Architectural Technology

Architectural Technology
Research & Practice

Edited by

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Foreword

As Vice President for Education and Chair of the CIAT Research Group it gives me great pleasure to support the first ever publication to specifically address the area of research, and in particular its relationship with practice, in the discipline of architectural technology. *Architectural Technology: Research and Practice* is not only groundbreaking because it is the first book of its kind, but also because it provides at long last one of the accepted foundations needed to underpin the emerging academic discipline, namely a recognised research base. The architectural technology discipline is well established at degree level and taught in many UK universities with counterparts around Europe. Architectural technology programmes are subject to a comprehensive accreditation programme run by CIAT, but the concept of academic disciplines requires a subject to be researched as well as taught. Differentiating a significant body of research that can also be identified as relevant to architectural technology is therefore an essential part of this process.

Research manifests itself within academic disciplines in many ways, from empirical research activities to applied research, mostly aimed at supporting the profession. In the case of architectural technology much empirical and applied research conducted in other allied fields is already there and can be directly applicable. However, establishing a body of research specifically applicable to architectural technology that is being conducted and promoted on a significant scale has yet to be fully established. This book takes a momentous step in that direction.

Recognising that the relative youth of the discipline requires that systems and networks need to be established where no existing procedures or formal structures exist, the Chartered Institute of Architectural Technologists (CIAT), as the professional body having always supported practice based research in particular, has responded with its recently re-established Research Group taking on the endorsement to 'promote the development of research applied to the education and practice of architectural technology' (http://www.ciat.org.uk/). The CIAT Research Group aims to focus on four distinct areas:

- Developing and defining architectural technology research.
- Encouraging, promoting and disseminating research.
- Building and encouraging knowledge exchange between practice, research and education.
- Promoting architectural technology as an academic discipline.

In aiming to address the interaction between research and practice in the field of architectural technology this book demonstrates the significance of research to those involved in architectural technology, and above all stimulates further research and debate. In doing so it also achieves its primary aim of highlighting the richness and potential of the subject area. With contributions from architects and architectural technologists, the passion for the subject is evident throughout the collection of chapters and case studies covering a number of different yet highly relevant themes. As the editor, Stephen Emmitt suggests, 'the underlying message is that architectural technology is not just a profession; it is a way of thinking and a way of acting'.

CIAT, in supporting this publication, is aware of the need for books such as this to sustain the process of research informed practice, as an aid for both students and those practising within the discipline of architectural technology.

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Introduction

Architectural technology as a discipline and as a knowledge domain has evolved rapidly in the UK since the early 1990s, and in doing so it has started to (re)establish the synergy between building design, technology and community as we strive for a more sustainable and stimulating built environment. The role of the architectural technologist, both the official role promoted in the UK by the Chartered Institute of Architectural Technologists (CIAT) and that adopted by others, such as architects, engineers and surveyors operating in the field, continues to evolve, shaped and reshaped by the time in which we live and the technologies to hand. The challenge for building designers is constantly to evaluate and question: why we build; what we build, how we build; and when we build. It is only through such soul searching that we are able to advance our understanding and create a more responsive built environment. In order to advance our understanding we need to consult a wide range of knowledge, which will be derived from research and reflection on practice.

Developments in architectural technology

Building design and technology have a very special relationship, since without the technologies to realise the built form architecture would exist only in our minds. The relationship between building technology and design can be traced back to the Enlightenment and the Industrial Revolution, periods when advances in technology and science were seen as the way forward, and times of solid faith in progress. Architects needed a thorough knowledge of scientific matters (applied mechanics and materials properties) as part of their education and daily practice. However, it was the engineers who took up the technical advances and new ideas in building the quickest. Cast iron, concrete, steel and glass gave engineers opportunities to build great structures, sometimes working alongside architects, sometimes with contractors.

As technologies multiplied in number and complexity the building profession started to fragment. Increases in building activity brought about social and structural changes (Bowley, 1960). Surveying, structural engineering and design activities were separated with the development of the professional institutions. The Institute of Civil Engineers was formed in 1818, the Institute of British Architects in 1834 and the Surveyors' Institute in 1868. One of the peculiarities of fragmentation in the UK construction sector has been the architects' gradual retreat from technical issues to concentrate on design, a characteristic found in the majority of educational programmes and in practice (Cole and Cooper, 1988). This has created a void between the design and construction phases, which has gradually been filled by architectural technicians and constructing architects (Emmitt, 2002; Barrett, 2011). It is the growth of a new discipline, architectural technology, and development of the profession (architectural technologists and technicians) that span the boundaries between design and production.

For many years the unrecognised work-horses of architectural practices, assistants, architectural technicians and architectural technologists, have been at the centre of many a successful business, forming the link between conceptual design and production and helping to translate design intent into physical reality. However, the assistants, technicians and technologists have had to endure a territory devoid of status, where career progression and standing were traditionally well below that of their design orientated colleagues. Writing in the later half of the 19th century the architect and critic John T. Emmett (1880) made a particular point of highlighting the plight of the architect's assistant. He claimed that assistants were by far the most important members of the architectural profession, essential to the smooth running of their superior's office, but largely unseen and certainly unrecognised. Emmett went on to urge architects' assistants to form an association or institute, in partnership with the tradesmen and workmen, which would lead to 'perfectly instructed, practical, artistic craftsmen', and who would become masters of their own destiny in a 'joyful and dignified career'. His words were not heeded, and it took almost 80 years before the institute advocated by Emmett was formed, not by the assistants, but by the Royal Institute of British Architects (RIBA).

The formation of a profession

The RIBA Oxford conference of 1958 proposed the abolition of pupillage and part-time courses for architects, and with it the formal creation of the architectural technician discipline. This essentially created a two-tier system, those responsible for controlling design (architects) and those with practical skills (the architectural technicians). To reinforce the distinction the technicians were given lessons in 'design appreciation' rather than studio-based design projects (Crinson and Lubbock, 1994). Of course, the two-tier system was already in place in the majority of professional offices, but now it had been officially recognised, thus setting the scene for the events to follow.

In 1962 the RIBA's report *The Architect and His Office* identified the need for an institution (other than the RIBA) that technicians could join to ensure maintenance of standards for education and training (RIBA, 1962). Technical design skills were identified as a missing component of architectural practice and the report urged the diversification of architectural education so that this shortcoming could be addressed, suggesting that architects who chose to specialise in technology (rather than design), the 'architechnologists', should still be allowed to join the Institute (RIBA, 1962). The report acknowledged that technicians were needed in architects' offices to raise productivity and standards of service, for which they would require education and training in the preparation of production information and technical administration; 'design' was specifically excluded from the technologist's training. The Society of Architectural and Associated Technicians (SAAT) was formed in 1965 and inaugurated as an Associated Society of the RIBA under Byelaw 75 of the RIBA's charter in 1969 (SAAT, 1984). SAAT did not encompass all technicians (estimated by SAAT at 20 000–25 000); many belonged to other societies, as reflected in its membership of 5300 in December 1983.

The constructive link

SAAT published an influential report in 1984, *Architectural Technology: The Constructive Link*, which drew on existing literature to develop a view of construction for the 1980s and beyond, highlighting the future direction for SAAT and its members. The book was important in helping to establish a sense of identity for architectural technicians since it helped to identify the technicians' role as complementary to that of the architect. The book was also important in highlighting the link between conceptual design and the realization of a physical artefact. As a construct and metaphor, the constructive link lies at the very heart of architectural technology.

In 1986 the SAAT was rebranded as the British Institute of Architectural Technicians (BIAT) and again in 1994 to the British Institute of Architectural Technologists. Although the acronym remained the same, BIAT took a significant step forward with the subtle change from 'technicians' to 'technologists' in the title, reflecting the growing stature of the discipline. With the change of name and the promotion of degree-level qualifications for its members, BIAT had started to redress the issue of status. The Institute's Innovation and Research Committee was established in 1996 and a small number of research events were organised in the following years. The Institute was granted a royal charter in 2005 and once again the name changed, this time to the Chartered Institute of Architectural Technologists (CIAT). Around this time the undergraduate programmes were maturing and design was becoming increasingly prevalent – present in the conceptual design of buildings and the conceptual design of building components and joints. With the change of status came the promotion of postgraduate degrees in architectural technology and with it an increased focus on the value of research.

Researching the constructive link

Since its birth in 1965 the architectural technology profession in the UK has evolved into a distinctly separate discipline from architecture. The profession has started to increase its leverage in the marketplace and with increased attention to the (thermal) performance of buildings, collaborative working and the role of building information modeling (see, for example, Harty, 2012) the profession is well positioned to make a significant contribution to the realisation of creative and functional buildings. However, without a sound theoretical and evidence based foundation it is unlikely that the architectural technology discipline will be afforded the credibility it deserves. It follows that the profession must embrace research and start to develop a distinct body of knowledge that adds value to the sponsors and users of buildings and to society as a whole.

The unquestioning faith in science and technology that dominated earlier times has given way to increased scepticism and caution, represented in the constant questioning of professionals. It is research – the gradual contribution to the development of a unique body of knowledge – that shapes a profession and underpins the values and competences of its members. This knowledge resource also helps others working alongside architectural technologists to understand others' roles and relationships.

CIAT's Research Group

It is almost 30 years since the publication of *Architectural Technology: The Constructive Link* (SAAT, 1984). During this period much research has been published that falls under the umbrella of 'architectural technology', although very little of this has been funded or conducted by the professional bodies representing architectural technologists. Relying on other professional institutions to stimulate research may be an economically prudent approach, but without a solid knowledge base the profession is open to criticism and questions of legitimacy. How, for example, can architectural technology claim to be a profession if there is very little research underpinning its knowledge domain? How can the members of CIAT respond to the challenges we face in the built environment, other than from an informed position?

Fortunately there are initiatives underway to help build a body of research.

BIAT's Innovation and Research Committee was instrumental in raising the profile of research within the profession. This committee was replaced by the CIAT's Research Group in 2010. The aim was to concentrate on the value of research to the profession and stimulate a number of projects to support this aim. One of the Research Group's initiatives was to look at how research informs the practice of architectural technology and vice versa. The outcome of that exercise was recognition of the need to set out what constituted 'research' in architectural technology, which in turn led to this book.

Research networks

There are many research networks that deal with specific issues concerning aspects of building design and construction, but two are particularly pertinent to the development of a research culture within architectural technology. These are the Detail Design in Architecture (DDiA) conferences and the International

Congress of Architectural Technology (ICAT). Detail Design in Architecture was established in 1996 in the UK with the aim of bringing together knowledge and developing our understanding of architectural detailing with an environmentally sustainable agenda. This conference network has been supported by BIAT, CIAT and the RIBA, with conferences held in the UK and The Netherlands, and more recently Turkey (2012) and Taiwan (2013). The International Congress of Architectural Technology was established in 2008 by individuals involved in educating architectural technologists. This European network has adopted a wider remit, questioning the role and scope of architectural technology (and architectural technologists), helping to explore the interfaces between practice, education and research.

Agenda

This book addresses the interplay between research and practice in the field of architectural technology. The aim is to demonstrate the significance and importance of research to those involved in architectural technology. The objective is to stimulate further research and debate within the subject area, and hence contribute to the development of the field. The purpose is not to tell readers how to conduct research, although some practical guidance is provided, but to highlight the richness and potential of the subject area. Taking our cue from the constructive link, the argument in this book is for research to underpin the link between design and production and between education and practice.

The book comprises a mix of chapters and case studies, bringing together a number of different themes under one set of covers. Together, the contributions provide a number of insights into the world of research as seen from the perspective of those working within the architectural technology field, comprising practitioners, academics and students. The underlying message is that architectural technology is not just a profession; it is a way of thinking and a way of acting. This is underlined by contributions from architects and architectural technologists passionate about architectural technology as a field of knowledge. Contributions range from the theoretical and polemic to the pragmatic and applied, further helping to demonstrate the richness of the field. There is a clear and deliberate bias towards environmental sustainability within the book, which reflects concern for our natural and built environment.

Architectural technology is the realisation of architecture through the application of building science: essentially a mode of action forming the constructive link between the abstract and the physical. It is a mode of action reliant on evidence derived from research and practice. Whether research and practice should be about reinforcing the status quo or about challenging our beliefs and accepted way of doing things will depend on the context, but both extremes are needed to expand our understanding. This book can only deal with a few aspects of architectural technology, essentially a glimpse into an exciting world of possibilities and opportunities.

Further reading

For a comprehensive overview of architectural technology see *Architectural Technology* (second edition) by Stephen Emmitt (Wiley-Blackwell, 2012).

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Chapter One

Theory and Architectural Technology

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Why theory, what has theory got to do with architectural technology and why worry about it? One answer suggests that it needs a differentiating design theory to reinforce its position as the primary technical design authority in the modern construction industry. In saying that, however, it also raises a whole host of further questions such as what is technical design, what position is being referred to exactly and why a differentiating design theory? This chapter is placed at the beginning of the book because it poses some of the principal questions that need to be addressed as the subject of architectural technology develops into a mature academic and professional discipline. Considering architectural technology historically in terms of alternative theories, through theories of technology and also by means of complementary design theories, allows the reader to reflect on architectural technology in its many expressions, be they historical, physical or even metaphysical. In addition, simply establishing and documenting its existence, confirming a theoretical and historical foundation to the discipline, permits continuing deliberation and development, providing a focused context for further relevant research.

Introduction

Why do we need a theoretical approach to architectural technology? Firstly, to answer this question we need to have some understanding of what we mean by theory. *The Concise Oxford Dictionary* offers three enticing descriptions:

- the sphere of abstract knowledge or speculative thought,
- exposition of the principles of a science, etc.,
- collection of propositions to illustrate principles of a subject.

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While the last two can have a significant role to play in many aspects of architectural technology, particularly those related to building physics and architecture generally, it is primarily the first, speculative thought, that gives us the catch-all definition we require, namely theory as ideas as opposed to practice and theory as thinking rather than doing. Most practising technologists, however, will know intuitively that all doing is preceded by thinking and sometimes very long and hard thinking. Calling it theory (e.g. this is all very well in theory but how will it work in practice?) simply gives us a framework and space to structure our thoughts.

Therefore a theoretical approach is already tied to many aspects of the practice of architectural technology but is particularly closely related to its existence as an academic discipline and how we take the subject forward in a controlled and managed way. In academic language, architectural technology is a vocational subject, meaning it is intended to lead on to practice as a professional. This is different to more academic disciplines where there is no closely related occupation. However, even vocational subjects need to be established as having strong academic principles or they exist merely as training programmes. Architectural technology now functions as both a professional discipline and also as an academic discipline and, as with most vocational subjects, these two aspects are very closely aligned (Wienand, 2011a). Although it may be possible to exist as a professional discipline without academic support, architectural technology is now predominately a degree level entry profession. It is taught as an academic subject throughout the UK and is supported by significant areas of research, all hallmarks of an established academic discipline. That is quite an achievement for a discipline of such comparative youth, and the next requirement is to bring what is a wide ranging research base into some form of recognisable arrangement.

This observation leads nicely on to the next set of questions, namely: why research, what is it aiming for, what exactly is architectural technology research, what for that matter is architectural technology? These questions can continue with: is architectural technology just detailing or is it technical design in architecture or perhaps much more than that, and what exactly are architectural technologists?

Leaving the research questions to others for now, we still have to ask: what is technology, what is theory, and therefore what is architectural technology; and what about theories of technology? All of these questions are fundamental to understanding the discipline of architectural technology and theorising allows us to consider these questions and many more in an attempt to provide a stable academic foundation for this exciting and immensely rewarding discipline.

Why we need theories

The concept of theory comes in many forms, from the everyday good idea to the verifiable scientific theory that takes on the mantel of ‘fact’ until proven conclusively otherwise, using scientific method. What they are all about, however, is ideas, and that is precisely why we need theories. Theorising can just be about ideas, making us think and see things in a different way, leading potentially to new innovative ideas. Essentially, though, it is about providing a structure to our thinking and a framework for our conclusions. For the discipline of architectural technology, viewed from either the academic or professional perspective, theories also allow us to use that framework to give some meaning to the past, the present and, in particular, the future. By taking that open and variable philosophical interpretation of what we mean by theory, we can use the simple form of 'ideas'. In this abstract or speculative sense, the strength of ideas comes from their very nature and therefore, as concepts, they are there to be considered in depth rather than any notion of being deemed factual.

Why exactly does architectural technology need theory? It could be argued (a theory) that it does not actually need theory and exists quite satisfactorily in its present form. That view suggests that it is a constant task based profession, that once mastered remains static for all time, which is clearly not true. The reality, as we all know, is that keeping abreast of change is a vital function of the practising architectural technologist, which leads us to two further questions: how does theory help us master change and, more fundamentally (we keep coming back to this), what exactly is architectural technology? The rest of this chapter attempts to confront this dilemma by using the concept of theorising to provide routes to the answers. For example, understanding how the discipline has got to the position where it exists today will help to provide some insight into what exactly it is. A deeper theoretical understanding of what architectural technology actually is may also help us to understand and grasp the present, predict the future and maybe also allow us to define that future.

Historical perspectives – learning from the past

The claim that theory can help us to understand how we got to where we are and therefore to understand who we are comes with the study of architectural history, and in particular the aspects of architectural theory that place philosophical thinking in distinct historic periods. It is recognised that the constantly evolving world of construction is not a smooth flow from one new idea to another but that just as with biological evolution it moves in a haphazard way, responding to whatever external influences are at play at any one time.

While architectural technology as a professional discipline has much in common with many allied vocational disciplines, such as civil and architectural engineering, building and quantity surveying, service and environmental engineering, it is probably closer to mainstream architecture than any other, especially when viewed from the perspective of the layperson. It can be argued that a study of the shared history of the two disciplines is where the subtle but real differences emerge that allow architectural technology to assume a separate and distinct identity. Both professions will see a significant heritage in the concept of the Master Builder that was so important to the buildings of the Middle Ages, or probably more accurately defined as the Gothic period of the 12th to 14th centuries. The comprehensive role of on-site designer, manager, builder and engineer that was the Master Builder would be entirely familiar to both modern day architects and architectural technologists. The collaboration with fellow craftsman, stonemasons and carpenters in the creation of buildings based on

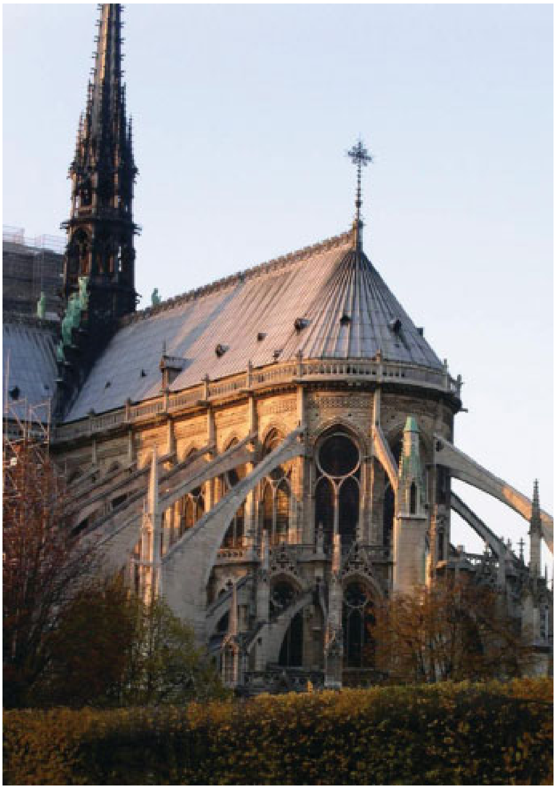

Figure 1.1 Notre Dame de Paris, illustrating the technical mastery, the depth of understanding and the pure technical design genius of the flying buttress.

verbal communication and full-scale layout in the field would also be instantly recognisable (Barrow, 2004). Historical texts that celebrate the triumphs of the Gothic era tend to focus on the architectural features that made it all possible and in particular the architectural legacy it provided for the history of Western architecture (see Figure 1.1). Few, however, really celebrate the technical mastery, the depth of understanding and the pure technical design genius required.

