Perspectives on the specification of Building Integrated Photovoltaic (BIPV) technology in construction projects

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PERSPECTIVES ON THE SPECIFICATION OF BUILDING INTEGRATED PHOTOVOLTAIC (BIPV) TECHNOLOGY IN CONSTRUCTION PROJECTS

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Innovative, low carbon technologies are already available for use in the construction of buildings, but the impact of their specification on construction projects is unclear. This exploratory research identifies issues which arise following the specification of BIPV in non-residential construction projects. Rather than treating the inclusion of a new technology as a technical problem, the research explores the issue from a socio-technical perspective to understand the accommodations which the project team makes and their effect on the building and the technology. The paper is part of a larger research project which uses a Social Construction of Technology Approach (SCOT) to explore the accommodations made to working practices and design when Building Integrated PhotoVoltaic (BIPV) technology is introduced. The approach explores how the requirements of the technology from different groups of actors (Relevant Social Groups or RSG's) give rise to problems and create solutions. As such it rejects the notion of a rational linear view of innovation diffusion; instead it suggests that the variety and composition of the Relevant Social Groups set the agenda for problem solving and solutions as the project progresses. The research explores the experiences of three people who have extensive histories of involvement with BIPV in construction, looks at how SCOT can inform our understanding of the issues involved and identifies themes and issues in the specification of BIPV on construction projects. A key finding concerns the alignment of inflection points at which interviewees have found themselves changing from one RSG to another as new problems and solutions are identified.. The points at which they change RSG often occurred at points which mirror conventional construction categories (in terms of project specification, tender, design and construction).

Keywords: BIPV, innovation, social groups, social construction of technology.

INTRODUCTION

Innovative, low carbon technologies are used in buildings, but the impact of their specification on construction processes is unclear. Often characterised as conservative, slow moving and resistant to change, the construction sector has been shown to be highly specialised, complex and full of innovative practice (Larsen, 2011). A key challenge for the sector is to improve innovation diffusion[2] so meeting the challenges of construction sector reform (Egan, 1998; Wolstenholme, 2009) and carbon reduction targets (Dept for Communities and Local Government, 2013).

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[2] Although the terms innovation, diffusion and uptake have separate literatures, this research considers the process of incorporation of an innovative technology on projects and the implications of this. The term innovation diffusion is used to describe that process.

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Many organisational and technical factors influence innovation diffusion (such as: policies, organisational structures and operationalization of technology), but this research focuses on the effect of innovation on the construction process. More specifically, the research explores the implications on building design and the project actors as Building Integrated PhotoVoltaics are specified and included on non-residential builds.

The research adopts a socio-technical approach and uses the Social Construction of Technology as a lens to explore diffusion of BIPV. This approach identifies groups of actors who have a shared interpretation and requirement from a technology and then explores how the requirements of different groups and of the technology itself give rise to problems and generate solutions. SCOT thus provides a basis to explore the tensions and negotiations which occur around the specification of new technology and their impact on both the design and project actors

LITERATURE REVIEW

Studies of innovation diffusion span a number of interconnected literatures. The discussion which follows draws attention to the issues of innovation diffusion within the construction sector, the need to explore of the effect of innovation diffusion on actors and the opportunity for using a SCOT approach to examine these issues.

Innovation diffusion studies

Models of innovation diffusion have been developed from simple linear S curve models (Ryan and Gross, 1943) to more complex 5th generation models (Rothwell, 1994) with iterative feed-back loops and concepts of integration. To explain the wide variations in innovation diffusion, there has been move away from these positivist stage models towards a more interpretivist view of understanding what occurs within these stages. Rogers (2004)- an innovator and proponent of innovation diffusion models, latterly stressed the emerging importance of networks and the effects of sociological interactions.

