BIPV

Although BIPV can satisfy a number of considerations (from aesthetic appeal and renewable energy generation to solar shading, ambient noise reduction and thermal insulation), the perception is often that its inclusion on commercial buildings is driven by Client desire to show green credentials, or to satisfy local planning authority requirements. Until BIPV is seen to make a sizeable contribution to energy generation in commercial buildings this may remain the case.

Technological options to integrate BIPV on buildings include:


Solar tiles


Solar slates


Solar roof

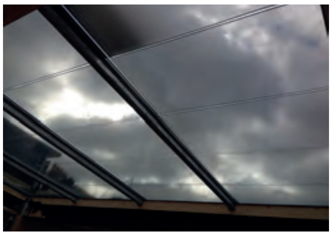

In-roof systems


Solar façades

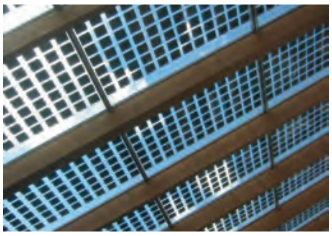

Solar rainscreen cladding


Brise-soleil


Solar shading


Solar windows


Solar glazing


Glass-glass laminated modules


Solar carports

In the UK, BIPV in commercial buildings tends to be bespoke systems designed for individual, often flagship buildings, which use very visible forms of BIPV – often on facades or as a form of brise-soleil.

In the residential sector, BIPV is more often used as roof tiles or membrane, completely or partially replacing the roofing fabric.

Considerations of site suitability, building use and location are important. The BIPV system's contribution to the building functionality, over and above electricity generation, include service provisions that are often overlooked. These include:

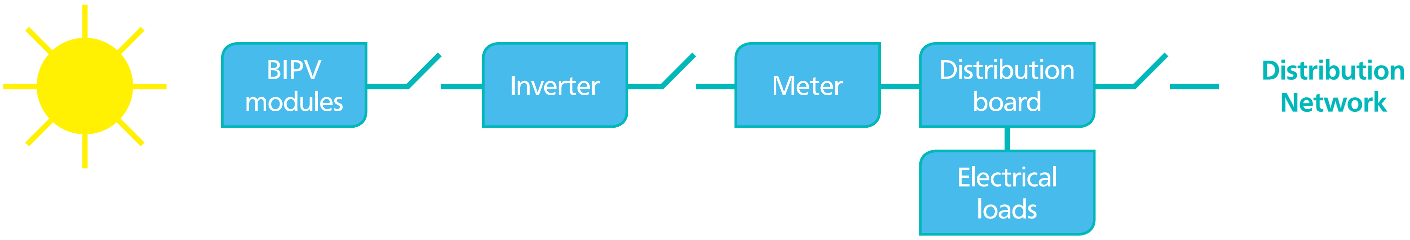
- modulation of daylight
- thermal insulation/ control
- weather protection
- soundproofing
- aesthetics
- visual obscurity
- structural support
- electrical efficiency

Product requirements

From the construction professional's point of view, it is important to note the requirements for product certification, and to understand the requirement of regulation surrounding connection of a PV system to the electricity distribution network. In the UK, to qualify for Feed in Tariffs (FITs), a BIPV system with an installed capacity of less than 50kW is required to adhere to the Microgeneration Certification Schemes (MCS) standards (MCS 005 or MCS 017 for PV products, MCS 012 for pitched roof integration and MCS 010 and MCS 011 for production and testing). Solar modules (often known as solar panels) and their mounting systems are required to satisfy building regulations (in terms of loading, strength, spread of fire, electrical safety and resistance to rainfall and driven rain)[6], and to consider the ventilation of units, whole life costing and end of life disposal[7]. Electrical compliance requirements include IEC safety qualifications (in terms of BIPV module and system safety, BS EN 50583-1 & 2: 2016) and BS 7671 wiring regulations. In addition, systems connected to the electricity distribution network need to comply with the ENA's Engineering Recommendations G83/2 and G59/3[8] (to be replaced with G98 and G99 in 2019), which regulate the parallel connection of any form of generation. Requirements for installation of systems larger than 50kW are covered by the IET's Code of Practice for Grid Connected Solar Photovoltaic Systems.

Whilst much attention is paid to the visible 'front end' of BIPV systems, i.e. the aesthetic and functional aspect that is on view, the importance of the electrical 'back-end' is often overlooked. For safe and efficient operation, BIPV systems require the modules and inverters to be matched with a string configuration that works for the quantity and electrical specification of both components, as illustrated in Figure 3. Cable runs require optimising and integrating into the buildings electrical infrastructure. Failure to select, design and locate these components correctly can result in significant system losses leading to a reduction in performance and electrical output. This can be particularly challenging when multiple bespoke BIPV modules of differing electrical outputs are used.

Figure 1 Typical BIPV system electrical connections



Environmental performance

A major motivation for Clients and architects to specify BIPV systems in commercial new builds is to achieve a particular environmental performance award (such as BREEAM) or Energy Performance Certificate (EPC) rating. BIPV can contribute towards BREEAM credits and are not dependent on the installed capacity (kW) of the BIPV system[9]. BREEAM credits can be awarded for:

- reduction of energy use and carbon emissions

- energy monitoring

- low carbon design

The inclusion of BIPV can also improve the EPC rating of a building by positively impacting the energy use per square metre of floor area and associated CO_2 emissions.

For domestic new builds BIPV can be used to meet the target CO_2 efficiency rating (TER), as per the requirement of Building Regulations Part L1A: conservation of fuel and power in new dwellings. TER sets a minimum standard for the energy performance of a building and is defined by the annual CO_2 emissions of a notional building of same type, size and shape to the proposed building.

In practice these assessment schemes encourage an early outline design of BIPV systems to provide an idea of potential solar generation output to offset against building energy consumption. These estimated generation figures are often then put to one side whilst the architects, and project managers concentrate on achieving planning permissions for the building as a whole. It is rare for the initial electrical performance criteria to be included as part of the BIPV system commissioning process. Whereas, in fact, they should be considered (and adjusted as necessary) throughout the design and build process, so that a BIPV system can be properly assessed against this criteria.

6 Building Regulations 2010, as amended for England & Wales or Building (Scotland) Regulations 2004, as amended for Scotland.
7 Designing with Solar Power: A Source Book for Building Integrated Photovoltaics (BIPV) (D Prasad & M Snow, Routledge, 2005)
8 http://www.energynetworks.org/electricity/engineering/distributed-generation/dg-connection-guides.html
9 BREEAM UK New Construction 2018 (https://www.breeam.com/discover/technicalstandards/newconstruction/)

Project delivery

The following section discusses how the practicalities of construction project procurement and management affect technology realisation. Procurement of construction projects takes several forms, but all projects are subdivided into stages. How projects are procured and managed has implications on BIPV and other integrated technologies.

