Unintended Consequences: institutional artifacts, closure mechanisms and the performance gap

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Abstract: Renewable technologies often feature in policies to improve the energy efficiency of buildings. Designers introduce predicted energy values for specific technologies, but are surprised when the technologies fail to perform as expected. The paper uses three building projects to explore the effect of construction processes on the energy performance of Building Integrated Photovoltaic (BIPV) technology. In two cases BIPV failed to deliver expected energy generation, while in the third, dramatic changes in project processes and technical specifications were needed to achieve the specified output. A Social Construction of Technology (SCOT) analysis documents how at certain points, the energy generation of BIPV disappeared from view as actors focused on building features. Theoretically, the paper contributes to the development of SCOT by taking on two criticisms; privileging of cognitive closure mechanisms and neglect of institutional analysis. It introduces the concept of inflection mechanisms as a second type of closure mechanism. More specifically, it draws attention to the role of institutional artifacts such as planning requirements and schedules in the contribution of construction processes to the performance gap. Lessons for practitioners concern the need to focus on distribution of design responsibility, sequencing of work, and the location of expertise.

Key words: performance gap, renewable technology, socio-technical analysis, energy performance, SCOT, closure mechanisms

Introduction

This paper is about how the best-laid plans for energy generation of renewable technologies often fail to deliver, due to a myriad of seemingly unconnected decisions and succession of unintended consequences. The construction sector is consistently identified as critical for sustainable development in general and for energy savings in particular (IPCC, 2007). While a wide range of technical solutions have been proposed (including better fabric design and renewable technologies), policy makers and sustainably minded professionals are increasingly concerned by the failure of many of these formulae to deliver on their promise (Zgajewski, 2015; Palmer, Armit, and Terry, 2016). The term 'performance gap' captures this concern. While it is generally defined as the gap between the energy performance of a building as designed and as built, the term has also come to signal a general frustration with the underperformance of supposedly green buildings. Within that conversation, renewable technologies occupy pride of place, both for their promise and for disappointment over their performance in use.

Most discussions of the performance gap focus on either energy modelling or on building occupants and their engagement with supposedly green buildings. More recently, construction professionals have begun to reflect on their own contribution to this phenomenon. A report by the Zero Carbon Hub focused on "how and where the Performance Gap occurs within the current housebuilding process" (ZCH 2014, p.2). The report identified 15 issues for priority action, 17 issues as a priority for research and 23 issues to keep an eye on, each corresponding to different stages in the building process. Stages included: concept design and planning, detailed design, procurement, construction and commissioning, and verification and testing. This paper contributes to that work by analyzing the effects of project and construction processes on energy performance of BIPV systems at handover. Whereas the ZCH report sought to develop a comprehensive list of discrete factors, mapped onto a pre-specified set of stages, this paper adopts a more holistic approach. As such it is both narrower and broader than the Zero Carbon Hub report. It is narrower, in that its focus is on a single technology (BIPV) and three building projects and it is broader in that it explores the dynamic interaction between seemingly discrete issues and considerations, project stages and the resulting performance.

The choice of BIPV for this study lies in its integrated character, such that construction professionals and building design considerations are necessarily involved in the optimization of the technology. Far from a unique characteristic, a number of renewable technologies, including ground source heat pumps and thermal mass storage systems, share this feature. To signal the physical integration of the technology into the building, the paper takes as its technical object the BIPV system and its interfaces with the building (referred to as the BIPV/building).

The paper begins from a simple question: How does BIPV come to deliver less energy than initially expected (or than it potentially could) on three building projects? In two of the three cases, the energy generation of the BIPV/building was negligible, whereas in the third it was significant, but involved significant changes to the "business as usual" project processes. The comparison across three cases serves to identify a number of construction-related considerations which affect the performance gap for BIPV in particular and building integrated renewable technologies in general.

To explore the energy performance of BIPV, the paper adopts a Social Construction of Technology (SCOT) approach. SCOT is one of a number of micro-level network theories used to explore the social construction of technology. An initial pilot study was used to develop the basic approach (Boyd, Larsen, and Schweber, 2015). The pilot study focused on the multiplicity of technological frames informing the ongoing development of BIPV/buildings. While it introduced the idea that institutional artifacts such as project schedules affected the configuration of BIPV/building, the absence of holistic case studies precluded an exploration of this suggestion. This paper draws on the findings from a much more rigorous and extensive SCOT analysis of three building projects (Boyd, 2016). Theoretically, the contribution of the paper lies in the identification of a set of inflection mechanisms which capture the way in which institutional artifacts entered into ongoing negotiations over the BIPV/building and ultimately affected BIPV performance.

The discussion below begins with a brief overview of the literature on green building and the challenges which construction professionals face. This literature underlines the importance of extra-technical considerations in the incorporation of renewable technologies into buildings. This discussion is followed by a brief overview of the literature on the performance gap and more specifically those studies highlighting the contribution of the design and construction process. The literature review concludes with a discussion of SCOT and its use in this paper. Key features include: a focus on a succession of problem/solution chains, the documentation of unintended consequences; attention to closure mechanisms; and a bounded concept of a network (which renders visible the effect of professional conventions and external requirements). For a more in-depth discussion of the difference between SCOT and other socio-technical network approaches including Actor Network Theory (Latour, 2005) and Large Systems Technical Analysis (Hughes, 1983) see Appendix A.

BIPV: background and context

Photovoltaic (PV) technology uses a suite of technologies to generate electricity from solar radiation. PV systems consist of: the PV cells which convert solar radiation into electricity; the matrix - usually glass, in which they are embedded (often referred to as "solar panels"); cables which carry the DC power from the panels; inverters which convert the DC electricity to alternating current (AC); and cabling from the inverters to the standard supply metering system. To optimise electricity generation, each part of the system must be matched. The way in which strings of cells are wired together, the sizing of the inverters and the overall length of wiring runs have considerable impact on overall generation potential of the BIPV system. Electricity from PV systems can be used to power the building where it is installed or can be exported to the grid. Photovoltaic systems are installed in two main ways: building applied photovoltaics (BAPV) and building integrated photovoltaics (BIPV). The technologies remain similar, but the challenges of their installation differ greatly (Holden and Abhilash, 2014).

Building Applied Photovoltaics are usually situated on roofs of buildings. The PV cells are mounted on top of the roof membrane and are not part of the structural element of the building. As the panels sit on the roof, often on a framework, there is little impact on the building structure and so BAPV is often installed as a retrofit technology to existing buildings. The major challenge for this technology is to maximise generation from the number and position of the panels and to minimise efficiency losses from cable runs by siting the inverter as close to the panels as possible. Contracts for BAPV installation in the UK are often turn-key and generally regarded as an add-on to the main design and construction of the building (Holden and Abhilash, 2014).

BIPV is very similar to BAPV in terms of its components, but the key distinction is that with BIPV the photovoltaic panels are integrated into the fabric of the building, rather than being placed on top of the structure. This integration into the building structure can include using BIPV in the roofs, windows, façades, louvres, brise-soleil and rain screens. With BIPV, the panels replace conventional building materials in part of the building - for example roof tiles, façade panels or window glass. The function of the panels is a combination of electricity generation, architectural aesthetic appeal and building function (in terms of water tightness, strength, durability etc.).

Unlike BAPV, BIPV has many interfaces with the rest of the building structure, which makes it both expensive (by virtue of its bespoke nature) and complicated (because of the number and type of interfaces with the building) (Henemann, 2008). In the UK, BIPV is generally restricted to commercial building projects, where each building is uniquely designed and where the adaptability of BIPV installations allows the technology to fit and contribute to the building architecture. The bespoke nature of the technology and the knock-on effects of its incorporation into a building project pose major challenges for construction professionals.

