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The uptake of BIPV within a project environment: the practicalities of integrating solar technologies into the building projects

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The uptake of BIPV within a project environment: the practicalities of integrating solar technologies into the building projects

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Abstract

Whilst the technical challenges of incorporating new technologies into buildings are continually discussed, the managerial challenges are less well understood. The issue is acute as many of these complex technologies such as advanced building skins (ABS) are integrated with the building structure, rather than being bolt-on additions. Building integrated photovoltaic technologies (BIPV) are an example of ABS and pose challenges for construction professionals. Research has until now understood BIPV through idealised project management processes, but with little empirical research. Using a socio-technical approach, this research aims to understand the "real world" of construction projects and to explore how practitioners make BIPV integration a reality. This research follows three building projects where BIPV was specified, following the negotiations, decision making and institutional logics, which play out. The implications of project management demands and conventions on the integration of the technology are explored, identifying institutional obstacles to integrating BIPV into the building. Findings include changing interests and requirements shaping the technology, friction interfaces between the technology and the other building elements and conflicting priorities of project management conventions and technical details. The importance of this research is to deconstruct the practicalities of incorporating BIPV into building projects so that construction professionals, technology developers and suppliers can understand the challenges and opportunities occurring as ABS are integrated into the building envelope.

Keywords: BIPV, project management, integration, construction projects, performance gap

1. Introduction

Advanced building skins (ABS) form a group of innovative technologies that are integrated with and form part of the building. Discussions around ABS often centre on energy generation efficiency, reduced energy consumption in the built environment, and other associated benefits. Increasingly however, practitioners and academics acknowledge that the drive for the latest technology and the pursuit of technical excellence has not been enough to secure the uptake of technology. ABS might be identified as eco-dressing or associated with flagship projects that proudly sport their sustainable credentials without dramatically improving the built environment. This lack of enthusiasm for the adoption of innovative technologies has been attributed to the performance gap between boilerplate performance and delivered performance, and this has led to a focus on technical improvements [1]. Whilst technological improvements are needed, that is not enough, with a growing acknowledgement within the project management community that managerial challenges associated with the practicalities of incorporating complex technologies are key but less well understood [2].

Turning to BIPV and to the practicalities of managing the construction of buildings, it is easy to see how technological performance and construction project management processes diverge. Over time project management logics have developed within the construction sector which pre-dispose project managers to split the technology along conventional project lines, blurring the distinction between the function of the technology (energy generation) and the other "normal" components that go to contributing toward a finished building. Thus, the PV cells can be considered as Mechanical artefacts, wiring and inverters as Electrical artefacts and the associated windows or façade panels as part of the fabric of the building. These artificial distinctions may seem superficial, but taken within the context of construction projects, can have profound effects on the delivery of the technology (BIPV) in terms of functional performance. Construction projects are temporary in nature, with multi-disciplinary teams coming together to deliver complex one-off projects, often incorporating new technology [3]. Project work requires complex interrelationships, agreed project processes and norms, factors that can work against the incorporation of innovative technologies as project management systems are designed to standardise build processes and to make construction projects efficient. This has resulted in prescriptive best management practices to optimise measured team performance [4], calls for integrated processes [5] and controlled management of changes [6]. Project management research thus tends to address this shift towards integration based upon unrealistic idealised and logical project management processes. This has led to a research focus on optimising project management processes rather than developing an understanding of how technical specifications are translated into physical artefacts.

This divergence between the technological focus of Engineers and Product Developers and the emerging practicalities of construction project management is not well understood and perhaps explains the tension between product design and installed performance. The aim of this research is therefore to understand the "real world" of construction projects and to explore how integration becomes a reality empirically.

2. Construction projects

The following section develops how the practicalities of construction project management affect technology realisation. It outlines how construction projects are subdivided into stages, the way that construction projects are managed and the implication of these factors for BIPV and other integrated technologies.

2.1 Project stages

Building projects in the UK are considered as linear stages in terms of the Royal Institute of British Architects (RIBA) plan of work [7]. These stages include: business justification (stage 1), feasibility studies (stage 2), project brief (stage 3), concept design (stage 4a and 4b), detail design (stage 5), production information (stage 6), mobilisation (stage 7), construction (stage 8), occupation and defects liability period (stage 9) and post-occupancy (stage 10). Each of these 10 stages has a defined set of outcomes and procedures and the responsibilities are clearly set out within Codes of Conduct and individual project files. Formal procedures for each stage include contractual arrangements, agreement of tender documents, sign-off procedures on designs and drawings etc. Up to stage 6, the design team comprises of the main contractor and its in-house design team, the project architect and a group of contracted consultants who advise, design and scope the project. A critical point is reached during stage 6, when the design team creates 'work packages' and sends them to suppliers for tender. It is at this stage that the project schedule is drawn up and responsibilities for detail design of work packages are allocated.