Building projects in the UK are considered as linear stages in terms of the Royal Institute of British Architects (RIBA) plan of work. These stages are common for all types of procurement, but the detail and timing of each stage varies. The stages are:

Stage 0	Strategic Definition
Stage 1	Preparation and Brief
Stage 2	Concept Design
Stage 3	Developed Design
Stage 4	Technical Design
Stage 5	Construction
Stage 6	Handover and Close Out
Stage 7	In Use

Each of these 8 stages has a defined set of associated tasks involving core objectives, procurement, programme, planning, key support tasks, sustainability checkpoints, information exchanges and UK government information exchanges. Project procedures for each individual project should be agreed between the project team before the end of Stage 2 and should include detailed agreements about the specific activities to be included within these tasks. Stages and tasks can occur sequentially, but often there is overlap between each stage.

Roles and responsibilities

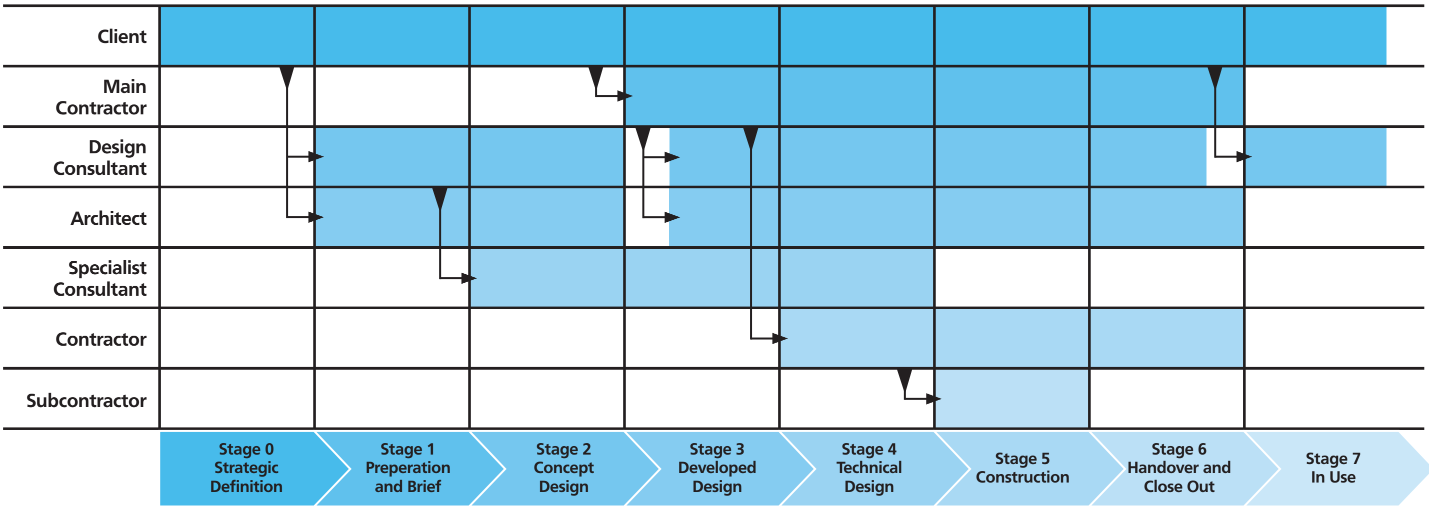
The members of the project team and the exact activities involved in each task within a project stage depend on the nature of the project and the procurement route used. Table 1 details the members of the project team for a typical design and build contract.

Table 1 Role and responsibilities of a typical design and build contract

	Role	Responsibility
Client	Specifies what is required.	Kicks off the project.
Main Contractor	Ensuring that the brief is delivered. After project is sanctioned, becomes the managing contractor responsible for delivery of the project.	Manages and delivers the project.
Design Consultant	Develops outline technical design, advises main contractor on work package content and deals with any design changes as they arise.	Initially part of the outline project design team. Once the project passes Stage 3 or 4, they are often novated to work under the main contractor.
Specialist Consultant	Advises architect and design contractor on specific aspects i.e. acoustics, M&E, lighting, various technologies etc.	Initially advises architect and design contractor. Can move to representing the contractor.
Architect	Develops the Client brief to an outline design. Advises the main contractor and Client on technologies, materials and design.	Initially part of the outline project design team (Stage 1). Once the project passes Stage 3 or 4, is often novated to work under the main contractor.
Contractor	Tenders for work packages and once selected, is responsible for the detailed technical design, delivery and installation of the work package.	Works for the main contractor.
Subcontractor	Contracted by the contractor to complete specified parts of the allocated work package.	Works for the contractor.

As shown in Figure 2, the design team (up to Stage 2) comprises of the Client, project architect and a group of contracted consultants who advise, design and scope the project. The main contractor and their in-house design team (which may, or may not, include a specialist consultant for the BIPV element) are involved from Stage 3 or 4, where the design is (in theory) detailed and costed. A critical point of the project is reached during Stage 3, when the main contractor design team defines work packages' and requests suppliers to tender for the work. It is at the end of Stage 3 that the project schedule is drawn up and responsibilities for the detail design of work packages is allocated.

Figure 2 Project team engagement with different project stages of design and build contracts



Contracts

There are 4 key types of procurement contracts for construction projects:

- **Traditional** - the Client appoints a design consultant to design the project in detail and prepare tender documentation. Contractors submit bids for the construction of the project, usually on a single-stage, competitive basis.
- **Single stage design and build** - where one main contractor takes sole responsibility, normally on a lump sum basis (Stage 3), for the bespoke design and construction of a Client's project up to its practical/ substantial completion.
- **Two stage design and build** - allows the early appointment of a main contractor, prior to completion of all the information needed to enable them to offer a fixed price (Stage 3). A limited appointment is agreed in the first stage, allowing the main contractor to begin work and in the second stage (Stage 4) a fixed price is negotiated for the contract.
- **Managed contract** - where the employer appoints separate trade contractors to carry out the works, and a construction manager to oversee the completion of the works for a fee.

BIPV procurement

As mentioned in the introduction, discussions regarding the uptake of BIPV often rely on idealised procurement routes that follow a more traditional construction contract method, where the building and its systems are designed in detail before work packages are put out to tender. In these types of contract the contractor may design specific parts of the works, but in general, the responsibility for the whole design is held by a design consultant who is engaged at project inception and is typically retained by the Client throughout project delivery.