Literature Review

The need for a socio-technical approach to the study of green building and the performance gap has been widely acknowledged. Within this literature, empirical case study research has proved invaluable in exploring the practical challenges which renewable technologies pose for construction professionals. The discussion which follows focuses primarily on this work, although an overview of the literature has also been introduced, to identify the broader conversations to which these case studies contribute.

Green Building

The challenge of green building for construction professionals has been periodically noted. In 2001, Rohracher (2001) published a general statement underlining the multiple product and process challenges associated with green building and calling for socio-technical approach. Häkinnen and Belloni's (2011) study of barriers and drivers for sustainable buildings took up a similar call as did Schweber and Haroglu's research (2015) into variations in the 'fit' between BREEAM and the building process. A number of studies focus on the role of one or more key actors in achieving this aim. Gluch (2009) explored the role of environmental managers, while Parag and Janda (2014) highlighted the role of middle managers. This work has similarly been matched by professional bodies interested in promoting their members' specific contribution. The Specialist Engineering Alliance (SEA, 2009) studied the complexity of sustainable building supply chain, whilst more technical guides identify the complexity of inter-related components (e.g. BRE, EA Technology, and

Sundog Energy 2002).

In most of this work, 'green buildings' are defined as buildings which limit their negative environmental impact, generally with reference to either waste, energy and/or water; in almost all of these studies, 'integration' is seen to be the primary condition for success. A key difference between these studies lies in the kind of 'integration' problem which they identify as critical and in the associated solution which they propose. Rohracher (2001) identifies the need to integrate different stakeholders within the design process, whilst Häkinnen & Belloni (2011) espouse the importance of integrating construction processes. The Specialist Engineering Alliance used a banner of "Sustainable Buildings need integrated teams" (SEA 2009, p.1) to highlight the need for integrated delivery teams, whilst the BRE (2002) guide signals a need for the integrated design of system components. This paper introduces another type of challenge by exploring the incorporation of integrated renewable technologies. While we start with a concern for the physical integration of the BIPV technical system into the building, the approach and findings underline the interdependence of the different integration issues.

As these examples all illustrate, case study research has proved critical in developing a sector specific understanding of the challenges of green building. Contributions can be divided into a managerialist literature focused on developing frameworks, decision making tools and evaluation methods and a more exploratory literature concerned with identifying the barriers to and opportunities for 'green building'.

In terms of research approach, managerialist studies tend to involve some type of experimental research design, be it a modelling or simulation exercise. In these studies, empirical case studies provide an opportunity to develop and test management and assessment methods. For example Von Malborg and Forsberg (2003) use life cycle analysis to evaluate different heat and electricity mixes in three commercial buildings. Hassan (2006) builds on earlier attempts to integrate existing management tools, including TQM, LCA and VFM, amongst others, to develop a managerial framework aimed at supporting green building. Other studies seek to develop multi-criteria decision making tools (Langston, 2013; Matar, Georgy and Ibrahim, 2008; Shen and Walker, 2001). In these studies, the technology is treated as a fixed component which, once selected, plays no further part in the development of the building. This is clearly evidenced in the neglect of challenges concerning the introduction or installation of renewable technologies. This omission can partly be explained by a radical distinction between technical and social dimensions and a privileging of either the choice of technologies or social factors, such as communication and skills.

In contrast, empirical case studies tend to analyse of ‘real-life’ projects. A review of the literature revealed a surprisingly small number of this type of paper. Notable exceptions included Fedoruk, Cole, Robinson and Cayuela (2015), Brown and Vergragt (2008) and Albino & Berardi (2012). Each of these papers documents the complexity of both the technology and the project environment. They also draw attention to the ongoing need for fine-tuning and to the obstacles which conventional construction management processes pose. This understanding, that both social and technical issues are at play, reinforces the need for further exploration. In particular this creates a space for an approach that links the development of technology, the network of actors involved and the various decisions which shape a building project.

The ‘performance gap’

The performance gap literature differs from the work on green building in its exclusive focus on energy and in its framing of the challenge as one of “sticking to the plan”. The concept of the performance gap refers to the gap between the energy performance of a building as designed and the energy performance in use. Research into the performance gap can be divided into three categories: work on the modelling of energy performance (De

Wilde, 2014; Menezes, Cripps, Bouchlaghem and Buswell, 2012), work on building occupants and the effect of their behaviour on energy performance in use (Sunikka-Blank and Galvin, 2012; Ornetzeder and Rohracher, 2006) and a third small but growing literature on the role of building delivery (Dainty, Thomson, and Fernie, 2013; Gorse et al., 2012). Viewed from the perspective of the construction industry, the energy performance of buildings is often disappointing (Zgajewski 2015). The concept of the 'performance gap' rests on a particularly rigid, stylized understanding of the construction process. It assumes that building designs are fixed early on in the process and treats subsequent changes (and in particular those which effect the energy performance of the building) as a problem. This image contrasts sharply with the experience of construction professionals whereby design decisions continue to be made throughout the delivery process, often for very good reasons, ranging from changes in client funding and goals to unanticipated problems with the overlay of systems or procurement issues (Hanna, Camlic, Peterson and Nordheim, 2002). In this sense, the performance gap is better understood as a gap between energy performance as modelled (at a relatively early point in the design process) and energy performance in use. Moreover, performance gap studies tend to assume that the energy performance of a building is a clearly understood parameter that is at the centre of professional attention from initial concept through to the commissioning of a building, whereas in fact the target is not always clear, measureable, visible or consistent.

While the concept of a performance gap may not be straightforward, empirical research into the problem has enriched understanding of the implementation of renewable technologies. Empirical case studies show that adoption is not a simple, one-way process and this points to the need to take into account standard building practices and performance measurement (Fedoruk et al. 2015). This paper adopts the Social Construction of

Technology (SCOT) to explore the overlay of different issues and considerations contributing to the performance gap in three BIPV/buildings.

The Social Construction of Technology (SCOT)

SCOT is one of a number of socio-technical network approaches which were introduced in the 1980s (see Appendix A). While the approach has developed considerably, this paper builds on the early version. At its most general, SCOT depicts the development of a technology as a contest between different actors with different visions for its form and use. Technological development is marked by negotiations over a succession of problems and associated solutions (Bijker, 2010).

Within SCOT, acknowledgement of both the physical aspect of technologies and their socio-technical nature can be found in the analytic distinction between technical artifact (the early focus of SCOT research) and technological system, both of which figure as possible units of analysis (Bijker, 2010). Whereas 'technical artifact' sets the shifting configuration of a set of interlocking physical parts as a research object, 'technological system' takes the heterogeneous network of artifacts, meaning and people as its research object.

For the purposes of this paper, the distinction is useful as it allows for an analysis of the changing network around BIPV/building conceptualized as both a technical artifact and technological system. Analysed as a technical artifact, BIPV appears as a collection of discrete component parts, the relationship between which changes as the BIPV/building develops. Components include: panels; inverters; wiring and control systems; as well as the parts of the building which are directly affected by BIPV, such as the building façade or electrical system. It is the panels in particular which are used to estimate the energy generation potential of the technology. This paper explores the gap between initial expectations for the technology and its generation potential at handover. Analysed as a technological system, a BIPV/building is characterized by a heterogeneous network of human actors and physical and textual artifacts, which are constituted around and constitute specific project/solution chains. This model is useful as it allows for an identification of the succession of negotiations shaping the development of a BIPV/building and of the knock-on effects of one problem/solution chain on subsequent ones.

