2015-09-02

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Bradbury, S

<http://hdl.handle.net/10026.1/4565>

10.1080/20507828.2015.1082059

Architecture and Culture

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A&C 3.3 – Bradbury – 07.07.15

Interrogating the dynamics of regulations on the design of energy performance in housing

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ABSTRACT Regulations are embedded in the practices of architects and, with growing regulatory complexity, particularly in the context of energy, understanding the role of regulations in shaping design decisions is becoming increasingly important. This paper conceptualises the design of buildings as a socio technical process. Using Actor Network Theory and controversy mapping techniques, it considers in detail how regulations, including non-energy related regulations, interact with the design process to shape the energy performance of a dwelling for which I was the project architect. In doing so the paper reveals that regulations are embedded in the design process and their flexibility impacts both upon on the role of architects as intermediaries and on the ability to predict performance outcomes on site.

The impact that codes and standards have upon on the built environment has been widely discussed in recent years, where the design of buildings and cities are framed by the legal conditions of regulation.¹ Studies have illustrated how the practices of architects are intertwined with the structure of the regulatory environment and how that environment can be seen as integral to the design process rather than being either separate from, or constraining, the activity of design.²

Over the last 20 years, regulations and standards in housing in England have expanded from dealing primarily with areas of public health and safety such as fire, drainage and structure to areas such as accessibility and adaptability, security, design quality and energy.³ With this expansion in regulation, it is becoming increasingly important that we understand how regulations are shaping design practice. However, in studies of building regulations, limited attention has been paid to theoretical descriptions or applications of findings, or research that looks in detail at the impact of regulations on the design process.⁴ This is despite calls for such studies.⁵

Energy is one area where there has been a significant expansion in regulation. In the UK, 9.4% of all carbon dioxide emissions relate to the heating of housing.⁶ With greenhouse gas emissions linked to global climate change and embedded in international carbon reduction targets, ensuring that new houses in the UK reduce their carbon emissions has been a focus for successive governments. In 2006, the UK government committed that all new

build homes in England would be 'zero carbon' by 2016.⁷ This is being delivered through incremental improvements to guidance for building regulations, the most recent published in 2014.

Despite this ambition, there is increasing evidence of a gap between the energy performance of completed buildings and the regulatory models used to predict performance.⁸ Research on this 'performance gap' has revealed that the causes are related to decisions that occur throughout the design, construction and occupation of homes.⁹ However this research focuses on comparing how buildings work on completion with design predictions and there has been limited work looking in detail at how the design process contributes to this gap.

The energy performance of a building is not stable through the design process because it is a function of the performance of the building fabric, its mechanical systems and the behaviour of its occupants. It varies as a result of changes to the design or specification of the building. As with any design change, this may be due to issues such as changing client briefs, value engineering or construction sequencing. In addition, as regulations are embedded in the activities of architects and influence design outcomes, changes in energy performance are also due to regulations including non-energy related regulations. Therefore, revealing how and why these changes occur would enable a better understanding of the role of regulation in the design process and its contribution to the performance gap.

Recent work by Yaneva on controversy mapping, a research method developed out of Actor Network Theory and applied to investigate design processes in architecture, has provided a method to understand how different human and material-object 'actors' (client, design team, contractor, drawings, models, materials and various regulations) come together to shape design decisions.¹⁰ This method offers the potential to reveal how regulations and other actors shape design decisions, and therefore energy performance, as part of a wider context.

This paper is intended to add to the evidence on how regulations influence the design process in the context of energy through a detailed evaluation of a housing project for which I was the project architect. Using controversy mapping, it will reveal how different actors shape the energy performance of a building and the performance on completion and in doing so will also offer some observations of the role of the architect in the design process and contribute to the debate about how to best regulate. First, I will set out the current regulatory context with regard to energy and the causes of the performance gap. Second, I will discuss in what ways regulations are shaping the work of architects and the potential for them to define new roles under certain conditions. Third, I will examine how regulations can be understood as part of a socio-technical network and, drawing on Actor Network Theory and controversy mapping, outline a methodology for interrogating the design process. Finally, I will conceptualise and illustrate, using a case study for which I was the project architect, how regulations interact with the design of buildings illustrating the different ways in which regulations are enacted in

practice and the impact of this on the performance gap and the role of architects.