A more common contract used for the procurement of commercial buildings is the Design and Build (D/B) contract, where after the Client has made the final investment decision (Stage 3), all the design and construction services of a project are contracted to a single main contractor. In the case of a single stage D/B contract this detail design occurs at Stage 3, but for a two stage D/B contract, this detail design occurs at Stage 4. Commercial build projects which are suitable for BIPV installations, are usually procured using this type of contract.

Under a two stage D/B contract the Client has a contract with the main contractor who is responsible for managing all aspects of the project once the final investment decision has been taken. Prior to the D/B contract being put in place (Stage 3 or 4), the Client engages a 'design team'. This team scopes out the project, agrees the initial design and develops outline costings. Following design approval, the Client then appoints a main contractor to run all aspects of the project from developed design through to construction, commissioning and handover (Stages 3 to 7). Members of the initial design team may be novated to the main contractor, where they will work for the main contractor for the duration of the project. In some cases, rather than being novated to the main contractor, the architect and design consultant continue to work as independent client advisors, liaising closely with the main contractor. This working arrangement is generally decided upon in Stage 2 and largely depends upon the Client's wishes.

Maintaining separation between the three roles can give the Client a better balance by having the independent voice of an architect and/or design consultant. However, this approach can increase project costs by prolonging decision-making timeframes. Throughout the remaining project work (Stages 3 to 7), the main contractor is responsible for detailing the design, appointing suppliers, managing and delivering the project on budget and on schedule.

It is common for the main contractor to switch its key representative during different stages of the project, for example the project manager at Developed Design (Stage 3) is likely to be a different project manager to the one at Technical Design (Stage 4) and again during Construction (Stage 5). As well as this fluidity of personnel, the supply chain can have multiple tiers (a series of sub-contractor relationships), thus becoming very complex. Companies within the supply chain serve the main contractor or main suppliers, whilst of course having their own alliances and interests.

Work packages

For all types of procurement contracts, documentation or work packages are prepared for tender and companies are invited to submit competitive bids for the contracts. How these work packages are divided up, and to what level they are detailed, depends on the type of procurement contract used and the usual practices of the construction professional responsible for their definition.

Like many integrated technologies, BIPV systems consist of multiple discrete components that have to be designed to deliver the required performance and efficiency. The system is then integrated into the overall building design and construction. Different engineers and product developers typically develop and optimise individual components (such as BIPV modules, inverters etc.), rather than teaming components together for system performance.

Every BIPV system has six main components as part of the electrical design. These are:

- BIPV modules (e.g. PV cells or thin-film and substrate)
- DC wiring - string cables which electrically connect the BIPV modules to each other and the inverter
- inverters - convert the DC energy generated by the BIPV modules into AC, these can be connected at either an individual module level (DC optimisers or micro inverters), or connect multiple BIPV modules together (string inverters). The inverters optimise the electrical performance of the BIPV modules by maximum power point tracking (MPPT) the current and voltage
- AC wiring - connects the BIPV system in parallel with the rest of the electrical infrastructure in the building
- metering - records the amount of energy generated and, in some cases, how much generated energy is consumed on-site or exported to the electricity grid
- switchgear and protective devices – are present on both the DC and AC side of the system, providing circuit isolation and protection

In addition, there is a mechanical element to a BIPV system:

- mounting system – method of holding and fixing the BIPV modules into the building envelope (i.e. roof mounting system, curtain wall frame etc.)

The selection and specification of components required for efficient technological performance of the BIPV system does not occur in a vacuum, instead, it is set against all the other considerations for design and project management of the whole building.

Outline design of the BIPV system occurs at Stage 1, but often this only extends to the quantity, size and type of BIPV modules needed and the number of inverters required. Detailed design of a BIPV system may only be carried out during construction (Stage 5), when the work has been allocated to work packages and the individual contractors are scheduled to deliver their portions of the project.

Typically when developing the design (Stage 3), questions arise over how conventional practices fit with emerging integrated technologies such as BIPV. Conventional project management logic of splitting work into mechanical, electrical, roof and façade packages are in conflict with procuring an integrated BIPV system.

Common question that this approach can present are:

At what point does the BIPV system stop and the façade/ roof package start?

Who is responsible for the connection of the BIPV system to the main electrical system?

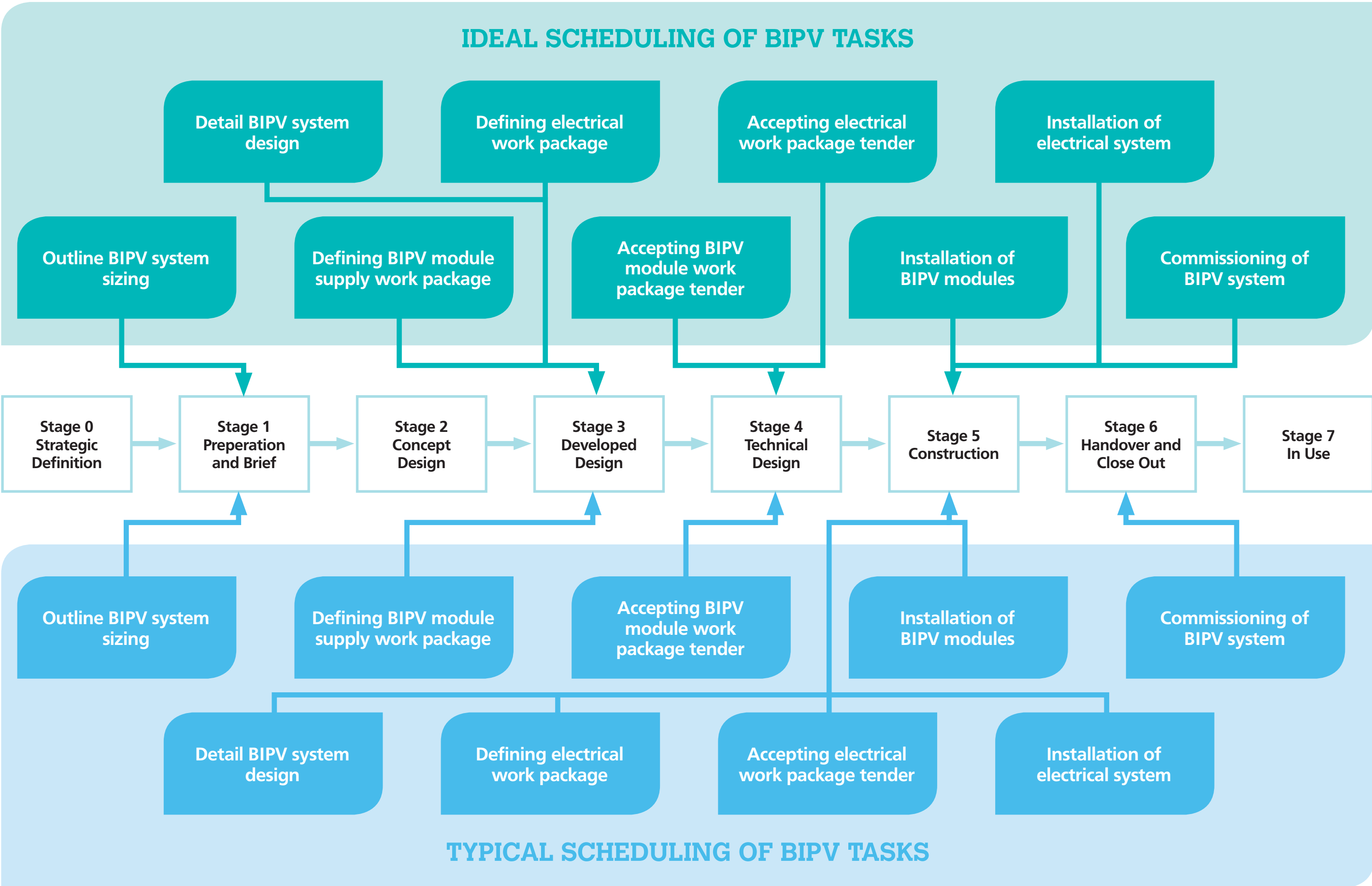
Who is responsible for the detailed design of the BIPV system, such as specifying the inverter?