SCOT begins, like other network theories, with an assumption of 'interpretative flexibility' (Bijker, 2010). The concept refers to the multiplicity of different interpretations which are ascribed to a technical artifact. This means that for any given technological system, different actors will define the technical artifact (around which the technological system is elaborated), the problem under consideration and the range of possible solutions differently. Viewed from this perspective, a SCOT analysis focuses on how particular actors manage to impose their interests and associated problem definitions and solutions on the developing technological system.

As indicated above, theoretical generalization in SCOT tends to be around mechanisms of closure (Misa, 1992). The term points to the gradual movement from negotiations and even competition for control over the development of a technical artifact to (temporary) closure. The point is not that the development is fixed forever, but rather that at some point in time, a particular version comes to be taken-for-granted, such that subsequent changes are defined relative to that version of the technical artifact.

Initially, SCOT scholars privileged the role of understandings and meaning in the fixing of a particular technological system. One of the key criticisms of SCOT concerns its neglect of structure. In a widely cited paper, Klein and Kleinman (2002) point to the way in which social structures 'explain' why some actors and technological frames 'win out' over others. A key point for this paper concerns the attention which they draw to structural factors affecting closure. These include power and dependency relations between actors and institutional rules governing decision making (Klein and Kleinman, 2002, p.39). SCOT scholars responded to this and related criticisms by exploring the role of power (Bijker, 2010; Bijker, Hughes, and Pinch, 1987; Klein and Kleinman, 2002).

This paper, in contrast, picks up on Klein and Kleinman's (2002) second point, regarding the role of externally established (institutional) rules. More specifically, it examines the way in which those rules enter into technological systems through the medium of textual artifacts. The term institutional artifact is used to signal the grounding of artefacts such as contracts, in in broader institutional arrangements. A central argument in the paper concerns the way in which these artifacts inflect the ongoing definition of both problems and solution sets. This effect is referred to as inflection mechanisms, to distinguish it from the more cognitively driven closure mechanisms that most SCOT theorists address.

In contrast with the more familiar concepts of 'intermediary' (Latour, 2005) and 'boundary object' (Star and Griesemer, 1989), which link actors or networks together without introducing new content or weighting outcomes, 'institutional artifacts' do both. They introduce rules which have been set outside of the technological system with the explicit intent of directing ongoing negotiations. While those rules can be modified, it is only with great effort and often involves an appeal to the relevant institutional body. A key contribution of this paper and of empirical case studies more generally, is to draw attention to the numerous unintended consequences which such rules and associated artifacts produce.

In sum, the paper contributes to the development of SCOT by taking on two long-standing criticisms, namely its privileging of cognitive closure mechanisms and neglect of institutional analysis. The paper focuses on the effect of textual artifacts which figure in the course of negotiations around specific problems and solutions. While the value or content of the artifacts are produced by and through the network in which they figure, the type of artifact and taken for granted assumptions of what general form they should take are external to the network. An analysis of these effects introduces a number of often overlooked aspects of the performance gap; it also contributes to theory development by adding a second type of closure mechanism, namely inflection mechanisms, to the SCOT toolbox. For further discussion of the way in which SCOT informed the research and the difference between SCOT and other networked theories, such as ANT see Appendix A.

Methods

As indicated above, this paper uses data from a much larger SCOT analysis. Whereas that broader study explored the co-development three BIPV systems and the buildings in which they were incorporated (Boyd, 2016), the focus of this paper is on the effect of that process on the energy generation potential of BIPV. To select the cases, the first author contacted a manufacturer of BIPV laminate panels, who provided contacts for five new build commercial projects, three of whom agreed to participate in the study. As indicated in Table 1, the building projects shared certain features and differed in others. All three were commercial buildings, all three used the same laminate supplier and all three used Design and Build contracts (a procurement method which supports early contractor involvement). The projects differed in the function of the buildings, the physical component of the building into which BIPV was incorporated, and the drivers for the specification of the BIPV system (See Table 1).

Table 1: Summary of case studies

	Vogue Terrace	**Future Green**	**Vogue Terrace**
Use	Commercial Offices	Science Hub	Medical Research Centre
BIPV system	Brise-soleil louvres	Windows	Roof fins
Generation target	None	50m2	221 MWh
Planning permission	2007	2009	2010
Construction start	2014	2013	2011

Completion date	2016	2014	2016
Contract	Design and Build	Design and Build	Design and Build
Initial driver for BIPV	Sustainability commitment Modern look	Sustainability Report Funding requirement	Planning requirement (1% of building energy use from renewables
BIPV Energy generation at handover	Reduced generation	Minimal	On-target generation

Data for the study included 28 interviews and two extended e-mail correspondences, conducted between February 2013 and June 2015. For each project, a loose type of snowball sampling was adopted (Bryman and Bell, 2003); interviewees were asked for names of other professionals involved in the ongoing development of the particular BIPV/building. Sampling was considered complete when no new names were suggested (Table 2).

Semi-structured interviews were used to collect data on the co-development of each BIPV/building. The structured but flexible nature of the method allowed the interviewer to both explore the interviewees' experience and query developments identified in previous interviews (Bryman and Bell, 2003).

Table 2: List of interviewees by case study

Vogue Terrace	**Future Green**	**Synergy Court**
Position	Position	Position
Laminate Supplier: Sales Manager	Laminate Supplier Sales Manager	Laminate Supplier: Sales Manager
Architect	Architect	Architect
	Mechanical Design Consultant	Louvre Supplier Sales Manager
	Electrical Design Consultant	Louvre Supplier Managing Director
	Façade Design Director	Louvre Supplier Design Director
Façade Sales Manager	Glazing Supplier Project Manager	Louvre Supplier Project Manager
Façade Project Manager	Main Contractor Design Manager	M&E Consultant Associate Director
Façade Consultant	Main Contractor M&E Services Manager	M&E Consultant Electrical Engineer
Main Contractor Design Manager	M&E contractor Project Manager	Main Contractor Package Manager
Main Contractor M&E Manager	Site Electrical Contractor	Electrical Contractor Lead Engineer
Wiring contractor Project Manager	Client Project Manager	Client
	Lettings Manager	Planning Officer

Interviews lasted between one and two hours and were recorded, transcribed and anonymized.

Analysis initially focused on the development of detailed SCOT diagrams detailing the succession of problem/solution chains contributing to the ongoing design of three BIPV buildings. This use of SCOT diagrams is novel; it was initially used as a pilot study (Boyd, Larsen and Schweber, 2015) and mobilized in the broader research project (for further explanation see Appendix B). For the purposes of this paper, the authors focused on those problem/solution chains which directly impacted on the energy generation potential of the BIPV/building. This produced a set of four to five problem/solution chains for each case.

Each chain was then analysed for its effect on the energy performance of the BIPV system. Findings were captured in a detailed table, which is reported below (Appendix C).

This analysis led to a focus on closure mechanisms in general and the concept of institutional artefact in particular, and the table was revised to include these issues. As the discussion which follows suggests, the same set of mechanisms figured in each of the three cases, albeit with different effects. The research design was approved by the School of the Built Environment at the University of Reading's formal ethics procedure.

BIPV/building projects

This section presents each project in terms of the problem/solution chains which affected energy performance of the BIPV system. The findings document how institutional artifacts inflected the definition of the problem and the range of conceivable solutions, and the affect of these (re-)definitions on the potential energy performance of the BIPV/building system at handover.

Vogue Terrace

Vogue Terrace is a commercial office building in Central London. It 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 for project selection. BIPV technology was incorporated in the brise-soleil louvres on the south elevation of the building. The development started in the mid-2000s, with Vogue Terrace being the last of the three buildings to be constructed. 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.