2.2 Construction contracts

Different types of contract are used to procure building projects and these formalise the way that projects are managed and run. Of these, design and build (D/B) contracts remain dominant within the UK. D/B is where after sanction of a project all the design and construction services of a project are contracted to a single firm. The client has a contract with the so-called main contractor who is responsible for managing all aspects of the project once it has been sanctioned by the client. Prior to the D/B contract being put in place, the client engages a 'design team'. This team scopes out the project, agrees the initial design and develops outline costings. The client approves the design and then appoints the main contractor to run all aspects of the project from design through to construction, commissioning and handover. Members of the initial design team may be novated to the main contractor, which means that they work on the project 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. Throughout the remaining project work, the main contractor is responsible for detailing the design, appointing suppliers, managing the project and delivering the project on budget and on schedule [7].

Despite claims to the contrary, it is common for the main contractor's firm to switch its representative during different stages of the project, so the project manager at concept design is likely to be a different project manager to the one at detail design and again during mobilisation and construction. As well as this fluidity of personnel, the supply chain can have multiple tiers - thus becoming very complex. Firms within the supply chain serve the main contractor or main suppliers, whilst of course having their own alliances and interests.

2.3 BIPV and construction projects

Like many ABS technologies, BIPV consists of many components that have to be matched as part of the overall system to deliver efficiency, that system must then become part of the overall building. Different engineers and product developers typically develop and optimise individual components, rather than teaming components together for system performance. Five main elements of BIPV combine to generate and use electricity. Firstly the solar generation technology (eg PV cells or thin film). Then the substrate which is included into a building element (the panel), followed by the wiring (which connects each generating panels. Inverters take the power from the panels and convert the output to AC power. Finally, the metering system that either uses the generated energy within the building or exports the electricity to the grid. Outline design of the BIPV system occurs at stage one of the RIBA process, but often this only extends to the number and size of panels needed and the number of inverters required. Detail design of a system may only be carried out after stage 6, when the work has been allocated to work packages and the individual contractors begin to deliver their portions of the project. The matching 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.

At the stage of work package definition, questions arise over how conventional practices fit with emerging integrated technologies such as BIPV. Conventional project management logics of splitting work into mechanical, electrical and façade packages are in tension with procuring an integrated BIPV system – at what point does the BIPV system stop and the façade package start? Where do responsibilities for the connection of BIPV to the main electrical system occur? Who has responsibility for matching the inverters to the BIPV cells? 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 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 processes or maximising the output of technologies. The interconnectedness of component design, together with construction project characteristics of staged procurement, a complex supply chain, conflicting firm priorities and long lead in times, manifests into a tension between delivering a project on time and delivering efficient energy generation.

3. How to understand the problem

Construction projects involve temporary teams made up of many different firms, using different processes and involve millions of components and technologies. The uptake process of innovative technologies is dynamic, and is governed by institutional logics in terms of contracts, professions, technology specialisations and supply chains. It is clear that the processes of integrating new technology into building projects will have effects on the technology, management of the project and on the constitution of the building itself [8]. In addition, everyday problem solving involve changes to the design and components used. These tensions are particularly in evidence in the case of ABS and BIPV in particular as they push directly up against established logics. Traditional rational approaches to innovation emphasise technological determinism; focussing on the technology and its development, but it is clear that a research approach which considers both the technical and social elements of project management within construction is needed.

3.1 A socio-technical problem

The inclusion of an innovative technology which is part of the fabric of a building poses several research challenges. The incorporation of such a technology into a construction project necessarily involves extensive accommodation at many levels and in many different ways as it interfaces with many aspects of the project and its components. These accommodations are made both to the technology and to the building in which it eventually forms, and can be in the form of technical adjustments which involve sets of design and solution issues, or of changes to standard designs or ways of working. The institutional logics are also clearly relevant, together with the fragmented and increasingly specialised nature of the stakeholders representing these interests. It is how these practitioners and stakeholders make sense of and experience the innovation through negotiation which is the focus of this research. Technical, design and process-management issues are often treated as distinct and separate, but in practice are interrelated. This premise of mutual constitution of the technology, the building and the project processes [8] challenges previous analytic distinctions between context and innovation and the practices of project managers. The combination of technical and social influences is becoming well recognised as having a particularly important contribution to play in understanding the adoption of sustainable innovation within construction projects [9].

To consider the implications of project management demands and conventions on the integration of the technology, the first challenge is to understand the different requirements which the technology and the building impose on the project team and on each other. The second is to explore the different and sometimes conflicting interests which arise around the implementation of the technology. The final challenge is to follow how the problems and tensions which arise in the course of a project are eventually resolved and how the technology is incorporated and thus adopted. These challenges point to the need for fine-grained analysis of what occurs when such technologies are introduced and the need for a research approach which allows for consideration of both the technical and social aspects of its adoption within the context of project processes.

3.2 The effect of project processes on the technology

As illustrated, the technology (ABS or BIPV) does not reside in some sort of vacuum. Rather its technical performance and characteristics develop as a result of its local contextual setting (in this case construction project management) and vice versa. This processual understanding of the nature of innovation and its adoption has highlighted several common aspects of project management which affect innovation and its performance [10] [11] [29]. Studies on processual innovation highlight the importance of the project management context, the management of decision-making within projects and the effect of shifting criteria during the course of a project. In addition, research identifies the effect of the nature of project teams, the role of leadership and inter-organizational relationships. These themes, which emerge from a processual understanding of innovation, resonate within the context of incorporating integrated technologies in building projects and mirror themes which have been identified in construction research. The following section looks at the nature of construction projects and reflects the themes above within the context of construction, with a view to exploring both the processual and material elements of innovation adoption.