The great Gothic epoch was only possible because the Master Builders were the ultimate technical designers before all else as the seminal work, *Architectural Technology up to the Scientific Revolution* (Mark, 1993) makes abundantly clear. Therefore, by taking a slightly different perspective, it is possible to theorise with some authority that the current professional discipline of architectural technology has very firm roots in the Middle Ages and we could be tempted to go even further back. However, by taking this particular moment in history and assuming a common heritage we can also then trace a lineage that supports but equally differentiates architectural technology from architecture.

It does not take long to move from the Middle Ages into the Renaissance (14th to 17th centuries), which witnessed a separation of the architectural design process from on-site technical design of construction and as such triggered an

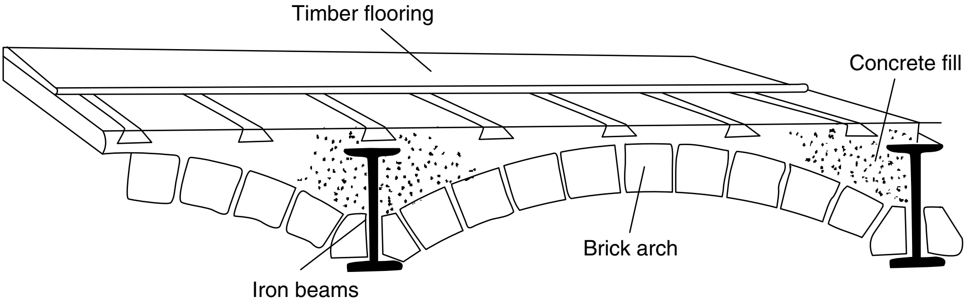

Figure 1.2 The Jack Arch of the Industrial Revolution, illustrating the fusion of the 'new' materials in wrought iron beams with the traditional brick arch providing larger spans of fire resistant suspended floors.

elevation of artistic and architectural design, leading eventually to the now familiar role of the modern architect. Other major developments followed as a consequence, such as the need to produce discrete depictions of their concepts; in other words, drawings. The complex philosophy of communication through drawing is interesting and continues to evolve today as new drawing tools and methods become available. The separation that came about in response to the need to impart specific construction information to builders as opposed to a drawing that depicted the final appearance of the building was another factor that helped to define a division between technical and representational illustration. Indeed, it is no surprise that two Renaissance architects, Brunelleschi and Alberti (Edgerton, 2009), are credited with the clear formulation of perspective drawing, a magnificent method for providing a three-dimensional appearance that from a technical standpoint has little use because, as it is 'not to scale', it is not possible to transfer dimensions. Again these historical observations can be used to support a theory that this division of drawing styles helped to precipitate another divergence between the two professions, with technical drawing traditionally the realm of the architectural draughtsperson having a clear lineage all the way to building information modelling (BIM) and an artist inspired façadism with the concept that creativity can exist universally (Wienand, 2011a).

While the architecture of the Middle Ages relied on and celebrated the impact of building technology and technical design on the final built form, the Renaissance delivered major advances in architecture that were not related directly to technology, with some notable exceptions. It was not until the Industrial Revolution that building technology took another major evolutionary surge forward, although this time probably under the command of the engineering profession. The technologies unwrapped during this period allowed the creation of many more wonderful architectural achievements and can also in theory be linked directly to current building design, where much cutting edge architectural design can be claimed to be 'technology enabled' (see Figure 1.2).

We have briefly examined distinct historical periods where the impact of technology on the ensuing architecture is markedly different. The Middle Ages was very much constrained and controlled by technical limitations, the Renaissance and beyond saw architectural exuberance unhindered by technical shortcomings and now we have technology essentially driving architectural innovation. Any theoretical exploration of the role of technology in architecture must also examine the role of architectural technology on building and therefore whether it is the 'technology to build' or the 'technology of building'. The answer is clearly both, depending on the circumstances, and is also potentially related directly to the role of an architectural technologist, but the relationship is also a lot more complicated as historic developments illustrate.

In the concluding chapter to his historically significant and remarkably inclusive work, *Construction into Design*, covering the period from the beginnings of the Industrial Revolution to the latter stages of the 20th century, James Strike (1991) contrasts external drivers on the introduction of architectural technologies such as fashion and war with the spirit of innovation and the potential for failure. He summarises these relationships as involving changing viewpoints, the nature of change and evolutionary themes and in so doing illustrates the apparently capricious world that governs the adoption of new technologies. In discussing changing viewpoints he points to differing views on the value of technology such as 'one generation reacting against its predecessor' or straightforward disagreements over the value of industrial technology in the production of architecture – an issue we still struggle with today when using state of the art technology to produce retro-styled buildings. The next point, closely related to changing viewpoints, is recognising in the nature of change that humans are slow and unpredictable when it comes to accepting the value of things new. Here Strike demonstrates this with the considerable time lags between the inventions of cast iron (Abraham Darby with smelting iron in 1709) and concrete (Joseph Aspdin with Portland cement in 1794) and their eventual use in building, let alone enthusiastic adoption. He also points to a discernable pattern in suggesting that: 'the story line for each material or technique is never identical, but the recurring stages often include: inception of the idea, testing of prototypes, trial use, failure, gestation on the shelf, reinvention, retrial, success through the construction of a seminal building, adoption, misuse, rejection due to failure or a change of fashion, introduction of legislation to control its use, gradual improvement of the material or technique, and finally general acceptance' (Strike, 1991).

Design projects that buck this trend are rare and Norman Foster's Willis Faber Dumas Headquarters in Ipswich (1975) is an example of the pure genius or luck required to succeed when challenging the current technical boundaries. Foster (2007), speaking about the project noted that he himself had written, 'But we don't have the time, and we don't have the immediate expertise at a technical level.' Perhaps the genius here is recognising limitations and rising to the challenge, fully aware of the risks. Returning to Strike's final topic, evolutionary themes, we enter the more predictable world of material and component developments; the scientific and research supported development of reinforced concrete or steel frame buildings for instance, following the earlier themes, but the high precision prefabrication of components is another significant factor, the Pilkington glass spider (planar system; see http://www.pilkington.com/) connector of Foster's building being a prime example.

Historical study allows us to examine previous scenarios with the advantage of hindsight and although normally written in authoritative styles, there is usually sufficient space to permit some degree of theorising of what might have been concluded to provide some otherwise unforeseen answers. A very noticeable omission so far in this historical overview is the exceedingly important impact of the Modern movement of the 20th century, on technology and architecture and by association also the building and design professions. An interesting example surrounds the comments and thoughts of Charles-Édouard Jeanneret, Le Corbusier, possibly the most influential architect of the period, who stated that 'Architecture is not building. Architecture is that cast of synthetical thought in response to which the multiple elements of architecture are led synchronically to express a purpose. And as this synthetical purpose is absolutely disinterested, having for object neither to make durable, nor to build rapidly, nor to keep warm, nor to promote sanitation, nor to standardize the domestic usefulness of the house, I would say, since it is above any utilitarian objective, it is an elevated purpose. Its objective is to bring us benefits of a different nature from those of material usefulness; its aim is to transport us to an inspired state and thus bring us enjoyment' (Le Corbusier, 1929). Corbusier's architectural theory does something very important and unforeseen here in that it helps to illustrate what could be a defining feature of architectural technology, namely the pursuit of that *utilitarian objective* (see Figure 1.3).

The great advantage of architectural theory in this instance is that it does not have to be verifiable or even particularly sensible, primarily it has to be inspirational and a motivating force for the individual architect or, as described earlier, a collection of propositions to illustrate principles of a subject. In a similar vein, a theoretical notion could assert here that while all aim to design buildings, architects aim to produce great architecture, engineers to produce sound structures and architectural technologists to produce high performance buildings, in that utilitarian form.

An interesting proposition from another of the 20th century's most prominent architects, Frank Lloyd Wright (1901), also illustrates the very subjective nature of some architectural theory when he lambasts the Renaissance, suggesting 'It is the setting sun which we mistake for dawn.' He stated that 'with the beginning of the sixteenth century, the malady of architecture is visible. It becomes classic art in a miserable manner; from being indigenous, it becomes Greek and Roman; from being true and modern, it becomes pseudo-classic. It is this decadence which we call the Renaissance' (cited in Braham and Hale, 2007).

There is little doubt over the considerable impact that Frank Lloyd Wright has had on 20th century architecture yet his comments above are significantly slanted and a personal observation that needs to be described as highly subjective. An architect can therefore theorise quite freely in a philosophical sense without it necessarily affecting the quality of his or her design outputs. Architectural theory in this case is based on the blurry concept of theory that directs the subsequent design process, the concept of 'isms', schools of thought and philosophical movements that thinkers believe to be true as opposed to being provable (Wienand, 2011b). Although architectural theory is most often seen in

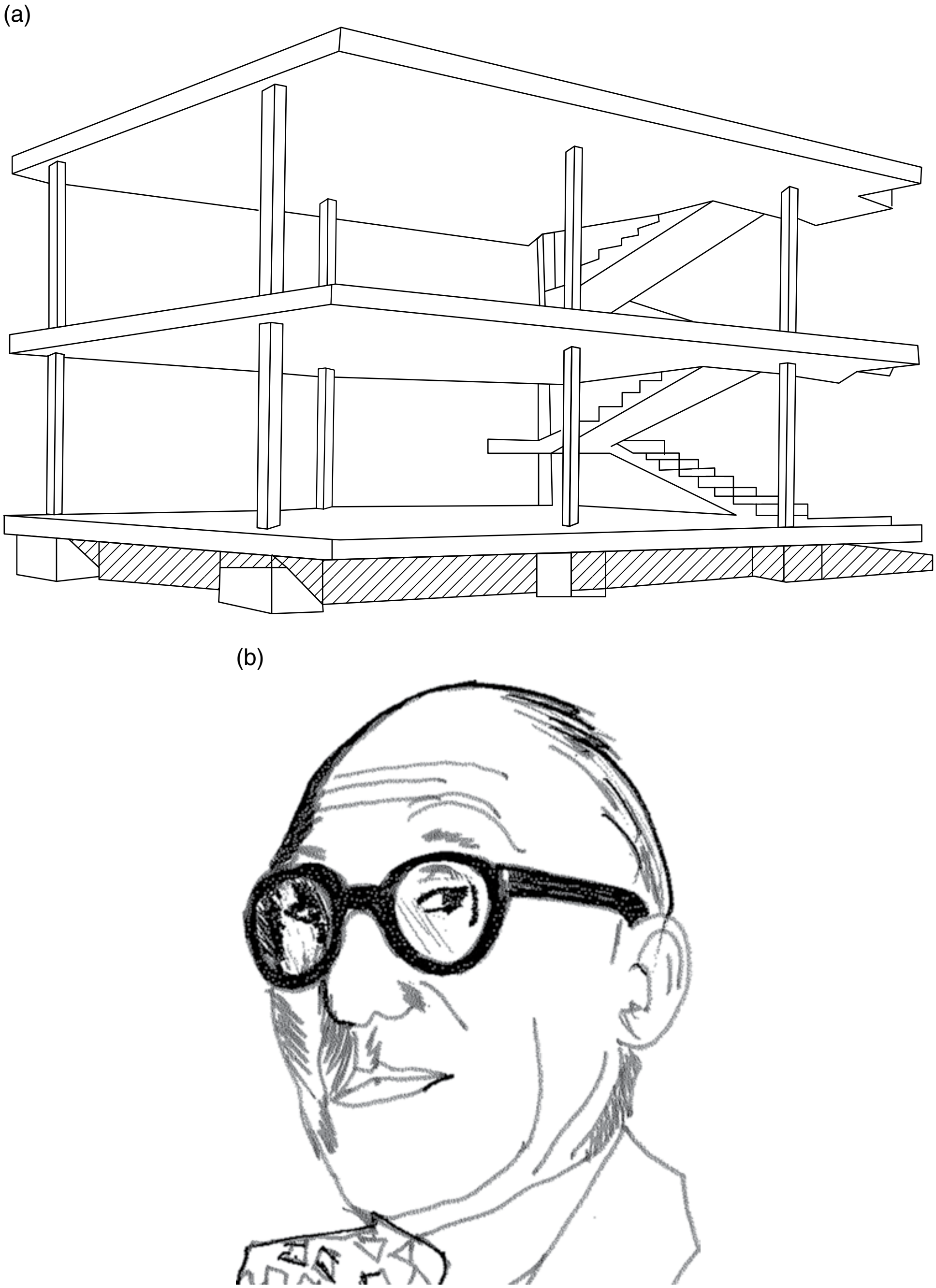

Figure 1.3 (a) The domino house by Le Corbusier – the pure simplicity of utilitarian design, approaching the aesthetic of Quaker plainness with its functionality. (b) Le Corbusier.

philosophical form – as manifestoes, historical essays, etc. – aspects of social and cultural study and the fundamental principles of proportion still require the application of scientific method. The difficulty these observations present is the inference that architectural technology as a design profession and being 'not architecture' is somehow beyond subjectivity and purely objective. However, can it be totally objective? Theoretically it can, but it certainly presents an interesting concept for further consideration and future propositions.

By taking this tour through architectural history we have highlighted the issue that architectural technology exists as an integral technical element in building design that either produces architecture or complements architectural design, but it also exists as a clearly defined professional discipline with a discrete and demonstrable pedigree, complete with contradictions and subsequent uncertainty. So just as with other professional occupations such as medicine, engineering and indeed architecture, the practice and products assume the same designation but describe quite distinctly different aspects; studying medicine is different to practising medicine and also quite distinct from taking medicine.

Separate disciplines have been described as being distinguishable by the way they present themselves and above all have been depicted as 'seeing things differently when they look at the same phenomena' (Del Favero, 2011). From this observation, another theoretical notion that helps to support the distinctive natures of architecture and architectural technology, and has some grounding in experience, is that when considering the 'phenomena' of architectural detailing, the two disciplines have a tendency to see things very differently; architects see the surface details that make up the architectural narrative of the building whereas architectural technologists see the technical design of joints that is mostly hidden and shapes the critical narrative around buildability.

Before moving on to the next section looking at the current situation with this slightly clearer view of architectural technology as having gained something from the past, it is clear that there are many questions still left to be answered. There are also some intriguing links to explore, such as how Corbusier's utilitarian objective could connect with the concept of buildability, a central tenet of architectural technology, or even more intriguing, as seen above, how the apparently simple concept of architectural detailing can mean very different things to different disciplines (see Figure 1.4).

The here and now

It has been suggested that a theoretical approach can help us to understand and grasp the present, predict the future and also maybe help to define that future. Having briefly considered the past, what is clear is that the discipline of architectural technology is closely linked to the evolution of technology and is, as such, constantly evolving. This poses the question, what exactly is an architectural technologist? This is difficult to answer in one sense but theoretically

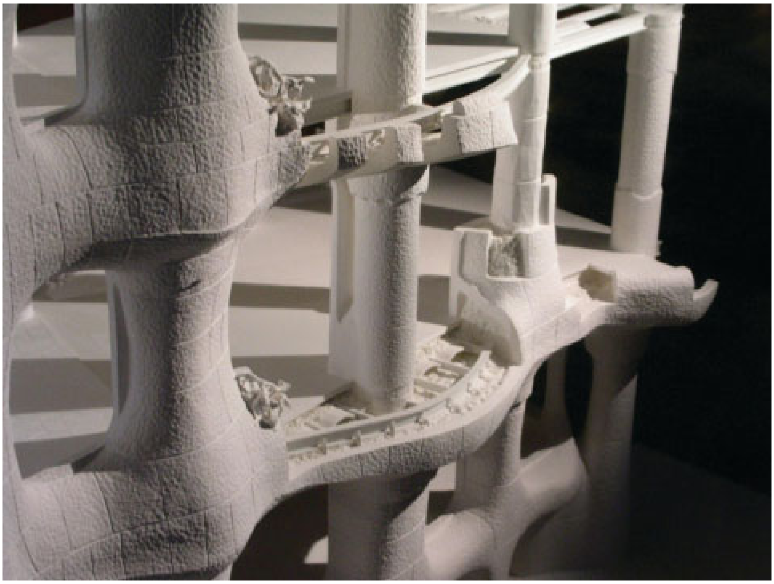

Figure 1.4 Gaudi's detail for supporting the overhanging 'rockface' of La Pedrera's main façade illustrates that for some the projecting stone is the detail yet for others it is the composite construction incorporating the steel frame and 'L' shaped stone units fused together with the concrete infill.

very exciting because the future is still to be written, and therefore anything is possible. This may seem to be an overly ambitious statement but, as noted in the opening section of this chapter, we are simply using theory as a framework and to provide space to structure our thoughts, to speculate and make propositions; there is no harm in thinking.

A reasonable start when considering a theoretical approach to the subject would be to explore any theories that already exist that may be applicable to architectural technology. In reality there are far too many to be considered fully but beyond the philosophical theories of architecture, already referred to, the theories of technology and in particular some transferable theories of design are of genuine interest.

It is useful at this point to examine some thinking around the concept of technology beyond the confines of architecture and building. A great deal of writing on the subject of technology comes in very emotive terms and some interesting theories place technology as just a tool or technology as an uncontainable force, and luckily even technology as having the capacity to save the world. The *instrumental theory of technology* suggests that technology is a tool and deemed to be neutral and 'indifferent to the ends it can be employed to achieve' (Feenberg, 1991). Unresponsive to political control, a hammer is simply used to hit things.

Substantive theory proposes that we are doomed; taking the example of the hammer it suggests that the invention of the hammer leads inexorably, for example, to somebody using it to hit another person, then sharpening the edges to make it more dangerous, leading to throwing it, then projecting it, leading to bullets and before we know it, we have World War Three. Martin Heidegger, an advocate of substantive theory, stated that 'Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it' (Heidegger, 1954).

It can be fun playing with these concepts but they should also make us think very carefully about aspects of our normal professional lives. In choosing a standard detail to solve a particular problem are we simply using the standard and correct tool or are we being driven to a solution by a wave of pressure founded on previous experience and possibly the fear of failure? The *critical theory of technology* comes to the rescue, suggesting that the substantive world view can be altered by human choice and that the instrumental view can also be overly naïve (Feenberg, 1991). Technology can adopt social values in its design as the overtly 'green' technologies demonstrate in making very clear choices to change direction for the common good as well as, for example, the deliberate design of cities for pedestrians and public transport.

Some thinking, slightly closer to architecture, comes from Stephen Kline, writing in 1985 where he defines technology as having four common usages. The first is the idea of hardware (or artefacts), the second uses sociotechnical systems of manufacture, the third usage he describes as knowledge, technique, know-how or methodology and the final usage is sociotechnical systems of use (Kline, 1985). All of these concepts can be related specifically to architectural technology and although not revolutionary in themselves, they do offer us the opportunity to reflect on and catalogue the professional process and in particular the outputs.

The idea of hardware relates to things made by man, the basic materials and components that we assemble in architectural design; sociotechnical systems of manufacture refers to the building and manufacturing process; knowledge, technique, etc., is the knowledge and skill base of all those involved in the design and building process; sociotechnical systems of use is how the building is eventually used. Using this basic theory we can make it more relevant by proposing (theorising) that architectural technology has expressions that can be identified in:

- the components we accumulate into buildings;
- that process of accumulation also known as building;
- the understanding of how to put them together;
- how that building eventually functions.