Local planning requirements in 2010 did not establish particular generation targets for renewable energy; instead they called for a sustainability review which included consideration of renewable technologies. The decision to incorporate BIPV into the brise-soleil louvres on the south elevation of Vogue Terrace was presented as both satisfying these planning requirements and providing the building with an up-to-date look. At this point, the energy generation potential of the building was framed in terms of the number of louvres on the elevation of the building, rather than a specific generation figure.

During the initial design phase, the main contractor carried out a cost analysis and identified the BIPV brise-soleil louvres as a major source of capital expenditure. The client insisted that the BIPV system be retained, so the brise-soleil louvres were redesigned to increase the number of PV cells in each louvre but reduce the number of BIPV louvres. The intent was to maintain the initial design output at a reduced cost.

A key moment in the story of energy generation on the project came when the client insisted that the same contractors be used on Vogue Terrace as had been used in the previous phases of the project (which had not included BIPV). This led to a chain of decisions about who was responsible for what, which effectively masked the interdependence between the BIPV brise-soleil louvres and the BIPV wiring system.

This decision to use the same contractor locked-in the façade contractor who had no previous experience of using BIPV. Recognising their own lack of experience, the façade supplier refused to include BIPV in their tender response. To accommodate the façade supplier, the main contractor re-distributed the BIPV system across other work packages, This involved a further division of the BIPV contract into visible (the panels and bracketry) and invisible (the wiring, inverters and cabling) sections. As part of this de-coupling of the BIPV system, and in an effort to maintain profit margins for the contractor, the PV panels were free issued to the façade supplier and the electrical portion of the system was put together as a separate wiring package which was to be included in the main electrical contract for the project. As the project moved forward, project management conventions led the main contractor to issue the electrical contract work package as part of the main building electrical work package, which was after the design of the brise-soleil bracketry and frames had commenced. The subsequent refusal of the main building electrical contractor to take on the BIPV system design further blocked any possibility of integrated design of frames, bracketry, and wiring as responsibility for the BIPV wiring was further sub-contracted.

The result was that the BIPV was treated as a bolt-on installation, with a lack of integrated design. The BIPV louvres were bolted to the glazing units and the wiring was run vertically and externally up the building to the roof mounted inverters, impacting the aesthetics of the building and increasing the length of wiring runs and reducing BIPV system efficiencies. The lack of interface between the electrical contract and the BIPV contract meant that the electricity generated by the BIPV system was not part of the buildings energy management system and there were no integrated commissioning plans.

As this brief account indicates, in the case of Vogue Terrace, there were no planning requirements for energy generation, the output of the BIPV system was only roughly estimated and the actual output was never measured. The second building project, Future Green, offers a different path to the final BIPV performance gap.

Future Green

Future Green is 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 Future Green project was completed by November 2014. The project was a joint partnership between a university, the City Council and several other partners.

Future Green used BIPV to win funding from the European Regional Development Fund (ERDF), in addition BIPV was considered to make a sustainability statement and to attract tenants to the building. Minimum requirements for ERDF funding included the achievement of (at least) BREEAM Excellent and a rated Energy Performance Certificate (EPC) of at least "B". The EPC criteria for the inclusion of BIPV is expressed in square meterage of solar panels, rather than specifying energy generation in kilowatt-hours (kWh). This shift in the measurement unit focussed the project team on the physical attributes of the solar panels, rather than the electrical output of the PV system as a whole. This shift in focus was important because it signalled the moment that energy generation was no longer a key factor for the project team.

When it came to procurement decisions, reliance on pre-existing relationships masked the failure to design the BIPV system. Towards the start of the project, the main contractor apportioned work packages as though the BIPV system was "just a set of windows". The Mechanical and Electrical (M&E) engineer, with whom the main contractor had worked previously, was given the task of apportioning responsibility for the BIPV design, which he divided into two parts. Responsibility for design and procurement of the panels was assigned to the façade contract, whilst responsibility for the electrical aspect was included in the main project M&E contract for internal work. Like the electrical contract, the façade contract was awarded to a contractor with whom the main contractor had collaborated in the past. One result of this process was that the main contractor was not aware of the requirement for design portions in either of the sub-contracts and missed the failure of both contractors to design his assigned portion of the BIPV system.

During the detailed design phase the architect (who was not novated to the main contractor and therefore acted independently), asked the façade supplier to re-position the BIPV cells within the glazed units so that the cell spacings were even and aesthetically pleasing. The façade supplier deferred to the architect in this decision even though as a result of the changes, the output from the cells was reduced. The façade contractor subcontracted the glazing panels (including the BIPV) panels, assuming that they would be fitted into the façade supplier's frames on site. This division of tasks and need to keep the project on schedule obscured the need for detailed design of the BIPV cell string configuration, which in turn led to a loss of generation potential as the string configuration was not optimised.

In order to reduce the effect of glare on the south and west elevations, and in keeping with current architectural practice, the architect had designed deep window reveals in the façade without considering the effect of these reveals on the BIPV generation. From the perspective of BIPV generation, this had serious consequences as it resulted in a total generation loss when the reveals cast a shadow over any of the PV cells in a string.

The overall result was that the BIPV windows made a strong, visible "green" statement but their PV functionality was severely compromised.

Synergy Court

Synergy Court is an interdisciplinary biomedical research centre in Central London, which serves 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 and planning permission was granted in December 2010. Ground works began in April 2011 and BIPV installation began in 2014. The estimated completion date was early 2016.

Synergy Court was intended to be a flagship research centre. Local, negotiated planning requirements demanded that 1% of the electricity requirements of the building be generated from renewable technology on-site. BIPV was included in the building to meet these conditions and as part of the client's sustainability strategy. The planning requirement fixed the energy generation target to 120MWh.

An initial problem arose with the insistence of the Planning Authority that the proposed shape of the building be modified. The re-designed building shape met the Planning Authority's requirements, but it also reduced the area available for PV generation, making it difficult to meet the generation targets. A fortunate by-product of this tension was that it forced the detailed design of the BIPV system on the agenda before the main contractor put the work packages out to tender. The work packages initially included BIPV fins within the roof louvre contract and the electrical work within the general electrical contract. Because of the particularly stringent generation target, all but one of the roof louvre suppliers contacted refused to quote on the package. This led the main contractor to issue a pre-contract design order (PCSA) to one of the roof louvre suppliers for a more detailed design of the BIPV system before the tender documents were finalised.

During the PCSA the roof louvre contractor suggested an innovative re-design using micro inverters and sub collectors which would meet the BIPV generation target. The contractor also insisted that the electrical work was included within the louvre work package as a turn-key contract. The main contractor agreed and as a result generation output and the BIPV system as a whole were taken into account in each subsequent design and installation decision.

The result of this procurement decision was that the BIPV system became an integral part of the building and a flagship technology within the flagship building. The generation potential of the BIPV system was designed to meet 1% of the building's energy needs and was connected to the building's energy management system, allowing web monitoring of the electricity generated.

Discussion

The comparison of three BIPV/buildings presented above draws attention to the relevance of planning requirements, generation targets and the contractual distribution of responsibility for BIPV generation in particular and for the performance gap more generally. It also highlights the reluctance of many sub-contractors to take responsibility for the design of this new technology and the distortions introduced by the successive passing on of responsibility. Every time contractual responsibility for the BIPV system design was either divided up or passed on, the risk of invisibility and, as a consequence the performance gap, increased. A summary of these three examples lays a basis for theorization and more practical recommendations.