3.2.1 The context of construction projects

Construction projects have the distinctive characteristic of being both fragmented and systemic. Their systemic nature comes from the number and interdependence of firms and actors involved in project procurement, ranging from architects, main contractors, and specialist consultants, to suppliers, designers and subcontractors. The fragmented nature of construction is a result of the highly specialised and diverse nature of the projects it delivers. Rather than being a stable, cohesive unit, construction projects involve temporary, multi-disciplinary, multi-firm projects teams, with different firms within a project having different priorities and sensitivities [3][12] . Membership of the project team changes during the course of a construction project, with actors joining and leaving the team at different stages. For example, it is normal for the main contractor's firm to change its representative during different stages of the project, so the project manager at concept design is likely to be a different project manager to the one at detail design and different again during mobilisation and construction [12]. The supply chain of a construction project has a complicated series of relationships and obligations that are typically bounded through complex contractual arrangements [13]. Firms within the supply chain serve the main contractor or supplier, but also have their own ways of workings and their own alliances and interests. Within the formal project arrangements and interdependencies, there are informal systems, relationships and procedures that further fragment the project team. These characteristics, coupled with both formal and informal systems, relationships and procedures, make the process of innovation uptake in the construction context complicated.

3.2.2 The management of projects, change and decisions

The current dominate discourse within project management is entrenched in the classical sociological idea of logical or rational decision-making. Increasingly however, research recognises that decisions within construction projects are taken with the involvement of many team members (with competing agendas), in the context of a social network, and include a technical element. Whilst this network approach identifies characteristics of effective networks and suggests best practice for project decision making, it does not go further into identifying the impact that decisions have on the development of the technology or building.

3.2.3 Shifting performance criteria

Process innovation literature identifies types of criteria that run through the implementation phase of innovations. These criteria do not operate in practise in the rational, linear manner described in the majority of the project management literature, but operate in a sometimes divergent manner which leads to periods where criteria shift as different information becomes available [14]. It is clear that these shifting criteria affect how decisions are taken over the course of a project, and that these decision chains will affect the materiality of the innovation and its context. Thus project success is considered in terms of project completion schedules, budgets and client satisfaction, rather than technological performance.

3.2.4 The temporary and evolving nature of project teams

The temporary and evolving nature of project teams have been shown to bring some advantages to projects in terms of new perspectives and competencies [15], but also involve issues with loss of information, expertise and common purpose. These contributions to project management literature are largely in the form of suggestions for improved project team performance but, from the arguments above, will have a large effect on the decisions made, the criteria adopted and ultimately on the performance and configuration of the innovation itself.

3.2.5 Leadership for innovation and uptake

One view of innovation leadership sees counterbalancing roles of leadership which do not reflect personal characteristics of one project team member, but are shared among decision-making executives, leaders and managers [16]. Disagreement between these decision makers acts as a series of checks and balances during the project, showing that decisions are made pragmatically in response to changing conditions and the differing perspectives held by other top managers, rather than by planned course of action. Within construction management circles the critical role of innovation leader or champion in successful innovation has also been also been identified who drives through innovation and overseas challenges [17]. These two views add support to the notion that innovation champions have an important role to play in the adoption of innovation, but also that one person cannot necessarily guarantee the outcome. Given the autonomous and highly networked forms of construction projects, where work is carried out away from hierarchical environment of parent organisations, the practicality of either a single person fulfilling this role or a rational or collegiate decision-making processes undertaken by the project team must be questioned. It also invites reflection – particularly in terms of technological innovation - on where leadership comes from in a project, who makes decisions in projects and what concerns or criteria frame their decisions.

3.2.6 Inter-organisational relationships and the supply chain

The complex inter-organisational relationships which occur on construction projects make the inclusion of innovative technologies on buildings difficult. The challenge of adoption of sustainable technologies within the construction sector is often treated as a problem of project team and supply chain integration, with the focus being on professionals and their procedures and competencies (Specialist Engineering Alliance, 2009). While this perspective highlights important issues, the focus on professional roles and formal procedures obscures the complex decision-making processes which explain how and why the solutions are developed and implemented. Little attention is paid to how innovative technologies involving cross-disciplinary issues affect the building in which they are incorporated, or the processes by which they are installed. What is missing is an understanding of how these interdependencies and the ways they are accommodated come together to shape both the technology and the building. In summary, it is argued that engineers and technology developers struggle to design efficient BIPV components and systems, but that the project management and design practices can obstruct the realisation of these optimised technologies. This can result in a version of BIPV being installed, which is often not as imagined or anticipated by the technology developers and which does not deliver on its promise.