Returning briefly to the *critical theory of technology* and in particular our ability to have an influence through the use of innovative ideas and technologies, the observation that the rate of technological and social change leaves us unable to optimise current technology is worth some consideration. In the not too distant past, technology changed comparatively slowly and knowledge and efficient use was optimised over significant periods of time; technology changes so quickly now that it is commonly used only to provide the springboard to the next expression (Jonas, 1979). Can this observation have an influence on our approach to architectural technology, particularly when contrasting modern with traditional

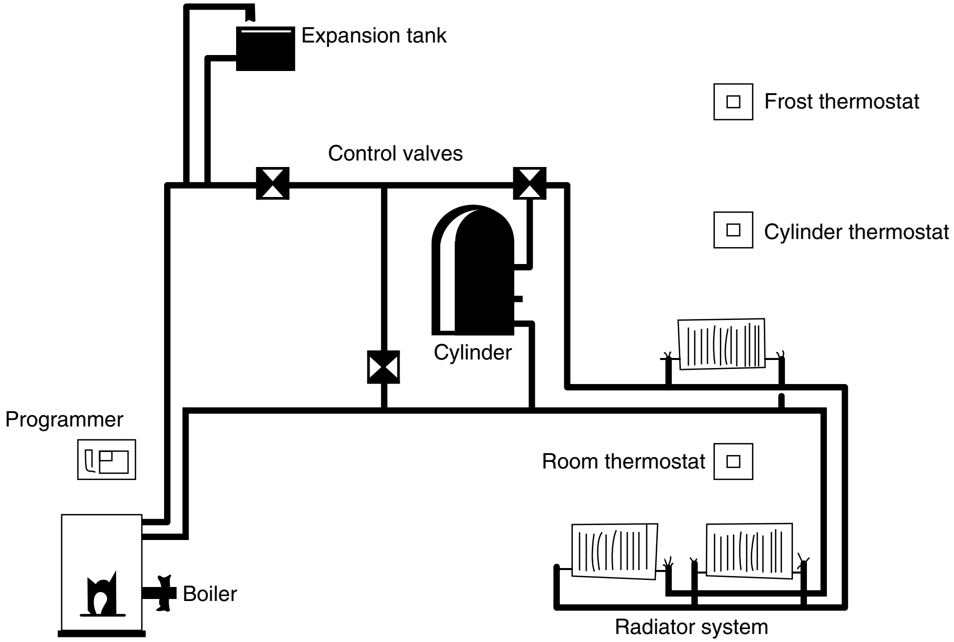

Figure 1.5 With the key caveat that 'if designed appropriately', a conventional wet central heating system has the capacity to be genuinely future proofed where the boiler can be replaced with a better system (wood pellets for oil, for example) and so can the controlling devices or even the radiators for that matter.

technologies? Should this thinking be used to justify a risk averse approach to technology in building, citing the fear that modern is changeable and unproven whereas traditional technology has stood the test of time, or should it inspire a design approach that adopts modern technology in a way that allows change to be accommodated? A good illustration of this would be the very simple instance of comparing fireplaces for heating to an electric heating system. The alternative wet central heating system, where the boiler can be changed to whatever the current 'best solution' is without overly affecting the rest of the system, is clearly a solution with some degree of genuine future proofing (see Figure 1.5).

There are some very clear theoretical challenges emerging for architectural technology and it is worth spending a little time examining these. Firstly, it is important to establish that architectural technology is a design based discipline and that therefore design theories can potentially have a significant role to play. It was suggested earlier in this chapter that in designing buildings architectural technologists strive to produce high performance construction as opposed to great architecture and core to this task is the production of architectural details, essentially the design of joints; joints to hold structures together; joints to hold materials together in components; joints to control the interface between controlled and external environments; joints to control movement; etc. Detail design is a highly creative process and not a simple technical exercise; it is a 'knowledge-centred activity that bristles with equal creative endeavour as the larger conceptual design phase' (Emmitt *et al.*, 2004) and although it is clearly more than a task based enterprise, it does suffer from the observation made earlier, that it is mostly hidden from view and therefore requires a different form of evaluation.

Visual aspects are important but it is mostly on performance that architectural details will be judged as well designed or not. To illustrate this challenge, consider that the theoretical ambition in design is to produce the perfect solution; in architectural detailing this is often just doing the job it is required to do. The perfect piece of joint technology is assessed on its performance and not on how it was designed, so whether it came from a book of standard details or was derived by a thorough process of design from first principles makes no difference. However, theoretical approaches can be useful in deciding what makes it a perfect solution. Consider the repair of a mortar joint in a 13th century Gothic cathedral where current thinking would suggest that the original lime mortar is copied as accurately as possible. This action would follow current conservation theory and would also come very close to fulfilling the concept of the perfect solution. The simple mortar joint in medieval construction consisted of a pliable material; lime mortar placed between blocks of stone took on exactly the right shape to connect two imperfect surfaces; loads are transmitted evenly, avoiding stress points, allowing tall, heavy, buildings to be held together with nothing more than the force of gravity. Slow drying lime mortar accommodates subsequent movement and is converted through carbonation slowly across many years into a much harder limestone material; a perfect joint? However, could a keyhole type operation that injects some kind of wonder glue, causing minimal damage to the existing structure, not be as good? The arguments against would normally centre on unknown consequences of the 'glue' or a suggestion that the action might not be reversible. Clearly these materials are available and are used in certain circumstances, illustrating that theoretical considerations can be used to arrive at the correct decisions – at least correct within the current sphere of knowledge.

A philosophical challenge poses the question, should architectural technology strive to produce new solutions or should it endeavour to produce a greater understanding of current solutions? Can we expect every detail designer to consider the thoughts of Heidegger (1954), Jonas (1979), etc., or is merely striving for the perfect solution sufficient?

Looking to the future

Design theory is not new and it has manifestations in many academic and professional disciplines. There are some fields, however, where the notion of design is central, yet as with architectural technology it is not necessarily what one first thinks of when considering the work of that discipline. Mechanical Engineering is one such discipline where the idea of function predominates. Writing in 2008, Jonathan Maier stated that until the 1980s engineering textbooks focused heavily on analysis and individual problem solving – the idea that function is mathematical, scientific and measurable. Two important works, *The Sciences of the Artificial* (Simon, 1996) and *Systematic Engineering Design* (Pahl and Beitz, 1996) developed an approach that saw design problems as being part of systems rather than individual components (Maier, 2008). Transposing this view to architecture, it could be argued that a systematic approach was always an integral part of the architectural technologist's attitude to design without them necessarily being aware of the fact. Both the aesthetic and technical concept of the completed building would be apparent when considering materials, technologies and design solutions; a house is conceptually much more than just a collection of materials and components, and so is any other form of building.

Yet as design theory has developed within mechanical engineering, many interesting observations with potentially major consequences have emerged. Describing work with colleagues, Maier (2008) suggests that the functional view of engineering can learn a lot from the design disciplines of industrial design (consumer products) and architecture, where the solution is seen as having much more to contribute than mere function; emotion can be central. They go on to develop the idea of affordance, a term borrowed from perceptual psychology, where 'the affordances of a product are what it provides, offers, or furnishes to the user or to another product' (Maier, 2008). This is different to its function so where a house may function as a shelter from the elements it affords comfort, prestige, investment, etc. The idea in its simplest form suggests that while functions remain constant, e.g. a house and shelter, the affordances are infinitely variable; consider the affordances from a 'house' belonging to a peasant from the Middle Ages, a 21st century pop star or the indigenous people of Papua New Guinea.

The concept of affordances includes both positive and negative versions however and this is where it starts to have real meaning for the discipline of architectural technology. The observation that adding extra heating capacity to an existing building in temperate climates can have unseen consequences is not new; there is now a deep understanding of the relationships between insulation, heating sources and losses, moisture control and condensation, etc., that was not there initially. A project systematically designed with a deliberate assessment of positive and negative affordances might have foreseen some of these issues and prevented the problems.

A proposition here theorises that architectural technologists are partway there in that they are usually very aware of the complete range of affordances from traditional solutions but remain fearful of new technologies. Adopting this systematic approach may help to mitigate some of the barriers to innovation sometimes found in the risk-averse world of technical design in architecture.

Carrying on with the theme of innovation, another very interesting variation on design thinking comes from the realms of industrial design. Understanding the nature of innovation is core to this concept and, in particular, the relationship with design. *The Concise Oxford Dictionary* suggests that to innovate is to 'make changes in'. This is not much help in itself but as the derivation is from the Latin *novo*, for new or *novare*, make new, we can take a meaning that suggests something like ‘changes that are new’. This definition can be interpreted as having two components, the idea (new) and the action (changes).

While it would be agreeable to suggest that innovation is truly democratic and open to all who wish to make changes, the reality is that it is an action that responds to a perceived need; something that by definition needs changing and understanding that need in depth is part of the process. The generation of original ideas therefore is very much linked to a defined problem and is dependent on the knowledge and imagination of the conceiver. ‘For instance the background, knowledge and experience of the individual will impact on his or her ability to imaginatively consider a given topic. In order to see the shape of a horse in the clouds one must be equipped with the knowledge of what a horse actually looks like’ (Wylant, 2002).

In architectural technology terms, this can be related to the individual designer’s skill palette, which is in itself a product of education, experience and desire to accumulate inspiration and motivation from many different sources. This palette can also be depicted as subject-specific skills such as experience of design and detailing particular building elements and the ability to adapt to new situations such as detailing of a particular element where no experience exists (Wienand, 2007). Where the industrial design process takes this further is in the idea of organised ideation, commonly referred to as brainstorming. This means not just having a meeting to discuss a particular problem but organising that meeting specifically to generate new ideas. The constitution is therefore very important with members potentially invited not just because of their inherent knowledge but maybe for their ability to turn things upside down – maverick thinkers who can offer some valuable insights. Therefore the process is important, the people are paramount and so is the organisation to ensure that a solution is possible. ‘The wild, nonsensical idea may eventually be discarded but open-minded consideration of the wild idea can lead to a potentially useful idea’ (Wylant, 2002). Although the idea of a wild uncontrolled ideas fest is not totally alien to architectural technology, it is certainly not part of the mainstream process.

In an earlier section it was argued that in terms of an eventual solution, ideas taken from the pages of a standard text differ little from those generated from first principles; however, there may be limited understanding of standard solutions with a much deeper understanding possible with new design solutions arrived at via a process of careful consideration and planning. It can also be argued that design solutions are often much easier to arrive at through a detailed understanding of the problem at hand; in fact, the deeper the understanding, the more evident the solution. The definition of the problem at hand is central to understanding and clarity helps to dismiss unrelated issues and to assign degrees of importance to others (Wienand, 2007).

As with the systematic approach of affordances above, an approach that masters the outputs of apparent but controlled chaos could help to mitigate some of the fears of innovation that can stifle good design. In the risk-averse world of technical design in architecture, design theory in architectural technology is still in its infancy but there is a good deal of interesting and relevant precedents from which to learn.

Conclusion

It has become clear that a theoretical approach to architectural technology provides a framework that holds together all of the various strands that make up the discipline. It provides an historic underpinning of the profession, a rationale for the academic discipline and a possible methodology for taking the profession forward as an organised, specialist technical design discipline, striving systematically for innovation and in full control of risk factors.

Speaking in 1950, possibly the greatest 'technical architect' of all time, Mies van der Rohe (1950) proposed that 'Architecture depends on its time' and that technology and architecture being closely related 'will grow together, that some day the one will be an expression of the other' (cited in Braham and Hale, 2007). It can now be argued that many buildings of the 21st century bear testament to his aspirations, but we cannot possibly suggest that we have a system in place that allows all buildings to achieve this aspiration; in fact it could also be argued that the architecture of the Middle Ages achieved this far more effectively. Essentially he described a system that values in equal measure the aesthetic and technical inputs; what is now fundamentally different is the complexity of the developing architecture. To master this complexity we need a professional approach to building creation that is inclusive, organised and multidisciplinary; indeed the term omnidisciplinary has been used by George Hazelrigg, a mechanical engineer, to describe the position where 'any and all disciplines may be involved in the solution to a particular design problem' (cited by Maier, 2008).

A very interesting new sphere of work has emerged around *evidence based design* that, when juxtaposed on the earlier observation of Del Favero (2011) that different professions see the same things very differently, provides a platform to adopt a genuinely 'omnidisciplinary' methodology to technical design in architecture. Where evidence based design merely suggests that design decisions should have a basis in factual proven knowledge as opposed to intuition solely, the argument can be made that architectural technologists have always taken this approach without necessarily being cognisant of the fact. The onus is therefore on the architectural technology profession to make this correlation more evident and this book is a major step forward in that process. Following a related theme, Brandt *et al*. (2010) argue that the architectural profession by comparison is too reliant on intuitive design and 'must be able to rely on evidence to anticipate the effects of our work'. In providing some intriguing case studies they also point to three primary areas of 'evidence': experiential such as modelling and simulation, social science and the physical and natural sciences. They also point out that while the physical and natural sciences are often viewed as similar in their difference to the social sciences, they do in fact represent two very distinct sources of evidence for building designers, physical sciences being vital to understanding how structures perform whereas natural sciences are more about how we as organisms react to buildings. The challenge for both professions and all those allied to the production of buildings is to make meaningful connections that encourage the dialogue and compel the desire to seek out and find the necessary 'evidence'.

We have now considered architectural technology historically in terms of alternative theories, also viewed it through theories of technology and in particular also by means of complementary design theories. What has emerged is that architectural technology in its many expressions, be they historical, physical or metaphysical, needs a theoretical basis primarily in order to establish and document its existence. In addition, it could also do with a distinguishing approach to design theory that reinforces its position as the primary technical design authority in the modern construction industry, a professional standing that is not without historic significance.

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Case Study A

Designing to Anticipate Future Climate Change: The Case of an Urban House

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The theme of this case study chapter is designing to anticipate future climate change, with a family urban house forming the focus of the work. The background and history to the one-off house project is described and the ideas underpinning its design are explored. Fundamental to these is an 'Activ-Haus' approach where context is used both experientially and as part of the carbon reduction strategy. Also discussed are the passive approaches employed in the design and the iterative use of modelling in its development. The use of materials, construction methods, control systems uniquely developed and the experience gained from making the building and then living in it is described. Ongoing research from the project includes the live monitoring of performance 'as built' and the behaviour of a variable exposed mass wall using different materials placed within a sunspace.

The practitioner's opportunity

Most precedents for low energy one-off houses have been designed to reduce energy and resource use with current climatic conditions in mind (Maxwell, 2008). In designing to these conditions, it has always been assumed that CO_2 levels could be stabilised at a level where average global temperatures would not rise more than 1.5–2 °C (International Energy Agency, November 2009). More contemporary updates in predicted levels of global warming suggest that this may no longer be achievable and that we should expect rises greater than 2 °C (International Energy Agency, 2010).

Architectural Technology: Research & Practice, First Edition. Edited by Stephen Emmitt.

The one-off house has traditionally given architects a chance to experiment for themselves and by 'putting their money where their mouth is' provides the opportunity to explore issues that have become of concern within their more general practice. Marsh Grochowski Architects had already developed an interest in working with researchers, functioning as designers within a research agenda set by others. With so much emphasis placed on energy conservation-based design standards set up using current climatic conditions, it was felt this project should be an opportunity to direct the research agenda elsewhere. Instead it could focus on the nature of the greater change in climate likely to be experienced over the next twenty to thirty years as temperatures rise and weather conditions become more uncertain – in particular, questioning whether the physical consequences of climatic change can be anticipated and designed for in an integrated and holistic fashion, and also looking at whether this could be done using an interest in context, passive design principles, behavioural narrative and zoned planning while at the same time maximising the affordable use of renewable and low energy technology and keeping material choice sensible in terms of embodied energy.

Bearing in mind that the majority of precedents for this kind of project have been in rural or suburban settings, this was also an opportunity to explore metropolitan brown field environmental design issues, with their greater levels of urban constraint. The advantages of a city location were the ability to minimise travel through the choice of location, explore the potential for live-work and also look at the possibilities for growing food in a restricted urban environment. All these are considerations relevant to reducing energy use and germane to the problems that will increasingly face city dwellers as global warming takes hold.

The context of environmental ideas

Marsh Grochowski Architects has had a strong relationship with the University of Nottingham, working to develop experimental built examples of domestic passive architecture over a number of years. This includes live testing of fabric and behaviour and has introduced the practice to the notion that there should be amended passive house principles for the UK. This piece of research at Nottingham, their *Passiv-On* programme, has been highly influential in the development of this project.

Similarly, much has been learned from the work of Bill Dunster, Susan Roaf (Roaf *et al.*, 2001) and the Vales (Vale and Vale, 2000), who the author taught with at Nottingham in the mid 1990s. The use of high levels of thermal mass coupled with sun spaces as thermal buffers and sources of pre-heated winter ventilation air is common in all their work and shown to be effective in modulating internal temperatures. This technique is explored in a wider context in *Solar in Cool Climates* by Porteous and MacGregor (2005). The use of night cooling is more commonly found in office buildings and explored in detail in *Passive Cooling of Buildings* (Santamouris and Asimakopoulos, 1996). Its use in domestic buildings is more novel. The potential for the use of phase change material as a substitute for thermal mass in lightweight buildings is the subject of an interesting study by

Rodrigues (2009) at Nottingham University. This project explores extending the use of phase change techniques as a thermal buffer against hotter summer temperatures.

When the project began in 2005 there was no predictive data about future climate trends for the UK. The first set was published in 2009 (Defra/Hadley Centre/UKCIP, 2009) and included localised data for the East Midlands, where Nottingham is located. However, there was much written about general trends and it was becoming clear that, Gulf Stream apart, global warming was taking place and the UK climate was going to get dryer and warmer.

Developing a methodology

The design data used in developing and modelling the project was based on both accepted approaches to passive and low energy design, established temperature data and experience developed in practice when collaborating on other innovative low energy projects such as Alan Simpson's House (Conran, 2009) and the E-on House (Burrows, 2008).

The elements of the multilayered design approach that was adopted were chosen through a process of reflection on the issues and identification of the opportunities given by the particular context. An interesting precedent is mentioned in Colin Porteous's (2002) book *The New Eco-Architecture*, where he describes a house by Sejima and Nishizawa, contemporary Japanese architects, which is arranged in concentric rings and of course builds on the very sophisticated layered approach of traditional Japanese architecture (Kerr and Sokol, 2006). The choice of measurement and recording of the outcomes was made in relation to the level of objectivity that could be ascribed to the data to be collected and the particular operational effectiveness to be tested.

The author of this chapter was the architect and self-builder of the house and as such the contents are based on the personal experience of himself and his wife. In this sense the author and family become both experimenter and guinea pig and so a clear distinction needs to be drawn between the subjective and objective nature of observations, particularly when dealing with aspects of life within the house. Of course this is part and parcel of the intriguing nature of architecture and its inevitable bridging of the objective and subjective to the point where perception can have a clear impact on the application of the science (Roaf, 2009).

The case study

Locating an affordable urban site was difficult. The development boom that began at the turn of the century made small urban sites very desirable. The area finally selected was to the south of the city centre of Nottingham, called the Meadows. It was a place with a reputation for drug dealing and gun crime, physically separated from the centre by an inner ring road. It had the advantage of containing cheaper site opportunities and a strong community spirit. The chosen site was on the corner of two streets of Victorian terraced houses and was well orientated and affordable. It was close to shops, ten minutes walk from the station and twenty minutes walk from the Marsh Grochowski office.

The site context

The site was originally part of the water meadows of the River Trent. As the city of Nottingham expanded southwards, the meadows were filled with Victorian industrial waste. When purchased there was a small single-storey meat factory there, built tight to the site boundaries. The factory was located on the corner of the two terraced streets, facing south and west. The southern aspect was completely open to a park and the ground was level. The westerly aspect faced a modern development of two-and three-storey houses within a walled enclosure. There were excellent views to the south and southwest and the park was protected from further development by covenants. The River Trent, on the other side of the park, flows from the southwest, giving a clear channel for the prevailing wind of commonly 4–5 m/s wind speed.