In Future Green the BIPV system was translated into "just a set of windows". The result was that, by the time someone thought to evaluate the energy generation potential of the building, it was too late to intervene. In Vogue Terrace, planning requirements and the client's brief initially kept the use of renewable technologies on the agenda. The client's concern for a modern look led to the choice of BIPV brise-soleil louvres. However, at a certain point, the client's preference for a general contractor with whom he had already worked and a complicated set of contractual arrangements (motivated in part by the reluctance of any of the relevant actors to take responsibility for the BIPV design) effectively removed the design of the BIPV system and energy generation from the agenda. In Synergy Court, in contrast, energy generation remained visible throughout the project. This effect can be attributed to the way in which externally imposed and challenging energy targets, together with early recognition of the challenge which this posed (in part because responsible contractors refused to take responsibility for something they could not deliver) pushed the project team to privilege BIPV system design over conventional ways of working and contending considerations.

Institutional artifacts and inflection mechanisms

From a theoretical perspective the concept of institutional artifacts captures these dynamics and their consequences for the performance gap. The term refers to (predominantly) textual objects which introduce rules or conventions into the development of the BIPV/building. Examples include: planning requirements, client requirements, cost analysis, work packages and schedules. As these examples suggest, institutional artifacts are shaped by rules or conventions, which exist prior to and independent of any particular project. Relevant rules may be formal or informal; the important point is that they are socially recognised, such that deviation from them is an active choice which needs to be justified.

The term 'inflection mechanism' points to the way in which these institutional artifacts contribute to closure. Whereas most SCOT analyses of closure mechanisms focus on closure around a technology as a whole, the focus in this paper has been on the closure of specific problem/solution chains which contribute to that broader process. Also where most SCOT closure mechanisms work through the achievement of consensus, inflection mechanisms effect technological development through their effect on taken for granted assumptions. More specifically, they affect decision making by shifting attention from one definition of a problem to another, by drawing attention to certain issues and obscuring others and by circumscribing the set of conceivable options. In contrast to cognitive closure mechanisms, their consequences are often unintended and unanticipated.

Three types of inflection mechanisms

A review of institutional artifacts at play in the three BIPV/building cases, suggests three such mechanisms. These are: the (re)-specification of the unit of analysis, the imposition of new parameters and recourse to convention. In the projects described above, these three mechanisms worked to either obscure and render visible both the BIPV system design and its energy generation potential.

The *(re)-specification of the unit of analysis* refers to the role of an institutional artifact in shifting the unit used in the evaluation of energy generation. For example, in the case of Future Green, the introduction of an EPC requirement of A or B served to substitute square meterage for KWh in the specification of installed cells. This effectively redefined the problem and eliminated the energy target. Conversely, in Synergy Court the Merton Rule (a planning requirement) fixed a kWh target for PV, protecting the energy target from attempts to unseat it. Finally, in Vogue Terrace the unit of analysis shifted from energy generation to the number of brise-soleil louvres on the South elevation. A key consequence was to shift the set of conceivable solutions from BIPV system design to bracketry and framework issues, which in turn delayed consideration of BIPV wiring design until after louvre frames and bracket design had been fixed.

The second, related mechanism involves the *imposition of new parameters*. In this inflection mechanism, institutional artifacts introduce additional parameters into the problem/solution chain. This effect can be seen in the way in which a cost analysis introduced specific budgetary constraints into what had previously been a technical discussion over energy generation in both Future Green and Vogue Terrace. The result in Future Green was to shift the range of conceivable solutions to those which met the less expensive EPC ‘B’ rating. In Vogue Terrace a parallel exercise by the main contractor, led to the free issue of BIPV louvres to the façade contractor, at the expense of an integrated technical design. Finally, in Vogue Terrace, the client’s brief introduced aesthetic considerations which primed over economic ones. More specifically, the client’s insistence on a ‘modern’ looking building ensured the retention of BIPV brise-soleil in the louvres and kept energy generation on the agenda, at least for the short term.

A third inflection mechanism involves *the primacy of conventions*, be it design conventions, project conventions or simply past practice. This inflection mechanism can be found in numerous moments in all three projects. In Future Green, scheduling conventions dictated a very short lead-in time for tendering. This in turn deprived the team of time for reflection needed to recognise and compensate for the way in which the work-packages cut across the BIPV system. The effect was that both the electrical and the facade packages failed to take into account the BIPV/building design. Similarly, in the same project, conventional guidelines for how to cope with glare for East/West facades and shading for South facing facades informed the set of conceivable solutions to the profile of the window reveals (obscuring the effect of shading on the energy generation potential of the BIPV system). Whereas in these examples, professional conventions excluded energy generation from the ongoing definition of problems and set of conceivable solution, in Synergy Court planning requirements in the form of the Merton Rule kept them on the agenda.

One of the more striking indirect effects of this mechanism concerns the way in which professional conventions shape the types of expertise available at any given point in time and mask the absence of BIPV knowledge. In Vogue Terrace, the client relied on the well tested method of hiring a general contractor with whom they had worked before. While this may have reassured the client, it also created an expertise gap. In what seems from the outside like a jumbled succession of sub-contracts and work packages, the design of the BIPV brise-soleil was passed like a hot potato from the architect to the main contract to the façade supplier to the laminate supplier to the electrical contractor and ultimately to the BIPV wiring contractor. With each pass, contractual arrangements decoupled the system design, further diminishing the possibility that the experts, when they were finally brought on the project, could salvage the energy generation potential of the BIPV system.

Similar impacts of conventions on the presence or absence of technical expertise can be found in Future Green. In keeping with convention, the main contractor relied on the M&E design Engineers to define and split up the work packages, the M&E engineers relied on the M&E and façade subcontractors to each design parts of the BIPV system, although neither had had experience of BIPV systems. The scheduling conventions of Design and Build contracts (a procurement type in which the contractor is brought on relatively early in the process and represents the client) relied on fast turnaround of the tender process which precluded detailed design of the BIPV elements and masked the effect of the deep window reveals on the energy generation potential. Each actor in the chain was convinced that the non-existent BIPV expert was in charge of the system design and that all would be well. In both Vogue Terrace and Future Green, the way in which conventions shape the types of expertise available resulted in BIPV systems being installed without ever having been designed. A complete table of these mechanisms and their effect on specific projects and problem/solution chains can be found in Appendix C.

The effects of inflection mechanisms on the performance gap

The identification of three common inflection mechanisms helps to shift the analysis of construction process and the performance gap from a list of discrete issues to an analysis of processes and unintended consequences. As the examples above illustrate, a *shift in the unit of analysis* is often the result of a new policy document or externally set directive. The contribution of this paper is to draw attention to the way in which the choice of units in client briefs and planning requirements serve to either obscure or keep energy generation on the agenda. In contrast, the *imposition of new parameters* is often more internally driven. In the three cases examined, it involved an appeal by one or more stakeholders to externally established rules and types of artifacts and was driven by particular interests. In SCOT terms, institutional artifacts were used to carve out a space for the imposition of one technological frame over another in negotiations around a particular problem/solution. While the introduction of financial or aesthetic considerations is generally explicit and even strategic, the knock-on effects of these moves for the performance gap were unintended. Finally, the *primacy of conventions* highlights the pervasive role of "business as-usual" in the adoption of new technologies. Whilst the effect of taken for granted, dominant practice has begun to be remarked and theorized in the literature on renewable technology (Lees and Sexton 2013; Fedoruk et al. 2015) and is at the centre of analyses of user behaviour (Shove, Pantzar, and Watson, 2012; Gram-Hassen 2010), it is relatively neglected in the growing managerialist literature on the performance gap. A key contribution of this paper lies in the detailed documentation of the unintended consequences of schedules, work packages, cost analyses and even reliance on established relationships.