4. Research design

Having outlined some the themes and issues central to understanding the divergence between technological design and project realisation, the research uses these themes in the micro-level occurrences that occurred during the incorporation of BIPV into the projects. Three building projects specifying BIPV were used as case studies. In each case, the research followed the technology as it became stabilized and was incorporated into the building. This allowed an understanding of the mutual interaction of technology and project management practices used by the stakeholders and the broader institutional logics of the construction sector. Over the course of the projects, different project stakeholders were interviewed, paying particular attention to their experience of the decision-making processes they engaged in, as the inevitable series of problems and solutions arose during construction. This series of events was then used to draw out the practicalities of incorporating BIPV into building projects. Using socio-technical analysis [18], the research follows the negotiations, decision making and institutional norms/features, which play out during the course of projects. As each narrative became clear, it was possible to see how project management processes impacted on the stabilization process of the technology and vice versa, thus enabling uptake to occur. In doing so the research sought to offer insight into the institutional logics surrounding the integration of BIPV into the building envelope. Theses insights were used to understand how decisions impacted on the performance of the technology and what lessons could be learnt by developers, architects and project professionals.

5. Three case study projects

The case studies used were live new build projects in the UK that incorporated BIPV systems with similar characteristics (in terms of the type of PV cell and substrate). The projects also used similar procurement contracts. These similarities meant that a comparison could be made without the complication of a different set of technical and procurement problems.

Vogue Terrace: A commercial office building in Central London which was part of a three-phase refurbishment project in which three adjacent blocks were reduced to a skeleton and then reconstructed. Although not exactly a new-build, the refurbishment was so extensive that it fulfilled the criteria of case selection. BIPV technology was incorporated in the brise-soleil louvres on the south elevation of the building. Vogue Terrace was the last of a three building development to be constructed from the early 2000's on. Initial planning permission for Vogue Terrace was granted in 2007, work on site began in August 2014, with work on the BIPV installation commencing in February 2015.

Future Green: A commercial science hub set on a 24-acre site in a large science park development in Northern England. The BIPV system was incorporated into the windows of the south elevation of the building. Design for the project started in 2010, construction began in late 2013, the installation of BIPV was completed by August 2014 and the building was completed by November 2014. The project was a joint partnership between a university, the City Council and several other partners.

Synergy Court: This final case was an interdisciplinary biomedical research centre in Central London to serve a medical research partnership between three national research organisations and three universities. The BIPV system was incorporated into roof fins on the building. Project planning began in 2001, with planning permission being granted in December 2010. Ground works began in April 2011 and BIPV installation began in 2014, the estimated completion date being early 2016.

6. Findings

Each case was followed and analysed using the criteria outlined above. This section reports solely upon the high level, over-arching, findings from the case studies which were developed from the ground up. Whilst details illustrate and bring these headline stories to life, it is argued that their presence and relevance is of paramount importance to all project stakeholders.

6.1 Changing interests and stakeholders (team members) affecting BIPV performance

During each project it became clear that different project members (stakeholders) formed informal groups which coalesced around developing interests. These informal groups transcended simple job titles or professional boundaries. An example of this was that an interest group concerned with Generation Maximisation was at times made up of architects, designers, planners and engineers, but at other times only comprised of the designers and planners. As such, the informal groups were temporary and fluid.

What can be argued is that the informal membership of such groups within the projects shifted and changed with *rhythms* that sometimes followed the standard formal project stages (initial design, tender, detail design etc.) but sometimes followed a different pattern. Thus, the mechanism for the forming of interest groups around a theme such as Generation Maximisation is difficult to pin down and includes many factors. At various times in the project the dominance of some groups was amplified by project stages (for example Design Optimisers dominated the solution of problems at the detail design stage). However at other times the dominance came from a source which was not obvious and which seemed to rise and then disappear, making the logic of decisions harder to follow. An example of this is when decisions were taken that seemed to follow from an unwillingness to engage with the technology but were actually based on minimising risk.

The data analysis forces us to consider that it was only when project stakeholders could see and understand which *frame of reference* was being used by other stakeholders, that integrated decision-making occurred. This view of decision-making allowed the implications of the current decision on generation as well as project schedule to be considered. For example it was only when the construction manager in Synergy Court understood that the supplier of the BIPV louvres had concerns over meeting generation targets that project schedule was adjusted to allow for more detailed front end design of the BIPV system.

6.2 Identification of *friction* interfaces

The friction interfaces, defined as where the BIPV assemblage (once it has become stabilised through the processes described in section 6.1) physically connects with the other parts/assemblages that form the completed building, were not apparent to the project teams from the outset. The friction points where stumbled upon at unexpected points during the project. The friction interfaces were experienced as a process, where unplanned mutual articulation of the BIPV assemblage and the rest of the building needed to take place. The content of this articulation was the interrelationship and interdependence between the performance of the BIPV assemblage and the performance and appearance of the rest of the building.

