The Challenges of Accommodating New Technology in Construction

Philippa Boyd
University of Reading, UK
email: n.j.p.boyd@pgr.reading.ac.uk
Graeme D Larsen
University of Reading, UK
email: g.d.larsen@reading.ac.uk
Libby Schweber
University of Reading, UK
email: l.schweber@reading.ac.uk

Abstract

The construction sector has a major role to play in delivering innovations to achieve UK low carbon energy targets and this research will contribute to understanding challenges that arise on building projects when new technology is included in the design. Innovative, sustainable technologies are already available for use in the construction of buildings, but their integration within construction projects is patchy. One of the factors potentially holding back this integration is the complicated collaboration and adjustments required between the many actors working on a single project. This research seeks to explore the accommodations made by a network of project actors when interacting with a new technology.

The research presented is part of a larger project which uses a Social Construction of Technology approach (SCOT) to understand the challenges of incorporating new technology into buildings. Drawing on case studies, the research explores the different accommodations made to both building design and project practices by multi-firm actors as an innovative technology is included within a building project. The case studies follow Building Integrated PhotoVoltaic (BIPV) technology as it is incorporated within building projects. The research focuses upon the dynamic interactions between actors, innovation and the building as a whole.

Empirical data is gathered at key project stagesfrom actors who are either directly involved with or affected by the introduction of the BIPV into the project. The paper situates the problematic in the literature of innovation diffusion and sets out the research objectives, theoretical lens and research design which inform this research. Although the research is on-going, initial emerging themes of the research are highlighted illustrating the complexity of the process. It is anticipated that the key findings of the research will illuminate how actors negotiate the challenges of adopting the new BIPV into the building project and what effects these have both on the final building and on the project actors working practices.

Keywords: accommodations, innovation-diffusion, projects, Social Construction of Technology, sustainable technology

1. Introduction

Often characterised as conservative, slow moving and resistant to change, the construction sector has been shown to be highly specialised, complex and full of innovative practice (Larsen, 2011). A key challenge for the sector is to improve innovation diffusion[1] thereby meeting the challenges of both construction sector reform (Egan, 1998; Wolstenholme, 2009) and carbon reduction targets (Dept for Communities and Local Government, 2013). There are many organisational and technical factors which influence innovation diffusion such as; policies, organisational structures and operationalization of technology, but this research focuses specifically on project level accommodations made as new technology is integrated within a building project.

When a new technology is specified on a building project, it potentially impacts both the way that the part of the building incorporating the new technology (the technical assemblage) develops and the standard ways of working (practices). Although a building changes throughout design, construction, commissioning and use, the inclusion of a new technology within a build potentially introduces new challenges for the project teams. This research explores the process of accommodation within a construction project and will ultimately contribute to current understandings of product diffusion and uptake of sustainable technologies.

Using Social Construction of Technology (SCOT), this research will follow a low carbon technology – Building Integrated PhotoVoltaic (BIPV) panels, through several new build, commercial construction projects. This approach will be used to identify the actors involved in accommodating a new technology, the meaning they give to that technology and the adjustments they make both to the design and to practices.

This research will build on suggestions that the specificity of the construction sector, the context within which decisions are taken and the relationship between groups of actors involved will affect how different firms accommodate new technology.

2. Sustainable technology and innovation diffusion

Sustainable technology lies at the heart of the sustainability agenda both in terms of the infrastructure it delivers and the legacy of the built environment it leaves. For the UK to make the transition to a low carbon economy, innovative low carbon technologies will need to be installed in new buildings. Innovative, sustainable technologies are already available for use, but anecdotal evidence suggests that their inclusion in buildings is patchy. This research aims to

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

make a contribution towards understanding innovation diffusion of sustainable technology in the construction sector.

The inclusion of Building Integrated PhotoVoltaic (BIPV) within non-residential new building projects is the focus of this research. BIPV is a low carbon technology which is integrated into the façade or roof of the building and as such can be considered as part of an assemblage within the building. Its inclusion within the design has implications for different groups of project actors – for example: client, facade engineers, HVAC engineers, electrical designers, and installation contractors. The technology is sufficiently developed to allow its inclusion in flagship building projects, but is not sufficiently widely used to be considered as a standard building component.

3. Literature Review

The literatures on innovation and diffusion are inter-connected and entwined and rather than dealing with them separately, this review looks at these combined literatures and identifies themes around the uptake and diffusion of new technology and the development of standard practices. The innovation diffusion literature spans different objects and levels of analysis; this section provides a brief indication of this range and then focuses on the project level.