The geology is interesting. Below a 10 metre layer of industrial fill and alluvial material deposited by the river is Sherwood (bunter) sandstone, approximately 40 metres in depth, under-drawn by a denser limestone bed which, in turn, sits over the Nottinghamshire coal seam (Taylor *et al.*, 2003). These conditions give rise to an aquifer running within the sandstone.

Layering ideas: the Activ-Haus+ concept and contextual design thinking

The design strategy for the house is one of multilayered ideas and concepts, each interdependent and supporting the other, allowing a breadth and richness of approach.

A fundamental layer is the notion of context. Here we mean something wider than just the site conditions; 'context' means everything about the situation of the project. All the possible parts of the situation, its history, its economics, its site conditions, its community, its geology, elements of contemporary thinking, etc., become opportunities for exploitation in the design.

Alongside this is the notion of 'Activ-Haus+'. This is not a new idea in terms of environmental thinking. There already is an 'Activ-Haus' movement that poses an alternative view to those supporting the 'Passiv-Haus' approach, where energy conservation through the use of an airtight highly insulated building shell is the primary focus. The 'Activ-Haus' approach suggests that high levels of air tightness are difficult to achieve in reality and generation of renewable energy can compensate for a less onerous emphasis on limitation of energy use. In this project we have expanded the idea of 'Activ-Haus' to suggest an approach where one's experience of climate and season are enhanced by the architecture, as opposed to being reduced, as they would be in a 'Passiv-Haus'. Layered with this and explored later in the chapter, is the way users can engage in the environmental experience of a building as part of its energy reduction strategy (Figure A.1).

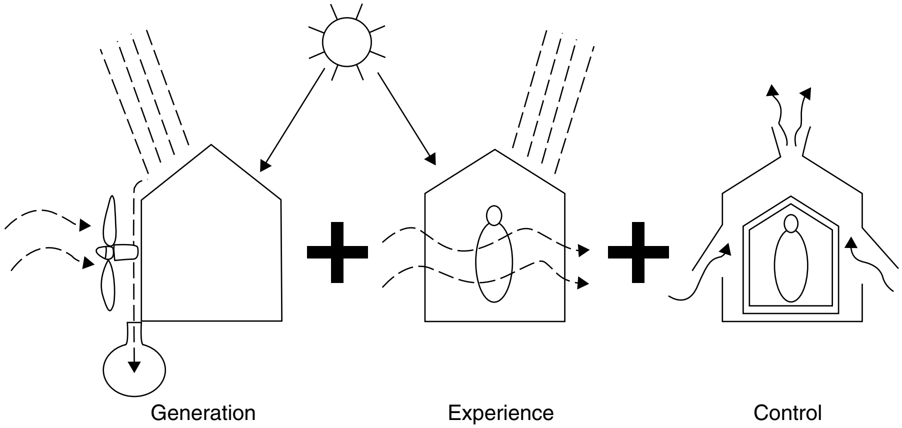

Figure A.1 The Activ-Haus+ concept.

So how in general terms does this project use the ideas of multilayering, context and an extended idea of 'Activ-Haus'? The layering of the primary ideas of context and 'Activ-Haus+' have already been mentioned, but within this chapter ideas will also be explored that involve novel environmental approaches, small scale urban relationships, variable responses to changing conditions, the use of multifunctioning elements, the combination of logic and experience, ideas of coding and perception, expressive detailing and resource use, to name but a few. Combination of these concerns with each other is used to bring a complexity and sophistication to the ideas and richness to the architecture.

The design exploits context wherever possible, from the physical and geological conditions, making the most of the sun, open sky and wind access and also the suitability of the geology for ground source heatpumps and water extraction. It exploits the urban situation and uses the open ends of the solid wall Victorian terraces as part of the energy reduction strategy. It uses the freedom given by the self-build process to provide an opportunity for experimentation and exploration and its social environment makes it eminently suitable as an educative tool.

As already mentioned, an important element of the brief devised for the house was that it should allow one to experience both the seasons and the particular exposure to the elements provided by the context. The implication here was that the house and the way it was used would change during the year, shrinking in the winter and expanding in the summer – in a way following hibernation patterns. This seemed a natural way to think about living and our response was to develop a design that was layered, with greater levels of insulation and airtightness in the inner layers and with outer layers more exposed to the outside world (Figure A.2). Such an approach would be able to aim for high levels of energy efficiency in the winter, while at the same time achieving high levels of natural cooling in the summer. Integral with this would be the immediate involvement of the occupant in experiencing, understanding and controlling their environment. Hence the adoption and extension of the term 'Activ-Haus+'.

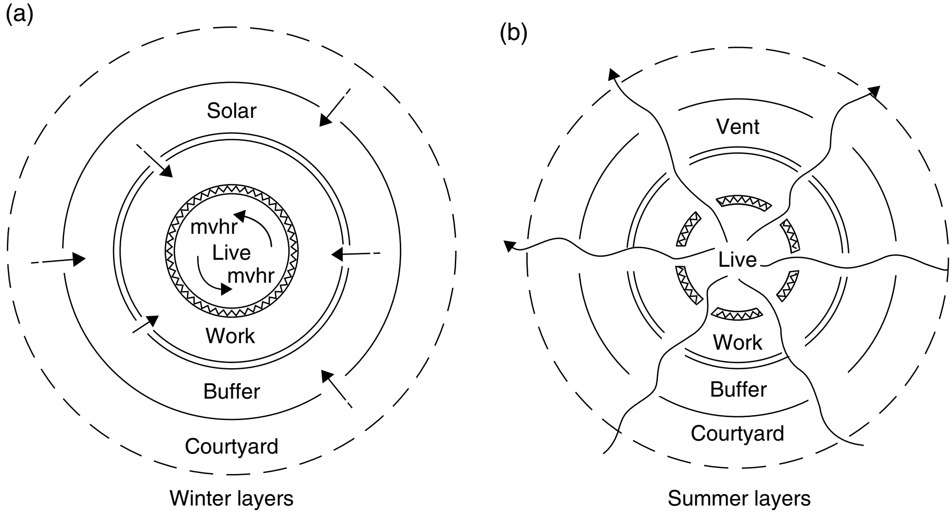

Figure A.2 The layered design approach: (a) winter layers and (b) summer layers.

This type of approach was supported on a technical level by the work that Professor Brian Ford *et al.* had produced, leading to the publication of the *Passivhaus Standard in European Warm Climates* (Ford *et al.*, 2007). In this document they proposed that the Passivhaus Standard should be varied to suit the different climates that exist across Europe and that the milder winter climate, differing lifestyle and expectations in Britain call for a different approach. Their suggestions for the UK do not rely on such high levels of air tightness and the use of continual heat recovery in both winter and summer, but provide the minimum fresh air requirement, preheated in winter, through solar buffer spaces, allowing manual control of the environment in the summer through the use of opening windows.

The layout and its relationship to context

Because of the windward aspect and the need to take advantage of the orientation of the site, a walled courtyard was formed on the southern corner. The northern and eastern boundaries facing on to neighbours' gardens were open fenced to allow in light and ventilation to the small rear garden area. With two existing terrace gable walls facing into the site, both poorly insulated and losing heat, the house was split into two elements, each one attached to an exposed neighbour's gable wall to insulate it.

Early schemes looked to minimise the external surface area to the north and east and use the full footprint of the original factory. This approach was poorly received by the city planners who wanted to improve the aspect for the neighbours over the pre-existing situation. The eventual design of the rear area reflected the rear extension arrangement along the terraces to achieve this.

The level of the new building was set 600 mm above pavement level in accordance with the Environment Agencies' 100 year flood level prediction at the time.

The ground floor was dedicated to the work aspect of the project, with the new studios able to view the south facing courtyard. The space below the floor was kept open so that it could be used for service distribution and act as a cool plenum to duct air from the north to the south side of the building in the summer.

(a)

1 Electric car
2 Workspace
3 Gallery
4 Sunspace
5 Composting toilet
6 Store
7 Studio
8 Courtyard
9 Recycing
10 Bedroom
11 Laundry
12 Sunspace
13 Larder
14 Living/Dining/Kitchen
15 Sunspace

Figure A.3 Plans: (a) ground floor and

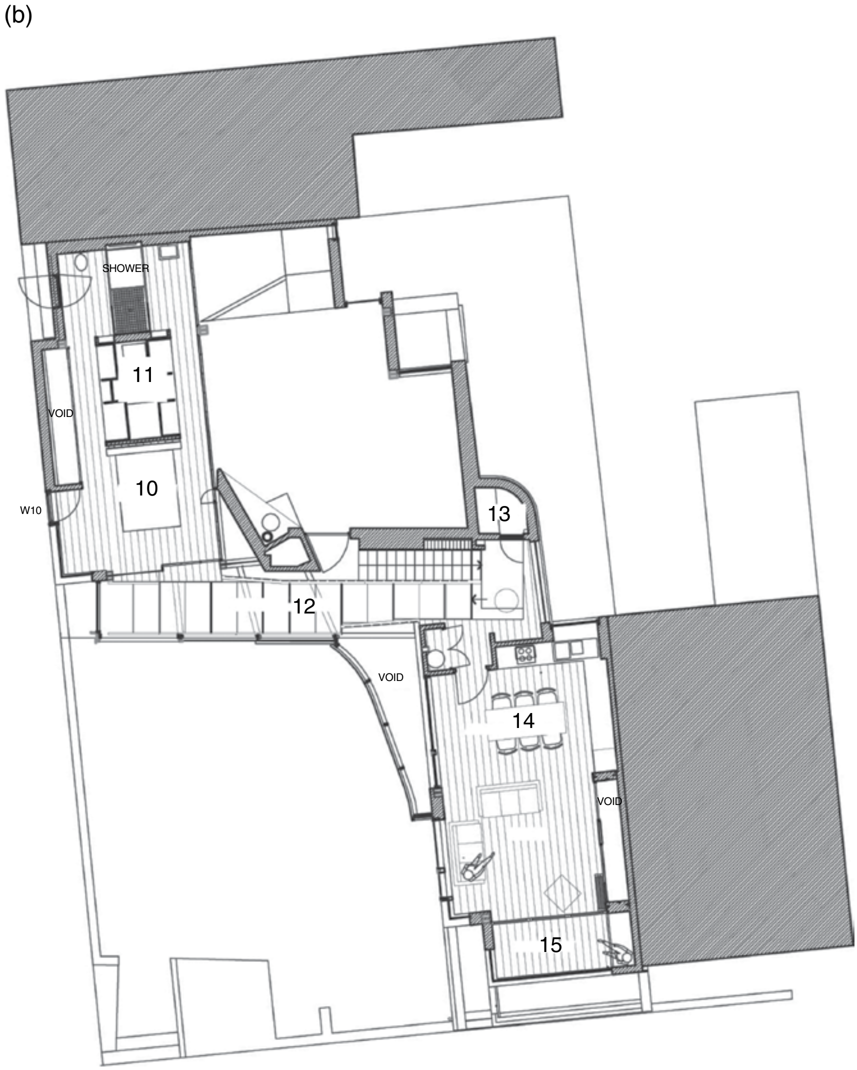

Figure A.3 (*Cont'd*) (b) first floor.

The living spaces were then placed over the work spaces, safe from flooding and able to enjoy the views of the park (see Figures A.3a and b).

In the northern corner of the plan a double height gallery was formed for showing the work produced in the studios. A separate entrance from the street enabled this to be accessed by the public without disturbing the working and living arrangements. This was ramped to allow disabled access into the gallery. The ramp is seen as a flexible space, part gallery and part charging space for an electric vehicle. The use of the gallery is also flexible, doubling up for formal entertaining and family gatherings.

Figure A.4 The house in context.

The house and studios are entered through the courtyard, which has an entrance on the street corner (see Figure A.4). Taking advantage of the solar orientation for winter pre-heat ventilation and summer stack ventilation, the south and southwest façades of the courtyard form an unheated sunspace, which is used as circulation within the private parts of the house. The sun space gives access to the smaller service spaces of the plan such as the composting toilet/shower and larder. The upper landing is used as a small library and a drying space. The computer control touch screen for the heating and ventilating is located in the sunspace at the heart of the circulation zone. The living spaces are split into two separate pods. One contains the living/dining/kitchen space and the other the bedroom/utility/bathroom space.

Passive design approach and initial modelling

Several different passive design approaches could have been used in the project, ranging from insulated mass (anticipating rising temperatures) to lightweight heavily insulated forms (anticipating continuing cold winters). There were issues with both these approaches in that they did not seem to allow for (a) the enjoyment of the particular qualities of the English summer, (b) a sense of personal control over environmental conditions and (c) a dynamic response to changing conditions over time.

It seemed to us that a building with high levels of insulation, but incorporating passive ventilation strategies with mass elements to improve thermal inertia in the summer, would be appropriate and have the potential for providing a dynamic response to the growing effects of climate change. In response the design incorporates a number of passive features. It has four different types of sunspace linked to natural ventilation and night cooling strategies. It has internal and external opening windows with cross ventilation arrangements for both winter and summer conditions. It incorporates high levels of insulation and high levels of thermal mass. It utilises shading devices of various types, both inside and outside the building, including eventually the use of planting in the garden.

Habitable and nonhabitable sunspaces

The design uses two variants of habitable sunspace. The larger is the two-storey volume used as the circulation area within the house. This addresses both south and southwest aspects to pick up the evening sun in the winter. In the summer, the western aspect will be increasingly shaded with planting. This space has a heavy mass wall to the rear and is vented with insulated shutters in the walls, at the rear and in the roof via another sunspace. The lower south façade can also be fully opened (see Figure A.5). The mass wall has the potential for increasing its mass dynamically through the use of water storage or phase change material wafers.

The smaller of the usable sunspaces is single glazed and also faces south and west. It forms a thermal buffer to the living space in the winter and opens up into an extended living space and open balcony in the summer. Both of the habitable sunspaces are used to provide pre-heated ventilation air to the living and working spaces during the winter. The other two sunspaces are not habitable and function

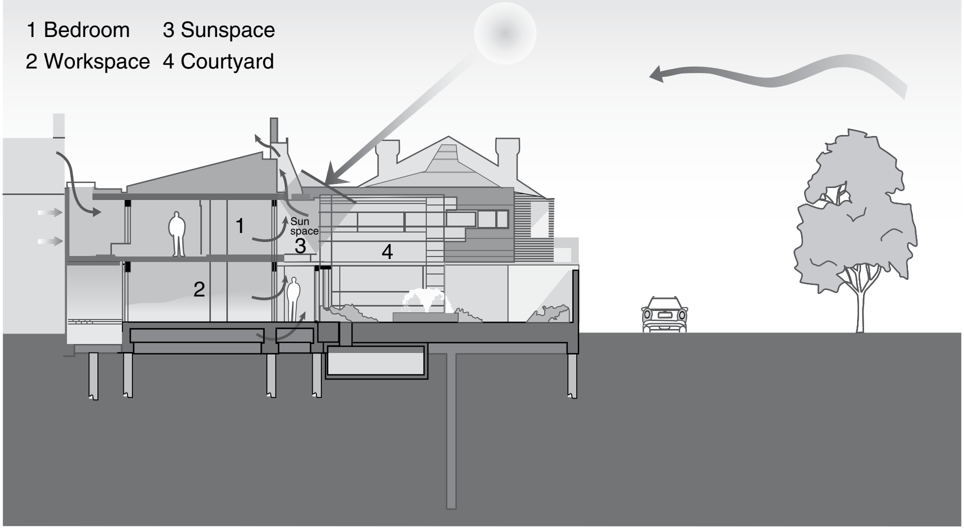

Figure A.5 Section through the main sunspace (summer condition).

within the solar chimney/windcatcher system. The larger of the two has been successfully used to grow tomatoes and aubergines in it during the summer.

Modelling of the building

Environmental consultants were commissioned to assist with testing and developing the design for the sunspaces and the natural ventilation system. To do this they built a model of the proposal using Integrated Environmental Solution (IES). This software was chosen because of its suitability for use as an iterative tool to inform the effects of design changes on passive building behaviour. The model was run several times to support design modifications and a report produced that formed the basis of the final environmental design (Cosa Solutions (Buro Happold Ltd), 2005).

Original IES model

To simulate warmer conditions, the modellers used the onerous CIBSE Design Summer Year weather data within the model. Comfort was assumed to be achieved if no more than 5% of the occupancy was above 25 °C and no more than 1% of the occupancy was above 28 °C. The model showed that for the permanently occupied space, the bedroom and the gallery performed best, followed by the living room, architect’s studio and art studio. As might be expected, the major sunspace performs poorly. As the occupancy times of each room are different, the proportion of occupancy that 25 and 28 °C were exceeded was tabulated. This showed that, apart from the living room, the architect’s studio (with four occupants) and the circulation area, the comfort criteria were maintained (see Figure A.6).

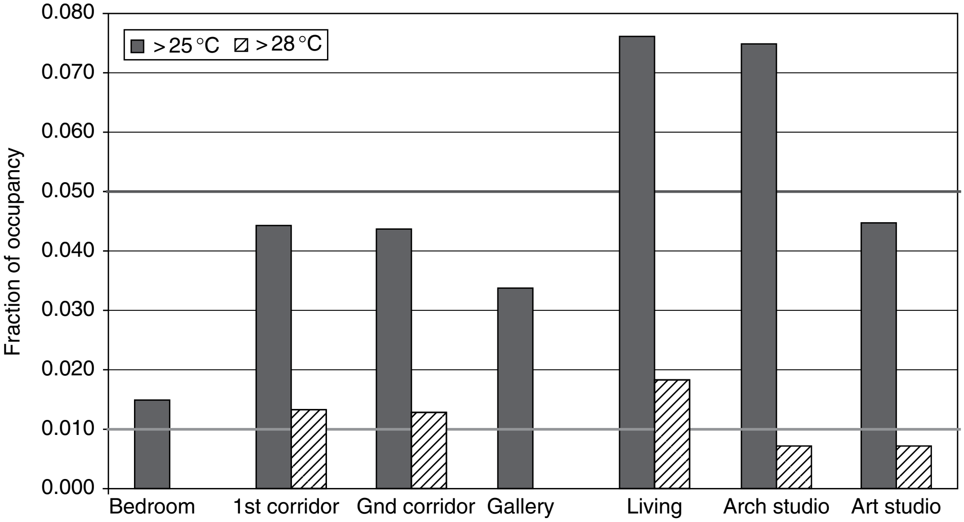

Figure A.6 Fraction of occupancy above 25 and 28 °C.

Amendments were made to the ventilation areas of the living room and the architect's studio. With these changes the architecture studio passes with the living room coming close. The circulation spaces also pass.

The rerun IES model

In the future temperatures are predicted to be higher, so it was decided to incorporate night cooling in areas that would be unoccupied at night and the model was rerun (see Figure A.7).This time all the spaces were well within the comfort zone and the frequency at which the temperatures in living spaces exceed 25 °C is very similar to the UK Passiv-On simulations (Ford *et al.*, 2007).

Because the weather data used was not looking forward, further shading measures were incorporated in the design and construction of the house to anticipate warmer summer conditions. The performance of the house using the UKCIP Climate Change Scenarios data has now been modelled with the addition of the further measures and this shows comfort conditions being maintained to 2050.

The performance of both the unheated sunspaces in the winter was also considered. The model showed that the temperatures in the major sunspace during waking hours range between 12 and 20 °C on a sunny day with external temperatures between –3 and 5.5 °C externally. Solar gain and thermal mass contribute to a significant 12–15 degree rise in air temperature within the sunspace. The small single-glazed sunspace provides pre-heat ventilation air to the living room 8–10 °C above the external temperatures.