The punctuated nature of responsibilities and the diverse supply chain in projects serve to strengthen the perceived importance of project procedures and practices, while in reality these are in tension with the integrated design approach and decision-making that is needed in projects that incorporate integrated, complex technologies such as BIPV. The main contractor has flexibility to interpret the project stages and procedures in many different ways, focussing upon efficient project scheduling and/or maximising the output of technologies. The interconnectedness of component design, together with construction project characteristics of staged procurement, a complex supply chain, conflicting priorities and long project lead in times, can manifest into a tension between delivering a project on time and delivering efficient energy generation.

Project schedules and budgets

Project schedules and budgets are outlined in the initial design stages and fixed as contracts are let (<Stage 5). Attention of construction professionals is fixed on achieving cost and time constraints and within these parameters the size and cost of the BIPV system can be considered as relatively small to negligible. As a result the BIPV system can fall off the radar in terms of detailed design and delivery and only comes to attention if overall project schedules are threatened. A knock on effect of this relative lack of importance in the overall project is to hide the need for considered decision taking and care over the assignment of work packages and responsibilities. Figure 3 demonstrates the disparity between an ideal project schedule for BIPV tasks and what is typically seen in construction project delivery.

Figure 3 Scheduling of BIPV tasks in construction project delivery



During the stage of drawing up work packages and the tender process for contractors (Stage 3 or 4), quantity surveyors will actively seek ways to reduce project costs and it is at this stage that work packages can be re-defined and split between façade, glazing, roofing, electrical and mechanical contracts. This process may happen without the input of the original design contractors and the implications of these decisions can seriously affect the output of the BIPV system. Typically, budgets are tight on construction projects and therefore cost-cutting exercises are commonplace.

Case Studies

BIPV product developers often assume that early and complete design of the BIPV system follows best practice, but this is seldom the reality within the complex and dynamic world of construction projects. Frequently work packages are subdivided to increase main contractor margins, designed on a 'just in time' basis and performance is separated from procurement. The following three case studies illustrate the importance of assigning the responsibility of BIPV systems to one contractor who can effectively manage and incorporate detailed design to achieve good system performance.

Case Study 1:

The building was at the final stage of a three phase office development. The Client required a building with an up to date appearance, which would achieve a BREEAM Excellent rating and have some 'green credentials'. Planning requirements dictated that the site included some renewable energy provision. During the initial design phase, a BIPV system was included as a brise-soleil on the south elevation of the building. Although initially included in the façade package, the façade contractor was not experienced in supplying BIPV systems and refused to provide a quotation. As a result the main contractor split the BIPV package into a) supply of the BIPV modules for the brise-soleil (which were eventually 'free issued' to the façade contractor to increase margins) and b) electrical installation of BIPV, which was envisaged to be part of the main building M&E contract. The electrical contract was drawn up after the BIPV module supply and façade contracts had been 'let' and the main electrical contractor declined to quote for this work. This resulted in the main contractor belatedly searching for an electrical contractor who would take on responsibility for the electrical installation of the BIPV system. By this point , many of the design decisions affecting the wiring route, number of inverters and position of the electrical cabinet had already been taken – albeit unwittingly.

This lack of integration is easy to understand, given standard construction project procedures, resulting in an impact on the final generation potential of the system in terms of system efficiencies and output. As a result of the late assignment of responsibility the timing and electrical connection of the BIPV was not ideal and had the potential to cause issues with installation warranties going forward. The BIPV electrical contractor had to install the wiring after the façade system had been signed off by the main contractor and connect the BIPV system into the electrical cabinet which had already been installed by the main electrical contractor. The system was commissioned in two stages, firstly through electrical testing of the installed BIPV modules, secondly the BIPV electrical contractor commissioned the overall system. Neither Client nor the main contractor had requested the monitoring of system performance and therefore the BIPV system was not integrated into the building's energy management system.

The initial design (Stage 3) planned for the DC wiring of the brise-soleil profiles to penetrate the glazing bars connecting to inverters situated on every other floor within the landlord's service riser. Intermediate plans (Stage 4) had the DC wiring running horizontally across the building to single penetration points on each floor and then connecting to inverters sited within the building. The final installed design (Stage 5) had the DC wiring running externally up the building to the three inverters which had been sited on the roof. None of these interim plans were designed at the detail design stage (Stage 4), but evolved through a series of adhoc meetings between main contractor, architect and subcontractors, that were called as problems with the design were identified.

Case study 2:

The building formed the first phase of a science park development. The Client wanted a building with obvious 'green credentials', which would achieve a BREEAM rating of Outstanding or above, and which would achieve an EPC rating of B or better. The BIPV system was to be included in the glazing of the windows on the south elevation of the building.

Once BIPV had been decided upon, the criteria for sizing the BIPV system revolved around satisfying the EPC requirement for reducing carbon emissions. This requirement was translated by the design team into a calculation of number of square meters of solar modules. In order to achieve an EPC rating of B it was calculated that this particular building required 50m^2 of solar modules, to achieve an EPC rating of A the building required 120m^2. As a result, at the concept design (Stage 2), the BIPV system was defined in terms of squared meters rather than generation output.