An understanding that innovation diffusion depends on a range of *"softer"* issues rather than being a linear series of events, has led to exploration of its characteristics, effects and specificity. Many studies focus on the effect of issues (like leadership, organisation and strategies) external to the technology (Dainty *et al*., 2002; Strang and Meyer, 2012), but few look at the effect of the innovation on the actors involved.

Although these areas of research draw attention to how more interpretivist issues may play a role in understanding innovation diffusion, they do not explore variations in the impact of an innovation on project actors across several firms. The project specific nature of work involving multiple firms within the construction sector suggests that the context of innovation diffusion is important.

Innovation diffusion within the construction sector

The construction sector has a very specific context involving temporary multi-disciplinary, multi-firm projects. Additionally different firms and different actors in a project may have different priorities and sensitivities (Pavitt, 1984; Malerba 2002).This makes the study of innovation diffusion in the sector particularly challenging. When considering the incorporation of BIPV within a building, the actors involved include manufacturers of panels, façade manufacturers and installers, mechanical and electrical engineers and commissioning teams. Each of these groups or individuals may be affected differently by the technology and may have different priorities in accommodating it(Dubois and Gadde, 2002). This is particularly relevant to the specification of BIPV on a project, where benefit to the client in terms of running costs or design aesthetics may represent negative impacts of unfamiliar processes and technology on the designers

Little is known about how innovation diffusion affects different project actors within a complex building project. In the incorporation of BIPV within a project, exploration of the accommodations made by inter-dependent project actors over the course of the project is complex – eg the efficiency of BIPV will be affected both by landscaping around the building (shading) and length of cable runs (losses), and architects and engineers will have to adapt their ways of working to take these into account.

In summary, the construction of a building relies on interactions between many project actors with complex relationships and dependencies. The inclusion of innovative technologies will require different accommodations in the project team and to explore how project actors accommodate the inclusion of BIPV within a project, a clear understanding of their inter-relationships and interactions is necessary.

Socio technical view of diffusion studies

Socio technical studies provide a way to understand the interdependencies and interactions between project actors and the technology on a construction project. This approach can be used to study the development of an artefact (or in the case of the incorporation of BIPV within a building project, the BIPV assemblage within the building) and interactions between groups of project actors. It has been used in the study of the construction sector: the networks involved in the design and construction of complex buildings (Valente, 2012), the tension between innovation and project efficiency (Jacobsson and Linderoth, 2010) and how differences are narrowed between project actors through interaction strategies (Dewulf and Bouwen, 2012). Soudain *et al*. (2009) explore accommodations made between project marketing and project management at the start of a project, but focus their work on a comparison of limited groups or negotiations at a particular point in a project rather than considering the project as a whole.

This research is concerned with actors, the way they interact with a new technology, how the new technology is shaped by these interactions and how that interaction impacts working practices. The approach chosen for this research is that of Social Construction of technology which looks at groups of project actors, the problems that they find with the technology and the development of solutions to accommodate these issues.

SCOT

Social Construction of Technology (SCOT) is an approach which privileges neither structure nor actors. Analysis involves interpreting the interactions between social actors and the technology under consideration. The approach has been applied to a wide range of research topics, ranging from the historic technological development of the bicycle (Bijker, 2009) to understanding decision making processes in the acquisition of IT software packages (Howcroft and Light, 2010). As a lens through which to view the incorporation of BIPV, it allows for consideration of the technical issues which the introduction of the technology raises, the relevance of those issues to the project actors, the solutions which were proposed and selected and the impact of these on both the technology and the build process. For example, when planning demands require particular generation levels, the design solutions can impact both the aesthetic layout of panels and the space required within the building for invertors.

In an early exemplar of SCOT Pinch and Bijker (1984) used the approach to identify Relevant Social Groups (RSG's) of actors who were involved in working through conflicting issues of bicycle design. Although subsequent criticism of the subjective nature of the identification of RSGs (Klein and Kleinman, 2002) showed limitations in the analysis, the approach has been strengthened through more rigorous consideration of the composition of these groups and power structures (Aibar and Bijker, 1997). Research underlines how RSGs are not made up by formal job titles and positions, but can be shared between actors from different firms and backgrounds.