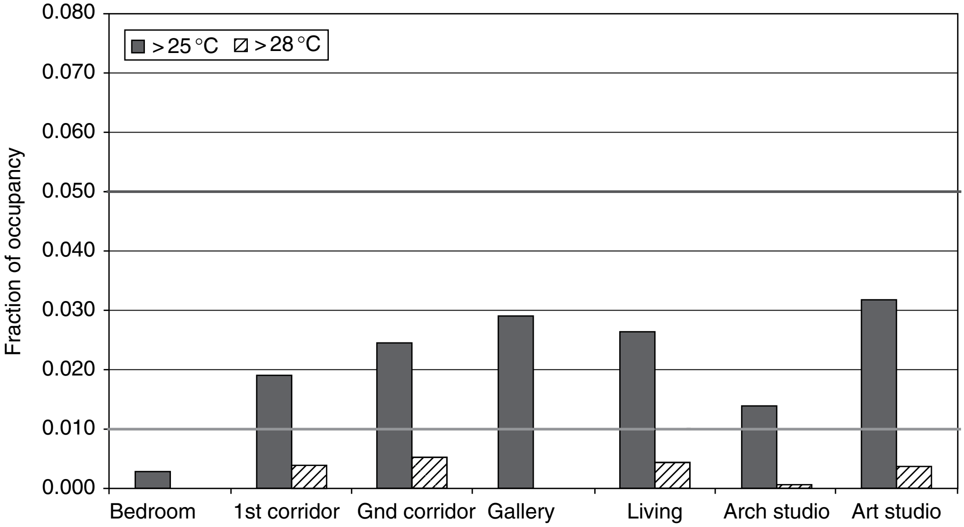

Figure A.7 Fraction of occupancy above 25 and 28 °C, with night purging.

Modelling the idea of the variable mass/phase change wall

Exploring and exploiting the effect of variable mass and the potential for using phase change materials (PCMs) as a thermal buffer in the main sunspace, the rear wall was constructed as a series of concrete shelves that would have a high surface area but could also support containers or frameworks of wafers of material that could have air flow across them (see Figure A.8).

A model of the sunspace was constructed in EnergyPlus by the University of Nottingham to study the effect of increasing mass through the introduction of containers of water and also the effect of using a phase change material within the wall. Energyplus allowed the modelling of PCM, which IES did not. It was proposed to extend the recycling ethos of the project by storing the water in recycled Ecover 1 litre washing up liquid bottles, of which 862 were collected. These would be unsuitable for the PCM where the surface area needs to be maximised and various options for placing this are being investigated.

The simulation was run with varying amounts of water and PCM, both with and without the automatic venting of the space. Some interesting effects were predicted. Firstly, with a surface area of 30 m^2 of material, the buffering effect of the mass wall reduced temperatures in the space by up to 2 °C, but that this diminished to 1 °C as ventilation levels increased. The effect was much more marked as

Figure A.8 The staircase and variable mass wall.

the surface area was increased to 60 m^2, where temperature attenuation doubled. Secondly, there was little difference in performance between water and the phase change material in summer operation. Studies are continuing to see if the use of water will be problematic in winter when there may be too much mass in the sunspace to maintain acceptable temperature levels.

Zoning and flexible planning

A common phrase used in the 1970s and now heard again is the expression 'long life–loose fit' (Commission for Architecture and the Built Environment, 2010). With scarcer resources and the need to conserve energy in construction, this idea of making buildings robust, malleable and able to suit a number of different uses can be seen to have renewed importance for the future. Our take on this approach to planning was to provide variable options for access, circulation and separation/adjacency and to work with an essentially malleable form of construction: timber.

One of the key live–work ideas we wanted to explore was the potential to provide different conditions in the core living spaces compared to the work spaces (see Figure A.9). The living spaces kept at stable temperatures operated with

Figure A.9 The work/gallery space with insulated bedroom above.

minimum energy while the work spaces could be freer and less intensively treated. As a result, the design places the more highly insulated living spaces above and surrounded by the work spaces, the latter able to keep the former warmer while in use during the heating season.

This approach works well with issues of airtightness, which inevitably arise with a strategy that maximises through-flow of air in the summer but tries to minimise it in the winter. We were unable to find motorised vents that were both insulated and completely airtight when shut. The only possible approach was to double vent using a buffer-space strategy, using two layers of insulated vents and then to further add insulating blankets to the inner vents in the winter to render them properly airtight. This approach has the added advantage that all automatic venting takes place in the sunspaces and a high level of manual control of ventilation is still possible within each living space. As described earlier, the end result of this layered planning (Figure A.10), with the focus on the courtyard space and the ability to open up the house in the summer and close it down in the winter, is that one feels part of an 'activ' rather than a 'passiv' house. The seasons are manifest and the natural environment part of the experience of living.

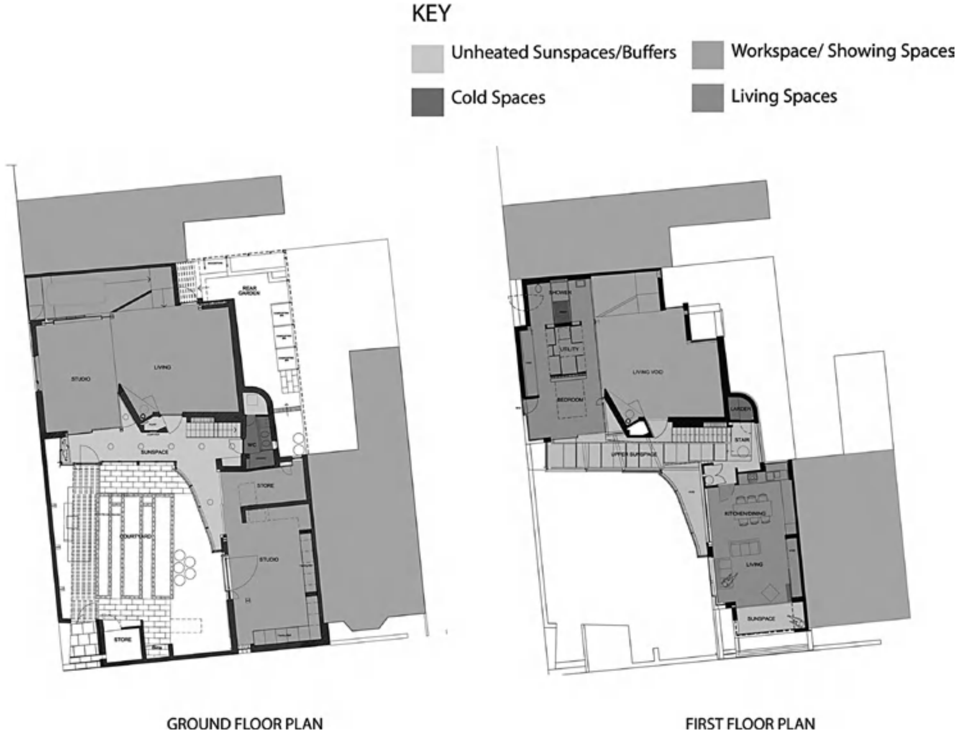

Figure A.10 The layers of the plan.

Behaviour

Designing and living in a house are to some extent complimentary activities. The designer needs to anticipate how the inhabitant will experience and respond to their building, while the inhabitant needs some understanding of the designer's intentions to get the best out of the experience. The relationship between the two becomes more critical in passively designed buildings as the operation of the building will probably not be automatic. Indeed, research has found that the more control an occupant has over their environment, the wider the range of environmental conditions they will accept and the less energy is expended in achieving conditions of comfort (Roaf, 2009). The idea that the building might to some extent be didactic and give clues as to how to relate to it to get the best passive energy results is therefore an important one, and something that this project starts to explore, albeit on a fairly basic level.

Areas where this was tried related to actions supporting the operation of passive ventilation system or opportunities to carry out everyday tasks in a way that would reduce unregulated energy consumption. An example of the first is the introduction of colour coded windows, so that openings into the sunspace, which would be used for winter ventilation, were painted white while those to be used in the summer for cross ventilation were painted black. This subliminally plays on the 'white is good' and the 'black is bad' association that we have in the west, set up this way as winter behaviour is more critical and less intuitive than summer behaviour. An example of the second area is the careful design of the handrail on the sunspace bridge so that it can be used for drying clothes in proximity to

Figure A.11 The sunspace used for drying clothes.

where they are washed. This encourages 'natural drying' in the sun and washing machine use when the sun is out and the electricity is 'free' (see Figure A.11).

Predicted energy use, insulation levels and airtightness

Standard assessment procedure (SAP) calculations carried out during the design phase show projected energy use figures as follows:

SAP rating: 98
Energy use: 50 kWh/m^2 yr*
Dwelling emission rate (DER) = 7.37 kg CO_2/m^2 yr*
Carbon footprint = 1403 kg CO_2/yr* Carbon footprint = –8202 kg CO_2/yr **

where the figures include the SAP appliance extension results (*) and the energy loss reduction to adjacent properties achieved through the planning approach (**). Note the power of the contextual layout strategy to reduce the carbon footprint.

Insulation levels vary in the building depending on orientation and sensitivity of the space. All timber frame walls have a minimum *U* value of 0.15 W/m^2K, with the large northern walls and the roofs having a value of 0.12 W/m^2K. Brickwork walls have a *U* value of 0.22 W/m^2K. Airtightness levels have been assumed to be around an infiltration rate of 0.15 m^3/h (as SAP), but these remain untested due to the difficulties of working with the layered approach. Heat recovery ventilation is used in situations where building regulations or general functions require a powered extract, i.e. ventilating the shower rooms and the kitchen hob. These are both within the most airtight parts of the layered envelope.

Actual energy use

The first year of readings (October 2010–September 2011) was taken during an annual cycle of some variability (see Table A.1). The early winter in 2010 was exceptionally severe, but the spring of 2011 was very warm. In the event, the energy use figures were better than predicted, with a total carbon footprint of 1242 kg. The heating load was higher than the Passiv-Haus requirement, but the total energy use was much lower. It is interesting to note that as global warming takes place, heating load will become ever less important in the UK, with ventilation and unregulated energy use becoming the major concern.

Energy and renewables

The strategy with regards to active energy was to find an appropriate mix of technologies, well supported by the context, able to cover basic domestic and workspace electricity consumption (excluding the heatpump). This was estimated at around 3500 kWh/yr. The requirement for a backup heating system was also considered as part of the strategy. The situation was ideal for solar, solar photovoltaic (PV), wind and ground source heatpump technologies, although the land available was

Month	Solar 1	Solar 2	Total Solar Generation	Elec AM	Elec PM	Total Electricity Use	Power Balance
September	5538 (+191)	338(+63)	254	12614 (+144)	6316 (+107)	251	3
October	5688 (+150)	379 (+41)	191	12908 (+294)	6475 (+159)	453	−262
November	5769 (+81)	395 (+16)	97	13643 (+735)	6837 (+362)	1097	−1000
December	5825 (+56)	401 (+6)	62	14746 (+1103)	7346 (+509)	1612	−1550
January	5878 (+53)	410 (+9)	62	15668 (+922)	7746 (+400)	1322	−1260
February	5949 (+71)	428 (+18)	89	16350 (+682)	8079 (+333)	1015	−926
March	6138 (+189)	492 (+64)	253	16886 (+536)	8337 (+258)	794	−541
April	6445 (+307)	592 (+100)	407	17038 (+152)	8424 (+87)	239	168
May	6754 (+309)	696 (+104)	413	17156 (+118)	8494 (+70)	188	225
June*	7042 (+288)	793 (+97)	385	17252 (+96)	8555 (+61)	157	228
July	7336 (+294)	892 (+99)	393	17358 (+106)	8620 (+65)	171	222
August	7595 (+259)	978 (+86)	345	17494 (+136)	8693 (+73)	209	136
Total	2248	703	2951kWhr/pa	5024	2484	7508kWhr/pa	−4557

Currently 2484 kg $C0_2$ per annum (excluding adjoining property savings) but Ecotricity 50% zero carbon therefore Carbon Footprint = 1242 kg CO_2pa
Approx 21 kWh/m^2/annum Regulated + Unregulated c/f Passivhaus 120 kWh/m^2/annum (15 kWh/m^2/annum for heating)
Conversion rate for grid electricity = 0.54522

Table A.1 The meat factory actual energy use and generation 2010–2011 (all figures in kWh).

small. Electric systems were favoured because of the almost certain decarbonisation of supply in the future and potential issues over security of other fuels.

Solar HW

The house had an exposed location with playing fields to the front so flat plate collectors were chosen for the hot water (HW) system rather than the more efficient but fragile evacuated tube type. This was a Shuco Sol 5 m^2 array, which works well. It is connected to the ground source heatpump for basic first stage heating up to 40 °C in the winter with immersion top-up over that level. Initial experience suggests that 70% rather than 80% of hot water generation from the panels is possible.

PV array

The PV array is split into two elements, installed at different times (see Figure A.12). The array initially installed was in the form of a large sunshade overhanging the main sunspace and contains 12 panels. A further array of 4 panels has been added to the rear of the building to top up the generation capacity following issues encountered installing a wind turbine. The panels used are the Sanyo HIT 210 and 215 hybrid units with SMA inverters. The initial array (2.52 kWp) has been in position for two years during the build and has been generating approximately

Figure A.12 Southern view of the house in context.

2300 kWh per annum, which compares well with the initial estimates of 2268 kWh per annum. The combined arrays were expected to generate in the order of 3000 kWh per annum, covering the majority of the house and office electricity use, and this is exactly the level of generation that has taken place to date.

Wind turbine

Although the site has certainly enough wind for a small turbine and planning permission was obtained easily, a planning condition on noise caused a serious issue. The turbine chosen was a Zephyr Air Dolphin 1 kW model, selected because of its low weight (17.5 kg), low noise and safety features that made it suitable for building mounting. Mounting brackets and wiring were installed during the construction, but it proved impossible to satisfy the public health department with the noise statistics supplied by the manufacturer and so the idea of using a wind turbine was abandoned and the generation target was met by adding the second small array of PV panels.

Heating approach

The heating source that seemed most compatible with the passive approach and an electric future was a ground source heatpump. Although there was only a small site area, it was possible to spread out vertical bore holes adequately and the presence of the sandstone aquifer made for very efficient heat transfer. The model chosen was a Dimplex SI ME 9, three-phase system with an advertised coefficient of performance (COP) of 3–4.

Backup

Uncertainty of the energy supply is an important consideration in thinking about the future, with the slow takeup of both large scale renewables and new nuclear. Consequently a backup heating system has been installed in the form of a 5 kW wood burning stove situated in the centre of the plan and close to the mass wall elements. The intention is to use this to 'charge' the mass at the end of summer change over a period when it needs to become a heat store rather than a heat absorber. Backup batteries will also be installed in the future to support the computer and water pumping system once battery technology has improved with the development of electric cars.

Appliances, power, daylight and lighting

The use of electricity within buildings is forecast to rise despite energy use for heating diminishing due to better insulated buildings and rising temperatures. Reduction in electricity use and the monitoring of its use were seen as essential components of the design. Consequently, appliance use within the house has been kept to a minimum. There is no refrigerator, dishwasher or tumble dryer. The washing machine is AAB rated. Food is kept cool in a north facing larder. This works well except in extremes of temperature when further modification is required in the form of baffling in very cold temperatures to stop liquids freezing and evaporative cooling in the height of summer to stop milk curdling.

Clothes drying is done in the sunspace using the bridge handrails or in the utility space, where a coil of the underfloor heating has been extended into a purpose-made drying rack. Both methods have shown themselves to be very effective. Cooking appliances are an AEG 91 AQF 10GE 3 kW single oven, an induction hob and a CDA MC21 900 W microwave oven. The microwave is used in preference to the main oven. The induction hob is used rather than a kettle.

Ecotricity was the energy supplier chosen as they generated the largest proportion of their supplied energy from renewable sources. A white meter was installed so that winter water heating and clothes washing could be done at night on cheaper tariffs if sunny days were not frequent enough. The power wiring within the house is all routed from one distribution board and all cables have current sensors attached to them as they leave the distribution board. The data are transferred back to the house computer, which will have the ability to shut down noncritical circuits to reduce consumption on standby switches, etc.

Light fittings have been carefully chosen for energy efficiency with the majority of fittings being light emitting diodes (LEDs) or florescent (see Figure A.13). The total ground floor sunspace circulation lighting (which is an LED) is rated at 24 watts. Gallery lighting was the most difficult challenge and this has been specified using a combination of Concord TeQ low energy fluorescent and CDM-T spots. All the lighting in the circulation areas is switched by movement sensors. In the bedroom floor lighting uses continuous photoluminescent strips, which have a total rating of 30 watts.

Figure A.13 Purpose made LED lighting to the larder entrance.

Control and monitoring systems

A monitoring and control system was developed with the intention of understanding and optimising the behaviour of the house and its technical systems. Running all the time meant that a low energy, low maintenance specification was important. As a result the main computer has no fan air cooling for the processor, a solid state hard drive and a liquid crystal display (LCD) touch screen monitor.

The main input/output (I/O) interface is a National Instruments PCI 6229 Daq card with 3 banks of 20 relays reading the data supplied to the control program, which is written in Labview 8.6. The front screen shows the layout of all the floors of the house. In the initial version of the system, which controls the heating, the layout displays the temperature for each room including the outside temperature as well as LEDs showing how many heating coils are in use. The second version extends the system to control the automatic vents and shows which vents are open and their approximate position, open or closed.

The third version, which is currently being developed, will control and/or record and monitor the various other systems. The electricity use of various circuits and circuit shutdown will also be covered.

Water and sewage

Future predictions for water availability are poor, so the strategy adopted was to maximise water available from the site, while minimising use in the house and any dependency on mains water. Initially the scheme included both rainwater recycling and grey water recycling. The latter was abandoned when the potential of making a well was discovered as this could provide water for irrigation.

Much contradictory advice was available when sizing the rainwater storage tank. Tony Marmont, an early pioneer, recommended a tank of 6000 litres minimum for domestic use. Conder, one of the companies supplying commercial systems, felt this was much too large and recommended a tank of 1000 litres. We opted for a 4000 litre tank as the house would only have two occupants, but the water would serve most uses. In the event we should have opted for the bigger tank. In times of low rainfall it has to be topped up from the mains.

The system is a conventional rainwater harvesting set-up, but with an ultraviolet (UV) filter and fully pumped delivery. It supplies treated water to all the appliances. A separate mains water drinking tap was provided at the kitchen sink. There are two toilets, a 2.6 litre low flush type and a dry composting toilet. There are also two showers, which have been fitted with air entraining heads from Oxygenic. The tap in the composting toilet is likely to have public or visitor use and is fitted with a flow control sensor. The washing machine was chosen for its low water and energy use. The usage of mains water for the first 5 months in occupation was 2 cubic metres and the water bill was £13.65, which is very low compared to the average UK householders' water bill. This has risen over time, partly from a leak in the garden tap pipework that was undiscovered for a while and partly due to full seasonal figures now being available. The first five months were a winter when rainwater was abundant. During the summer, the tank has run dry on occasions, requiring topping up from the mains and justifying the recommendations of Tony Marmont for a 6000 litre tank. The mains water usage for 2010–2011 was 27 m^3.

The air entraining shower heads need to be run at slightly higher water temperatures than normal because the air entraining head cools the water. The energy balance of this will be studied in due course.

The composting toilet, made by Natural Solutions, is a two-chamber dry toilet with urine separation built into the active chamber. A very small, continuously running fan is fitted within the chamber to create a negative pressure. So far the composting toilet has proven easy to use and maintain and is problem free.

Materials, embodied energy, reuse and recycling

The use of materials of low embodied energy or high recycled content will become an ever greater concern in the future as energy levels for servicing buildings reduce as a proportion of the overall building energy profile. There was pressure from the town planners to use materials that ‘fitted in’ and a need for some robustness of treatment at street level. In response, a local red brick with cor-ten steel elements was chosen for the exterior construction of the site wall and a white brick for use within the courtyard and studio interiors to maximise lightness and reflectivity.