The review draws attention to particular issues of innovation diffusion within the construction industry and outlines how this research will address them.

3.1 Generic models versus empirical research:

Generic models have been developed to predict or improve innovation diffusion but have often failed to take into account what happens with respect to complex inter-relationships and dependencies. Much of this literature focusses on identifying universal models and seeks to identify best practice (Tidd, 2001). In the case of BIPV, models would predict the development of the BIPV market and manufacturing output, rather than the effect of the technology on the project actors.

Models have been refined and amended, from linear models which tend to address simple product innovations (Ryan & Gross, 1943; Rogers, 1976) to more sophisticated models which incorporate market effects of push and pull and supply chain integration (Graves, 1987; Rothwell, 1994). Despite this increasing sophistication, the call for increasing integration of information and design, has drawn attention to the importance of networks, the effects of social interactions and how integration affects working practices (Rogers, 2004; Freeman, 1996; Fleck 1988). The use of theoretical models within the Construction sector raises the question of how closer integration of systems and practices affects working practices within both intra and inter-firm project teams.

A response to these and similar observations concerning the iterative, processual and complex nature of innovation has been to explain and explore variations in innovation diffusion

(Tushman & Anderson, 1986;Abernathy & Clark, 1985) , whilst others draw attention to how different innovative technologies require different accommodations within firms (Henderson, Clark, 1990). These literatures leave unanswered the question of how innovation diffusion affects different project actors within a complex building project differently.

In summary, there is a disparity between development of generic models of innovation diffusion and what actually occurs during the process. Linear models of innovation diffusion fail to take into account the specificities of different sectors (particularly the multiple and complex relationships within the construction sector) and so the diffusion of BIPV within the construction industry cannot be understood simply by adopting these models.

3.2 The construction sector and inter-firm dependencies

The specific nature of innovation diffusion varies across individual sectors and firms. Different firms involved within a project may have different priorities and sensitivities (Pavitt, 1984; Malerba 2002). The construction sector involves temporary multi-disciplinary, multi-firm projects and this makes the study of innovation diffusion in the sector particularly challenging.

Characteristics of the construction sector (the involvement of many interrelated firms, project-led work, long lead times and changing client requirements) have been the subject of extensive innovation and diffusion research (Nam & Tatum, 1988; Winch, 2003). The relationships between project actors is a defining feature of the construction sector and needs exploration and understanding as to how this way of working impacts innovation diffusion (Gambatese & Hallowell, 2011; Isaksen & Tidd, 2006; Harkola & Greve, 1995). Characterisation of innovation tends to examine innovation within single firms. The uptake of innovations, and their effect on the firm have been described and explained (Henderson and Clark, 1990) and strategies, organisation and interventions which affect innovation diffusion have been defined. Although this draws attention to how these elements may play a role in supporting or hindering accommodations to design and practices, it does not explore variations in the impact of an innovative component on project actors across several firms.

A further characteristic of innovation diffusion in the construction sector is the tension between the perceived negative impact of innovation on the project (in terms of both efficiency and success) and the benefit of technological innovation on the building. This has been explored using the concept of tight and loose couplings (Dubois & Gadde, 2002), which explain the logic of operations within the construction sector and goes some way to understanding how the different groups involved with the specification of BIPV may view the technology and solve problems arising during its incorporation into the building design.

In summary, the construction of a building relies on interactions between many firms with complex relationships and dependencies. Authors recognise that innovation diffusion should be understood in relationship to these and that the inclusion of different innovative technologies will require different accommodations within firms. So to explore how project actors accommodate the inclusion of BIPV within a project, a clear understanding of their inter-relationships and interactions is necessary.

3.3 Impact on project level actors

Studies in innovation diffusion highlight the role of the individual within the firm and how ways of working within firms contribute towards innovation diffusion (Kissi *et al.,* 2012; Larsen, 2005; Valente & Davis, 1999), but do not address the impact of innovations on the individuals or their ways of working. When considering the incorporation of BIPV within a building, the actors affected may include manufacturers of panels, façade manufacturers and installers, mechanical and electrical engineers and commissioning teams. Each of these groups may be affected differently by the technology and may have different priorities in accommodating it.