Energy regulations and the performance gap

The UK government's 2006 commitment that all new build homes in England will be zero carbon by 2016¹¹ is being delivered through incremental improvements to Part L1A, the guidance document that sets out how to comply with building regulations. Part L1A adopts a performance-based approach that uses an energy model called the Standard Assessment Procedure (SAP) to produce an overall energy performance prediction of a home. Prior to 2006, Part L set performance targets for individual elements of the building such as windows, walls or services. However SAP allows flexibility in the performance of individual elements as long as the overall performance target is met. This means that, through the design of a building, it is possible to negotiate the energy performance of individual elements against other issues such as cost or visual appearance.

However, there have been a number of studies that have identified that new houses are not performing to the same energy standard they are predicted to do by the Standard Assessment Procedure.¹² Causes for the performance gap have been identified as a result of failures in the fabric of the house, in problems with design, installation, commissioning and use of mechanical systems and in variations in user behaviour.¹³ Often the causes are not just a result of one factor but due to complex interactions between building fabric, mechanical services and the behaviours of householders which occur throughout the design, construction and use of a building. The performance gap associated with the fabric energy efficiency of the house (the performance of the material and mechanical elements without the interaction of the user) has received particular focus in the UK as it forms part of the definition of zero carbon homes from 2016 and has been identified as a major contributor to the overall performance gap in housing.¹⁴ Of the limited number of tests on dwellings using the co-heating test method which measures fabric energy efficiency of dwellings, none of the buildings tested meet their design performance with some houses underperforming by up to 120%.¹⁵ Work by the Zero Carbon Hub, which has operational responsibility for delivering the government's target, has set out a range of recommendations for industry and government to reduce the performance gap. These include increasing regulation in areas such as post completion monitoring and improving the predictive regulatory energy models.¹⁶

However, research into the performance gap focuses on looking at the performance of homes at completion, rather than design intentions through the use of building performance evaluation techniques, without a detailed study of the design process. In addition there is limited consideration given to how regulations work in the design process.

Architects and regulations

Research into the impact of regulations on the practice of architects has revealed a complex relationship between design and regulations. Rather than being transmitted and followed, regulations in practice have been shown to be

a constituent part of the activity of an architect.¹⁷ Imrie is explicit in exploring the interrelationship between architects' practices and regulations showing how regulations have the potential to directly influence the design process.¹⁸ He highlights how regulations on issues such as accessibility and energy have led to changes in the form of buildings. However, these changes are not the result of a direct implementation of the regulations on the form of the building but rather the interpretation of regulations by a network of social and material actors which are particular to specific project contexts.

Through interviews with architects, he illustrates that they understand regulations as being embedded in the process of design and are translated through interactions with the material context of the building and the social context of the design team and enforcement officers. It is the messy and complex nature of designing buildings that shapes how regulations are implemented in practice. Fischer and Guy go further by exploring how, in the context of regulations on energy efficiency, it is the negotiation between design team members and regulations that shapes the design outcomes. They emphasise that it is the project's contexts which are important in understanding how regulations are enacted.¹⁹ They suggest that, under the right conditions, architects could operate as intermediaries, particularly in situations where there is complexity and weak enforcement regimes. They suggest that

The challenge ... is for architects to look beyond their traditional role and reinvent themselves as interpretive intermediaries, thereby escaping their perceived inability to act within existing constraints.²⁰

Importantly, they highlight the potential of the architect to act as 'interpretive intermediaries'.²¹ This means using the uncertainty and flexibility of regulations in specific project contexts to mediate between differing goals of actors such as engineers or contractors. Acting as an intermediary has the potential to reinforce the importance of the role of the architect as part of the design process. Understanding the different conditions in which regulations are translated into the design of buildings offers the potential to understand new roles for architects.

Studying regulations in the design process

There have been a small but increasing number of studies of buildings as socio-technical regimes where the material and social contexts of design are seen as part of a single network. These studies have shed light on the tools, methods, social contexts and cultures of designers and engineers.²²

The enactment of regulations in housing is dependent on the relationship between social and material contexts. Therefore, analysing the design and construction of buildings as a sociotechnical process has the potential to reveal how regulations are translated into design. Actor-network Theory (ANT) provides a theory and a methodology which can be applied to the design and construction process, viewing buildings as socio-technical objects.²³ Originally developed out of Science and Technology Studies as a method to study science and technology, it has been widely applied to engineering practices

and more recently the design of buildings.²⁴ From an ANT perspective, the design of buildings and therefore their energy performance is distributed between human actors (for example architects and contractors) and non-human actors (for example regulations and materials). This network of human and non-human actors collect around controversies, which is the point at which a piece of technology (or building) is not yet stabilised or 'black boxed'.²⁵ This refers to the way in which the internal operation of technology is not questioned: "when a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity".²⁶