Sitting on piled foundations to deal with the filled ground conditions, the main structure and upper and rear walls were constructed of a timber frame to maximise insulation levels and maintain low energy construction. To support mass construction elements, a main structural frame of parallam was chosen. Pairing parallam beams and columns with steel flitch plates enabled hollow core concrete floors and ceilings to be supported and thus to distribute the mass throughout the building. Concrete is used sparingly and mostly in a prefabricated form. All timber used was FSC certified and the majority of suppliers were from within a two mile radius of the site.

Three types of insulation were used: hemp, Rockwool batts and expanded polystyrene sheet. All are low embodied energy or negative carbon materials. Upper wall cladding was either locally sourced sweet chestnut rain screen or zinc longstrip, which was also used for the roofing. The zinc was chosen because of its long life, appropriateness to the form and its nonpolluting effect on recycled rainwater. The timber frame construction incorporated a 50 mm Ultratherm wood fibre tongue and grooved board across the outside of the studwork to overcome cold bridging and with the application of a Sisalkraft 714 vapour barrier to the inside gives a very airtight form of construction.

Although contaminated material had to be removed, during construction as much material as possible was reused. Temporary works were designed for reuse as part of the permanent structure, palettes were stripped down to make fencing, steaming pipes cut down to become planters, leftover aluminium door tracks used as construction joints and waste timber saved for firewood. Recycled crushed brick was used to make up site levels and blockwork made from recycled

Figure A.14 Detail of the overlaying of elements in the main sunspace.

palettes was used to form the deep beds in the garden. The toughened glass used in the first floor of the sunspace was recycled from waste stadium balustrading made to incorrect sizes. The form of the bridge structure had to be designed around the found sizes.

Architectural and experiential detailing

An important aspect of an integrated approach to design is that the conceptual and contextual approach of a project can set a narrative that is able to be carried right through to the making of the building at a detailed design level (Figures A.14 and A.15).

The house demonstrates this both in the way materials are chosen and the way they are detailed. For instance, for the main sunspace glazing, a white polycarbonate system was chosen because it could be detailed without visible joints and therefore allowed the idea of a large solar collector to be expressed, supported by the contrast with the black cladding. It can also be seen in the way the roof forms express the solar and wind assisted passive aspects of the building, and the volumes and paths of natural ventilation are articulated externally within the façade.

Working in the opposite direction, qualities of materials are also considered in developing the aesthetics. For instance, the parallam timber structure has a different grain on each face. The vertical grain is turned to the side face of

Figure A.15 Views through the layered spaces.

columns and beams to align with the central flitch plates while the wilder grained face is expressed to the rooms. The layering ideas of the zoned plan are taken through to the way elements of different materials meet, with overlapping being the predominant jointing technique. This layering is also expressed in the way the building is experienced with many opportunities for views through and across the different spaces and for light also to filter between them, changing the nature of experience with the time of day and season.

The more obvious seasonal operation of the building is also expressed and appropriate user engagement in environmental control is encouraged by using colour coding. As previously noted the windows that are used in the winter to ventilate from the sunspace are painted white, while the windows that are used for through ventilation in the winter are painted black. Of course many of the details that make the environmental approach work are hidden and do not become expressed in the construction, but service concepts such as increasing levels of airtightness in inner zones invisibly are included.

Making a functional garden

With a courtyard garden (Figure A.16) of only 10 metres × 10 metres not enough food could be grown to support the occupants, so the planting needed a very specific brief. This posited the garden as an external room extending the ethos and philosophy of the house. High value crops such as fruit, rarer vegetables,

Figure A.16 The south-facing courtyard garden.

herbs, medicinal and complimentary plants were chosen. Deciduous trees provided dynamic summer shading of the sunspace and hawthorns were employed to increase security and shelter.

Conclusions

Living in the house has been a fascinating experience, monitoring how well the original ideas have worked and also experimenting with the way in which life and house interact. It has been reassuring to find that most of the original environmental ideas have worked and that through the process of learning new habits and adjusting to a new lifestyle, more energy has been saved than predicted.

Systems like the composting toilet and rainwater recycling have also been easier to use than expected, although we have inevitably found that we have missed a trick or two. Certainly the rainwater harvesting tank should have been bigger, but more importantly we never realised the potential for using the urine separated out by the composting toilet as an accelerant in the composting bins. We could have easily piped the waste pipes from the urine traps to the rear garden and cannot now access them easily enough to make that change.

In terms of measured results we have clear evidence of the reduced water use, and because of the level of mass within the building we have been able to create very comfortable internal conditions during the winter while maintaining air temperature at below 18 °C. A clear practical difficulty that has been observed is the ability to achieve a high level of airtightness in the winter and free flowing night cooling in the summer using the same vents. The buffer provided by the sunspaces is greatly beneficial in doing this and could point the way to a sensible retrofit approach for improving passive cooling in domestic situations.

The development of the control systems has been more time consuming than envisaged and has been slowed down by engaging enthusiasts rather than consultants in the process. The ventilation system has now run over two summers on manual operation. The night cooling operation works effectively and summer temperature levels in the sunspace have not been excessive or uncomfortable.

The model predictions for the buffering effect of the mass wall were not as marked as hoped, probably because of the effect of the mass already built into the sunspace. There would also seem to be a loss of effectiveness when using ventilation techniques with phase change materials. We are now exploring this in reality, a full year of readings have been taken with the bottles empty and they are currently being filled with waste shower water and salt ready for testing in the summer. The following year a slightly different bottle filled with PCMs will be tested also with different levels of natural ventilation. Interestingly the modelled temperature rise in the sunspace using the predicted climate data almost exactly matches the reductions in temperature modelled in the mass wall when further water/phase change material is added.

The process of developing a lifestyle that works with the house will be the subject of continual adjustment and learning to ensure that energy efficiency benefits are realised. Within the community the building has certainly been effective and has aroused great interest and debate around sustainability issues and is well liked for its contextual approach.

The project is already leading on to further work looking at design and behavioural response and it is intended to use the house to support further research on the efficacy of the zoned and buffered space approach, comfort at lower levels of ambient temperature and the development of the dynamic climate change response principle.

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Chapter Two
The Morphological Construct

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The architectural technologist is usually employed to remove rather than add ambivalence and equivocation inherent in a concept. The contribution may be by asking the right questions about the aims and objectives of a project/research proposal. However, the aims and objectives themselves may be lacking in credibility. If we take game play as a metaphor, the morphological construct of the title to this chapter is the game that uses social and environmental knowledge that individuals must share in order to work with each other. The analogy is of a box containing parts for a game to be played, but it is not a metaphor until the game is understood by the players. Research projects, like building projects, require us to choose those we play and decide when to play them. Playing the wrong game well is possibly worse than playing the right game badly.

Introduction

What does it mean to be lacking in knowledge? If there is a building to be produced what knowledge do we need? Is it similar to the kind of knowledge we need for research? Is research the same as building in that we need knowledge to put together a design or plan? We need to put knowledge together in order to put the building together. We need to put knowledge together to guide a research project to fruition.

When we look around us we see that what we put together can look familiar or different to what we know. As construction professionals we can perhaps see similarities in parts of buildings that are different. If not professionals in construction then we can probably still see that some buildings look alike while others seem to be different. As researchers we can explore the possibilities of what creates similarity and what difference. In order to do this we have to look behind the appearance into the programme of the building or the research project. To some

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degree, probably more than we may be prepared for, the research project and the building project are similar. Obviously they are not similar in form but in the way the workers find and use knowledge. Those working on a project will seek out relevant phenomena. If they do not have it they will look for it. They may even make knowledge. For example, the new type of building may require new as well as old knowledge – airports after the invention of aircraft.

Working on the individual project tends to make those who contribute myopic, using what they already know. They play the game they already know well. Shaping the knowledge into the arrangement that is needed begs the question of need. Widening the search for knowledge too much begs the question of parameters. There is obviously some constraint at work as a boundary and also an editor editing the knowledge. What is outside the boundary and what is inside it has to be considered in order to make need relative to time and space. The morphological construct is the game in the box with instructions. It is, has been and will continue to be invented but how and by whom? Is it the individual worker? Is it the group that works together on the project? Is it the society or the individual with the need? Is it the need itself in the sense of some part of the human condition that must be provided for – housing, health, education, transport, manufacturing and so on. It seems to be all of these at once.

The problem with the morphological construct is that it can assume many forms and contain knowledge of many different sorts and yet it is a work in progress. It has been created by new knowledge of the way the brain works, or rather by knowing how the brain relates to everything else. We may have referred to the problem of having an ideology or a utopia; we may have thought of it as in the head or in material form. All of those concepts are only partly right.

Rationality is important and the morphological construct appears because of it. However, the box and the contents are apparent to some and not to others. The box, the morphological construct, is invisible to all in the material sense but the contents are variably accessible. Assembling for the game and making it apparent and then playing it require understanding and interpretation. The box and the instructions on it is the *aide memoire* of the game. Paying attention to the box and the rules makes the game more apparent but also more defined, final, fixed, agreed amongst the players.

What about knowledge that is inside my head, as much of it is for the individual? This knowledge can be expressed using language, drawing and even facial expression. So ultimately the equitable nature of the morphological construct is rational and knowable or as yet inexpressible. This makes the project not only a problem of assembling knowledge in a rational way but also finding knowledge that expresses what has not yet been expressed – like the airport that evolves out of our use of aircraft, the train that evolves out of our use of steam, the house that evolves out of a dream.

Every single project uses the morphological construct because that is what rationalises knowledge and makes social action possible. It is the control of the editing and the boundary that is common to all constructs. The knowledge available to the construct may be more or less than is used in it. Those who sustain it as an expression of their participation in the project have a choice in how they control it. Simply making the construct rational is too liberal an understanding of the control required. The construct is in effect an expression of the participants who work together to sustain it and the knowledge that they feel is worth having. If they repress those feelings they repress the expression of their own curiosity. If they use only the knowledge that is on the shelf near their place of work then their ability to adapt and improvise is threatened. That is the argument for experiment in even the most ordinary and commonplace project.

The appearance of knowledge

As Lyotard (1994)[1] suggested, Wittgenstein's model of game play is the most appropriate model for our use of the morphological construct. The very large narrative model suits our linguistic abilities but is not an accurate representation of actual events. Historical stories are entertainment but not truth. The box containing the game is not like a box in volumetric space. It is the boundary of appearances assembled for the game. In that sense it is a box. The individuals play the game and may follow instructions and these may be on the box. However, the individuals can choose to ignore the box and the rules and ignore or evade appearances as much as possible. The ultimate box is the life of the players and the world we live in, still variable so it seems.

The game is played any way we can express it and play it. Thus in the world of actual events we see very many games played all over the world and in diverse ways. All of them have in common the facts that some knowledge is in the head, some is available as appearances shared with others, some is common to our race (human) and some is common to groups that vary from time to time and place to place. The common denominator is knowledge and the game or, as most people prefer to call it, the system or culture perhaps.

Knowledge appears to us in a number of quite different ways. The biggest barrier to understanding the morphological construct is our belief that we can see knowledge. This was a belief attributed to Descartes (Damasio, 1995), mainly, and Kant (Forster, 2000). The Cartesian, after Descartes, approach assumes consciousness is a processor that allows us to see knowledge. Unfortunately the systems we assemble are not all in the surroundings. Quite obviously parts of those systems are in the head and also the body on which the head is fixed. As Searle points out, many games are set by society and its use of language in what he calls 'licenses' to use statements of truth (Searle, 1995). As the philosophical psychologist Jerry Fodor points out, the brain simply does not work as a processor and no one really knows at present quite how it works exactly (Fodor, 2000), but it is quite definitely not a truth machine or a processor of what we sense or see.

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[1] Roger Scruton (1995) provides the reader with an excellent exegesis of much of the work of Wittgenstein (and Kant, see later) but stops short of linguistic philosophy, thus forcing the game into metaphysics.

Descartes tried to show that a specific part of the head interprets everything that is perceived. Kant attempted to show that the interpretation we make transcends issues of experience and perception in order to provide a model of reality. Those who attempt to make Descartes' and Kant's theories work use metaphysics, which is unfair. That is the world of voices in the head and aliens making our world. Metaphysicians make claims to show that systems are rational by using metaphysical arguments that are self-fulfilling. They say that there is meaning in the universe, for example, when it is quite clear that there is sometimes meaning and at other times chaos as far as humanity is concerned and for individuals in particular.

It is clear that knowledge appears to us but it is not always clear exactly where it comes from. We are nearly all familiar with hallucinations and dreams. We can assemble all sorts of knowledge in our heads; some individuals claim to be able to assemble colours and music in their heads. Obviously what is in their heads is not music or colour but the appearance of music and colour. That or they are deluding themselves and/or others. We know also that knowledge appears to us through perception. We know that we are home when we get home. We know we are about to eat a sandwich made of cheese or what looks like cheese at least.

In the interest of exploring more about what was in the head and what was in the surroundings a researcher called Husserl attempted to pin knowledge down completely (Dreyfus, 1982). He hoped that individuals could declare exactly what they experienced. The first problem is ambivalence. We know from a researcher called Brunswick that perception is not capable of complete accuracy. He wrote, as was published posthumously:

> Perception, then, emerges as that relatively primitive, partly autonomous, institutionalized, ratiomorphic subsystem of cognition which achieves prompt and richly detailed orientation habitually concerning the vitally relevant, mostly distal aspects of the environment on the basis of mutually vicarious, relatively restricted and stereotyped, insufficient evidence in uncertainty-geared interaction and compromise, seemingly following the highest probability for smallness of error at the expense of the highest frequency of precision.
>
> (Brunswick, 1956).

Unfortunately, this means that an individual does not even see exactly the same as another although what is to see is almost the same. They would need to know everything in the universe in order to correct the errors inherent in perception. Then they would need to explain what they did to the rest of us. Books have been written about communication and they all agree that we are not capable of explaining mental content precisely (Anderson, 1996). This is because communication relies upon the same perception that Brunswick found was inexact and because some mental content is not capable of transfer between us as an exact method.

The most famous work on the expression of mental content in the form of language is that of De Saussure (1983). The impact of that work as it has been brought into the education system is to emphasise the ambiguity of the signifier. This is the ambiguity of the relationship between what a person says and what they say or use to indicate what they mean. In fact as Lacan points out in his, later, work linking De Saussure to ambiguity of language, the situation is worse than this (Lacan, 1977). An individual can mean what they say but they use words that mean something quite different to any other individual. There is equivocation in any description. Lacan is simply pointing out that language is a referencing and relationship system rather than a rational mind using language to explain its thoughts exactly. The morphological construct is a referencing and relationship game, or system, that we know as knowledge. As a system it is required to be rational, but all that means is that it has partly whole properties that allow it to be a game.

The conclusion (Thompson, 1999) is that knowledge is best understood as the coded version of appearances that can be linked to appearances metamorphosed into commodities. What we see may be coded by our nervous system. It depends on a metamorphosis of phenomena that Piaget (1971) called assimilation.[2] We have to accommodate, notice, phenomena and assimilate them. Sleeping fixes knowledge (Alleydog, 2005). Only then do we have commodities in place of phenomena that exist in perception and knowledge of phenomena as commodities in the head as well albeit as separate phenomena as knowledge.

The morphological construct

Clearly the location of this boundary and its contents is an analogy. We must not understand boundary and contents as space as we do for buildings. Cartesian space is volumetric: depth, width and length. The space of the morphological construct is a space in which the metamorphosis is possible. Psychiatrists and philosophers have taught us, within the past hundred years, that we should call it a space of appearance (Winnecott, 1993; Arendt, 1969). This is not a palimpsest for consciousness because we do not have control over it.

The space of appearance has been connected to phenomenology (Baird, 2003) because the use of the word phenomenon is helpful when we talk of knowledge that is sometimes volumetric, like a brick, and sometimes in the head, like the knowledge of a brick. It may be better to call it a space of metabolism or a metabolic space since it is the space of time and space and people and environmental phenomena. The morphological construct is made and forgotten as the metabolism of the human race existing in the world.[3]

The total amount of information coming into our body is several million bits of information a second, far faster than we can cope with consciously as known bits of information (Lewkowiez and Lickliter, 1994). Brunswick's work is useful in that it alerts us to the fact that a load of phenomena participates in some kind of assembly process but with ambivalence as far as other human beings are concerned.

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[2] Do not follow Piaget on Structuralism. However, please note that his theory of the structure of knowledge is no longer adequate for, as happens with research, bits of it remain useful, other bits do not.

[3] Kurokawa worked on this with the metabolism movement but that dealt with the adaptability of buildings rather than of people (Kurokawa, 1994).

What we do has to be understood as based on several factors but mainly the separation of what appears to us and what does not but that varies among individuals. This is of course especially true at different locations around the world. What appears to us in one volumetric space is not what in fact is perceived in another so that there are phenomena that do not appear to us but do appear to others; thus knowledge can be theirs and not ours. This is true even though the phenomenon is definitely in the world. The chances for accommodation vary. This conserves the concept of a real world. It would be ludicrous to believe that the world is not real in the sense of believing that life is a dream and nothing more than a dream.

However, it is clear that once phenomena have appeared to us and once they have been assimilated, coded into the nervous system, those phenomena can be used in the assembly of a construct. The morphological part of the construct is the metamorphosis of those phenomena and the knowledge arising from them. If the game is to be played by other individuals we have to have protocols of assembly. Are we allowed to use knowledge gained in this or that way? This simple question is the key to interpretive efforts to understand the games people play by paying attention to the constructs they use to play them. The knowledge they use comes from the head and the appearances we can see or are available to the senses or it is metaphysical and we can never ever see it or find it in our heads.

What some call the space of appearance, the metabolic space, the space in which the metamorphosis of knowledge appears to us out of phenomena, is partly the result of the temporal, occipital and parietal lobes (TOPs) of our brain cross referenced by the corpus callosum linking one side to the other. However, while much of the cross referencing takes care of the dynamic homeostasis required biologically to maintain the body in a healthy state of equilibrium it is our frontal lobes that sort out the social, environmental and personal values. Taken all together the cross referencing within the individual is typically referred to as the emotional requirements because they can alert us to problems with the games we are playing (LeDoux, 1996). Recent research has hypothesized that the nervous system is capable of both reinforcing games and inventing games (Dietrich, 2004).

Knowledge can be rapidly assembled into a construct, recognised or, as we call it, correlated to other phenomena and acted upon almost as if a reflex action. Because we are related to each other by way of human DNA we can share the rapid assembly of constructs with the behaviour of others by making or altering relationships so that phenomena are presented to other people like us as knowledge. This is particularly true if we share environments and social activity with other people. It is the basic mechanics of culture and in the short term it is the basic methodology of any project. It is the way the game can be played and we learn how to do this by a process of being taught and learning to edit for ourselves. The rules of editing are allowing or disapproving of phenomena, making them unwelcome or accommodating them for assimilation. Knowledge results from phenomena being accommodated and assimilated and phenomena exist in the head and outside of the head, in the body and outside of the body, in other bodies and outside of other bodies. The expression of phenomena may be an expression of knowledge but only to those who know.

Like cultures, projects share knowledge in the form of both assembly of the constructs and appearances of phenomena, especially amongst individuals who become constant to that project. Those who move from one project to another may even share a similar rapidity of assembly of the construct with categories of people. As we see in construction there are particular cultural similarities between all engineers, all architects, all architectural technologists, all builders, but of course each individual still has a unique role. That unique role is the element that can introduce dissent and thus slows down the assembly of constructs and alters the system so as to produce change. Every project, every game is unique in that way but sometimes individuals are not encouraged to think, discouraged from exploration and adventure.

Many projects may share the same morphological construct and constructs with other projects, making it easier for individuals to circulate amongst more than one project using the same protocols in other projects. Skills depend upon a morphological construct, a structured arrangement of constructs and appropriate behaviour, by which we mean appropriate to the game. The individual may become more robotic as we get more and more used to using the same protocols and assembling the same phenomena, as knowledge, into the same constructs and behaving on that basis so that the game acquires a long term place in our behaviour. We become part of the game and the game becomes a system: family life, working life, community life (Lefebvre, 2004).