Vogue Terrace offers a useful example, relating to how the wiring from the BIPV louvres penetrated the building. The architect envisioned that the wires would be incorporated into the window frames. However, the façade supplier assumed that the wires would be taken externally across the building and run through one central point to the inverters. The project manager had no idea that either of these views might be an issue – the architects solution threatened the integrity of the façade and the façade suppliers view affected the performance of the BIPV by introducing system losses. In the end, through lengthy negotiations, a compromise was reached with redesigned brackets holding the frames, running cables vertically up the building and installing inverters on the roof, rather than inside the building. The manufacturer of the brackets, nor many of the stakeholders, had no idea of this and would not have assumed that their brackets would be part of the problem, or be the chosen focus for the solution. Likewise, the re-location of the inverters to the roof had implications for many of the other elements that went to form the completed building. The knock on effects on the programme and site logistics could not really have been foreseen.

This illustration shows how both the building and the technology were affected by the friction interface, and how the building needs to be viewed as *a complete system*, whereby every component has the potential to influence and reshape the building design and other components. This finding bring to the fore the notion of co-development of the building (with all its component technologies and parts) and the BIPV system. In doing so attention is drawn to the role of contracts, guarantees, schedules and risk in decision making which obscured technological implications and prevented integrated development of the building and technology.

6.3 Conflicting logics of project management and the technical system (BIPV)

The analysis of the case studies drew attention to the sector's established 'plans of work' e.g. the RIBA and construction project procurement processes which by their nature seek standardisation and separation. Once identified as key variables, it became clear that these institutional logics had a strong relationship with the development and adoption of a bespoke BIPV system (in the UK BIPV has no off-the shelf solution).

All three case study projects were based on Design and Build contracts with clear project stages and processes, based upon institutional logics of the sector. In two of the case studies, these standard processes (institutional logics) - of developing work packages and selecting firms to tender - had a profoundly negative effect on the design and integration of the BIPV system as part of the building. Early division of design work between mechanical and electrical disciplines, and the very early development of work packages before detail BIPV system design had taken place, made it difficult to integrate all the elements of the BIPV system and for an assessment of the whole BIPV system performance to take place. By contrast, in Synergy Court the contractor concerned refused to quote on the BIPV system unless the detail design of a complete system was carried out prior to tender (using a pre contract service arrangement or PCSA). This resulted in the redrafting of the work package to include both mechanical and electrical elements of the design and the BIPV contract was subsequently awarded on a turnkey basis. The resulting system design was very different from the original design, using different PV technology from the original specification and incorporated over 600 micro-inverters.

The arguments from the data illustrate that a BIPV system cannot be efficiently designed if mechanical and electrical packages remain separated. A simple analogy would be trying to design car whereby the engine and gearbox engineers are contractually separated and working in isolation, and whilst also working in isolation of the rest of the production team. Thus, the project management processes used in three case studies have not developed fast enough, to accommodate innovative technologies such as BIPV. Similarly, the process of awarding of contracts relied on previous relationships (based upon a traditional separation of mechanical and electrical) which adversely affected the contractor's ability to deliver the work package.

The effect of issuing the contracts for the BIPV was evident at the design and installation stage, where the siloed way of working within work packages created artificial boundaries between parts of the BIPV system and those stakeholders engaged in the rest of the building. Façade installers did not consider the way that wires would penetrate the façade until close to installation and the siting of cable runs and inverters was not considered by the main contractor until the main electrical work was carried out. It would seem that the contracts generated artificial boundaries between the stakeholders which were not picked up by the project design coordinator role. These examples demonstrate how the conflicting priorities of project management and the early design of technical details of the integrated technologies are in tension with each other.

7. Discussion: Implications for Advanced Building Skins

The arguments point toward some very real challenges for the project stakeholders in a number of forms, central to which are the institutional logics that have come to represent the construction sector. ABS, as a technology or product, are currently dealt with by the construction sector (these institutional logics) as uniform, standardized, stable physical artefacts with a clear manufacturer and expert knowledge [19], However, the empirical evidence from this research contradicts such a view offering a different version of reality. This version of reality is far more aligned with the socio-technical nature of trying to create and implement an Advanced Building Skin, which extends way beyond viewing the technical aspects in a vacuum [18]. Understanding this is essential for stakeholders, but especially so for engineers and product designers, as they try to turn their designs into a physical reality that forms part of a finished building. Much of the Project Management literature and certainly the work plans and contractual arrangement processes used within the construction sector appear still to be embedded in assuming rationale and logical decisions with complete and perfect information in a stable contextual setting. Clearly, such rational assumptions simply do not fit the world experienced by the practitioners involved in this research. Thus, the empirical evidence from this research pushes back and challenges the rational perspective, whilst emphasising the iterative socio-technical nature of the process of innovation uptake.

Currently there is dearth of research seeking to emphasise this headline point raised by this work. However, recent years has seen an acknowledgement of these arguments within the Project Management literature, with a call to move away from rational and logical traditions. Some academics have championed the need for Project Management literature to reconsider its approach, calling for a shift from the traditional problem solving to more of a problem structuring approaches which can be seen to resonate with these research findings ([20], [27], [28]). Pollack's on-going work [28], whilst not about advanced building skins or BIPV, resonates strongly with the reality of the stakeholders that were part of this research and the need to rethink the process of which they have become part of and how a project should be managed.