Research on enhancing and modelling innovation in projects focusses on optimisation of practices within firm based project teams, rather than on understanding the dynamics between project actors (Gambatese & Hallowell, 2011). Similarly Dewulf and Bouwen (2012) explore how differences are narrowed between project actors through interaction strategies, whilst Soudain et al. (2009) explore accommodations made between project marketing and project management at the start of a project. These researchers limit their work to comparison of limited groups or discourse analysis at a particular point in a project rather than considering the project as a whole.

Little is known about how innovation diffusion affects different project actors within a complex building project differently. In order to understand better the effects of innovation diffusion in construction projects, this inter-dependence should be examined more closely and the accommodations project actors make in dealing with a new technology highlighted. In the case of incorporation of BIPV within a project, an exploration of the accommodations made by inter-dependent project actors over the course of the project is required – for example, the efficiency of BIPV will be affected by landscaping around the building and architects will have to adapt their ways of working to take this into account.

3.4 Design accommodations

The process of innovation diffusion in construction projects can be explored by understanding the way that the new element disrupts everyday ways of working and looking at resulting accommodations that are made by project actors. Variations in how technology is adopted and used by different organisations has been studied by Whyte (2003), who calls for further research into interactions between actors in the adoption of IT.

The introduction of a new technology into a build will have both intended and unintended consequences and this will affect innovation diffusion. Harty (2008) explores the relationship between inter-firm project teams and their interactions with the technologies. He distinguishes between those which can be contained within an implementer's control and those which overflow outside of it. This characterisation of innovation helps to identify the importance of understanding actor relationships with respect to the technological innovation and resulting accommodations.

In terms of BIPV, decisions made at the start of the project in terms of number and density of panels used will affect design of electrical ducting and siting of invertors, which will directly impact project costs. The way that these conflicts are resolved and how the design accommodates the requirements from different actors is key to understanding the process of innovation diffusion for this technology.

The discussion above highlights the need to understand the interplay between the project actors, the technology and the design of the part of the building which incorporates the technology and this will be addressed by this study.

3.5 Socio-technical relationships

The proposed research is concerned with actors, the way they interact with a new technology, how the new technology is shaped by these interactions and how that interaction impacts working practices. It is therefore appropriate to use an approach which includes in its analysis: the accommodations, the object and the actors. Socio-technical studies have highlighted the networks involved in the design and construction of complex buildings (Valente, 2012) and have been used to to understand the tension between innovation and project efficiency (Jacobsson & Linderoth, 2010). Schweber and Harty (2010) recommend the use of social-technical network analysis to explore the changing relationship and form of artefacts and practices. They suggest that Social Construction of Technology (SCOT) may be a useful approach in considering such issues.

The incorporation of BIPV within a building project invites research to understand the interactions between the development for the artefact (in this case the BIPV assemblage within the building) and groups of project actors and indicates the appropriateness of using SCOT as the theoretical lens for this research.

4. Research details

The proposed research is concerned with actors, the way they interact with a new technological assemblage and how that technological assemblage is shaped by these interactions. Firstly it addresses the question of what impact the new technology has on the building design: in terms of how the technical assemblage (the technology and the part of the building which incorporates it) changes throughout the design and through to handover. Secondly it asks how project actors change their ways of working when a new technology is specified into a build.

In answering the first question the research will investigate; how the building design related to the new technology changes over time, how and why design changes are negotiated and the types of design changes that occur. In answering the second question the research will investigate; how the project actors change over time, how they negotiate the way of working and how they understand the technology and if that understanding changes across the project.

5. Theoretical lens

The approach of the Social Construction of Technology (SCOT) focuses on 'relevant' social groups (a group of individuals who share the same set of meanings attached to the artefact), how they frame a technology (what elements do the social group have in common forms a technological frame) and how they interpret it. In early studies the approach has been used to understand the development of Bakelite, light bulbs, bicycles and refrigerators (Bijker, 1999; Pinch & Bijker, 2012) and latterly has been extended to study assemblages of technology, rather than just a single object (Bijker, 2009). More recently it has been used to understand the tension between innovation and project efficiency (Jacobsson & Linderoth, 2010) where the use of technological frames assisted the analysis of barriers to innovation diffusion.

As an approach SCOT calls for an exploration of the complicated relationships between objects and actors and considers that technology is constructed through its social context. Thus SCOT puts the technology at centre of the analysis, identifies groups of relevant actors involved in its development and explores how each group frames the technology, their actions and reactions to conflicting requirements and how these shape the technology and society (Bijker, 2009). The process of design and construction is examined in terms of how different sets of project actors/stakeholders define the problems of the new technology and propose different solutions (**Error! Reference source not found.**.)

