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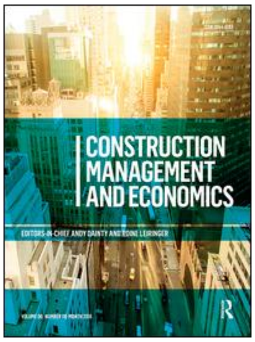

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The co-development of technology and new buildings: incorporating building integrated photovoltaics

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Current approaches for the reduction of carbon emissions in buildings are often predicated on the integration of renewable technologies into building projects. Building integrated photovoltaics (BIPV) is one of these technologies and brings its own set of challenges and problems with a resulting mutual articulation of this technology and the building. A Social Construction of Technology (SCOT) approach explores how negotiations between informal groups of project actors with shared interests shape the ongoing specification of both BIPV and the building. Six main groups with different interests were found to be involved in the introduction of BIPV (Cost Watchers, Design Aesthetes, Green Guardians, Design Optimizers, Generation Maximizers and Users). Their involvement around three sets of issues (design changes from lack of familiarity with the technology, misunderstandings from unfamiliar interdependencies of trades and the effects of standard firm procedure) is followed. Findings underline how BIPV requires a level of integration that typically spans different work packages and how standard contractual structures inhibit the smooth incorporation of BIPV. Successful implementation is marked by ongoing (re-)design of both the building and the technology as informal fluid groups of project actors with shared interests address the succession of problems which arise in the process of implementation.

Keywords: Building integrated photovoltaics, carbon reduction, innovation, project, social construction of technology

Introduction

Renewable energy technologies are seen to be a key element in the reduction of carbon emissions. Much attention has been given to the development of renewable technologies and end users (Green, 2004; Lees and Sexton, 2013). In contrast, relatively little research has explored their incorporation into buildings during construction. Building integrated photovoltaics (BIPV) technology is a renewable technology that incorporates aesthetic function with reduction of carbon emissions and as such has great potential in commercial buildings. The bespoke nature of the technology and the knock-on effects of its incorporation into a building project pose major challenges for construction professionals. A socio-technical approach is adopted to explore the incorporation of BIPV into the design and construction of commercial buildings. The analysis documents the different interests and issues shaping the ongoing co-design of both the technology and the building.

Current literature on BIPV focuses on two main areas: technical challenges of the technology and barriers to its market diffusion. Research into technical challenges has addressed issues such as performance (Sozer and Elnimeiri, 2007), reliability (Laird, 2009) and cost (El Chaar *et al.*, 2011). Most of this work focuses on formal features of the technology and its anticipated impact on energy use. Missing from the discussion is any attention to the process of incorporating BIPV into buildings. This is especially surprising given growing awareness of the professional and social challenges which sustainable construction poses for the sector (Rohracher, 2001). Current discussions underline the importance of project team integration for sustainable construction (Kibert, 2013; Swarup *et al.*, 2013). Research underlines the need for greater coordination of project team members and design features as well as early involvement of specialist engineers in the design process (Specialist Engineering Alliance (SEA), 2009); however, the accommodations required with BIPV are both broader and more subtle. The

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introduction of renewable energy technologies into buildings can complicate construction by requiring changes in building standard design and building processes.

BIPV is a low carbon technology which is integrated into the façade or roof of the building and as such has complex interdependencies with building design. In the UK, the technology is sufficiently developed to allow its inclusion in flagship building projects, but has not yet been adopted as standard practice. Most current uses involve customized versions of the product. Its interfaces with standard build elements (where it fits into the design) are clearly defined, but poorly understood. Inclusion of these technologies within a building design has implications for project actors, including: clients, civil engineers, HVAC engineers, electrical designers, installation contractors and commissioning engineers.

The successful incorporation of BIPV into a building depends on the technology itself, the building within which it is situated and the range of actors involved. This can be illustrated by considering the need for the architect (with his or her concern for building aesthetics and functionality) to take into account the effect of the depth of window recess on the efficiency of BIPV (in terms of shading from the recess falling on the photovoltaic (PV) cells). The interrelationships between the technology and the physical building and the project team interactions around them are a critical issue in the uptake of low carbon technologies in general and of BIPV in particular. This mutual articulation is under-represented in the literature and typically over-simplified.

Studying the inclusion of an innovative technology which is integrated within the fabric of a building poses several research challenges. These include: understanding different requirements which the technology and the building impose on the project team and on each other, exploring the different, sometimes conflicting interests which arise around the implementation of the technology and following how the problems and tensions which arise in the course of a project are eventually resolved and the technology is incorporated into the building. These requirements point to the need for fine-grained analysis of what actually happens when such innovations are introduced.

Social Construction of Technology

Social Construction of Technology (SCOT) explores how technology shapes and is shaped by its social context. In contrast to more positivist approaches, SCOT privileges neither technology nor actors; rather analysis focuses on the interactions between actors and the technology under consideration. The approach has been applied to a wide range of topics, ranging from the technical development of the bicycle (Bijker, 2009) to decision-making processes in the acquisition of IT software packages (Howcroft and Light, 2010). SCOT has a loosely defined method which starts by identifying the technology or artefact, considers it as an assembly of parts (a technological assemblage) and then explores how the component parts and the final assemblage develop over time. The SCOT approach presents four key concepts: relevant social groups (actors who share an interpretation of the technology), interpretive flexibility (the different meanings and interpretations of the technology for various groups), design flexibility (differences in interpretive flexibility allow multiple ways to design a technological artefact and these differences can give rise to various conflicts during design) and the technological frame (the shared cognitive frame structures the behaviours, thoughts and interactions among actors in that social group). These concepts are mobilized to develop a detailed understanding of the way technology develops and how stabilization and closure (the process of diminishing differences in flexibilities between the groups and the reaching of consensus) occur (Bijker *et al.*, 2012).