Conclusion

The exploration of the three cases focused on the gap between early expectations for BIPV energy generation and generation as designed at the point of handover. As such, it focuses on particular (extended) moments in the production of the performance gap over which construction professionals have control (and for which they are responsible). Given the importance and promise of renewable technologies, these moments are important. Theoretically, the paper contributes to the development of SCOT by expanding the range of closure mechanisms identified from those that depend on negotiation and consensus to more indirect inflection mechanisms. These inflection mechanisms highlight the role of broader institutional arrangements on everyday decision-making and their consequences for the incorporation of new technologies whose systems cut across established conventions.

The report by the Zero Carbon Hub (2014) identified a number of discrete construction-related factors which contribute to the gap between building-as-designed and as-built. This paper builds on that systematic analysis by exploring how these different factors came together in three commercial projects. In doing so, it documents the consequences of a large number of seemingly small, independent (non-)decisions about things which ostensibly have nothing to do with energy generation on the performance of BIPV/buildings. More generally, it identifies some of the overlooked challenges involved in keeping the design of the BIPV system and energy generation on the agenda and the role of institutional artifacts such as work packages, schedules and client requirements in either obscuring or maintaining that visibility

Theoretically, the use of SCOT, and more specifically, an analysis of problem/solution chains and closure mechanisms at play, provides a basis to expand the types of closure mechanisms involved in the stabilization of new technologies and their associated networks. In addition, to the well studied cognitive closure mechanisms generally discussed in SCOT research, the paper introduces three types of inflection mechanisms. The analysis points to the way in which institutional artifacts shift the unit of analysis, introduce new parameters and introduce organizational conventions in ways which compromise the energy performance of the BIPV system as initially anticipated.

Informal conversations with colleagues and professionals suggest that the findings extend to the introduction of any new integrated technology. As scholars and policy makers are fond of saying, construction is a very complex, highly fragmented sector (Gann, 1996; Reichstein, Salter, and Gann, 2005; Fernie, Green, and Weller, 2003). The claim, which is clearly correct, is generally followed by a list of problems which this poses and a call for integration. The contribution of this paper is to explore in detail what that integration involves, at the project level. Instead of looking for who can best play the essential integrator role, the paper takes a step back and asks what gets in the way of the best laid plans (for low energy buildings). The main finding concerns the role of dominant ways of working and more specifically seemingly unrelated institutional artifacts, which privilege certain criteria over others, introduce units of analysis and contribute to the location of expertise and the sequencing of decisions. These have often, far reaching, but often unintended, consequences for the energy performance of renewable technologies and the building as a whole.

Practically, the detailed analysis of the ways in which these different considerations enter into the everyday work of developing a building suggests a list of issues which policy makers, clients, construction professionals and promoters of BIPV, integrated technology and innovation will want to take into account. These include: a systematic reflection on the fit between the system requirements of the new element and conventional divisions of labour - be it work-packages or schedules; explicit reflection on the fit and consequences of different metrics and parameters; and awareness of the unintended consequences of contractual divisions of responsibility for the location of expertise. One of the main responses to the growing recognition of the role of construction professionals in the performance gap has been to call for someone, be it the project manager or an integrator, to take ownership of energy generation and keep it on the agenda. Without weighing in on whether this needs to be one person or a more distributed responsibility, this paper contributes to that argument by drawing attention to the myriad of often apparently disconnected micro-level processes and decisions which need to be taken into account to render that role effective.

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Appendix A: Networked approaches: the specificity of SCOT

The Social Construction of Technology (SCOT) is one of a number of socio-technical network approaches to technological development which were introduced in the 1980s (Hess, 1997, p.106). Others include Hughes' Large Systems Technical Analysis (1983) and Actor Network Theory (Latour, 2005). The discussion which follows reflects on the similarities and differences between these three and the reasons for the choice of SCOT in this paper. As such it is directed at those readers specifically interested in the use of socio-technical approaches. In the interest of full disclosure, it was sparked by the comments of two reviewers, both of whom recommended the replacement of SCOT by ANT. The suggestion that research produced with one approach could be reported using another one was disturbing and led to this reflection on the differences between networked approaches and the way in which SCOT informed the production of the data and argument.

Large systems technical analysis, ANT and SCOT share a critique of both economic and technological determinist approaches and an associated assumption concerning the heterogeneity of the research object. Technologies are analyzed as a network of artefacts, meaning, people and practices, such that the same physical artefact in two different settings is a different socio-technical object. In their early versions, all three approaches focused on the problem of how to account for technological development. Where they differed was in the concepts which figured in their network models and in their relative emphasis on stability vs. fluidity, the role of structure and the nature of agency. For example, Hughes' work examines national electric power systems over long historical periods of time. Its focus is on how these systems came to assume one form rather than another and on their internal dynamics. Agency in Hughes' account is located in the socio-technical system and in the momentum which they demonstrate, once configured.

ANT, in contrast, focuses on the way heterogeneous networks constitute human and non-human actors. Actors, in ANT, do not exist independent of the network in which they are constituted and agency is distributed across the network rather than being associated with a particular actor. Physical artefacts figure in the analysis either as actors in their own right or as intermediaries, linking actors into an ever changing network. Whereas Large Systems studies privilege structures and their effects, ANT focuses on the fluidity and messiness of socio-technical life. It rejects the attribution of characteristics to actors or objects, independent of the socio-technical networks in which they are constituted. Finally, it rejects explanation in terms of "external" structures (since in ANT there is no internal/external divide). In ANT, technological development involves the ongoing transformation of both society and technology.

In contrast, SCOT offers a model of technological development as driven by networks of (pre-existing, but changing) actors and artefacts which come together around the definition of problems and solutions, leading to the development of a technology. Unlike ANT, SCOT networks have boundaries, such that they can be represented in diagrams. Differences in interpretation are often ascribed to the actors' broader social position and associated interests. Theorization in SCOT focuses on the processes of closure and stabilization (in comparison with ANT which privileges the openness and fluidity of both the social and the technical). The concept of closure refers to the point at which a particular version of the technology is accepted (by the actors involved) as fixed. In early versions of SCOT, this depended on cognitive consensus as to the meaning and physical attributes of the technology.

Curiously, the difference between these analytic approaches was far more pronounced in the 1980s than it is now. Each one has expanded to address new research problems, blurring the boundaries. ANT scholars have begun to pay more attention to the stabilization of networks, while SCOT has expanded its focus to include the role of 'technology' in the constitution of society. Similarly, a number of studies either treat the different approaches as one or combine them in a single theoretical framework (Pont and Thomas, 2012, Bruun and Hukkinen, 2003, Howcroft and Light, 2010).

This paper adopts the opposite approach by privileging those features of SCOT which distinguish it from other networked approaches. The claim here is not that SCOT is more "realistic"; to the contrary, this paper follows (Bijker, 2010) in parking ontological questions at the door. Analytic concepts are treated as tools to explore empirical phenomenon. They draw attention to certain aspects and obscure others. From this perspective, the choice of approach depends on (and, of course, informs) the research question. SCOT was selected as well-suited to the study of the ongoing reconfiguration of a renewable technology and building design as a way of explaining the shape of three BIPV/buildings at the moment of handover, with implications for the predicted energy performance of BIPV. While not anticipated, the choice of SCOT also drew attention to the role of externally fixed artifacts in each of those stories. Thus, while the particular requirements for BREEAM or work-package divisions were specified by actors within the network (and thus internal to it), their form, availability and use depended on broader societal commitments which had been solidified prior to the project and which extended beyond its lifetime. For the purposes of this reflection, it may be worth noting that this argument could not have been produced using ANT, which does not allow for an internal/external divide.