The construction management team saw the BIPV system as part of the glazing of the building and the work packages were split along conventional lines into the glazing package and the main M&E contract. In this case the work packages were defined by the main contractor, but detailed by the M&E design contractor. The M&E design contractor included design portions in the tender documents (a requirement for more detailed design of the BIPV system was required to be carried out by the successful subcontractor), however, the main contractor was not aware of this inclusion. The contracts were 'let'. The successful sub-contractors had not noted the requirements for design of the BIPV elements and were not familiar with the technology. This led to confusion over wiring configuration of the individual BIPV modules, delays in installation and very late design of the system from the DC wiring up to the point of AC connection. The main contractor, who had no experience of BIPV systems, commissioned the BIPV system as a simple on/off test. There were no expected electrical design characteristics against which to compare a tested output.

The initial design (Stage 4) was for a central display to be installed in the building's atrium which showed the generation performance of the 50m^2 thin-film BIPV system. Intermediate design and changes to the available technology resulted in a 50m^2 monocrystalline PV module being specified to sit within 400mm rebates which resulted in loss of generation over large parts of the day from shading. This design change resulted in a severe loss of functionality and performance – the windows were now opaque and the system generated very limited amounts of electricity. Because of the poor generation levels, the project team relocated the generation display out of public view.

Case study 3:

Planning requirements for a medical research building required 1% of the building's energy use to be generated on site by renewable technology. The architect and Client used an initial design of a standard roof-mounted PV system to reach the required target, however the planning authority required the building to fit in with the locality which resulted in a curved roof. This made it hard to achieve the required energy generation using traditional PV modules and as a result a series of parabolic louvres which included BIPV panels and roofmounted inverters were specified in the tender (Stage 3).

Tender packages split the BIPV into louvre and electrical contracts, and included a specified output level for the BIPV louvre system. The louvre suppliers were not prepared to tender for the system as designed and insisted on a Pre-Contract Service Agreement (PCSA) to design the BIPV system in detail. This resulted in the system using micro-inverters on each louvre, a plug and play wiring connection system and efficient DC cable runs. The louvre supplier insisted on a 'turnkey' BIPV contract so that they could supply and control all of the BIPV system up to multiple AC busbars at sub-roof level.

The electrical contractor was responsible for the final AC connection from the AC busbars to the electrical distribution board. This detail design and clear definition of responsibility resulted in a system that generated the required energy as efficiently and effectively as possible. The louvre supplier commissioned the BIPV system and connected it to the buildings energy maintenance system so ongoing performance could be monitored.

Practical Implications for BIPV developers and construction professionals

Purpose of specification

Clients and architects often have good motives for the inclusion of BIPV on construction projects, but these can become diluted or confused over time. The main benefit of the generation of renewable energy can be lost amid the demands of schedules, cost and project procedures.

It is important that Clients define clear system performance targets, in terms of estimated energy generated per year (kWh/yr) and how the energy generated is to be used and monitored. Project managers and architects should be cognisant of these targets when making decisions as the project progresses. Construction professionals should consider the implications of all decisions which may involve BIPV system components and their impact on BIPV performance.

Assignment of responsibilities and accountabilities

As illustrated in the case studies, it is often not clear as to where responsibilities lie. Who should be responsible for the overall BIPV system design? Who can effectively translate architect's ideas into work packages? Who should carry out the detail level of design? Who is accountable for final delivery of the desired output?

Often construction teams assume that the BIPV system has been fully designed (< Stage 5) and that there is a BIPV 'expert' who has overseen the system design. Often this is not the case – and in most cases the BIPV system has only ever been designed in outline (Stage 2), or for a purpose other than optimising energy generation. Only one of the three case studies detailed included an integrated system design approach that was delivered as a turnkey contract.

Input into the system design by experts is further complicated by the tender process. There is no guarantee that specific BIPV suppliers who give their expertise and advice at initial project stages (Stage 2/3) will win the contract and so can be reluctant to give away expertise and time. The system's generation potential can, and does, get diluted as pressures of project schedule and costs accumulate. Issues where building components meet BIPV components (i.e. friction interfaces) can occur and are often resolved pragmatically - without consideration of the knock on effects on generation potential. BIPV DC cable penetrating through a façade is a typical example of a friction interface.

Responsibility for commissioning of the BIPV system needs to be clearly defined. Who is responsible for commissioning and what should it involve? Who is accountable for the performance of the BIPV system, e.g. BIPV product manufacturer, system designer, or electrical contractor? Accountability for the final output should be assigned before the work packages are defined and awarded.

Specification and selection of system or components

BIPV systems are often outlined in initial stages of the building design (Stage 2) and at this stage the quantity of BIPV modules or area of solar generation is determined. At the same time, the approximate installation location and number/ type of inverters are specified.

Following this initial design, several iterations of work package content and outline building design ensue, but BIPV is often not considered as a complete system until after the initial design (Stage 4) has been completed.

The allocation of BIPV module integration design responsibility needs to be carefully considered and taken into account at the appropriate stages (ideally during Stages 2 and 3).

BIPV module suppliers are often reluctant to provide detailed designs until supply contracts are awarded, as their expertise can be used to establish a criteria for tender, but then lose out in the competitive stages or for the BIPV element to be dropped altogether from the build programme. This lack of upfront design can have a significant impact on the final installed system performance. It is unusual for BIPV systems in commercial buildings to be supplied as turnkey contracts, as detailed in case study 3, unless they are standardised in-roof systems. It is unusual for designers of the balance of system components (i.e. inverters, wiring etc.) to be consulted at early design stages (< Stage 4).

Construction scheduling is established at Stage 4 of a project and this sets the timings for work package definition and the tender process. Conventionally mechanical and electrical (M&E) contracts are awarded later than façade and glazing packages and so this split of design responsibility is compounded and therefore needs to be carefully considered. It is unusual for Pre-Construction Service Agreements (PCSAs) to be issued to subcontractors and, as a result, the detail design of the BIPV system is rarely done before contracts are awarded.

Construction teams are characterised by their temporary and evolving nature and it is unusual for the team associated with the outline design or work package definition (Stage 3) to continue to be assigned to the project as it progresses into the detail design stage (Stage 4). This disconnection is continued in the construction stage (Stage 5), when often the site project manager is a specialist in site management and has not been associated with the design stages of the project. This discontinuity in personnel makes management of an integrated technology difficult.

New build projects: key decision points

The process of integrating BIPV technology in building projects requires a synergistic approach in terms of the challenges that specifying an integrated technology puts on construction companies. This can be in terms of construction scheduling, continuity of personnel, decision points and occupancy use.