In the study of relevant social groups, actors or groups of actors who have an interest in the artefact or assemblage are identified and their interactions with the technology are examined. A SCOT analysis charts the problems which the groups identify, the solutions proposed for each problem and the mechanism by which the differing requirements are ultimately resolved.

An exemplary study which has been used as a point of reference for the method is Pinch and Bijker's (1984) exploration of how the many early bicycle designs were reduced to the single accepted two wheel model with pneumatic tyres and gear train that we largely see today. Pinch and Bijker (1984) broke down the assemblage of the bicycle into smaller artefacts (these included the pneumatic tyre, the gear assembly and the braking system) and considered the relevant social groups (RSGs, see below) of actors who were involved in bicycle design and use (for example sport cyclists, producers and women cyclists). The study worked through conflicting issues of bicycle design, explored the specific issues each group had with the technology and tried to understand the different solutions which were proposed and ultimately why they were adopted.

The loose definition of the method allows multiple ways to apply the approach to technology development and different authors have emphasized different aspects of the approach. Given that the focus of this research is on the relation between BIPV and the building, this paper focuses on the identification of relevant social groups and then begins the process of understanding the mechanisms of problem identification and resolution which arise.

SCOT and BIPV

This study applies SCOT to the uptake of BIPV. In contrast to many commercial technologies which achieve a certain degree of stabilization prior to being commercialized and diffused (or are mass diffused in distinct versions), BIPV in the UK is largely a bespoke technology which is adapted to every building. Whereas the fluidity between innovation and diffusion is often noted in the literature on innovation, in the case of BIPV this boundary is particularly pronounced. The use of SCOT to explore the uptake of BIPV highlights this continuous process of innovation.

As a lens through which to view the uptake of BIPV, SCOT privileges the technical issues raised by the introduction of this new technology, 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. In turn this analysis allows for the consideration of key moments at which the shape of the technology was determined, why this might have been and importantly, how changes to the technology affected the building design and construction process.

In the same way that the bicycle was analysed as an assemblage of parts, the BIPV technology can be broken down into discrete component parts or artefacts. These include panels, inverters, wiring and control systems. The parts of the building which are directly affected by BIPV include artefacts such as the building façade or electrical system. Each of these components has characteristics which are variously interpreted by different groups and which are considered to be part of the building itself. For example, the BIPV panel assembly forms the waterproof façade and is also part of the aesthetic quality of the building. SCOT can be used to map out how these various artefacts and characteristics intertwine and lead to problem identification and solution between groups of actors. Where BIPV is concerned, the solutions (although often technical in nature) affect both the project actors and the resulting design: shading is an issue which can affect the design for the building, the construction personnel and the generation potential.

As this brief discussion suggests, a particular strength of using SCOT to study the implementation of BIPV is that it can be used to unpack interdependent technical developments in a complex environment, by paying attention both to the actors involved and to the context in which it is developing. In this case it is the dynamic co-development of the building and the BIPV that is to be studied, rather than negotiations leading to the stabilization of a generic version of the technology (as is more usual in SCOT).

Applying SCOT

A SCOT analysis starts with the choice of a technology, breaking it down into its various artefacts (panels, inverters, wiring, etc.) and following it to identify relevant actors involved in its development. Actors who have common interests in the artefacts are identified as relevant social groups (RSGs). In the case of BIPV, these interests may include: concerns over the performance of the building (energy performance, water tightness, reliability, etc.), the future operation and maintenance of the building, etc. It is important to underline that these groups are not made up of formal job titles and positions, but can include actors from different firms and professional backgrounds (for example a client and architect may both be concerned with design aesthetics, whilst local councils and electrical engineers may share a common concern with electrical generation potential). For an illustration see Aibar and Bijker's (1997) description of the extension of Barcelona.

The approach calls on the researcher to identify the conflicting requirements which each group may have of the technology or artefact in question (for example, the architect may want a smooth appearance, whilst the design engineer needs an angled façade), the issues which arise in the development (or in this case incorporation) of the technology, and the various solutions proposed to solve each problem. This exploration of the successive definition of problems and development of solutions sheds light on how the new technology is included or absorbed into the building.

In SCOT, diagrams such as Figure 1 are used to map the configuration which forms around each problem and possible proposed solutions as the assemblage is incorporated into the building. The development of these diagrams is seen as an essential part of the analysis (Bijker *et al.*, 2012).

As Figure 1 indicates, the heterogeneous assemblage is depicted as a network of components or artefacts (hexagons) and actor groups who have particular involvements with these artefacts are added (lozenges). Problems which the RSGs identify with the artefact are mapped to the artefact (circles) and possible solutions are added (octagons). One advantage of these diagrams is that they highlight the way in which a solution which resolves a problem for one RSG creates a different problem for another. In this way the process of problem solution and technological development can be followed.