In evaluating the choice of SCOT, relevant issues concern the skill and consistency with which the analytic concepts and associated assumptions are applied and the fit between the question and the answer, not the intrinsic superiority of one approach over the other. As Bijker is careful to specify, "These statements are not ontological, implying a realist existence of artefacts without human and social processes (or, alternatively, a phenominalist existence as sense data or an idealist existence as ideas). They are theoretical propositions making claims about how the development of artefacts in relation to social processes is best understood" (Bijker, 2010, p.68). For proponents of ANT who prefer a post-human approach, it is worth noting Gingras' (1995) observation of the extent to which ANT scholars slip back into a social technical distinction when (conducting and) writing up their research. For a by now classic debate within science studies about these issues see (Callon and Latour, 1992, Collins and Yearley, 1992, Bloor, 1999, Latour, 1999).

Theoretically, the paper contributes to the development of SCOT by taking on two long-standing criticisms, namely its privileging of cognitive closure mechanisms and neglect of institutional analysis. Bijker in his analysis of closure identifies two key mechanisms: rhetorical closure and closure through redefinition (Bijker et al., 1987), both of which are cognitive and actor driven. The empirical analysis in this paper is used to suggest a different type of closure mechanism, which is grounded in structure external to the network and tacitly driven. More specifically, the paper documents the role of institutional artefacts in the subtle inflection and deflection of problem/solution definitions, with significant consequences for the energy performance of the BIPV/building in each case. As such it builds on Pinch's own call on SCOT to focus on the "mundane embeddedness of technologies" and his interest in co-existence of different interpretations (Pinch, 2010). While this approach would seem to converge with ANT (as one would expect, given the networked, socio-technical character of the two approaches), it differs in the distinction between internal and external network arrangements and in the associated location of the identity of actors and artefacts, outside of the socio-technical network in which they are engaged.

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Appendix B: The use of SCOT to analyse the co-development of BIPV and a building

This appendix gives a detailed account of the analysis used in the early stages of the research. The account follows on from the selection of case studies and semi structured interviews which were highlighted in the main text.

In each case study, analysis followed the same steps. For each case study, starting with a project stage (initial design, pre-tender design, tender, detail design, installation etc.) a search was made using the NVivo software and all examples of problems which occurred during that stage were identified. SCOT diagrams for each stage were then constructed, with consideration given to those artifacts, technological frames (Bijker, 2012, Boyd et al, 2015), problems and solutions which had been discussed in the interviews. These diagrams reflected: the dynamics between actors in each technological frame; the problems which arose; and the solutions which were adopted.

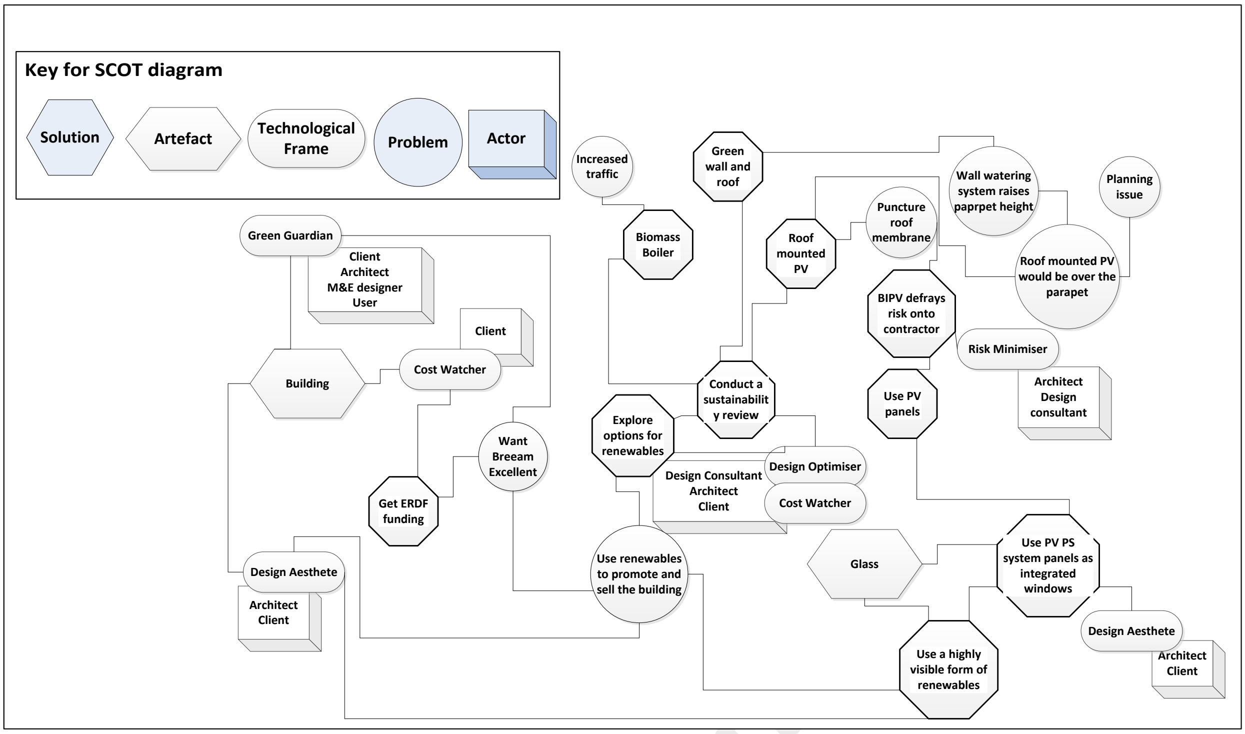
As analysis proceeded, it became clear that the constitution of technological frames changed over time and that adding a note of which actor mobilised which frame at each time would allow for exploration of this dynamic. In a departure from the recognised outline method (Bijker, 1999), technological frames were used in SCOT diagrams rather than the more usual RSGs and the actors within each of these frames at any moment were also noted. Table 3 shows the technological frames identified and summarises the main interests of actors mobilising the frame.

Table 3: Technological Frames

Technological Frame	Main interest of actors who mobilised the Technological Frame
Design Aesthete	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 Optimiser	The process of design is efficient
Generation Maximiser	The PV system generates to its maximum potential
Cost Watcher	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.
Time Sentry	To keep the project running on time
Risk Minimiser	Prevent risk in the form of warranty claims, broken contracts or poor performance

Each project stage was explored, until a complete map of the project had been drawn up as an exhaustive series of SCOT diagrams. Figure 2 exemplifies a SCOT diagram, which for the initial design phase of Future Green. The diagram shows the interlinking chains of problems and solutions, together with the technological frames mobilised and the actors who were part of the frame during each stage of the decision making process.

Figure 1: SCOT diagram of initial design phase Future Green



Problem/solution chains which were related to generation potential were extracted from the SCOT diagrams and these chains were used in the further analysis outlined in the main text.