Controversy mapping is a more recent application of Actor Network Theory which involves the representation of these networks over time to reveal how different actors come together to shape the technical or scientific project.²⁷ The objective of controversy mapping is to use cartographic methods to represent actors' disagreements over "matters of concern" in controversies.²⁸ These are the issues around which actors disagree and it is the process by which matters of concern are closed that reveals how objects are made. The design process of buildings is well suited to this type of examination as it is precisely through the negotiations between clients, design teams, contractors, sub-contractors drawings, models, building components and various regulations that buildings are designed. Recent work by Yaneva has illustrated the potential of this method in the context of architecture.²⁹ However, controversy mapping in architecture has focused mainly on mapping networks and representing these relationships in network diagrams without connecting this directly to changes in the design of buildings. In addition, the data collected from projects has been limited to looking at openly available online data mainly connected to large public controversies such as the Olympic Stadium in London.³⁰ This therefore limits the perspectives one can view the controversy from and makes it difficult to trace the connections to design changes. What follows aims to illustrate how these networks shape the design project and specifically the energy performance of the building using data gathered from project archives and interviews and linking this to design changes, as such is a new application of this method.

Energy efficiency as an example

Taking the example of a house for which I was the project architect the following sections of the paper will illustrate how regulations can operate in the design process in the context of energy efficiency. The intention is to examine how regulations interact, how this may contribute to the performance gap and offer some insights into when Architects can act as intermediaries.

The project under study comprises two prototype houses in York designed to test ways to reduce the gap between the regulatory prediction of performance and the performance on site (Figure 1). Over the course of two years, I was engaged in the design and construction process attending all design team and client meetings as well working as part of a team in the office to develop the designs for the project. My own observations were combined with a detailed study of project archives from the client, contractor, architect, environmental engineer, and building performance assessors as well as interviews with the

design team. These observations from multiple perspectives enabled me to develop “second degree objectivity” whereby it was possible to reveal and represent the many contradictory positions of the actors in the controversy.³¹

In order to understand how regulations influenced the design decisions, I identified when and why the energy performance changed through mapping the energy controversy following the approach described by Venturini.³² This was done by following the actors to identify when and why the energy performance changed by representing information from interviews, emails, drawings, specifications, programmes, cost plans, energy models, contracts and other key documents. Additionally, a construction and post-completion survey that reported on the tested performance of the building on completion and identified key construction defects was also referred to. This enabled me to see all decisions that shaped energy performance including those related to regulation.

The changing energy performance predictions for the project over time were modelled using the evolving architect’s specifications and drawings as a data source. This was because they represented the approved information for the design project throughout the design and construction process. The energy models analysed only the fabric energy efficiency and were consistent with the calculation method used in the current regulatory energy model.³³

Interpreting sociotechnical systems

An illustration of the changing fabric energy performance over the project timeline for one of the houses is provided in Figure 2. Each point on the graph is a matter of concern that impacted on it. Point 32 on the graph illustrates the as-built test results of the house and therefore the performance gap. Table 1 illustrates each matter of concern and the actors involved. In order to understand the role of the architect in mediating changes in fabric energy efficiency (acting as interpretive intermediaries) it is insufficient to understand only that changes have happened. From an ANT perspective, it is important also to describe how the actors came together in each matter of concern. Callon and Latour³⁴ suggest it is at these points that actors are enrolled into projects through the process of *translation*.³⁵ This involves the alignment of individual interests or goals whereby they become allies in a project enabling it to move forward.³⁶ In *Padora’s Hope* (Figure 3), Latour describes this as the point where two actors come together and there is a “translation of their goals which results in a composite goal that is different from the two original goals”.³⁷ Hence in figure 3, actor 1 and actor 2’s goals are translated to make a new composite goal, goal 3.

Returning to Guy and Fisher’s work, they suggest that the mediation between different actors offers an opportunity for architects to act as ‘intermediaries’ working between different professional contexts, interpreting regulatory requirements.³⁸ One would assume then when interrogating each matter of concern we could see the architect facilitating the mediation between actors goals. However, in examining the data, mediation whereby there was a translation of goals occurred very rarely.