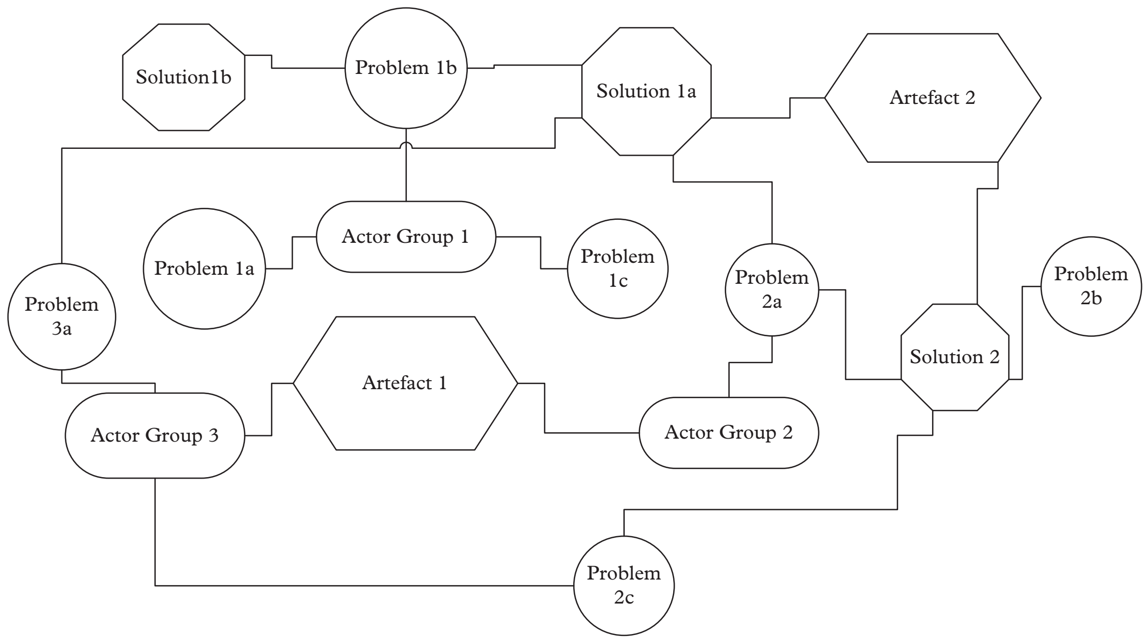

Figure 1 Generic diagram for a SCOT analysis

Research design

This paper presents a pilot study which was used both to produce an initial mapping of the challenge which construction projects face in accommodating BIPV and to develop an approach to SCOT capable of handling the complexity of the mutual constitution of BIPV and a complex building. In developing this approach the emphasis has been to focus on the types of problems and problem-solving that occur over the course of construction projects, rather than on the development of any particular bespoke version of BIPV technology. To this end, the identification of RSGs through problem identification and solution is privileged, rather than the process of stabilization and closure.

The pilot study rests on three in-depth expert interviews. Each interviewee has over 10 years' experience of using BIPV and each one identified five to 15 BIPV projects in which they had been involved. Over the span of each interviewee's involvement with the technology they had undertaken various roles in the projects and were able to give perspectives from many of these. Their long-term involvement with BIPV allowed them to comment on over 30 projects and offered insights into the accommodations made on projects where BIPV is specified. Table 1 summarizes their involvement with BIPV and the role that they currently fill.

Semi-structured interviews were used to explore interviewees' experiences on projects with BIPV. The interviews were over an hour long, rich in content and reflected the interviewees' wealth of experience in the field. Topics included the interviewees' professional trajectory and their experience with BIPV. Questions focused on specific construction projects and the involvement and interests of specific actors, rather than general observations. The purpose of the interviews was to identify the range of issues and solutions which emerged in the course of projects. Interview transcripts were coded for interests and concerns of project actors, problems arising from the specification of BIPV on the build (in terms of both technical detail and other project actors) and the tensions arising from the proposed solutions.

The coded data was used to identify RSGs and then to develop SCOT diagrams for the process of problem solution and technological development in general. Whereas SCOT generally studies the historic development of a specific artefact from inception to stabilization, the aim of this pilot study was to identify the types of themes and issues which arise in the specification of BIPV on construction projects in general.

This work will be followed up by more intensive case studies which allow for greater precision on how and when different issues arise, their management and effect on both BIPV and the project as a whole.

Findings

Relevant social groups

Six relevant social groups were identified, each with distinctive criteria, concerns and interests. These were:

Table 1 Interviewees and their experiences with BIPV

	Interviewee 1	Interviewee 2	Interviewee 3
Years with BIPV	15	30	10
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 Manager, Engagement, Project Manager
No. of projects identified during interview	10	15	5–10 discrete projects, 100+ related projects
Involvement with BIPV R&D	Yes	Yes	Yes
Current main project role	Supplier	Consultant	Client

Design Aesthetes, Green Guardians, Design Optimizers, Generation Maximizers, Cost Watchers and Users. Design Aesthetes are concerned with the look and feel of the building; they see BIPV as being an integral part of the building identity and making a positive contribution to the design aesthetics. Green Guardians are mainly concerned with carbon emission reductions and renewable energy generation. The motivation for this concern is often the meeting of planning or Building Research Establishment Environmental Assessment Method (BREEAM) requirements. Design Optimizers are less concerned with the individual aspects of the project, but are rather concerned with ensuring the design process is efficient and that details are clarified before construction starts. Generation Maximizers are concerned with ensuring that the BIPV assemblage generates as much electricity as possible, both in terms of fulfilling the planning conditions and as a contribution to reduction in building running costs. Users are the actors concerned with the final product: they require the PV system to supply electricity in a way which has no negative impact on the day-to-day running of the building. These groups, together with their main interest are summarized in Table 2.