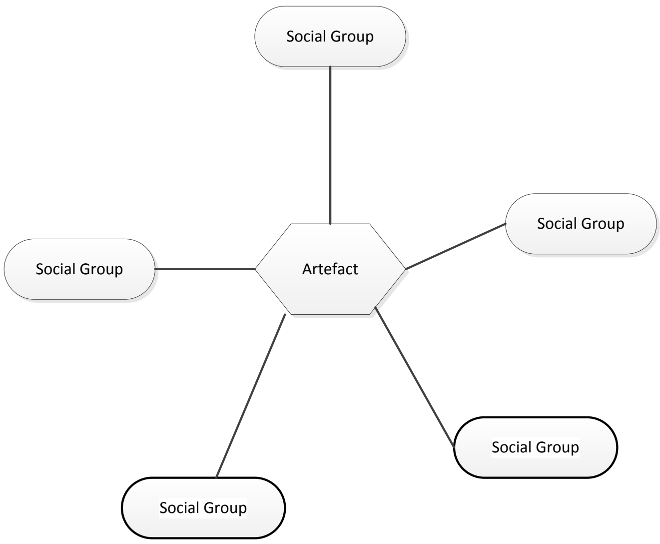

Figure 1: The relationship between an artefact and the relevant social group (Bijker et al, 2012; p.29)

As with the development of more simple artefacts like the bicycle, construction involves the successive fixing of different aspects of the design (from procurement to construction and commission) see **Error! Reference source not found.**. This complex process will not be the result of total consensus about every detail and many of the decisions taken will impact the development of the building design. This process of problem definition and solution are repeated through the project until closure occurs. The use of SCOT focuses attention on these negotiations; it also accommodates constraints such as power balance and common interests through the use of technological frames.

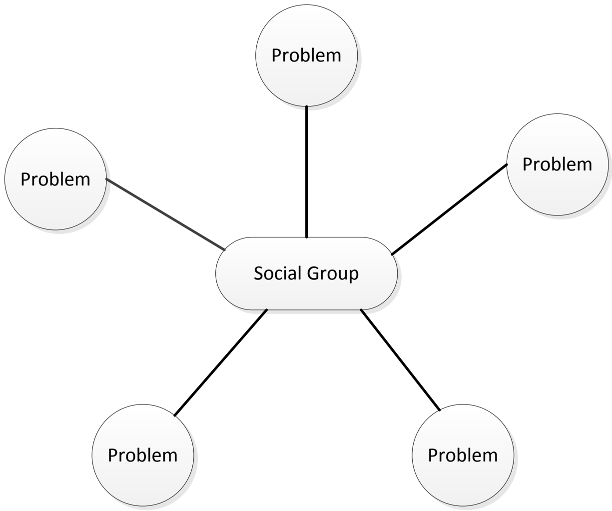

Figure 2:The relationship between one social group and the perceived problem (Bijker et al., 2012; p.29)

6. Research design

The use of SCOT calls on the researcher to identify the relevant social group associated with the technology and explore their relationship with the new technology. Drawing on case studies, this research explores the different accommodations made to both building design and project practices by project actors as BIPV and explores how this is enacted in practice.

6.1 Sampling

The exploration follows the technology into several BIPV projects with the aim of identifying the network of actors and artefacts involved. Empirical data will be collected in two forms: semi structured interviews and documents. Semi-structured interviews will use SCOT to explore how the technology is incorporated into the constructed building and this will draw attention both to the impact of the new technology on the ways of working and to variations in those accommodations made by different actors within the same project.

Project documents and in particular drawings will be used to identify design/practice changes which inform the interview process. For example; changes to drawings which involve the fixing of BIPV cells will highlight possible points of discussions between designers and these invite discussion of any resulting accommodations.

6.2 Data Analysis

Coding of data will establish relevant social groups, their technological frames, identification of problems and conflicts and accommodations to practices and design. Documents will be used to explore the evolving design and their evolution will be used to identify the changes made to the design and meeting notes are used to understand the background of these changes.