Table 2 illustrates typical key decision points in a new build project, questions that should be considered and the stakeholders likely to be involved.

Table 2 Key decisions to be made during design and delivery of a BIPV system

Key decision	Questions to ask	Stakeholder
Initial design and sizing of the BIPV system (Stages 1-2)	What are the drivers for installing BIPV and therefore what should the units of design be (i.e. m^2 or kWh)?	Local planning authority, architect, main contractor, design consultant, Client
Defining work packages (Stage 3/4)	Is the BIPV to be supplied as turnkey system? What is the scope of the work package? Who is responsible for mechanical and electrical design, installation and commissioning of the BIPV system? What are the friction interfaces with other parts of the building? How will the wiring enter and be routed through the building? Who will coordinate the whole design (mechanical and electrical)? What are the overlaps between work packages? Who is responsible for guaranteeing system performance?	Main contractor, design consultant

Key decision	Questions to ask	Stakeholder
Selecting contractors (Stage 3/4)	Have they the expertise to check that the design meets current standards? Have they been involved in early design discussions? Is the final design/ specification up to date and optimised? Who is making the final connection to the electrical infrastructure?	Main contractor, design consultant
Detail Design (Stage 4)	What is the target energy generation of the system? What are the potential friction interfaces? When are the associated work packages to be let? What is the limit of responsibility/ scope for this work package? How does the BIPV system impact other guarantees for the façade, glazing or main M&E work? Who is completing the fire risk assessment? Who is completing the lightning protection risk assessment?	Main contractor, design consultant, BIPV supplier, M&E BIPV contractors, main M&E contractor, façade/glazing roofing suppliers/ contractors
Construction (Stage 5)	Who is responsible for considering the safety requirements for live components[10]	Main contractor, BIPV supplier, M&E BIPV contractors
Commissioning procedures (Stage 6)	Who is responsible for commissioning the system? What are the design electrical characteristics of the system in which to compare commissioning test results?	Main contractor, BIPV supplier, M&E BIPV contractors
Operation and Maintenance (Stage 7)	Is the system to be part of the EMS/ BMS and who is responsible for the connection? How and who will monitor the operation of the system? How will the BIPV system be maintained – accessibility of both mechanical and electrical parts? What is the decommissioning/ technology replacement strategy for the BIPV system and at what point should it be triggered?	Main contractor, Client
Cost management (Stages 1-7)	Do any changes proposed (to reduce costs or hasten scheduling) impact on the overall generation potential of the BIPV system?	Main Contractor, quantity surveyor
Ad hoc problem solving (Stages 1-7)	Does this decision impact the BIPV generation potential in terms of both mechanical and electrical systems?	Main contractor, design consultant, architect, BIPV supplier, M&E BIPV contractors

Refurbishment and retrofit projects

Triggers for retrofit may include Client requirements, local planning rules, building certification (i.e. BREEAM and EPCs) or available incentives. Retrofit of BIPV systems is complicated by virtue of its interconnections with the existing building infrastructure. The BIPV modules need mounting (often replacing a part of the existing building envelope) and the wiring routes and location of inverters have to be considered. If the retrofit is limited to a BIPV system, a turnkey contract would be recommended as the interfaces with the building are clear. If the inclusion of BIPV is part of a wider refurbishment project, then the issues identified for new build projects, in terms of friction interfaces, risk and responsibilities, would also apply. In both new build and refurbishment, the design targets, detail design and issues of commissioning are equally important.

10 solar modules generate electricity as soon as they are installed and are consequently live during daylight hours

Operation and maintenance

The operation and maintenance requirements of BIPV is often overlooked by the Client, architect and contractor. Consideration for such activities should be considered during construction design stages (Stages 2, 3, 4) to ensure successful installation, ongoing performance and to comply with the Construction Design and Management Regulations (2015)[11].

Architects and BIPV system designers may be reluctant to discuss component failure at these early stages however preparing for such event can ensure that maintenance does not become uneconomical, or indeed, impossible. For example, specifying a standard string inverter at design stage may not be sensible if the failure of a single BIPV module has the potential to significantly reduce the entire yield of the system.

It is also good to understand the design life of the different functionalities of the BIPV system (i.e. electrical production, weather protection etc.) and what degradation in a single functions is acceptable before components are replaced or decommissioned. For example, should the BIPV modules be replaced when electrical production has degraded beyond the manufacturer's performance warranty (i.e. 20% over 25 years), even if they are continuing to function well as a curtain wall?

Adequate and safe access to maintainable components is required throughout the lifetime of the system. The provisions may include considerations of inverter/BIPV module replacement, how and when BIPV modules will be cleaned, periodic checks of electrical connection integrity, and confirmation of functionality of safety and isolation devices.

Performance monitoring should form part of all BIPV installations. Any standalone monitoring (typically provided by inverters) should be integrated into the building energy management system (BEMS) so that performance information is easily accessible and interpreted accordingly. Visibility is crucial. BIPV systems should also be included as part of any fire safety monitoring equipment within the building. All stakeholders should be clear as to how these different systems will communicate in practice. This is most successfully achieved by way of robust handover documentation.

It is generally best practice for Clients to employ a specialist contractor to monitor and maintain the BIPV system. This should include ongoing monitoring of the system performance ratio (relationship between actual and theoretical energy outputs) or an equivalent benchmark to determine whether the system is operating as expected.

11 Construction site requirements and project management in relation to health and safety duties and roles. Construction (Design and Management) Regulations, Statutory Instrument 2015 No. 51, (TSO, 2015)

Realising the value of BIPV

The multifunctional properties that BIPV products can provide is well documented. Some products provide more functionality than others however typically products will provide at least three of the following functions as a minimum:

- aesthetic design
- structural component
- electricity generation/ CO_2 reduction
- electrical efficiency
- soundproofing
- thermal control
- weather protection
- shading/ modulation of daylight
- visual obscurity
- whole-life costs compared to conventional materials

In-roof mounting systems using standard solar modules have become more commonplace in recent years in the UK, particularly for domestic new build applications. The primary drivers for this market change are:

- more stringent building regulations with regards to energy efficiency standards
- local planning requirements to meet energy demand with low carbon generation
- requirement for improved energy performance
- aspiration for better environmental performance certification rating
- improved market confidence in technology performance
- modularity and simplification of system design
- financial incentives for renewable energy generation
- new business/ ownership models for solar assets
- increasingly flexible and dynamic energy market
- continued reduction in pv system equipment costs
- experienced workforce

Where a solar PV system is specified, BIPV can now be installed at a similar cost to that of BAPV, once the material and labour costs associated with conventional building materials and methods are accounted for. It is expected that this market will continue to thrive, as costs continue to fall and energy efficiency regulation requirements increase.