This analysis of the RSGs involved in the implementation of BIPV reflects the methodological tenet that RSGs are composed of project actors who share a view of the technology rather than those who occupy common positions or roles. For example, on one of the projects mentioned, the main interest of the architect was that the BIPV should 'tick the Green Box' (Interviewee 1), whilst on a different project the architect required the BIPV to be an integral part of the clean lines of the building façade (Interviewee 1).

Examples from the three interviewees indicated that project actors join and leave RSGs in the course of a building project. For example, the M&E design engineer may begin as a Green Guardian RSG, but join the Cost Watchers when the project goes to site. This tendency to switch can be ascribed to changes in actors' responsibilities and interests as the project progressed. In an example reported by Interviewee 2, the M&E design engineer initially supported BIPV as part of the total sustainable design of the building and designed panels accordingly. As the project entered the construction stage and the M&E design engineer was novated to the main project contractor, cost became an issue. In his new role and in the new context, the M&E designer suggested replacing the BIPV panels with conventional metal cladding. The proposal met cost reduction targets, but totally missed the Green Guardians' targets of green generation (it also failed to satisfy planning conditions). From the perspective of SCOT, this shift can be analysed as a movement from

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 Optimizers	The process of design is efficient
Generation Maximizers	The PV system generates to its maximum potential
Cost Watchers	Project costs are kept to a minimum and financial case is maintained
Users	The system is fit for purpose and the generation does not negatively impact facilities management

one RSG to another. This example suggests that the reconfiguration of RSGs often occurs as the contractual relations between client, main contractor and subcontractors change and this can affect problem resolution.

Problems and solutions

All interviewees agreed that explicit understandings of the requirements and needs of the different parties involved in the project are an important determinant of success in the inclusion of BIPV. For example, Design Aesthetes may be on the quest for a very visually pleasing profile to the building, but may be unaware that their design jeopardizes the weatherproofing of the façade which is the main concern of the Design Optimizers. A striking feature of the interviews was that all three interviewees saw the acquisition of this shared understanding as a challenge.

Interviewee 1 underlined the importance of the project team understanding the underlying qualities of the technology and linked this to the requirements of the different project members.

> Do you just want to produce decentralized 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.
>
> Interviewee 1

In terms of RSGs, the Design Aesthetes' quest for power production to be an integral, aesthetic augmentation of the building was in tension with the Green Guardians' need to gain BREEAM points by maximizing power production with a bolt-on, roof mounted system. This suggests that clearly communicating the various RSGs' requirements from the technology is key to the successful resolution of design issues.

Interviewee 2 gave an example which illustrates what happens when the original requirement of the Green Guardians (that the building used PV to power the borehole) is lost and the concerns of the Cost Watchers prevail.

> It was supposed to go in as a glazed roof [but] the client ran out of money so they [the contractor] changed it to a tin roof with some solar on. About a year later they [the client] 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'.
>
> Interviewee 2

In this case the client's focus changed from Design Aesthetes to Cost Watcher and pressure was brought to bear on the project management team to offer solutions to meet cost reduction targets. As discussed above, conditions of planning consent were compromised and expensive rework was needed. In this instance, lack of explicit understandings of the requirements and needs of the different parties involved in the project resulted in rework and increased costs.

Interviewee 3 acknowledged that unless the requirements of the user group are understood, the short-term gains to the Cost Watchers of not including BIPV would prevent Green Guardians from developing sustainable buildings.

> Last year we sold three sustainable stores that had almost all singing all dancing stuff … [which were very hard to get through the sanction process] … so there's definitely a market out there – a lot of pension funds, [who are] saying, 'we've clients that want sustainable green portfolios'.
>
> Interviewee 3

In this example, understanding the needs of the user group (in this case future purchasers of the buildings) allowed Green Guardians to counter tension from Cost Watchers so that BIPV was incorporated into the new building design even when it appears to be an expensive addition.

These examples illustrate how different RSGs within a project can have different understandings and requirements of the technology (interpretive flexibility). It also shows how these differences can cause misunderstandings in design and construction.

The mutual articulation of BIPV and buildings

As projects proceed from conception to commissioning and construction, problems arise around the inclusion of BIPV. Three examples from specific building projects illustrate how problems, potential solutions and the resulting negotiations between RSGs shape the ongoing development of both BIPV and the building in which it is incorporated. These involved: unanticipated shading from a football stadium roof, missing equipment and lost power generation.

Unanticipated shading

The first example involved the inclusion of BIPV on the roof of a new football stadium. In this case, rather than being a standard roof mounted system, the photovoltaic panels were integrated into the roof structure and the resulting opacity used to provide solar shading for the spectators. The BIPV was designed to meet renewable generating requirements from the local authority, to use the opacity of the roof integrated PV panels to provide shading to spectators and to enhance the aesthetic appeal of the building. In this extract Interviewee 1 explained that this shading affected grass growth on the pitch and that, as a result, the spacing of the PV cells had to be adjusted to allow for even grass growth.

> 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

The interviewee went on to talk about the rework that this required and the subsequent reduction in generation potential.

The artefact under consideration in this case was the panel assembly which included the façade configuration and generating characteristic. The RSGs in this instance included Design Aesthetes (who were concerned with creating an interesting and pleasing roof construction as well as using green technology to generate electricity), Cost Watchers (who were concerned with minimizing project costs and optimizing generation potential) and Users (who were mostly concerned with the maintenance of the stadium and care of the grass). The problems and solutions which were identified between RSGs and their effect on the parts of the assemblage are illustrated in Figure 2.