As an illustrative example of the application of SCOT to BIPV in terms of the relationship between the façade and the relevant social groups see **Error! Reference source not found.** below:

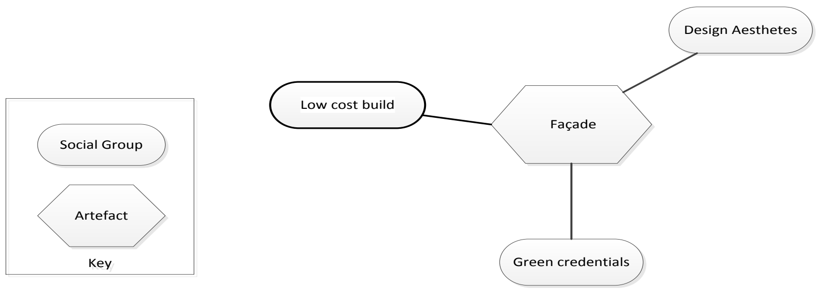

Figure 3: Substantive model for BIPV relationship between façade and relevant social group

The different actors or social groups will have different problems associated with the design and different commitments for choosing the solution. As an illustration of those concerned with developing an aesthetically pleasing design are shown in **Error! Reference source not found.** below.

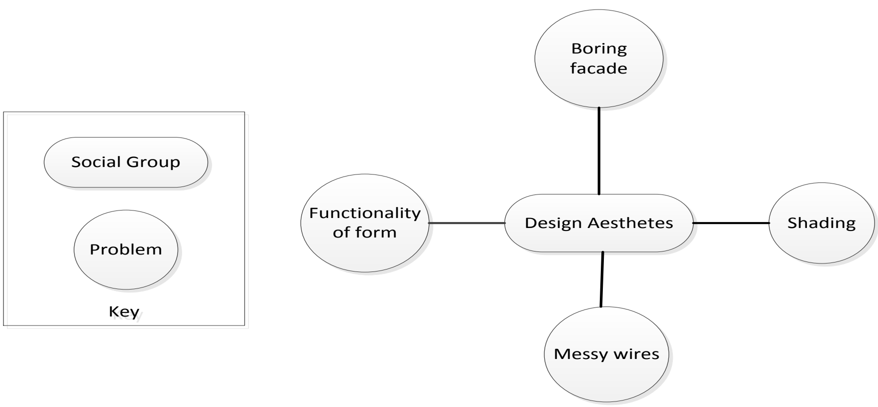

Figure 4: Substantive model for BIPV showing the relationship between Aesthetic designers and the perceived problems

The types of accommodations made on each project will be identified and an exploration made of whether any comparisons can be drawn out from the data. These may be in terms of the types of accommodations made, but details will emerge as the research progresses. This is a departure from previous work, which uses SCOT to demonstrate interpretive flexibility by highlighting differences between case studies

7. Concluding comments

The use of SCOT as a method highlights four aspects of the incorporation of a new technology into a project which are often overlooked. First, it provides for a systematic analysis of the different understandings and expectations associated with the new technology and the groups who hold them. Secondly, it explores the problems associated with introducing the technology and the way in which those expectations inform different team members' engagement with the technology. Thirdly, it identifies continuing cycles of problem definition and solution – which is appropriate to the process of design and build. Finally provides the basis for a systematic comparison across projects using the same technology and to look at similarities and differences with solutions and ways of working.

Although the research is on-going, initial findings identify at least four groups with distinct expectations and understandings of BIPV cells. These include Low Cost Build, Design Aesthetes, Green Build Credential Seekers and Low Energy Use groups. Relevant Social Groups (RSGs) are complex and are not purely defined by the actors' role. Actors may be members of more than one group: in this example, the "Low Cost Build" RSG includes client and main contractor, whilst the "Design Aesthete" RSG includes the client, architect and planners).

Problems presented to the RSG by the inclusion of the technology shape the design in unexpected ways which have implications for other RSGs. For example, wiring requirements impact both the Design Aesthetes RSG (how to conceal cables and where to site invertors) and "Low Cost Build" RSG (additional plant rooms and cabling costs), whilst satisfying the "Green Credentials" RSG.

Early substantive models around the development of solutions around the façade show how continuing cycles of problem definition and solution come together and how the assemblage of the panel within the façade develops - for example how panel connection, invertor location and and wiring routing impact on space allocation and generation efficiency.

In time, it this research will provide a systematic comparison across projects and will show similarities and differeces of how actors negotiate the challenges of adopting the new BIPV into the building project and what effects these have both on the final building and on the project actors working practices.

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