Key concepts to carry forward from this review are: the notion that RSGs are composed of project actors who share a view of the technology rather than those who occupy common positions or roles, the fact that project actors do not necessarily remain in one RSG throughout the project, and that solutions develop from closing down the tensions and negotiations that occur as the project develops. These concepts inform the research which will examine the interdependencies and interactions between project actors and the technology on a construction projects.

RESEARCH DESIGN

BIPV as an artefact

BIPV technology is not fixed in format and is typically bespoke in design. It consists of several components: the photovoltaic cells which are laminated into the façade/louvre glass, connectors and wiring which take the DC generated electricity from the cell to the invertors, invertors which convert the electricity to AC and an export system which exports surplus generated electricity to the grid. Each of these components have implications for the design of the BIPV and similarly the design of the building will dictate the number of cells used, their configuration, length and location of wiring, position of invertors etc. By considering BIPV as a whole set of components, it can be considered as a technological assemblage which interfaces with the rest of the building design and so lends itself to a SCOT analysis of the issues, conflicts and resolutions which occur as the technology is accommodated within the design. When considering issues and tensions during the project, the assemblage is broken down into its several sub-artefacts eg: invertor equipment, façade configuration (brise-soleil/rainscreen), generating characteristic etc.

Interviewees, Project Actors and RSGs

For the purposes of this research three concepts must be made clear:

- *"Interviewees"* - the people interviewed for the research. They are used as initial informants to scope out the issues for a subsequent detailed analysis.
- *"Project Actors"* - project personnel mentioned by the actors during interviews and who fulfil traditional project roles. In this research it refers to generic project actors (project manager, client, design engineer etc).
- *"RSG"* - groups of projects actors who view the technology through a common frame. One project actor may belong to more than one RSG and may find themselves in a different RSG as particular issues arise.

From interviews the research identifies groups of project actors who have a shared interpretation and requirement from the technology (Relevant Social Groups). These

RSGs are distinct from the traditional project actor roles of client, supplier, project manager, QS, M&E designer etc., and are drawn up around shared frames through which they relate to the technology.

Interviewees

The three interviewees had very different perspectives and experiences of the inclusion of BIPV in projects. Their long term involvement with BIPV allowed them to comment on over 30 projects and gave insights into the accommodations made on projects when BIPV is specified. Table 1summarises their historical involvement with BIPV and the role that they currently fill.

Table 1: Characterisation of Project Actors

	Interviewee 1	Interviewee 2	Interviewee 3
Years associated with BIPV	15	30	10
Historical roles undertaken	Façade Engineer Façade Sales Manager BIPV Sales Manager	M&E Engineer Head of PV Business Development BIPV consultant BIPV Advisor to government	Head of Sustainability Initiatives Manger Engagement and project Manager
No of projects identified during interview	10	15	5-10 discrete projects 100+ related projects
Involvement with BIPV research and development	Yes	Yes	Yes
Current main project role	Supplier	Consultant	Client

Data collection

Data collection used semi-structured interviews to focus on projects that incorporated BIPV with which the interviewees had been involved and their range of experiences over those projects. The interviewees experience of BIPV over many years, in different roles within and outside their respective firms. Each interview covered the interviewee's background, involvement with BIPV and experiences on construction projects.

The purpose of the set of interviews is to identify the range of issues and decisions which might be expected to emerge in the course of a project as these inter-relationships play out amongst the project actors. Project actors mentioned during the interviews were included in subsequent analysis. Interviewees 1 and 2 (see Table 1) cross referenced each other during the interviews. The nature of interviews (and responses) allowed membership and changes of RSG's by project actors to be followed throughout the course of each interview

Data analysis

Interview transcripts were coded against an initial set of nodes using NVivo 10 software. The analytic framework for the coding was derived from a Social Construction of Technology approach.