As Figure 2 illustrates, the use of BIPV to provide shading as part of the façade configuration addressed the Design Aesthetes' concerns and was supported by the Cost Watchers. The User group was unaware of the impact of the solution on grass growth, but when the stadium was used this became a major problem. Shading was in tension with the visual impact of the building (part of the aesthetic appeal of the panels) and the generation potential of the façade configuration.

Faced with this problem, it was decided to reduce the shading density of the roof by reducing the density of PV cells in the roof. This decreased the generation potential of the stadium and so affected project payback, a direct concern of both Cost Watcher and User RSGs. The solution also affected the Design Aesthetes by changing the homogeneity of the design, decreasing the opacity and therefore the shading of spectators. The solution was a result of the negotiations during which the User group's need for a playable pitch was recognized by the other groups.

Missing equipment

The BIPV assemblage includes an inverter which converts the DC electricity generated by the panels to AC electricity which can either be exported to the grid or used within the building. In this example during the course of a discussion with the BIPV supplier it became clear that there has been a failure to include the inverter or necessary wiring in the design. The following excerpt highlights the issue.

> … 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

The interviewee went on to describe the implications of this omission for the design and the problems and solutions that were discussed.

Here the RSGs involved are Design Aesthetes (using BIPV panels to give green credentials to the building and to make a design statement), the Cost Watchers (interested in delivering the project on time, using standard procurement packages) and Generator Maximizers (concerned with getting the maximum generation potential from the design). The artefacts under consideration in this example are the panel assembly and the inverters. Figure 3 illustrates how problems and proposed solutions affected different RSGs.

The Design Aesthetes concentrated on the aesthetics of the design and were keen to ensure that wiring did not compromise the lines of the building. The Cost Watchers were interested in delivering the building construction in an efficient manner and used standard procurement packages to allocate work to subcontractors. They did not appreciate that the envelope subcontractor did not consider the inverters to be part of their package and the issue of inverter procurement and siting and wiring up of the panels was forgotten. This resulted in the delays mentioned by the interviewee and hasty allocation of inverter space and wiring systems.

The chosen solution to the missing pieces of equipment was to site the inverters in a cupboard. This satisfied the Design Aesthetes' requirements that wiring did not detract from the clean lines of the building, but resulted in the Design Optimizers having to devise a new wiring junction system and drilling of panel frames to pull cables from the building exterior to the inside of the building. The resulting delay in construction progress and increased costs from 'extras' were a problem to the Cost Watcher RSG and also severely compromised the Generation Maximizers' need for optimum electricity generation because of long cable runs to