There were instances where different actors' goals were not translated until after the project was completed which contributed to the performance gap. One example was the translation of goals between the energy model and the timber frame construction system. During design development no detailed drawings of the floor junction from the timber frame subcontractors were provided. The result was that the thermal performance of this detail was taken as a standard value and not accurately accounted for in the energy models. When the house was tested this junction performed worse than assumed and contributed to the gap in performance (Figure 2, point 32). In the development of the design, the primary concern was how to fix the timber frame to the ground. However, when the house was tested, the energy performance of the junction became relevant to the overall performance. The actors (the timber frame and energy model) moved from what Latour would term 'disinterest' to alignment in order to account for the performance gap. This lack of communication between actors during the design process has been typically attributed to the performance gap in housing.³⁹ As Henderson has highlighted, one of the greatest challenges in complex technical situations is making visible the dependencies that are important.⁴⁰ In this instance, the architect was not able to act as an intermediary as the matter of concern only emerged on completion of the building. But even when these matters of concern were visible and part of the design process it was not always possible to mediate between goals.

An example of not being able to mediate goals is when the design was updated to reflect the requirements of Lifetime Homes standards, a regulation that sets minimum requirements for accessibility which allow for the adaptation of a dwelling for disability. Early in the project it was necessary comply with Lifetime Homes standards by providing a disabled accessible downstairs bathroom and wider corridors (Figure 2, point 5). The change needed to be accommodated within the form of the current design as this had been used in pre-planning consultation discussions with the planning officer. The redesign resulted in a more complex geometry on the ground floor which the design team were aware would cause problems with airtightness but were not able to resolve because they could not change the appearance of the building. This did result in a number of difficult airtightness details at the entrance that caused problems during construction (as evidenced in the three pressure tests that were undertaken) and contributed to the performance gap on completion (Figure 2, points 27, 28 and 29). Here, as the Architect, I was not able to mediate between the regulatory requirements because they were not flexible. It was not possible to negotiate issues of external appearance, as these had been agreed in discussions with the planners, or the requirements of Lifetime Homes, as these were set as national standards.

A lack of translation of actors' goals and therefore enrolment into the project is what Latour attributes to the failure of technological projects to become "objects". He uses the example of Aramis, a personal rapid transit system for Paris.⁴¹ However, unlike with Aramis, the lack of translation of actor goals did not stop the project although it did contribute performance issues on completion. It was necessary to discard the goals of the architect to have a simple building form in order to enroll more actors into the project (Lifetime

Homes Standard and the planning officer) without which the project could not move forward.

There are other examples of actors' goals not being translated in the design process which did not, however, contribute to a gap in energy performance. This is best illustrated in relation to the development of the design of the windows. The initial specification of the windows was developed by the environmental engineer who suggested the minimum thermal performance should be equivalent to Passive House standard (Figure 2, point 6). However, after the planning submission, the architects were "novated" to work for the contractor. Whereas before the goal had been to create the best performing building, the contractor's goal was to reduce costs. They instructed me to produce a revised specification which included a proposal for a double glazed window offered as a cost saving and as a way of supporting a local business (Figure 2, point 9). The controversy soon shifted again as the local supplier was not able to meet a national security standard 'Secured by Design' which was required as a funding requirement for the client. Additionally, the window sizes in the approved planning drawings were larger than the maximum size that the firm could make due to the warranties they had in place. In order to enrol all the actors (planning drawings, Secured by Design standards, warranties, the client and the contractor), a double glazed unit sourced from a continental European manufacturer was selected and incorporated into the specification which met all the regulatory standards and was better performing than the local supplier's window but which remained cheaper and poorer performing than the triple glazed window (Figure 2, point 11). Later in the design process, the window opening mechanism had to be amended to comply with Lifetime Homes which located all the handles at the bottom of the windows (Figure 2, point 14). This resulted in an improvement in thermal performance of the window. At each step, the controversy over the window changed as actors with different goals joined the project. However, there was no mediation of some of the actors' goals with that of the energy performance of the window. As the performance of the window was flexible and the other regulations such as Lifetime Homes were prescriptive (and inflexible), the requirements of these regulations were transported into the project and superseded the current design proposal resulting in an unpredictable change in energy performance.