Interviews were analysed for different interests and concerns of project actors, issues arising from the specification of BIPV on the build (both in terms of technical detail and other project actors) and the effect that these issues had on project progress. The latter included the progress of the build, and also the effect the issues had on other project actors and solutions implemented.

The interviews were used to establish an informed understanding of what is involved in the specification of BIPV on a project and how it is specified, accommodated, and actualised within construction.

FINDINGS

The use of SCOT allowed two issues to be examined: the identification of types of RSGs likely to emerge on a construction project specifying BIPV and their associated interests and the type of tensions and negotiations that occur as the RSGs accommodate the technology into the project.

One particular theme which emerged from this concerned the importance of inflection points: this refers to the reconfiguration of RSGs as the phases of the project progress.

Relevant social groups

Although not exhaustive, six RSGs associated with projects were consistently identified by the interviewees. These groups have been named as part of this research and these, together with their main interest are summarised in Table 2.

Table 2: Relevant Social Groups and their interests

RSG	Main interest of RSG
Design Aesthetes	BIPV is part of the building which is a flagship architectural design
Green Guardians	BIPV reduces carbon emissions of the building and meets planning requirements
Design Optimisers	The process of design is efficient
Generation Maximisers	The PV system generates to its maximum potential
Cost Watchers	Project costs are kept to a minimum and financial case is maintained
Users	The building is fit for purpose and the generation reduces running costs

Although all three interviewees agree that explicit understandings of the requirements and needs of different RSGs is an important determinant of successful inclusion of BIPV, a striking feature of the interviews was that they all see this as a problem. A comparison of statements by the project actors interviewed Table 3 illustrates this agreement.

Tensions and Negotiations

As projects proceed from conception to construction, tensions develop around the inclusion of BIPV. Scot analysis illustrates how these tensions, potential solutions and the resulting negotiations can shape the design and occasionally influence the technology. Three tensions are illustrated below (figures 1, 2 and 3) and the preceding extracts from interviews illustrate how RSGs identify problems with the assemblage or design and how their proposed solutions can conflict with the interests of other RSGs which results in tension and negotiation of the solution between groups. The diagrams have been simplified to highlight the dynamics of one chosen solution.

Table 3: Explicit understanding of the interests of Relevant Social Groups

	Summary	Statement
Actor 1	Establishing the requirements from the technology is key to the successful resolution of design issues.	"…do you just want to produce decentralised power, or do you want something that's part of the building fabric? …If you want just power and you've got an area of roof, stick the panels on the roof..."
Actor 2	Lack of clarity of requirements resulted in planning issues and increased costs	" it was supposed to go in as glazed roof [but] the client ran out of money so they changed it to a tin roof with some solar on. About a year later they rang up to say "the whole purpose of this building was that the roof powers the borehole, which heats and cools the building, and [now], we haven't complied with the original planning requirements. "
Actor 3	Understanding the impact of client requirements will ensure that the feature is incorporated even when it causes tension	" last year we sold three sustainable stores that had almost all singing all dancing stuff so there's definitely a market out there - a lot of pension funds, [who are] saying, "we've clients that want sustainable green portfolios "

Unanticipated Shading:
*".. Football stadia roofs are ideal … the thing is that you put all this PV in there, and it's giving you a nice bit of shading and it's giving you light, but …certain times of the year …it's also shading the grass, so the grass won't grow evenly, so they've had to alter the spacing of the panels to make sure that there is the same level of light [on the grass]…"*Interviewee 1

Figure 1 illustrates how the impact of unintended shading of the grass under the roofing area potentially impacts the shading performance of the façade configuration (part of the aesthetic appeal for using the panels) and its visual impact.