The project management literature is not alone in seeking to move the body of knowledge beyond the rational and logical. Indeed, the traditional construction management literature has begun to acknowledge and now champion the competencies required for the project stakeholders of today and tomorrow. Dainty *et al.* [21] argued that project stakeholders do not need yet more hard technical tools, models, software etc but in fact greater soft skills based around different competency models. Again, whilst such arguments don't focus upon advanced building skins or BIPV *per se*, they strongly resonate with headline findings of this research and the need to rethink how we approach projects and the skills stakeholders need.

Thus, the research points toward an increasing need to consider the building design as a whole system, where every single component which forms each assemblage which then goes to form a completed building are considered together. Currently the institutional logics of the construction sectors adversely impact the opportunities of achieving this. It is argued here that these institutional logics manifest in part as fragmentation, categorization, separation and specialisation of actors, organizations, processes and technology (which in part seek to manage the 'risks' through contracts, guarantees and penalties etc) are now a long way behind the needs of the complex technologies being developed today. In effect these institutional logics are now hindering innovative practice and the uptake of innovation on projects especially those as complex as advanced building skins and certainly BIPV. Three key findings emerged to support this assertion and these are outlined in the following sections.

7.1 Project team members and the technology

The findings support research which seeks to move away from the study of problem solving in favour of exploring the way that different project actors bring different perspectives to problem solving (problem structuring) [21]. This is often done through a process perspective aligned with socio-technical thinking and makes a new contribution in highlighting the way that these perspectives shift during the project.

Olson et al [22] argued that changes to project group membership have a direct impact upon patterns of cooperation between members. This is further compounded, when those project group members are seeking to negotiate and define a new technology (the BIPV) with competing and indeed at time changing interests in this case BIPV. This research supports Olson *et al.*[22] whilst adding to the debate emphasising fluctuations. Decision-making tended to be taken over by practical demands at key moments in time, by the decision makers involved in the project at that given time and their interests, without reflection on the implications for the BIPV system. Interestingly, there were times of relative stability punctuated by times of extreme disruption. These changes are however not occurring in a vacuum but were interrelated. Emerging changes surrounding how the BIPV was defined and understood within a given project setting. At other times the dominant power driving the uptake came from a source which was not obvious and which seemed to *rise* and then *disappear*, making the logic of decisions harder to follow, something that resonates with the challenges when studying teams experienced by Emmitt and Gorse [23]. Central to all of this, was the processual and ongoing fluidity of the members of the project team and their thinking around certain interests in shaping the technology (the BIPV). The case of BIPV challenges a number of assumptions which inform research into innovation in general and sustainable innovation in particular and certainly within a project management context. In much of the literature, innovation, product development, commercialisation and adoption are treated as distinct stages in a linear process [24]. This research demonstrates that although project management procedures often assume this linear progression, the reality is very different with significant innovation and change happening very late in the construction process.

Having discussed the points above, it is important to also see the context within which the project stakeholders are operating rather than simply placing blame at their feet. The complexity of the project and the standard project processes tended to take the attention of the project manager, client and contractors away from the generation targets of the BIPV system and privileged what has traditionally been seen as part of the golden triangle of project management, scheduling and costs of the project [25].

7.2 Friction interfaces (BIPV and other building assemblages)

The friction interfaces between the BIPV and the other building assemblages are a central point for the discussion. To be clear, friction interfaces occurs once the BIPV has become stabilised through the negotiations (already described).

The friction points where stumbled upon, and stumbled upon at unexpected points as the project proceeded. The friction points were experienced as a process, whereby unplanned mutual articulation of the BIPV assemblage and the rest of the building needed to take place. These were not however experienced in a linear, rational or logic manner, thus contradicting much of the project management tradition. Instead, the friction interfaces resonate with shifts in project management [27] and the process, on-going, iterative approach to project management and problem structuring as argued by Pollack [28]. Furthermore, analysis of the co-development of the building, with all its component technologies and parts (of which the BIPV system is just one), drew attention to the institutional logics of the sector. Especially relevant was the role of contracts, guarantees, schedules and risk in decision making and these effectively hampered the process. This resonates strongly with the constant discourse within both academia and the construction sector for improved project delivery methods based upon process thinking and moving beyond instrumental, overly generic improvement agendas and best practice recipes that have little bearing in real life situations experienced by project stakeholders [30], [31].

The points made thus far of course have real power and agency. In that the changes to the design of the BIPV system show that the system envisaged at the start is not necessarily that which is delivered. Design personnel change, the rationale for decisions is lost as project personnel change and the expertise of contractors varies hugely across the industry. Innovative technologies are particularly vulnerable to this rolling change as friction interfaces and technical understandings are unclear often leading to an unfair critic.

Key issues include product standardisation and the integration of the building process. In the UK, as long as BIPV remains a bespoke product, conflicts between project efficiency and technological performance will remain in potential tension. One way forward might be to develop a suite of BIPV systems to respond to different types of customer and building needs (for example, developing options for high generation potential, aesthetic high transparency applications, and integrated façade panels), accompanied by much clearer communication of the technical issues involved as well as of the trade-offs between different considerations.