This illustrates the most common type of change in fabric energy efficiency in the design process where two actors came together and there was not a mediation of goals but rather one goal superseded the other. In these instances, the architect is not acting as an "intermediary" and reinterpreting regulations as the standards and regulations are not flexible.

The situations where there was a translation of goals and the architect took on a mediator role and was able to "re-interpret regulations" occurred in very few instances.

An example of this was the discussions between myself and the timber frame manufacturers regarding the methodology to calculate heat losses from thermal bridges (Figure 2, point 19). Recent research had shown that timber

frame buildings were performing worse due to higher levels of heat losses through thermal bridges and the use of a British Standard for timber content in timber frames which was not appropriate.⁴² However there was no national guidance in place at the time, uncertainty over how to calculate thermal bridges, and a lack of clarity about the accreditation of the particular system being discussed. As a result there were no clear standards and the energy performance of the thermal bridges in the timber frame had to be negotiated between the supplier and the architect. The outcome was an energy performance that closely matched the timber frame system and therefore did not contribute to the performance gap on completion. It was possible to mediate between the goals of the supplier, the construction system, the regulations that were in flux and the regulatory energy model.

Another example was the design of the airtightness membrane in the roof where small models were produced to illustrate the location of the membrane in order to achieve the continuity of the airtightness line (Figure 2, point 15). These models were used in discussions at design team meetings but also on site with operatives (Figure 4). Here, the goals of different actors, the construction system, site operatives and air tightness membrane were translated to find the best design solution. It was possible to do this as these issues were in control of the design team (location and specification of materials) and therefore the power to mediate was at a very local level. Unlike in the previous examples, it was possible to mediate between actors' goals either because the power resided very locally to the project (the design of the airtightness membranes) or because there was flexibility and uncertainty in the application of regulations forcing a discussion on how to achieve compliance (the calculation of thermal bridges).

Conclusion

When tracing changes to the energy efficiency of the building fabric in this project, it is evident that they arose as a result of the interactions between clients, design teams, contractors, sub-contractors drawings, models, building components and various regulations. Regulations influenced design throughout the whole timeline of the project suggesting that they are embedded into the practices of architects. This reinforces findings by other scholars that the process of design cannot be separated from the influence of regulations.

Reasons for changing fabric energy efficiency normally resulted from matters of concern that were not related to improving energy efficiency and were related to regulations, although not necessarily regulations related to energy. In this project, the regulatory energy model (SAP) did not have any influence on the design decisions as the houses were performing better than the minimum requirement in the regulations and therefore there was never a need to make changes to the design to achieve compliant performance. In other projects closer to the regulatory minimum, it is likely that this would be the case. However, the fact that non-energy related matters of concern including those involving regulation were shaping the energy performance suggests that the way in which regulations are translated into practice is much more complex than is suggested in literature.

The causes of the energy performance gap identified above are currently attributed to the lack of knowledge and skills of different actors and a weak enforcement regime with a desire to increase regulation to reduce the gap. However the gap is related to the ability to translate goals of all actors (including regulations not associated with energy efficiency) into the final project. Where actors' goals are not part of the design process or cannot be mediated due to their inflexibility, a gap will arise between prediction and performance.

This paper illustrates how more prescriptive regulation which does not allow for any flexibility may not be a solution to reduce the performance gap as it can lead to an unpredictable design process where goals of regulations are transported into the design of projects without being translated; for example, the relocation of handles on windows for disabled access that changed their thermal performance. Although prescriptive regulations have been shown to deliver more predictable outcomes on site, in this project the prescriptive regulations acted to override the performance requirements or simply did not allow for mediation between actors' goals.⁴³ At worst, tighter prescriptive regulation could also contribute to the performance gap where it is not possible to resolve the conflicts of competing regulations; for example the need to incorporate Lifetime Homes standards while respecting planning drawings which created a complex geometry and problems with airtightness.

Here we can see how, when regulations are controlled from outside of the project, they are not mediated. Latour would suggest that these actors need to be given due political process to be included in the project.⁴⁴ Very often this is not possible when the standards do not allow for negotiation. However regulations also provide balances against interests of other actors in the design process. Therefore careful consideration needs to be given to the amount and type of flexibility in regulations. True mediation and translation of actors' goals only occurs where there is provisionality and uncertainty, and therefore flexibility, in regulations or they are controlled very locally. Here the architect is able to act as a mediator and re-interpret regulations. By doing this, it is possible to mediate between actors' goals and hence give more certainty to outcomes on site. This provides an insight into possible models where the value of the architect as mediator can be realised.