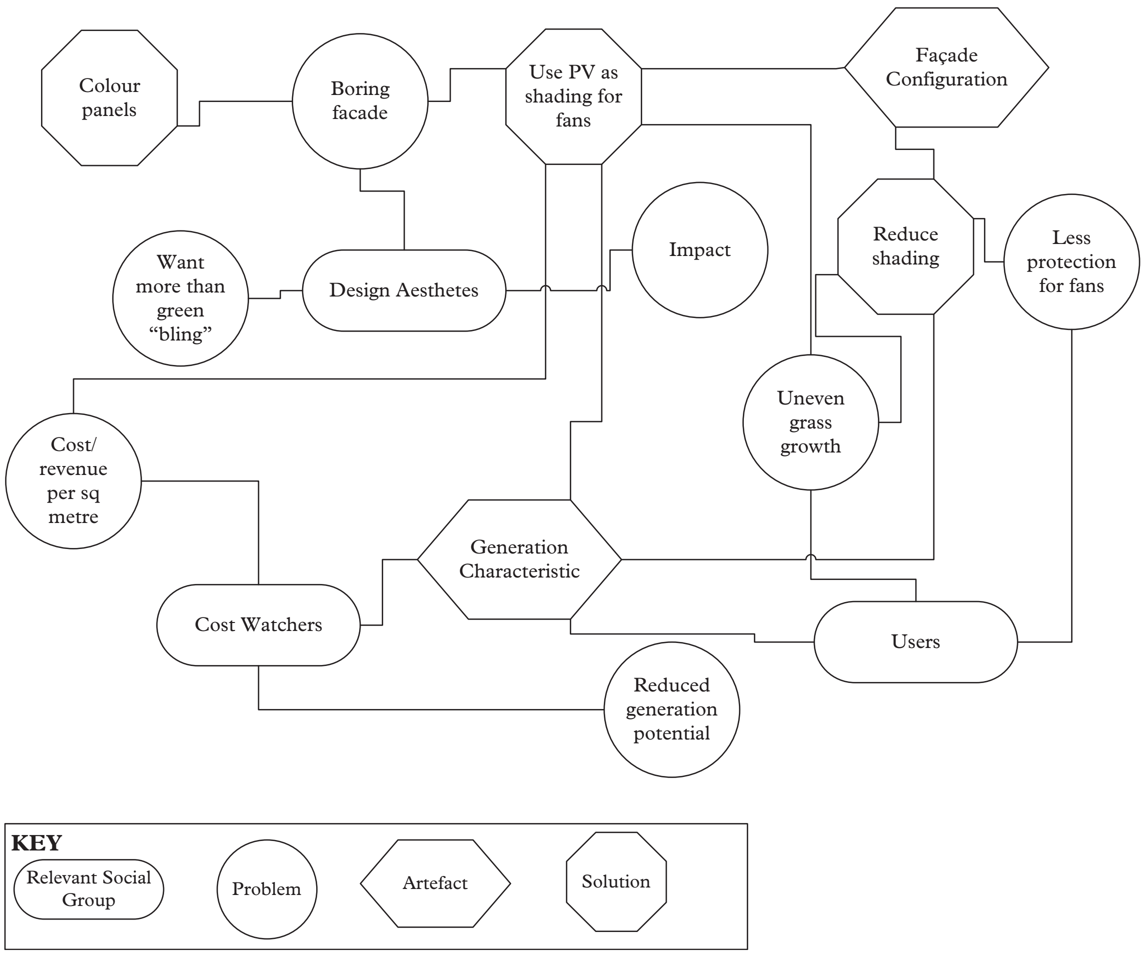

Figure 2 Diagram of unanticipated shading

the inverter. In these negotiations, the needs of the Design Aesthetes prevailed, in some part due to the client requirement for a building with green credentials.

Lost power generation

In this third example a proposal to use BIPV on a building went through the standard project approval process. The project actors in the Cost Watcher group required a more complete investment case which resulted in project sanction delays. The loss of time resulted in delays to the start of the project and this delay affected the project payback as generation from long summer hours in the first year was lost and the higher feed-in tariff window was missed.

> 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

In this vignette the two most interested RSGs were the Cost Watchers (interested in the correct and complete application of the capital project sanction procedure) and the Generation Maximizers (interested in achieving the maximum generation potential of the project proposal). The artefact under consideration was the entire assemblage of panels, inverters and wiring, and in particular its generation potential characteristic. The SCOT diagram in Figure 4 illustrates how problems arose between the two main RSGs identified and the possible solutions that were identified which could satisfy these two groups.

As the diagram indicates, lack of understanding by the Cost Watcher group of the time dependent nature of BIPV energy generation and a lack of flexibility of the client sanction procedure led to substantial loss of generation potential through delayed project sanction.

In the end the project actors in the Generation Maximizer group developed a rolling stable of upgrade projects which were timed to accommodate likely delays in the sanction process. In this case, the Generation