Constructs may acquire familiar and rapid behavioural responses because they allow social and environmental behaviour that we approve of or find rewarding in some way. This is especially true in the case of financial reward. The individual uses those commodities to inform and control behaviour by engineering social and environmental relationships to suit a self-fulfilling set of conditions, a way of behaving that people expect and repeat to meet expectations – what some call a teleological hegemony where behaving correctly relies more and more upon assembling the same constructs rather than inventing new ones. Because of this creativity is squeezed out of the system. When people work for money, for example, they can be successful without necessarily or ever playing games that produce an ecological environment. Thinking such thoughts and reading books or exploring ideas linked to ecology produce something called the sack or an amused intolerance.

In this sense what we are investigating here is the way in which projects (games) can come to rely upon technical excellence yet eschew not only individuality but inventiveness as well. How the two are connected to commercial activity is not yet quite fully understood or taught in our schools because the system, the game, is taught rather than explored. Rather we should say that when and if the game is taught rather than explored then it loses sight of its own beginnings. The fact that we created the game in the first place shows that those individuals must find knowledge in their heads by exploring appearances and looking behind the obvious, by thinking for others as well as themselves.

Because the project is generally most successful when less ambiguous behaviour is manifested and individuals unequivocally declare their support, there is a tendency to confuse a good project with something that is known about and technically excellent whereas in fact a considered more open approach may have been more appropriate. Such a scheme can still go on to a technically excellent outcome although not without 'breaking a few eggs' as they say. The requisite skills for the design office and indeed construction generally are thus not just the game we know but also the creation of an appropriate game for what we find out. Metamorphosis must be a metonym for creativity rather than conditioning.

Discussion

For a long time now the production of the environment has been produced by playing a game called building. Books on the history of architecture assemble pictures of the past as if there is a narrative or story linking the ancient past to what we do today as an evolving or unfolding progression. There is a large amount of metaphysics in that belief because it is impossible to find any phenomena with the capacity to evolve change in that way. The changes in what appears are the result of changes in the games we have played. Those games may still be relevant to us now. When we interpret them we find those games use phenomena that appear to us, in a complex way of course, and that some groups assimilate and others ignore.

What we can believe in is the ability of individuals to assemble morphological constructs and assemble appearances so that phenomena appear to other individuals so that metamorphosis is available to them. Knowledge can be assembled into a construct and individuals can learn to do that. The construct can be created by individuals and the common denominator is of course the human being and the world in which we live. The specific part of the world will be different and the individuals will create different constructs according to the phenomena that appear to them. Thus the classical buildings appear as having mathematical links because we have made them that way. We point at decorated buildings as having links to artists, sculptors and the like who express their feelings in stone. The games are different. The people are essentially the same. The games they play create knowledge by emphasising phenomena differently.

The morphology of the construct will vary according to the size and scale of it but the construct is sustained by the individuals who assemble it. Once they become reluctant or unwilling to sustain a construct it will wane and disappear. Thus, rather than an evolving narrative as the picture books tell us architectural history must be, it is the appearance and disappearance of assemblies produced by game players who create the games they play as Wittgenstein suggested. For that reason we have become very confused about culture (Rapoport, 2005). The fact is that any individual will become conditioned to behaviour of a specific kind over time as they are, shall we say, immersed amongst others similarly immersed in a series of behavioural and environmental conditions. Individuals ineluctably code knowledge from phenomena that appear out of various media that we are bound to process as directed by what DNA we have in common (Ott, 2004). That is a restriction as much as a palette of possibility and it is a common situation for all of us humans. We can be conditioned but as we mature we find the will to resist, and perhaps in some cases individuals resist even earlier. The metabolic space is not entirely predictable.

Ott claims that we code and construct using schemas of kinds that are specific to humans, thus emphasising the experience of a space of appearances in common. Once again the rule of reality is maintained when we assert that phenomena appear to us all in very similar ways all things being equal. The knowledge that we code and assemble is what differs between us and makes different games possible. Since human beings are capable of an incredibly wide range of games the social and environmental diversity adds all of its possibilities to our species in a way that we see around us – constant adaptation and improvisation with constructs sustained when conditions are appropriate and hopefully beneficial to those playing the game and others. The 'and others' is of course not always true. Often the game benefits some and not others (Marx, 1991).

Sustained constructs appear as fairly straightforward and apparently mechanical processes as indeed it was considered to be by the behaviourists (Skinner, 1993). However, it is only if all the individuals were entirely content with their lives and the long term outcomes of their behaviours at all times would the behaviourists claims possibly be true, and even then it is impossible to 'construct' the universe. Individuals have to construct their own world as interactive and social in the environment. In project work the chances of such a long term comfort zone would be much less. The 'if' in this case is not even truthfully possible or probable because workers on a project may be looking for better and perhaps quicker, cheaper, more satisfying ways to behave and the larger questions of evolution are always working to upset any long term projection of behaviour as predictable. Nevertheless, it is true to say that games seem to have a life of their own but in fact they do not. Culture is a game created by us and may be played in many different ways. The social construct is, however, very compelling and influences individuals a great deal.

Within each individual and within each environment there are nearly always possibilities for exploration and discovery. These occur in various ways that may be acceptable or unacceptable socially. By socially we must mean not socially in a worldwide humanity sort of way but socially as other individuals who are around us sort of way. Socially in that sense means other human beings, and this is important to those who produce the environment because we nearly always work in groups. Socially in this sense means people who allow or do not allow us to do things in the games we play and they may passively or actively permit or deny us the opportunities for exploration, for thinking. As we know, we are often expected to know what to do without thinking because stopping to think slows us down. We are told that we do not know what we are doing if we have to think about it! Employers sometimes want individuals to act like robots rather than like thinkers. Designers sometimes want time to think when there is only time to act.

When we attempt to assemble constructs quickly and easily we eschew those that take longer and are more difficult to draw together. We would be wise to take account of those who make a point of attempting to assemble constructs that take longer. The amount of practice in such skills is something that our universities say they are attempting to promote but our workplaces can sometimes deplore that attempt. This is often the difference between places of education and places of work. Once upon a time the places of work were going to become places of education, but that was in England and the time was immediately post World War Two.

We are arguing that the production of the built environment, the assembly of appearances, the place of work is a *sui generis* form of research because it does not sit within the same universal and infinite truth as physical science does. While the science of rocks and seas and metals is common to our species there is no pure science for the production of the environment we need for the games we play socially and environmentally. When we form groups, massive groups as in electorates or smaller groups as in families, we play games that come from what is unique to us as groups and environments as well as what is common to us as humans. Our argument is based upon the fact that social acts in politics and philosophy are different from social acts in buildings. We can explain this by accepting that the origins of knowledge are different. Large scale political economic constructs have to be imagined and expressed as models. These often place individuals in the role of ball bearings rather than as people (Sime, 1985).

Morphological constructs that appear as fixed may last for generations but will eventually make way for new constructs because of the longer term effects of evolution. The social use of constructs will change over generations and even over a single lifetime. The social use of constructs in building will even alter during the life of a single building project. In general terms the social use of constructs in one building will be the equivalent of research when the individuals in that group are left to think for themselves but merge their diversity into one construct if possible. The use of constructs by individuals allowed to be free to make them known in buildings as they see fit is the equivalent of the removal of prescribed assembly. It is the understanding of technology as the assembly of knowledge in free association with others rather than the robotic assembly of prescribed knowledge.

The same freedom or lack of freedom applies to joining a group. A wise designer will be aware of the way the opinion of the social group he or she is involved with might alter the understanding of the building he or she works upon. Are the participants meant to think or are they there to get a job done quickly and for a specific cost? Environmental design extends the need for wisdom out into the street and beyond three-dimensional spaces to a different sort of space, which is the metabolic space, the social space with its protocols for who might think and who might do what they are told and nothing else, the importance of accumulation and social knowledge and of resistance and dissent.

The social space forces morphological issues upon the constructs produced by individuals in the relative unknown of the individual. Individuals working on a project have the capacity to work on an assembly in the space of appearance but will always have experiences that alter the way they think. This is more than rational thinking. It is emotional thinking linked to all sorts of knowledge. Who am I working with? What am I doing to the world and so on? The individual may make themselves subservient to others for various reasons but they will still feel that perhaps they should act less submissively. Other individuals will deliberately force others to play the games they feel are important. The balance of what people might generally do and what is possible in the world will also apply although it may well be ignored. Very large scale constructs, social theories and political economic theories will come to bear on individuals.

Knowledge of building was and is contained in the three subject areas of research from the beginning, known, known of and not known, not yet assimilated. Rather than see evolution as a gradual unfolding of a narrative we need to understand it as a holding on and letting go of protocols that structure the games we play. The protocol does not go away unless it is let go of or the phenomena are no longer available to make an appearance. If we consider the conservationists, for example, we must applaud their desire to keep *some* examples of our history. It would be imprudent to erase heritage if only because it would be a waste of resources. However, rather than introduce, as some do, a reification of all historic phenomena we could also see a project by project experiment that leads to some interesting and beneficial discoveries.

Forget the universal and the infinite and think instead of what we need to do in order to interpret the games we play. Is that what we have always done or is it a new construct? The three categories of knowledge, known, known of and unknown, relate to all subject areas including building. The same three categories of knowledge apply to everyone who has ever lived and who will ever live. We could run those rules back over four million years to the time of Lucy (Johanson, 2009), one of the first walking forms of humanity. We are infinitely programmable individuals with the capacity for social action on a very large scale indeed. Lucy was a prototype and we are the evolved version. The games evolve more quickly than our DNA. Differences between Lucy's world and our own world now have more to do with the evolution of the games than the evolution of our bodies. It will suit us more if we stick to the obvious facts of the last few centuries as new knowledge has been created in neuroscience but we would need to go back a thousand years to find significant changes in human DNA.

During those last few hundred years we have seen what we call technology (Ihde, 2002) evolve as an important aspect of what we know and do in relation to buildings. Most of the metaphysics in the interpretive effort we make has been set aside by scientists. However, we seem to see technology as an evolving accumulation of excellent systems rather than a palette of possible actions by technologists that hone and shape the games we play into a more knowable set of protocols and phenomena. The desire to improve the production of building as a process on an almost automatic and universal scale producing appropriate projects for a wide variety of situations fails to encourage education in the workplace. We have only to consider Dubai through to the work of the now dead architectural teacher Samuel Mockbee (Dean and Hursley, 2002) to see clearly the fact of diversity. Becoming excellent in social action is often left out of what we consider to be knowledge of the subject of building construction and yet it alters what we do. Condoning playing the Dubai game is a political act, as is condoning the Mockbee game. Both can co-exist on the planet but one helps poor people and the other does not. Individuals must choose and live their choices authentically or not.

Ruskin favoured the feudal system, as did William Morris, because the patron could encourage the exploration of the feelings of individuals and the expressions of those feelings in gothic buildings. The feelings of classicists is hardly different from the feelings of those favouring the arts and crafts, but what they love is pure rationality expressed in mathematical geometrical forms. The common denominators are the human race and the world we live in. The Bauhaus shifted their feelings into providing for the worker using an industrial process. The argument of the game played being the use of an elite 'artistic' position directing attention to colour, shape, utility and so on. The complexity of these differences between these games is well documented in architectural theory although not always without an unwelcome use of metaphysics used to reify one game over another.

Social mechanisms and new systems alter the amount of energy we spend in looking for new knowledge, the unknown sort of knowledge, requiring what we might call learning time. Our desire to get on and improve any process may of course be social and global but it is not and could never be inclusive of all people and their desires if it is prescriptive. People are individual and unique just as the present is unique. Quite literally our knowledge and the effects of its use are incorporated into the way we build and inevitably alter what buildings look like. In a similar and quite literal way the energy individuals put into building and mediating building has an effect upon what our environment looks like. How those individuals make choices about what they care about is metaphysical unless we have a chance to pin it down to the people involved or the resources used. For example, if people do things for money or time or speed we need to compare that to the distribution of the benefits of doing alternatives. Is it for one or two individuals or for all of us? If we use this resource is that going to make more of us healthy or more of us sick? It is not the construct but our participation in it that matters.

In many cases, if viewed from outer space our behaviour in very large groups would look exactly ant-like but we know for a fact that every single individual is different. If we pluck any single individual out of that very large group we would confront a person and not an ant. Yet if all our outputs were different then we would have a chaotic input such that the infrastructures we construct and share could not ever work. What we refer to as politics seeks to mediate such problems, but the origin of this ability we have to construct large scale interactive systems lies inside each one of us together with our ability to behave in a social or group manner. That depends upon an interpretation that uses people and appearances so that what is in the heads and hands of people takes over from metaphysical voices in the head and metaphysical perfection in the world.

What we understand in common might be called a morphological construct (Figure 2.1) that is capable of rational understanding as a whole and yet fluid to the degree that even the parts can vanish into thin air and become obsolete as knowledge even though the phenomena remain. In that way we can produce systems

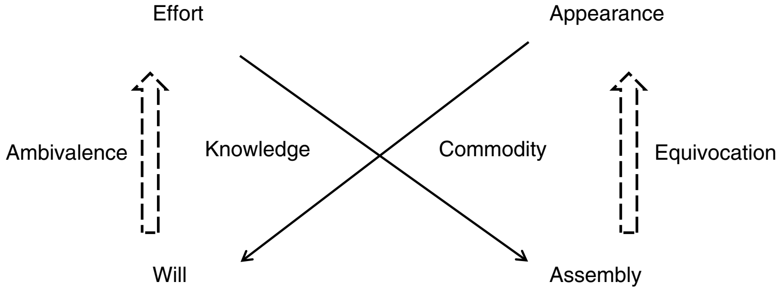

Figure 2.1 The morphological construct.

that make sense and yet appear to be entirely different to other systems apart from underlying similarities brought about by living on the same planet with other human beings of the same species/race. The term 'genius' is a chimera and belongs to the same metaphysics as the perfect world. The will to exist as individuals in this or that group, to keep the construct alive or to kill it off, is what it is about.

Our ability to argue, to mediate, to use language, to create and use systems that help to accommodate change to such a large degree is apparent all around us. What we have in common with each other are the media that appear to us. This in effect allows a voting mechanism of the values we code for with respect to social and environmental phenomena to select for us as individuals what then becomes both social and environmental (Calvin, 1986). In effect we vote by both our thoughts and our actions, by knowing and doing what we may do in a social way with the strong choice of exactly how we do it resting with each and every individual. Going to work for a specific firm or on a specific job has always been an option and is a vote for a construct, consciously or not.

Conclusion

For quite a while now the academic community in particular has been split by concerns that are metaphysical. The explanations of what is best for us as a spatial form and what is in the head that makes us what we are all point ultimately to what is outside the games we play, beyond our ken, beyond mind, beyond science. If we look at the games we see only people and environment. If we look at the way neuroscience tells us the people interact with the environment and each other it is not any kind of provenance for the game. We can see the way people code phenomena and make knowledge (Churchland, 1995). We can see the way knowledge is assembled into constructs (McGilchrist, 2010). We can see how this makes life difficult for people (Laing, 1975), why they join and leave each other's company.

We can read how we use phenomena to extend the capacity we have to express our feelings, what is in our head that appears to us and can be assimilated as knowledge and assembled as phenomena in the space of appearance (Simon, 1996). We can read how different media play a part in our games (McLuhan, 1964). We can read how using those media allows a dialogue to evolve in which individuals can resolve issues (Schrag, 1992) on a large social scale without necessarily using metaphysics. Unfortunately we cannot stop people in power referring to metaphysical provenance for most of what we do. Antiquity, unknown powers or forces, in the head or in the world, aliens, genius, soul, all used when individuals, people like us, run out of arguments to play games the way they want. The use of exile, actual force of arms, police, army, guns is much more revealing. Also, the outcome in terms of distribution of the quality of life is much more revealing when people talk about the value of political economics: large scale metaphysics for the masses.

The fact is that large scale games are very difficult to organise. The smaller scale games we play are easier but less harmonised so that larger scale games have to be laid down within and between them. Look at the old medieval towns and you will see wiggly streets working around houses that evolved. Look at modern towns that have evolved over centuries and you will see straight roads, in the main, carrying drains and cables and buildings with building lines set up by a local authority on pain of demolition of the building and imprisonment of the owners. Look at global finance. It is easy to build an expensive building on one or a few sites. It is very difficult, seemingly impossible, to build enough houses to house all those in England whose quality of life would be improved by having one. In fact we do not even have a plan of how to build enough houses to house all those in England whose quality of life would be improved by having one. We are obsessed with property at the expense of housing people and it shows. The game we play seems to be about money in a one-dimensional way (Marcuse, 1968).

As a race we are still evolving. It will do no good to imagine that we have a part of our heads that thinks for us and a force at work in the world that acts for us. The games we play are created by us but we are not one individual we are many and we are all unique in space and time. Our world is unique in space and time. Finding games to play is always going to include some new moves, some new knowledge. Finding new knowledge is otherwise known as research. It is neither always new to everyone nor new to the situation but it may be assembled differently by accident or design.

The morphological construct is a research tool that allows individuals to pin down their own involvement and that of others in any construct. It differentiates between what is social and what is global in terms of the human race and the world at large. It uses knowledge and protocols that are the rules of the game. Inevitably the researcher using this research tool, known as Hermeneutics in academic circles (Snodgrass and Coyne, 1997; Thompson, 2007), will find a boundary and some or all knowledge prescribed by a force that is in reality ignorance. We must also remember that every office, every designer, lives in the metabolic space as described above.

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Case Study B
A Sustainable Window: A Process of Development

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This is a story about an idea, scientifically researched by doing a PhD, thereby developing a step by step procedure for designing joints/details. This was followed by a number of practical stages, namely prototyping, testing, presenting, collaborating and evaluation. Prototyping was necessary for the sake of a better understanding of the third dimension and for the sake of communication and conviction. Testing the principle of the window was to see how it performed as an integral whole, not just on separate performance requirements (chunks of knowledge). Conferences were an important forum in which to present the idea to academic and commercial communities, providing the opportunity for discussions, feedback and also possibilities for collaboration. Collaboration with a manufacturer on additional research helped with the development of the design into a marketable building component. Application of the window in two real life projects was the next stage – a pilot for a renovation project and a small new build housing project. In the context of the story so far, the last stage was evaluation, looking back to evaluate and reflect on the time and effort compared to the results so far and then looking ahead to determine what must be done and the possible spin-offs and potentials.

Introduction

In 1996 I completed my PhD thesis, *A Typology of Joints, supporting sustainable development in building, based on a case study of the typo-morphological principles of a window in a cavity-wall* (Olie, 1996). I was (as I still am) a practising architect, being educated by Professor Peter Schmid in Integral Bio-logical Architecture at the Technical University of Eindhoven. At that moment, with

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Architectural Technology: Research & Practice, First Edition. Edited by Stephen Emmitt.

20 years of practical experience, I was puzzled by the phenomenon of joints in building. Puzzled because it seemed that we had trouble to be able to get a grasp on joints in general; there was no common theory/approach/method to deal with joints. Knowledge was accumulated through centuries of experience by trial and error. The best we have in communicating this knowledge are textbooks and manuals showing 'best practice' joint solutions for joint situations. Explanations are about the behaviour of joints in practice and not about anticipating the performance of joints based on knowledge of principles.

My doctoral thesis dealt with questions such as: What is a joint?, Why are there joints?, Who develops joints?, How best to develop joints? It even considered the questions of where and when joints are interesting when looking at the execution of a building. The aim was to achieve a fundamental understanding of the phenomenon of joints in general and in particular environmentally sustainable joints in order to develop real joints in practice. Having developed my theory on joints the thesis then focused on a case study, the window in a cavity wall (see Olie, 1996).