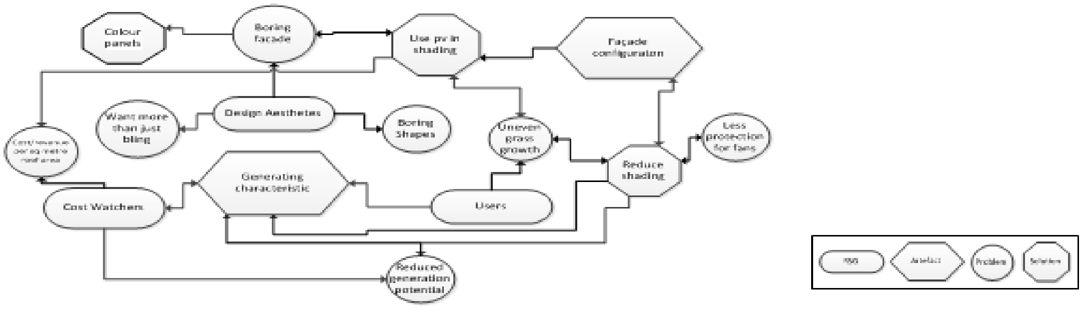

Figure 1: SCOT diagram of unanticipated shading

Three RSGs are shown, together with the problems they identify and the potential solutions. Arrows indicate how these solutions impact on the RSGs and result in tensions. The solution to reduce shading density by reducing the density of PV cells decreased the generation potential and affected project payback, but also impacted the design aesthetes. It is the ensuing negotiations that result in the ultimate solution.

Lack of familiarity with technology
"…so - where are you putting your wiring? Oh, we didn't think about the wiring. Where are you putting your inverters? Oh, do we need inverters? Really basic sort of [issues which came up] - as they were ordering stuff. The order was stopped for six weeks …" Interviewee 2

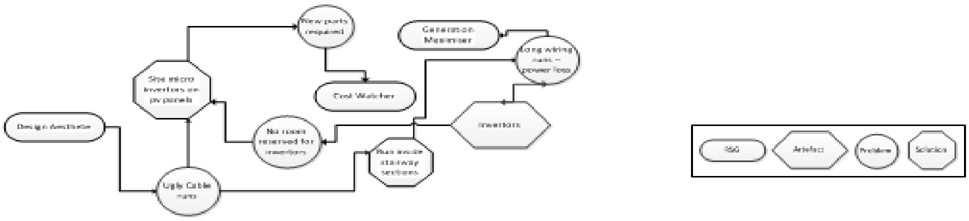

Figure 2: SCOT diagram of lack of familiarity

In this example, mapping the issues of *"invertor siting"* and *"hiding wiring runs"* (Figure 2) shows that the solution of using micro-invertors produced tensions between the cost watcher and Design Aesthetes RSGs. The lack of familiarity of problems associated with long cable runs added to the situation.

Project Sanction delays

"…So the feed in tariff changes every three months and…is it going in before the peak months or is it going in the middle of the winter when I get a kicking for saying, why didn't you do it during the summer?…" Interviewee 3

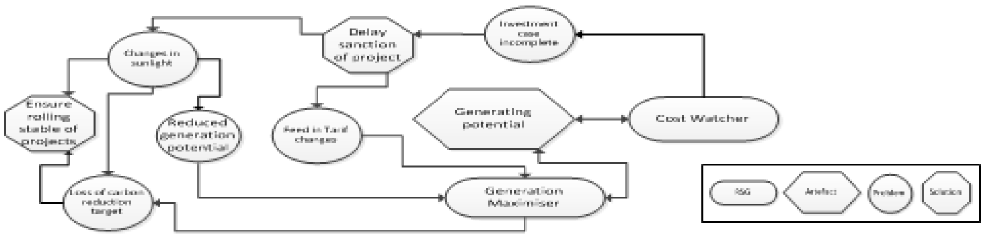

Figure 3: SCOT diagram of project sanction delays

Lack of understanding by Cost Watcher RSG has led to substantial loss of generating revenue potential through delayed project sanction. Tensions between The Generation Maximisation and Cost Watcher RSGs have brought about a solution which uses a rolling stable of projects to accommodate likely delays (Figure 3)

Inflection points

One emerging theme is that although all three interviewees find that their concerns shift as the building and technology develop (shift from concern with aesthetic to concern with costs), the points at which these concerns change often occur at stages which mirror conventional construction categories (in terms of project specification, tender, design and construction). The use of SCOT highlights how project actors change RSGs over a project's span and some of these inflection points correspond with changing phases of the project. These changes are illustrated in Figure 4 below.