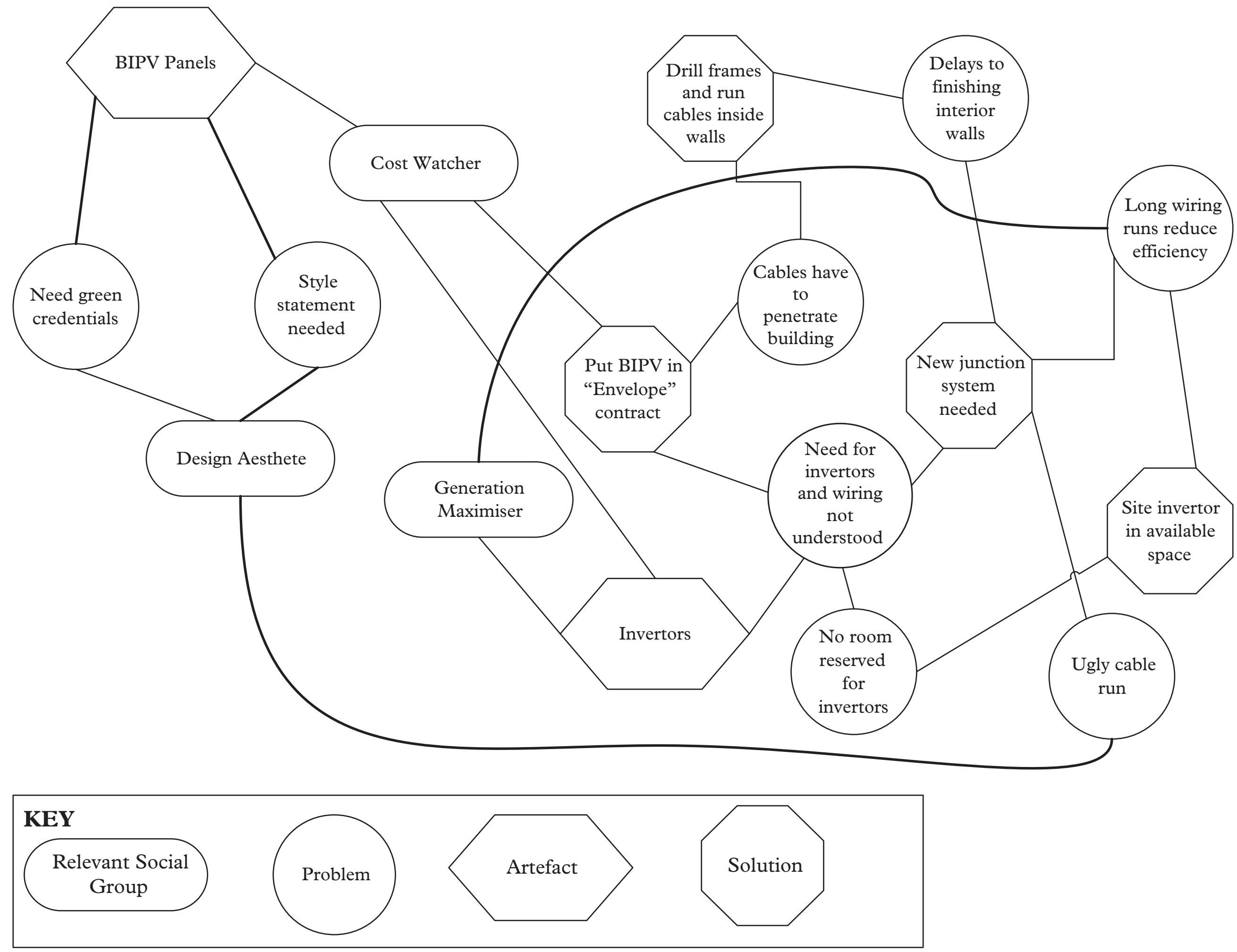

Figure 3 Diagram of missing equipment

Maximizers understood that the Cost Watchers requirement was entrenched in company procedure. Rather than negotiating a change to the company capital projects sanction procedure for projects involving renewable energy, the Generation Maximizers developed a way to fit in with the procedure whilst being able to manipulate it by timing proposals to fit in with the project sanction windows.

These three examples illustrate the tensions and negotiations that occur as RSGs try to solve problems and come to a solution. By setting out the issues in SCOT diagrams, it becomes clear how the aims and ambitions of different groups influence both the building and the technology.

Changing configuration of RSGs

One striking feature of many projects was the movement of individual project actors from one RSG to another as BIPV and the building developed together. An example of this was in a medical centre project where the planning permission for this building was linked to a particularly challenging shape of the building and very exacting electricity generation targets. At the beginning of the project, the Design Aesthetes RSG included the client(s), architect and BIPV supplier, and their main concern was the look of the building and the advantages that BIPV can give in this respect. Planning permission was initially refused but then granted on the basis of a new proposal for a complex façade and stringent generation requirements. As the project proceeded, the concerns of the architect shifted from aesthetics to the generation potential of the building which moved him to the Generation Maximizer RSG. This RSG was joined by the M&E design engineer as the ability of the technology to deliver the required power output came under question.

During pre-contract stages the main contractor also moved from the Cost Watcher group to the Design Optimizer group, as the need for pre-contract design

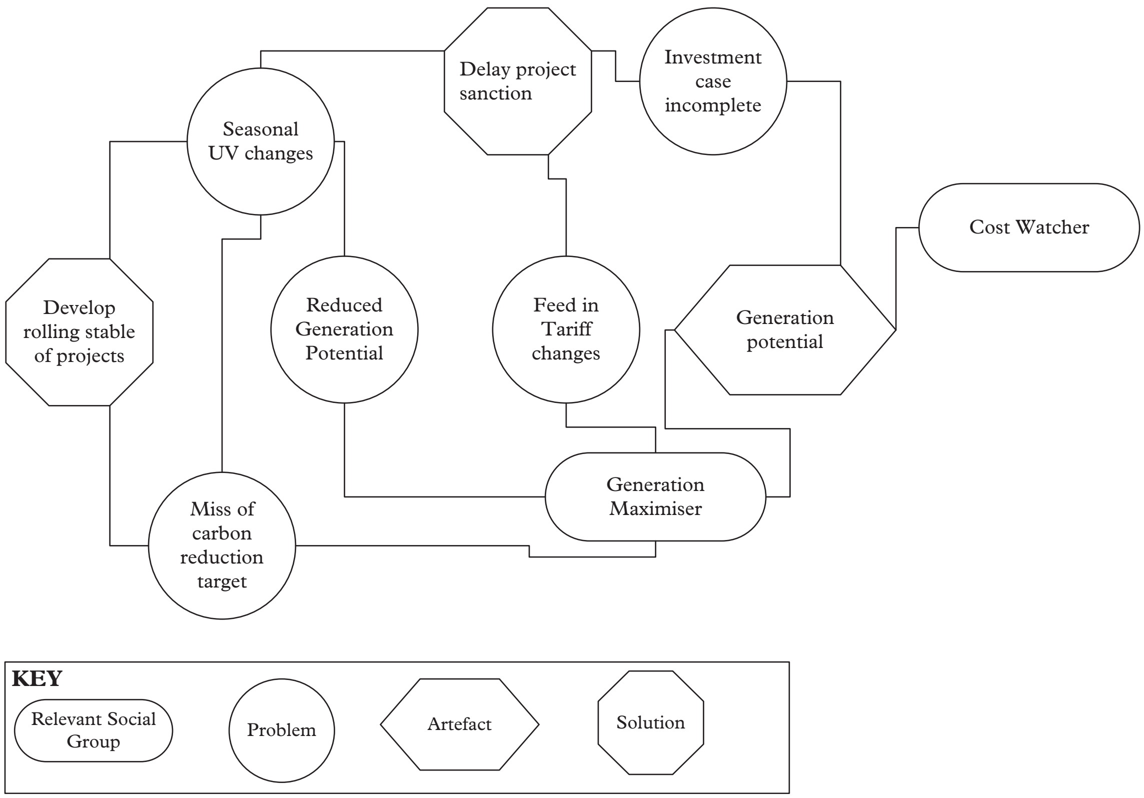

Figure 4 Diagram of project sanction delays

work on the BIPV package became evident as the best way to resolve the generation issues. Following tender and award of contracts, the main contractor once again became more closely aligned with the Cost Watchers. At this point the architect rejoined the Design Aesthete group, whilst the subcontractor, who received the panels as 'free issue' (part of the Cost Watcher group's solution), aligned with the Design Optimizers. As construction started, the actors within the Generation Maximizer group became fewer in number, but the electrical subcontractor joined the group as concerns over wiring and junctions became evident.