The market for commercial applications is considerably less active with most systems being primarily specified as an aesthetic way of meeting building regulation and local planning requirements. Such installations are typically bespoke and therefore more expensive per Watt-peak (£/Wp) when compared to domestic systems.

It is therefore important for architects to demonstrate the added value to a Client by assigning value to the other functions BIPV can provide. For example, the use of semi-transparent BIPV glazing modules will provide not only electricity generation and aesthetic properties, but also increased natural lighting or shading levels compared to solid walls or standard glazing respectively. This could reduce the need and/or cost of artificial lighting in addition to improving the wellbeing of building users, as well as meeting other requirements of the building design (i.e. energy efficiency and low carbon generation). In certain cases the specification of BIPV has led to the reduction of steel costs for structural components, due to reduced loading and the structural integrity of the modules themselves, in comparison to traditional construction products.

It should be noted that whilst financial support mechanisms such as the FIT may have previously helped support BIPV applications, such mechanisms often have a limited life and the FIT, for example, is scheduled to close in April 2019. Demonstrating a cost/benefit analysis that assigns value to all BIPV functionalities, rather than just those associated with revenue or cost savings, is critical to ensure continued specification and support for the technology and successful delivery of BIPV systems.

Available BIPV products

There are a number of BIPV products available on the market for use as a building integrated component. These products typically incorporate either crystalline silicon (c-Si) solar cells (i.e. monocrystalline or polycrystalline) or thin-film cell technologies, such as amorphous silicon (a-Si), Cadmium telluride (CdTe) or Copper indium gallium selenide (CIGS). Thin-film modules typically have a lower electrical conversion efficiency in comparison to crystalline modules, requiring a larger surface area to achieve the same output. However thin-film technologies are cheaper to manufacturer and can be applied to a wide variety of substrates, including commercially available construction products and flexible or curved surfaces. Table 3 provides details of the range of BIPV products currently available and their typical applications for construction projects.

Table 3 Example of BIPV products

Building Component	Example Manufacturers	Cell Tech	Relative Cost	Application
In-roof mounting system using standard solar modules	SolarCentury, Viridian Solar, GSE Integration, Redland IRFTS, Bisol	c-Si	*	Pitched roofs, typically new build and re-roofs
Roof tile	Romag, SolarCentury, GB Sol, Tesla	c-Si	***	Pitched roofs, typically new build and re-roofs
Semi-transparent glazing	Polysolar, Onyx Solar, Sapa Solar	c-Si/thin film	****	Windows, skylights, atriums, facades, curtain walls, canopies, new build or refurbishment
Coloured, semitransparent insulating modules	Sapa Solar, Polysolar, Onyx Solar	thin film	*****	curtain walls, facades, new build or refurbishment
Flexible roof membranes	BiPV Co	thin film	****	curved roofs, curved facades, new build or refurbishment
Bi-facial modules	Trina, LG Solar	c-Si	**	Canopies, new build or refurbishment
Conventional building material with BIPV coating	BiPV Co	thin film	*****	Roofs, new build or refurbishment

Some thin-film modules have a characteristic unique to the technology, referred to as a 'soaking-in period'. This refers to a period of time when the thin-film module exhibits an increased voltage and current (above their product specification), following their initial exposure to sunlight. It is important to ensure that the inverter specified is capable of accommodating these electrical characteristics.

BIPV power output warranties are consistent with standard solar technologies i.e. stepped (90% at 10 years and 80% at 25 years) or linear to 80% at 25 years.

Future of BIPV

BIPV will continue to be specified and installed as part of high-profile bespoke commercial build projects, particularly in urban environments where land value is at a premium and glazing areas are considerable. With standard solar PV systems now considered to be mainstream, Clients are typically receptive of the technology and are aspirational towards adopting new and innovative BIPV products to help improve building energy efficiency. Indeed, BIPV has the potential to play a significant role in achieving nearly-zero-energy buildings (NZEB), as required by the EU's Energy Performance of Buildings Directive[12], and energy-positive buildings. However, with limited demonstration projects and a comparatively immature BIPV supply chain, many architects with negative experiences may be reluctant to specify the technology again and instead try to meet specifications by other means. The approach to how the technology is integrated into design and construction processes needs to be improved to help deliver successful BIPV projects.

Like BAPV, BIPV cell efficiencies are continuing to improve. New and innovative products will continue to be developed, offering architects a growing variety of colours, shapes and functionalities to suit any application. Due to the high development costs associated with BIPV, its relatively niche market, and lengthy construction project timelines, many BIPV manufacturers often discontinue their products (and revert back to their conventional solar products) or worse, are forced to fold the company if BIPV is their sole product. Indeed, this is the case for five of the eight products highlighted in BRE's BIPV publication from 2012. This trend may be perceived as a risk to a construction project. There are, however, a number of long-established BIPV product manufacturers who remain successful in the current market.

Further amalgamation of PV technology and conventional construction products could perhaps stimulate more interest in BIPV within the construction industry. Being able to specify a direct replacement BIPV product would simplify decision making. There is currently considerable research into innovative BIPV coatings to conventional materials[13]. Standardised prefabricated BIPV technology would help to reduce product costs through economies of scale.

The subject of health and wellbeing in the built environment is of ever-increasing importance and this may provide new routes to market, for example the use of semi-transparent facades to provide improved daylighting, heat transfer and comfort to building users. It can also act to filter harmful UV radiation.

Improvements in product standards for BIPV will allow products to be certified demonstrating performance and compliance with other relevant structural and safety standards, reducing market uncertainty in the technology and investment risk.

Building Information Modelling (BIM) could be the key to improving the image and accessibility of BIPV to the construction industry. BIM has the potential to reduce the installation issues highlighted in this document, whilst at the same time increasing the transfer of BIPV product and application data to stakeholders worldwide. BIM utilises information-rich models through collaborative working processes in order to improve the quality of information provided at the design, construction and operational phases to save costs by eliminating waste. BIM is triggering a digital revolution within the construction industry, creating digital pathways in which to streamline the manufacturing processes of building products and bespoke components.

BIPV delivery costs are typically high and it is thought that this has stifled deployment considerably, worsened by the rapid cost reductions seen for BAPV in recent years. Whilst in-roof mounting systems using standard modules has supported the domestic BIPV sector, commercial BIPV system costs remain high. It is likely that this will continue to be the case into the future; standardisation of costs can be difficult due to the inherent uniqueness of each application, and the multifunctionalities the product is providing in a given building space.