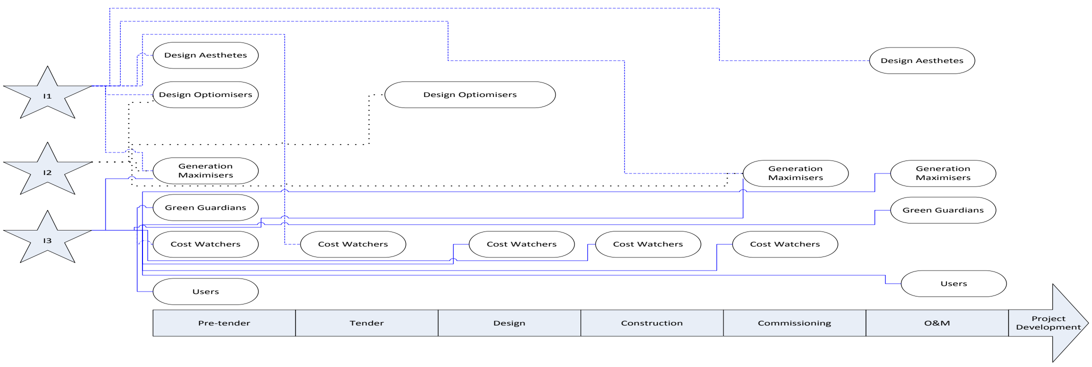

Figure 4: Inflection points of RSG composition

DISCUSSION AND CONCLUSIONS:

Rather than treating the inclusion of a new technology as a technical problem, the research explores the issue from a socio-technical standpoint to understand the accommodations which the project team makes and their effect on the building, the project actors and the technology. In doing so it identifies some of the common issues which the three interviewees have found following the specification of BIPV. Over the course of interviews, they spoke about three common types of experience:

- Accommodations forced on the design at late stages in the project due to unanticipated effects of the technology on build (shading from the configuration of the PV panels affected grass growth on the pitch and resulted in a reduction in panel spacing which negatively impacted generation).
- The unanticipated consequences of a design (the requirement to hide cables resulted in long wiring runs to the invertors, which resulted in generation loss, a new design for micro-invertors which resulted in more parts being required).
- The effect of standard firm procedures in delaying new projects which include BIPV (the standard procedure of hard negotiation of capital items resulted in delays to project sanction and loss in generation potential as the seasons changed and hours of daylight reduced).

Particular advantages of using SCOT have been to show that it is the way the project actor views the technology rather than their formal project role which brings problems into focus. This allows understanding of how RSGs become conscious of issues, how these caused tensions between the groups, and how the solutions have effects on the build, the actors and the technology.

- It has identified six RSGs which seem common to BIPV projects.
- It has shown that the composition of RSGs change over the span of the project and that this brings about changing tensions and negotiations with other members of the greater project team.
- It has been sufficiently flexible to unpack some of the issues surrounding conflicting solutions and effects on the build.

A key finding is that as groups of actors who have a shared interpretation and requirement from the technology (Relevant Social Groups) develop better understandings of the requirements of other RSG's, they begin to generate sophisticated solutions to the problems arising from the inclusion of new technology.

Further research will develop detailed analysis of specific projects to understand the accommodations made to projects, process and technology during the inclusion of BIPV, the process by which RSG membership changes, how tensions are negotiated and closed and the effect of the power hierarchy in construction projects.

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