This description of how project actors move between RSGs as the project proceeds highlights how RSG membership is not restricted to the project actor's role, and shows how actors' interests change over time. A key factor in these changes is the change in contractual relations, but they are also linked to the co-development of the BIPV assemblage.

Discussion

Rather than treating the inclusion of a new technology as a technical problem, the research explores the mutual constitution of the building, the technology and the project actors. In doing so it identifies some of the common issues which arise during the specification of BIPV. These include:

- Late accommodations and compromises to design as a result of lack of familiarity with the technology.
- Delays and misunderstandings arising from unfamiliar interdependencies of trades within a project.
- Effect of standard firm procedures which do not allow for the specificities of the technology.

Examples of late accommodations arising from lack of familiarity with the technology are the unanticipated effects of shading on the stadium pitch, re-siting of inverters on a roof to get around problems of wiring penetrating the building façade and the hurried replacement of roof panels to allow for the interconnection with ground source heat pump. These issues forced unintended changes to the building design and/or BIPV design; in many instances the project team was unaware of the effect of the technology on the building and vice versa.

Delays and misunderstandings arise from the unfamiliar boundaries between mechanical and electrical design (both of which make up BIPV), and the need for nested design of electrical systems and building envelope design. These can be illustrated with the case of the envelope contractor being unaware of the need to include inverters in the design and in the realization on a different project that control systems supplied with the inverter package did not fit with the control system for the main building. In these cases, the BIPV technology forced accommodation of changes of practices on the project actors.

Standard firm procedures in some cases do not allow for the specificity of BIPV. As shown in the findings section, rigid project sanction procedures preclude considerations of seasonal generation potential and result in reduced electricity generation. It would seem that in some cases changes in contractual relations over the course of a project impose expectations and problems when an innovation is introduced on a building project.

The approach used to analyse the data has brought into focus the conflicting requirements and views of the project actors which remain hidden in many accounts of BIPV.

Applying SCOT to BIPV

As indicated above, SCOT defines groups of actors in terms of their interests, rather than their roles (Aibar and Bijker, 1997); the term relevant social groups refers to 'all members of a certain social group share the same set of meanings, attached to a specific artefact' (Pinch and Bijker, 1984, p. 30). From the interviews six types of meanings of the specification of BIPV were identified: Design Aesthetes, Cost Watchers, Generation Maximizers, Green Guardians, Design Optimizers and Users. The identification of these RSGs draws attention to how individual actors become conscious of issues surrounding the introduction of BIPV, how these potentially introduced tensions between themselves and groups with other interests, and how the solutions adopted impact on the building, the technology and the actors. A major methodological challenge arose around the question of whether the RSGs which developed around the incorporation of BIPV are merely groups of actors who share a common concern with BIPV or whether they share a broader set of meanings or orientation. Within SCOT a number of scholars associate RSGs with distinct technological frames which are defined as: 'the shared cognitive frame that defines a relevant social group and constitutes members' common interpretation of an artefact' (Klein and Kleinman, 2002, p. 31). It may be that the fragmented, very complex nature of construction projects, in which the same person may play multiple roles (both informal and formal) in the course of a project, favours the formation of more fluid, issue specific, temporary groups. Similarly, it may be that the relatively peripheral importance of BIPV in the social identity of many of the actors supports shifts in their interests in the technology as the immediate context changes.

The effect of contractual relations on interests

The way that the configuration of RSGs changes over the lifetime of the project seems to be somewhat related to changes in contractual relations over the course of a project. Construction projects are distinctive in the way in which individuals move between different contractual positions and this adds another layer of complexity to the process. There are similarities here with the analysis of the rebuilding of the Tjorn Bridge (Walter and Styhre, 2013), where the authors note that the innovative way the bridge was rebuilt was made possible because normal contractual boundaries and ways of working were changed.

The findings underline the way in which BIPV extends across work packages (and subcontracts) and the extensive knock-on effects of small design changes and the problems which a lack of awareness of these interdependencies pose for project teams.

Concluding remarks

This exploratory research set out to examine the co-development of BIPV technology and the building within which it sits. The research also looked at the problems which arise over the inclusion of BIPV, the solutions which are found and the negotiations which are at play. Findings support the use of SCOT to explore the complicated interrelationships between the artefacts and the actors. The analysis identified several interests and associated RSGs, together with a variety of issues.

Given the pilot study nature of the research presented in this paper, certain aspects of SCOT cannot be addressed. For example, the concepts of stabilization and closure can only be addressed with distinct case studies and the more complete studies proposed would address these and other aspects.

Two challenges in using SCOT have been identified thus far involving the definition of relevant social groups and the definition of artefacts. In addition, although using SCOT throws some issues like problems and tensions into relief, it seems to mask other issues like contractual delineations and risk allocation. These are areas which would support the need for further research. This paper rests on analysis of three interviews which covered over 15 projects. Whilst the small number of interviews and the absence of complete case studies limit the claims in this study, ongoing research will move beyond this initial analysis to more comprehensive and coherent case studies which will include the experiences of people who have worked on the installation aspects of BIPV systems.

The next stage of research has already identified three projects which use the same basic technology and interviews with a wide range of project actors are ongoing at the time of writing. This will allow for fleshing out of the co-development story of BIPV and the building and will contribute to a greater understanding of how innovative technologies within the construction sector affect the status quo.

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No potential conflict of interest was reported by the authors.

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