Appendix C Inflections mechanisms: how institutional artefacts shape problem and solution chains and energy performance

Future Green

Problem/solution chain	Type of institutional structure	Project specific requirement (as specified in institutional artefact)	Effect of IA on the ongoing redefinition of problems and solutions	Effect of problem/solution chain on energy performance	Involvement of IAs in closure
50m2 BIPV	Planning requirements Funding requirements Cost analysis	A sustainability report EDRF Funding BREEAM excellent EPC A or B Costings assigned to EPC A and B	Identification of renewable options (client chose PV) Specification of energy performance in terms of Meters squared Expands definition of EPC 'A' and 'B' from a technical set of options to a cost AND technical set of options.	No energy generation target Frame problem in terms of meters squared (vs KWHs); design of BIV system reduced to a question of how to fit 50 sq meters of cells into windows. Redefines possible solutions in terms of energy AND cost Result: Settles for EPC B rating (50 Meters squared)	(Re)-specification of the unit of analysis Imposition of new parameters (energy in sq meters and cost)
Treatment of BIPV as "just a set of windows"	Project management – scheduling conventions Project management – division of tasks Project management – criteria used in invitations to tender (and in award of contracts)	Lead in time for tendering in project schedule Work packages Informal preference for past collaborators	Insufficient time to recognise the need for an integrated work package for BIPV BIPV design split into electrical and facade packages (decoupling of BIPV system design and installation)	Main contractor does not take time to recognise the integrated nature of BIPV components and the need for integrated design. Design requirements for BIPV system within work packages not identified by contractors. Lack of	Primacy of conventions (project conventions over substantive considerations e.g. technical, aesthetic etc.) Primacy of conventions (distribution of expertise privileges certain parameters and obscures others)

			Use of contractors who lack BIPV knowledge and skill.	specialist knowledge and skill precludes BIPV system design	
Positioning of cells in window integrated BIPV	Contractual structure – grants significant decision making authority to the architect	Architect not novated (acting client representative; independent from the main contractor and from engineering specialists)	Façade supplier and architect re-position cells wholly on the basis of aesthetic criteria. Façade supplier defers to architect (fails to inform architect of energy performance implications)	Loss of generation potential owing to sub-optimal spacing between cells	Primacy of conventions (contractual structures empower certain actors over others)
Configuration of PV cell strings in PV panels	Project management – division of tasks Project management – scheduling convention	Sub-contracted work package (façade w/BIPV glazing) Time allocated for façade delivery	Façade design split into façade and glazing (omission of BIPV string configuratio n) Time pressure obscures technical issues	Keeps focus on façade delivery rather than BIPV output and delivery Losses in generation potential as string configuration not optimised	Primacy of conventions (project conventions over substantive consideration s)
Shading of PV cells by deep window reveals	Design conventions/standar ds	Guidelines for how to cope with glare for East/West facades and shading for South facing facades	Architec t focused on profile of window reveals (and not on the effect of shading on PV cells).	Total generation loss when reveals cast a shadow on any of the PV cells in a string	Primacy of conventions (design conventions over technical consideration s)

Synergy Court

Problem/solution chain	Type of institutional structure	Project specific requirement (as specified in institutional artefact)	Effect of IA on the ongoing redefinition of problems and solutions	Effect of problem/solution chain on energy performance	Involvement of IAs in closure
Specification of energy generation target	Planning requirements	Merton Rule	requirements for 1% of the electricity requirements of the building be generated from renewable technology on-site	The kWh target for PV was fixed	(Re)-specification of the unit of analysis (kWh)
How to design x kWh of output	Planning requirements Project management process convention	Building design requirement – to fit in with surroundings Specification of generation target Under-specification of BIPV system in tender bids for louvre contract Pre contract Service Agreement (PCSA)	Rejection of the initial building design posed problems for meeting Merton Rule requirements Made generation target non-negotiable Passes the problem of BIPV design on to the louvre contractors Gave recognition to and time for detail design	Focused attention on achieving electricity output from BIPV system Forced main contractor to pay attention to BIPV design Keeps energy target visible Forced very early detailed design Encouraged innovation Kept generation potential on target	Primacy of conventions (planning requirements over project conventions e.g. budget and schedule) Primacy of conventions (contractual structures empower certain actors over other)
How to achieve generation target (technical solution)	Planning requirement Project management process convention	Merton rule PCSA PCSA	Kept focus on output Gave louvre supplier authority to suggest turnkey (override conventional work package division) Predisposed main contractor to accept new work package as turnkey project to deliver	Louvre supplier insisted that the electrical work was included within the louvre work package as a turnkey contract Continuity in design and procurement ensured that generation output was considered for each design decision	Primacy of planning requirements over project conventions (budget and schedule) Primacy of conventions (contractual structures empower certain actors over others)

			BIPV		
How to demonstrate achievement of generation output	Project management – division of tasks	Work package Contract details	Maintains focus of louvre supplier on measuring and monitoring BIPV output	Opportunity for innovation in web monitoring Connected to the building's energy management system, allowing web monitoring of the electricity generated	Primacy of conventions (contractual structures: formal specification of responsibility e.g. ownership of the problem)

Vogue Terrace

Problem/solution chain	Type of institutional structure	IA and associated project specific requirement	Effect of IA on the ongoing redefinition of problems and solutions	Effect of problem/solution chain on energy performance	Involvement of IAs in closure
Choice of renewable energy technology	Planning requirements Client requirement	A sustainability report Client brief: visible green credentials (modern look)	Identification of renewable options Preference for external manifestation of renewable technology - client chose BIPV louvres.	PV was specified on Vogue Terrace Decision to use BIPV in louvres rather than PV Energy generation output is linked to the number of louvres in external façade.	Imposition of new parameters (energy in kWh and aesthetics)
How to control escalating costs	Client requirement Cost analysis Project management process (from client requirement to design brief)	Client brief: visible green credentials (modern look) Project budget – reduce estimated costs for client. Design brief - generation target for BIPV	Retention of BIPV brise-soleil (in louvres) despite cost Re-design of BIPV/louvres: increase the number of cells per louvre to reduce the total number of louvres Maintains focus on quantitative aspect of design in terms of numbers of cells	Inclusion of BIPV louvres is non negotiable Retained original total generation potential (despite cost cutting and redesign) Reduces numbers of louvres, but keeps target generation output	Imposition of new parameters (client aesthetic concerns plus energy target in kWh)
Contractor selection	Client requirement	Client brief – specified contractor based on existing relationships (rather	Use of contractors who lack BIPV knowledge and skill	BIPV system design is sub-contracted out, with difficulty (a number of firms refuse to take on the	Primacy of conventions (Client preferences for past collaborations over BIPV

		than BIPV competence)	Contractor refuses to include BIPV in work package	risk)	system design and procurement) .
Work packages – how to get BIPV system designed and supplied.	Project management – division of tasks Project management – scheduling conventions Cost analysis	Work packages Priority to “let” façade package before electrical package Improve project margin for main contractor.	BIPV design split into electrical and facade packages (decoupling of BIPV system design and installation) Electrical package includes BIPV wiring (see below) Free issue BIPV louvres to façade contractor	Division of the BIPV contract into visible (the panels and bracketry) and the invisible (the wiring, inverters and cabling) sections Late design of wiring system, obscuring interdependence between louvre and wiring design. BIPV considered as bolt-on louvres to façade Lack of integrated design	Primacy of conventions (contractual structures: formal specification of responsibility leading to decoupling of system design)
Work packages – how to get wiring for BIPV system designed and delivered.	Project management – scheduling conventions Contractor practices/norms	Work packages – grouping all electric work in one package	(background: main electrical contractor refused to take on BIPV wiring; separate work package issued for BIPV wiring) Delay in consideration of BIPV wiring design until after louvre frames and bracket design	Late design of BIPV wiring and associated system losses BIPV treated as a bolt-on technology; decoupling of BIPV system design No interface between two electrical contractors No integrated commissioning plans	Primacy of conventions (project conventions over substantive considerations e.g. integrated BIPV/building design Primacy of conventions (distribution of expertise privileges certain parameters and obscures others (hid need to integrate wiring and louvre

					bracket design))