7.3 Conflicting priorities on an uneven and shifting playing field

Finally, it is important to acknowledge the conflicting priorities of the project stakeholders with the role played by the contextual setting of the sector. A number of aspects of the BIPV system posed challenges for the stakeholders within the construction projects. These included either a failure or conflicting understandings of the fully integrated nature of the technology. This challenged the stakeholder's *modus operandi*, a finding that is understandable due to the embedded practices of the construction sector.

Traditional approaches have viewed the contextual setting of a project, firm or the sector as static, something of a blank canvas upon innovation and improvement agendas are deployed or installed on (refs). The empirical findings of this research paint a very different picture. Fortunately, more recently there has been a growing, yet still small, body of literature acknowledging and championing the fact that the contextual setting is actually an active variable, something this research resonates with strongly [30], [31], [32]. Therefore, effectively what we have is a very complex system (the BIPV) being designed on a live project, whilst at the same time influencing and also being influenced by the unfolding design of the rest of the building, all with conflicting priorities. This is occurring with changing project stakeholders, changing interests and priorities over time. Central to our understanding is this is not occurring within a vacuum. Importantly, the contextual setting of the project and the logics of the construction sector play a role.

Having accepted that the contextual setting of the project and the broader construction sector play a role, it is argued this is further complicated because that contextual setting itself is not static, but an active variable both shaping and being re-shaped by the processes undertaken [30]. Procurement methods change, planning restrictions change, available budgets change, regulations change and so on. A small group have long championed the need to see beyond the sector as a static blank canvas upon which work plans, innovation or improvement agendas are deployed, but rather an active variable [21], [30], [31], [33].

8. Concluding Comments

This research set out to understand the uptake of an ABS, namely BIPV. In doing so, the research deconstructed the practicalities of incorporating BIPV in a building project. This was done by privileging the stakeholders (including engineers and product developers) involved and looking beyond professional boundaries in order to understand the interests that formed around BIPV at different times and how negotiations unfolded given the project complexities and institutional logics of the construction sector. It was through those negotiations that the BIPV design became stabilized, forming part of the finished building. The research is timely and relevant as buildings continue to become increasingly complex and greater demands placed upon what is expected of an ABS. The research helps all stakeholders to understand the challenges and opportunities that integrating ABS into the building envelope brings and the complex processes involved.

By seeking to understand the reality experienced by a number of stakeholders involved in the uptake of BIPV the research championed the fact that the contextual setting of the broader construction sector, and its' institutional logics, conspire against the delivery of a successful BIPV system. Analysis of the case studies demonstrated several key challenges associated with the uptake of integrated technologies in construction projects. These challenges broadly fall under three banners: project processes, the evolving nature of complex system design and the locus of technical expertise. These challenges apply to the adoption of other ABS, where the integrated nature of the technology presents similar complexities.

The headline from this research is simple; all stakeholders, but especially engineers and technology developers, need to understand and push back against the institutional logics of the construction section if their envisaged innovations (in this case BIPV) are to be realised. Findings show that BIPV expertise resides in diffuse pools of different types of knowledge and rarely comes together in cohesive product development or design. Currently, engineers and product developers can design what appears to be an efficient BIPV system on paper. However, the processes through which the design must then pass for uptake to actually occur within a building *morphs* the design into something else (often lesser) than initially considered. Practitioners could focus on understanding the technology as a system rather than focussing on individual components. In the case of BIPV, like many types of ABS, there is no single product and there is no single expert. Instead, it is argued that the expertise for ABS resides in diffuse pools of different types of knowledge. A range of institutional logics (professional boundaries, contracts and so on) which shape the construction sector currently silos those diffuse pools of knowledge. This siloing allows 'issues' to slip through the cracks or creates barriers. Project managers should consider where the expertise resides, rather than making assumptions about the technology. The informal role of *systems integrator* is key in the design and installation of BIPV. This role can reside across multiple actors through a project but caution is required as it can give the false impression that someone is designing the system as a whole, whilst in fact it is evolving on an ad-hoc basis. This failure has the potential to bring innovations like BIPV under unfair criticism for underperforming or having an adverse effect on the cost, time and overall design of a building.

Finally, until technology developers understand how construction processes unfold and until construction processes take innovative integrated technologies into account, the divergence between technological benefit and project efficiency will only increase.

9. References

[1] T. Zgajewski, “The Energy Performance of Buildings: Promises Still Unfulfilled. Egmont Paper No. 78, May 2015,” 2015.

[2] M. Poole, A. Van de Ven, K. Dooley, and M. Holmes, *Organizational change and innovation processes: Theory and methods for research*. 2000.

[3] K. Pavitt, “Sectoral patterns of technical change : Towards a taxonomy and a theory,” *Res. Policy*, vol. 13, no. 1984, pp. 343–373, 1984.

[4] D. J. Sage, A. R. J. Dainty, and N. J. Brookes, “Who reads the project file? Exploring the power effects of knowledge tools in construction project management,” *Constr. Manag. Econ.*, vol. 28, no. 6, pp. 629–639, 2010.

[5] A. Wolstenholme, “Never Waste a Good Crisis,” 2009.