This paper also illustrates how energy efficiency in housing is not a stabilised object (or a "black box", in Latour's terms). Rather, energy efficiency in housing is fluid and shaped by 'matters of concern'. Understanding how these matters of concern shape the energy performance of a building through the design process and beyond will help to reveal ways in which we can improve the energy performance of buildings.

The use of controversy mapping in the context of fabric energy efficiency is a new application of the method. Controversy mapping, although effective in illustrating matters of concern and actors involved in projects, has been less successful in showing the impact of controversies on the design of buildings over time. As fabric energy efficiency is a function of the performance of all of

the material elements of a project it provides a helpful analogue for design changes through a project. Therefore using this application of controversy mapping to illustrate design changes has potential not only for understanding how energy efficiency changes but how design process can be studied more generally.

This paper is a small step in uncovering the relational characteristics of regulation in the design process. However much more comparative work is needed to understand the many different contexts and cultures that exist across design practice.

Simon Bradbury is an architect and academic. He is the program leader for the Master of Architecture course at Plymouth University. He was trained as an architect at Cambridge University, the Massachusetts Institute of Technology and the Architectural Association. He has a background in both practice and government and his research work is interested in investigating the socio-technical configurations of low energy housing, design process and regulation.

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Matters of concern that influenced the fabric energy efficiency, number correlate to Figure 2
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	Non Human Actors	Human Actors	Matters of concern
1	Outline specification and plans issued by Architect		
2	Standard Assessment Procedure	Architect, environmental engineer	Energy performance
3	Lifetime Homes , winter garden, windows, bathroom	Architect	Accessibility, airtightness, visual appearance
4	Homes and Communities Agency, local authority	Client	Funding
5	Scheme Development Standards, Lifetime Homes , Homes and Communities Agency	Architect, Client	Funding, accessibility
6	Building fabric (Window, building envelope, wall, floor, doors)	Environmental engineer, client, architect	Energy performance
7	Ventilation system	Environmental engineer, client, architect	Health of occupants, maintenance
8	Planning application submitted		
9	Construction system, windows	Architect, contractor, client	Construction sequence, thermal performance, air tightness, cost
10	Scheme Development Standards , winter garden, roof, Planning drawings	Architect	Funding, external appearance, construction sequence
11	Planning drawings, Secured by Design.	Architect, contractor, client	Cost, energy performance, security, external appearance
12	Scheme Development Standards	Architect	Funding
13	Ground floor slab	Architect, contractor	Health and safety, sequencing of construction
14	Lifetime Homes	Architect	Accessibility, funding
15	Roof, airtightness membrane	Architect	Airtightness
16	Services, airtightness membrane	Architect, M & E engineer	Airtightness, sequencing
17	Building fabric	Architect, environmental engineer	Thermal bridges
18	Building regulations application submitted		
19	Building fabric	Architect, environmental engineer	Thermal bridges
20	Roof, insulation	Architect, contractor	Condensation, airtightness
21	Services	Architect, M & E engineer	Sequencing
22	Standard Assessment Procedure	Architect, environmental engineer	Energy performance
23	Services, airtightness barrier	Architect, M & E engineer	Airtightness, sequencing
24	Start on site		
25	Rooflights	Contractor	Energy performance
26	MVHR unit	Environmental engineer, ventilation supplier	Energy performance
27	Building fabric, airtightness membrane	Contractor	Airtightness
28	Building fabric, airtightness membrane	Contractor	Airtightness
29	Building fabric, airtightness membrane	Contractor	Airtightness
30	Building fabric, Standard Assessment Procedure	Contractor, environmental engineer, architect	Airtightness
31	End of construction period		
32	Building fabric, Standard Assessment Procedure	Contractor, client, architect, environmental engineer, researchers	Airtightness, thermal bridges, thermal performance.

* Regulations and standards are highlighted in **bold**.

Figure

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Figure

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Figure 1

Two prototype houses
Studio Partington

Figure 2

Change in fabric energy efficiency of the prototype house over the timeline of the project.

Figure 3

Translation of actors goals
Adapted from Latour, *Pandora's Hope*

Figure 4

Air tightness membrane model
Studio Partington

Table 1

Matters of concern that influenced the fabric energy efficiency, number correlate to Figure 2