Multi-functionality is perhaps the key driver for BIPV products and its value can only be realised through training and education to Clients, architects, designers and contractors. This guide can be used to develop an understanding as to how BIPV products and systems best integrate into design and construction.

The application of flexible BIPV technologies will continue to increase as architectural design and building shapes become more complex. New high-profile construction projects with BIPV will provide the best marketing for the technology. A number of successful high-profile BIPV case studies exist, however, BIPV faces continued difficulties in becoming a mainstream technology for reasons set out above. It is likely that the main driver for increased deployment will come from government policy intervention in the form of increased minimum efficiency standards, rather than financial incentives. A strategy such as this would almost certainly drive investment into the value chain and promote competition and cost reductions.

For domestic applications, the market for in-roof mounting systems using standard modules will continue to grow. There is also potential for solar roof slates that blend in with conventional materials to become more mainstream as products from well-known brands, such as GB-Sol, gain traction alongside new entrants to the BIPV market, such as Tesla. As with all BIPV applications, conventional roofing contractors may show reluctance to the technology and this could well be a barrier to its uptake.

The BIPV market is still very much at the start of the adoption curve however with potential market disrupters such as Tesla getting involved, there is potential for an increased pace of deployment going forward.

12 The Energy Performance of Buildings Directive requires all new public buildings to be nearly-zero energy by 2018 and all other new buildings by 2020.
13 specific.eu.com

Innovative technology case studies

Customised design BIPV – THE UMWELTARENA

Installed in 2017, this BIPV façade marks the entrance to the Swiss Umweltarena (National Exhibition Centre for Environmental Technologies). ÜserHuus designed the BIPV modules to optimise electrical performance and vibrancy of design through digital ceramic printing. A detailed BIM model was developed during planning to reduce project delivery time and cost. The BIPV modules were installed on a standard ventilated façade system.

Of the 33 laminated units installed, 27 of them are printed BIPV, 3 are standard BIPV modules without print and 3 are glass laminates with text and logos. The public monitoring revealed electricity production of the printed BIPV modules was on average 76% of the standard BIPV modules without any print.

BIPV construction material - SOLAR SQUARED

SOLAR SQUARED manufactured by BuildSolar takes the latest solar technology and embeds it within conventional construction materials, reducing product costs. Standard construction glass blocks provide a modular approach and simplifies installation.

Available in various colours, sizes and textures, SOLAR SQUARED incorporates concentrating PV technology, which magnifies and focuses sunlight on a small solar cell, generating electricity. Ideal for urban environments, an intelligent inner optic maximises the direct and diffuse sunlight harnessed.

Transparent BIPV – OPVWindows

Thin-film PV glazing manufacturer Polysolar, are developing the next generation of organic polymer based PV materials. These manmade materials are liquid printed extremely thinly on to a substrate, making them both low cost to manufacture, and easily manipulated for the specific building function they need to perform. A process has been developed that delivers a clear glazing unit, OPVWindows, that can be manufactured to any size and finish, allowing easy integration with existing glazing and façade supply chain and construction processes.

Glossary

Building Applied Photovoltaics (BAPV) - Photovoltaic technology which is applied to the structure of the building for example the roof mounted photovoltaic arrays.

Building Information Modelling (BIM) - Utilises information-rich models through collaborative working processes in order to improve the quality of information provided at the design, construction and operational phases to save costs by eliminating waste.

Building Integrated Photovoltaics (BIPV) - Photovoltaic technology which is integrated into the fabric of the building for example the façade.

Building Maintenance System (BMS) - A computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment.

Building Maintenance Unit (BMU) - An automatic, remote-controlled, or mechanical device which is used to maintain or clean the exterior of a building (e.g. hoist).

Energy Management System (EMS) - An energy management system which monitors and controls services, ensuring the building operates at maximum levels of efficiency.

Free issued - When material is purchased by the Main contractor and issued to the contractor free of charge for inclusion in the work package.

Friction interface - Between the BIPV system and the Building. Physical interfaces between the BIPV.

system and the building – for example where the BIPV wiring penetrates the façade or where the Inverters are sited.

Novated - Novation is a process by which contractual rights and obligations are transferred from one party to another. In construction, novation refers to the process by which design consultants and architects are initially contracted to the Client, but are then 'novated' to work for the contractor.

Pre Contract Service Agreement (PCSA) - Enables a contractor to carry our detail design work for which they are paid.

bre INNOVATION PARKS NETWORK

Exhibiting excellence in sustainable construction

Demonstrating solutions - Testing technologies - Showcasing skill

The BRE Innovation Parks Network has been established to inform sustainable development at a global level and stimulate innovation within the built environment. With Parks established in the UK and China, and further facilities being developed in Brazil, Chile and Canada, the Innovation Parks Network is unique in its approach, its global reach, its independence and its impact.

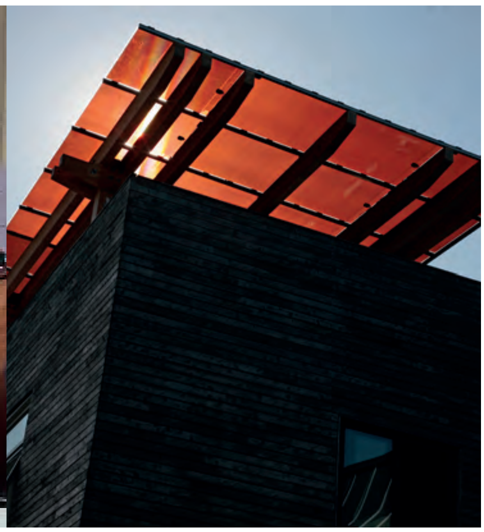
The Innovation Parks feature full-scale demonstration buildings that have been developed by industry partners. These buildings allow organisations to demonstrate, research and test products, innovations and building systems in an independent environment.

By showcasing on the Innovation Park, organisations have access to a unique audience of clients, specifiers, industry and trade leaders, as well as Government, education establishments and media, all hosted by BRE and backed by the BRE brand.

BRE Innovation Parks Network offers:

- Collaborative approach between research, industry and academia.
- Opportunity to reach new customers, test capabilities and connect with experts.
- Versatility and flexibility of display options.
- Potential to design and construct, or collaborate on a new demonstration building.
- Use of the display as a test bed for new ideas in a controlled environment .
- Be an active part of the BRE Innovation Parks Network around the world that would offer a preferential entry into new, thriving markets.





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BRE National Solar Centre
Eden Project, Bodelva,
St Blazey PL24 2SG

T +44 (0)1726 871830
E nsc@bre.co.uk
W www.bre.co.uk/nsc