[6] P. E. D. Love and H. Li, “Quantifying the causes and costs of rework in construction.,” *Constr. Manag. Econ.*, vol. 18, no. 4, pp. 479–490, 2000.

[7] B. Gething, “Green overlay to the RIBA outline plan of work,” 2011.

[8] P. Boyd, G. D. Larsen, and L. Schweber, “The co-development of technology and new buildings: incorporating building integrated photovoltaics,” *Constr. Manag. Econ.*, vol. 33, no. 5–6, 2015.

[9] H. Rohracher, “Managing the technological transition to sustainable construction of buildings: a socio-technical perspective,” *Technol. Anal. Strateg. Manag.*, vol. 13, no. 1, pp. 137–150, 2001.

[10] A. M. Pettigrew, “Longitudinal Field Research on Change Theory and Practice,” *Organ. Sci.*, vol. 1, no. 3, pp. 267–292, 1990.

[11] A. H. Van de Ven, “Central problems in the management of innovation,” vol. 32, no. 5, pp. 590–608, 1986.

[12] F. Malerba, “Sectoral systems of innovation and production,” *Res. Policy*, vol. 31, no. 2, pp. 247–264, Feb. 2002.

[13] D. Sinclair, “BIM overlay to the RIBA outline plan of work,” *London, UK RIBA*, 2012.

[14] A. Van de Ven, D. Polley, and R. Garud, “The innovation journey,” 2008.

[15] A. H. Van de Ven , R. W. Rogers , J. P. Bechara , & K. Sun, "Organizational diversity, integration and performance". *J. Org. Behav*, vol. 29, no. 3, pp. 335–354. 2008.

[16] A. Van de Ven and H. Angle, “Suggestions for managing the innovation journey,” 1989.

[17] J. A. Gambatese and M. Hallowell, “Factors that influence the development and diffusion of technical innovations in the construction industry.,” *Constr. Manag. Econ.*, vol. 29, no. 5, pp. 507–517, 2011.

[18] W. E. Bijker, “How is technology made?--That is the question!,” *Cambridge J. Econ.*, vol. 34, no. 1, pp. 63–76, Nov. 2009.

[19] B. P. Jelle and C. Breivik, “State-of-the-art Building Integrated Photovoltaics,” *Energy Procedia*, vol. 20, no. 1876, pp. 68–77, Jan. 2012.

[20] L. Crawford and J. Pollack, “Hard and soft projects: a framework for analysis,” *Int. J. Proj. Manag.*, vol. 22, no. 8, pp. 645-653, 2004.

[21] A. R. J. Dainty, M.-I. Cheng, and D. R. Moore, “Redefining performance measures for construction project managers: an empirical evaluation,” *Constr. Manag. Econ.*, vol. 21, no. 2, pp. 209–218. 2003.

[22] E. M. Olson, O. C. Walker, R. W. Ruekert, and J. M. Bonner, “Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance,” *J. Prod. Innov. Manag.*, vol. 18, no. 4, pp. 258–271, 2001.

[23] C. Gorse and S. Emmitt, “Investigating interpersonal communication during construction progress meetings: challenges and opportunities,” *Eng. Constr.*, 2003.

[24] R. Rothwell, “Towards the Fifth-generation Innovation Process,” *Int. Mark. Rev.*, vol. 11, no. 1, pp. 7–31, 1994.

[25] R. Atkinson, “Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria,” *Int. J. Proj. Manag.*, vol. 17, no. 6, pp. 337–342, 1999.

[26] B. Liberatore, M. J., & Pollack-Johnson, “Factors influencing the usage and selection of project management software,” *Eng. Manag.*, 2003.

[27] L. Crawford, J. Pollack, and D. England, "Uncovering the trends in project management: journal emphases over the last 10 years", *Int J. Proj Manag*. vol. 24, no. 2, pp. 175-184, 2006.

[28] J. Pollack, "The changing paradigms of project management," *Int J. Proj. Manag*., vol. 25, no. 3, pp. 266-274, 2007.

[29] A. Pettigrew, “What is a processual analysis?,” Scand. J. Manag., vol.13, no 4. pp. 337-348. 1997.

[30] S. D. Green, G. D. Larsen, and C. Kao, (2008) "Competitive strategy revisited: contested concepts and dynamic capabilities." *Constr. Manag. Econ*., vol. 26 no. 1, pp. 63–78. 2008.

[31] S. Fernie, S. Weller, S. D. Green, R. Newcombe and M. Williams, "Learning across business sectors: context, embeddedness and conceptual chasms". In: Akintoye, A (Ed.), Proceedings 17th Annual ARCOM Conference, 5-7 September, Salford, UK, vol. 1, 557–565. 2001.

[32] C. Kao, S. D. Green, and G. D. Larsen, "Emergent discourses of construction competitiveness: localized learning and embeddedness". *Constr. Manag. Econ*, vol. 27, no. 10, pp. 1005–17. 2009.

[33] G. Larsen, “Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks,” *Constr. Manag. Econ.*, vol. 29, no. 10, pp. 987-1002. 2011.