Why a window? To be more precise: why the joints between the glass pane(s) and the wall? As a start I had distinguished three ways to look at joints. First of all it was considered as a transition/intermediary between different materials or spaces; this aspect I called the 'Mediator', being the pragmatic aspect, the goal of building and controlling the passage of specific factors from one side to the other and vice versa. However, to achieve this we must devise the means, actual building means; this aspect I called the 'Creator', being the syntactic aspect. When we have eventually built these joints and we experience these joints as they are and experience their performance, then we are talking about the relationship between the means (Creator) and the goal (Mediator) and I called this the aspect of 'Informator', the semantic aspect, dealing with the understanding of joints in particular and the built environment in general. More specifically:

- Mediator, the joint as intermediary,
- Creator, the joint as system of parts, and
- Informator, the joint as object of experience with their specific factors involved such as Light, Air, Warmth, Moisture, Sound, Radiation, View, Minerals, Plants, Animals and People for Mediator, Execution, Durability and Maintenance for Creator and Material, Image and Control for Informator.

Having distinguished these three aspects the question was, which joint situation should I choose to develop a convincing example joint? That joint situation should be between extreme climatic conditions, dealing with all the mentioned factors concerning the hole in the outer wall: the window.

The published literature I know has the character of manuals, being more or less systematically organised. One of the better examples is *Architectural Detailing* (Allen and Rand, 2007), which is well organised showing patterns of details. In my thesis I developed a step-by-step procedure to design a joint principle (for additional information see Emmitt *et al.*, 2004). This 9 + 1 step procedure will be explained first, followed by the various steps towards the production of a window solution.

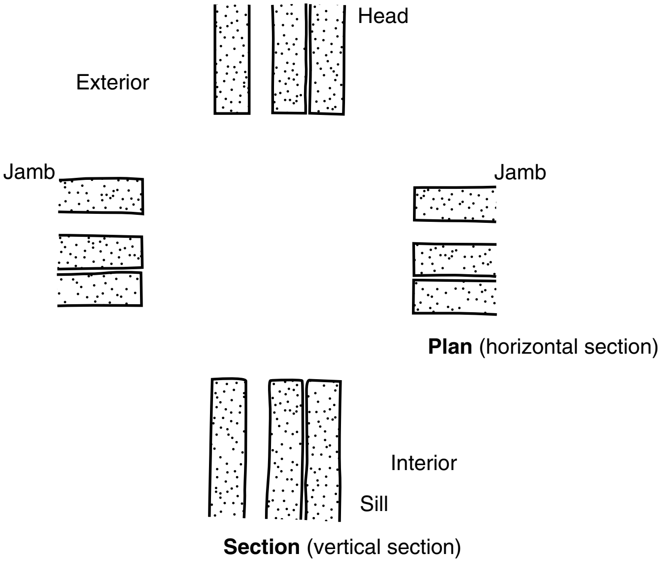


Figure B.1 Step 1.

The 9 + 1 step procedure

At every step decisions have to be made. This means that for every joint situation the outcome may differ depending on who makes the decisions, and the outcome can differ when the same person uses the procedure again at another moment in time. The following procedure resulted in the solution principle for the window that was developed further as prototype.

Step 1: determining discontinuity of main components

What we see in Step 1 (Figure B.1) are the main components of an exterior cavity wall with the inner leaf, cavity with insulation and air space, and the outer leaf, as well as a hole for Light and View.

Step 2: determining additional component(s) and functional continuity

In Step 2 (Figure B.2) we decide to fill in the hole with a transparent medium like glass, which does not prohibit the passage of Light and View but can control the passage of Air, Warmth, Moisture, Sound, Radiation, Minerals, Plants, Animals and People. We additionally decide to apply two layers of glass for better control. In this step we are dealing with the aspect of the Mediator, so we can state the following as the first criterion for sustainable details/joints: *Controlling the passage of Light, Air, Warmth, Moisture, Sound, Radiation, View, Minerals, Plants, Animals and People should be as optimal as possible, also considering simultaneousness and change in order to achieve sustainable details/joints.*

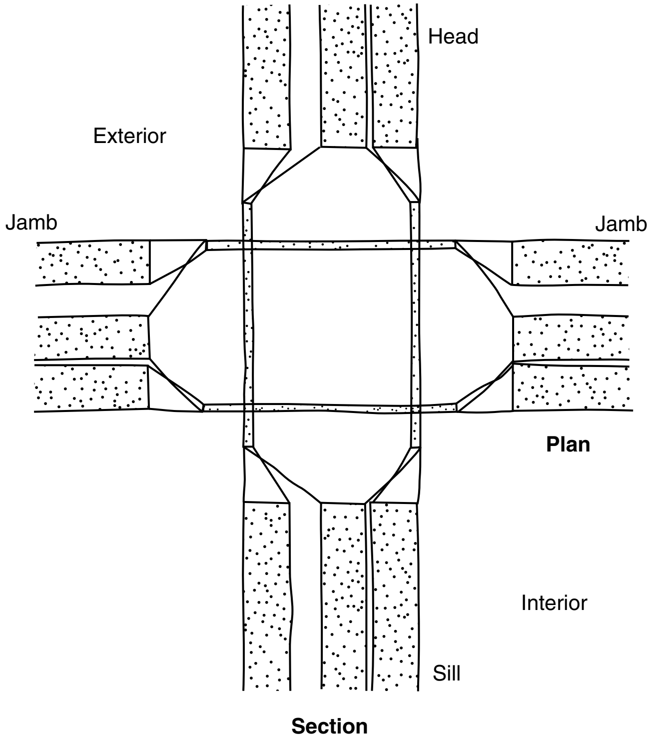


Figure B.2 Step 2.

Step 3: determining jointing parts and assembly direction

In Step 3 (Figure B.3), by considering the number and kind of jointing parts we can state a very important criterion to achieve sustainable details: *Use as few jointing parts as possible and those that are the most biodegradable (Creator).* As discussed later, the solution principle is without use of lead/plastic flashings, aluminium/rubber/foam gaskets and sealants (in contrast to what is commercially available).

We decide to apply a jointing part between a glass pane and a main component. We do this for each glass pane separately. (Later I added more specifically an assembly sequence and a *disassembly sequence*, for reasons of maintenance, replacement and change of parts.)

Step 4: determining size and position of additional components and jointing parts

In Step 4 (Figure B.4) we decide to position the glass panes at the outer limits of the wall. The functions of sealing are anticipated in the size of the jointing parts. The reasons behind these choices will become clear in the following steps. (Later I added the aspect of *change* of size and position to this step.)

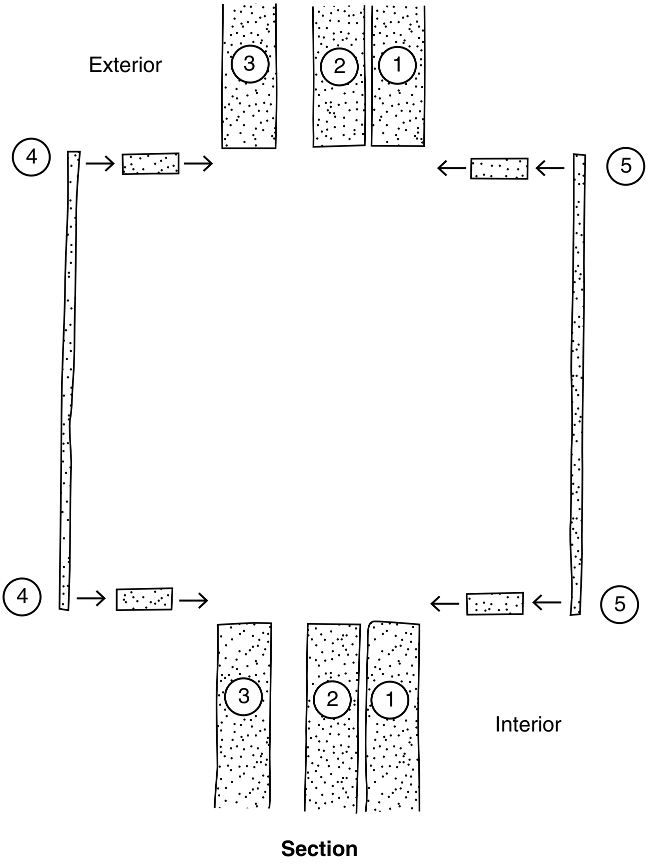


Figure B.3 Step 3.

Step 5: determining preliminary shapes of joint faces

In Step 5 (Figure B.5) the preliminary shape has been determined to be the 'labyrinth principle' of the factor Air for the function of sealing. Note that there is as yet no difference between the head, jamb and sill joints.

Step 6: determining specific shape of joint faces

This step (Figure B.6) deals with the factors of the Mediator only. On the exterior we must prevent the passage of Moisture, and hence the specific shape principles for the head, jamb and sill.

Step 7: determining prevention shapes

Prevention shapes are intended to keep the 'load' on seams to a minimum, especially on the exterior considering Air and Moisture (Figure B.7).

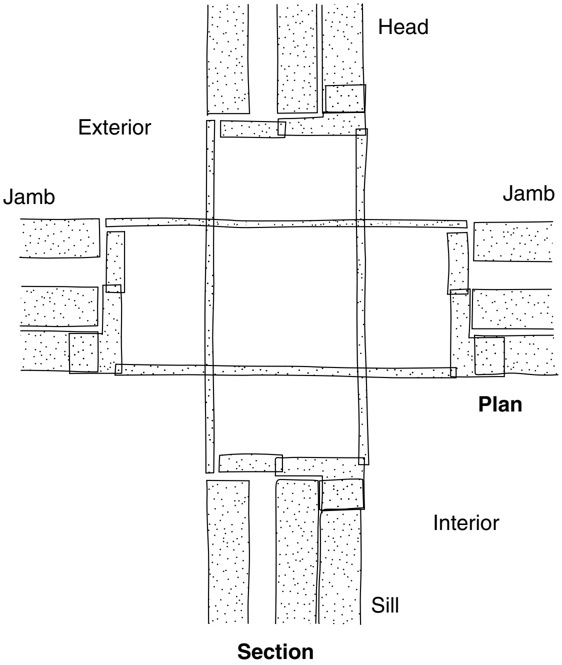


Figure B.4 Step 4.

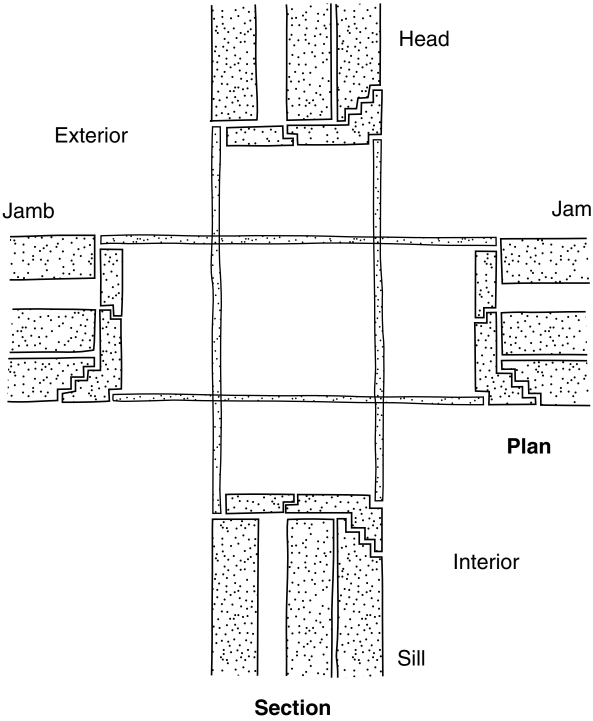


Figure B.5 Step 5.

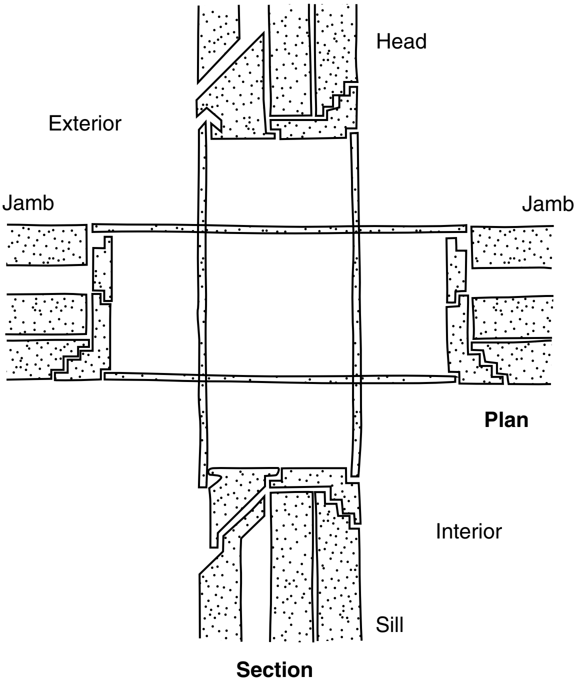


Figure B.6 Step 6.

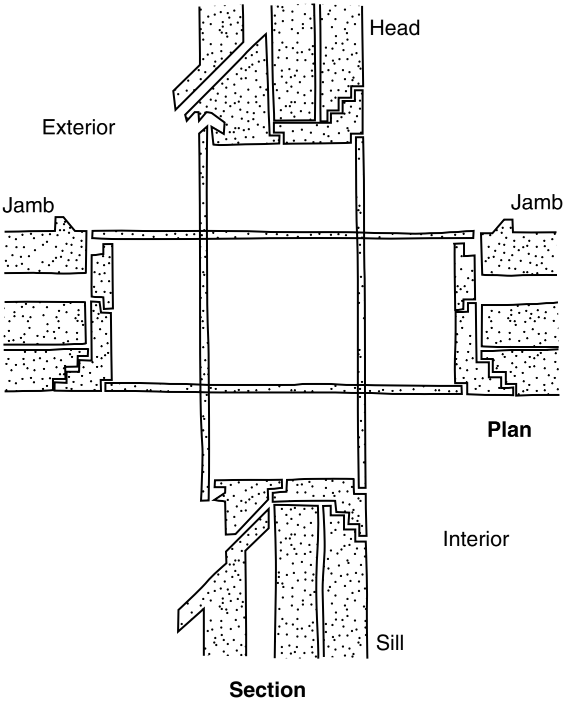


Figure B.7 Step 7.

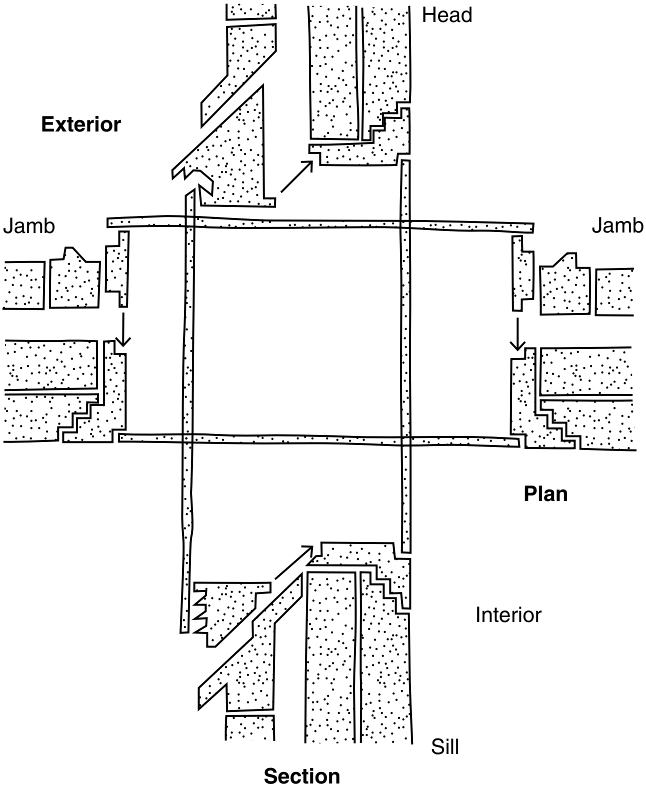


Figure B.8 Step 8.

Step 8: determining correction shapes

In this step (Figure B.8) our attention goes to the Creator factors of Execution, Durability and Maintenance. Considering assembly as part of Execution we must modify the shape of the interior sill.

Step 9: determining primary and secondary sections of parts

The bold lines in Figure B.9 represent the essential shapes considering the aspects of Mediator and Creator. The other lines may be seen as secondary, representing 'solution space' for freedom of design for purposes of sign, symbol or ornament in order to strengthen personal or cultural identity.

Step 9 + 1: determining a solution variant

After determining position, size and shape (the morphology) of parts and whole we now determine actual materials and dimensions relating to their properties and behaviours, thereby incorporating the necessary tolerances in dimensions

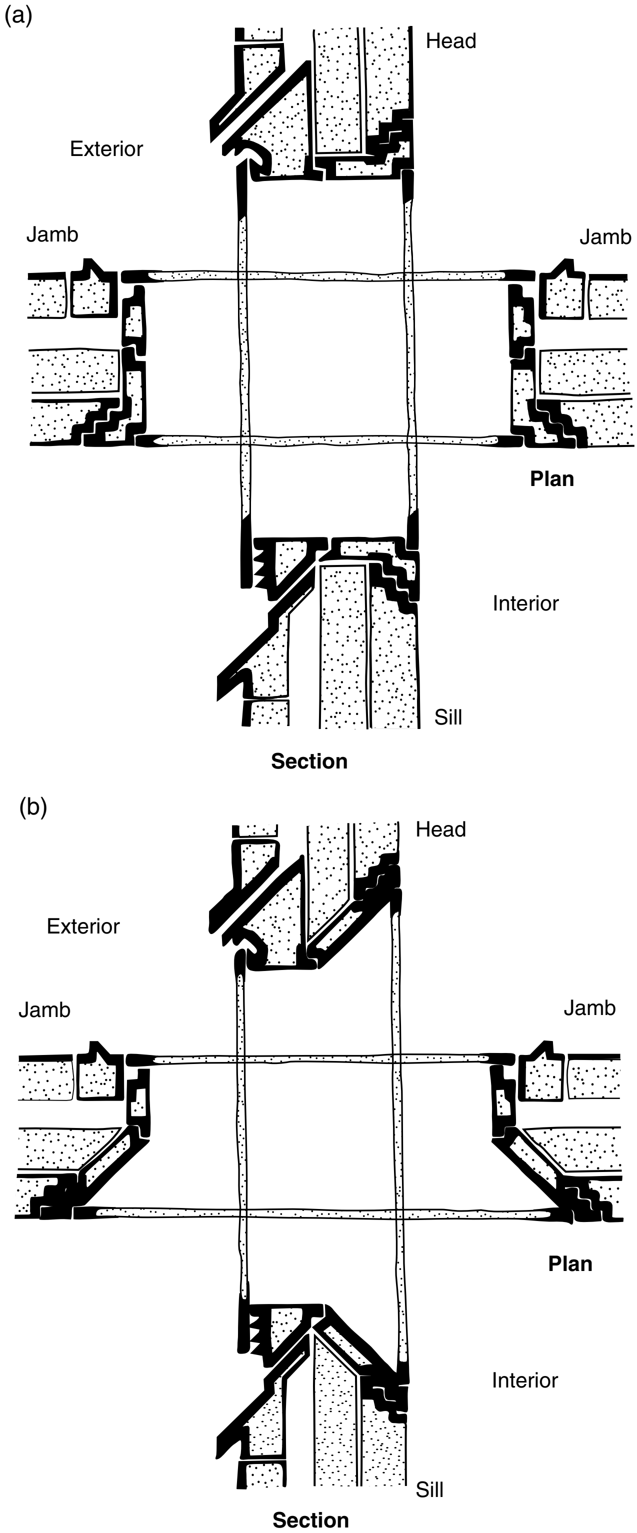


Figure B.9 Step 9.

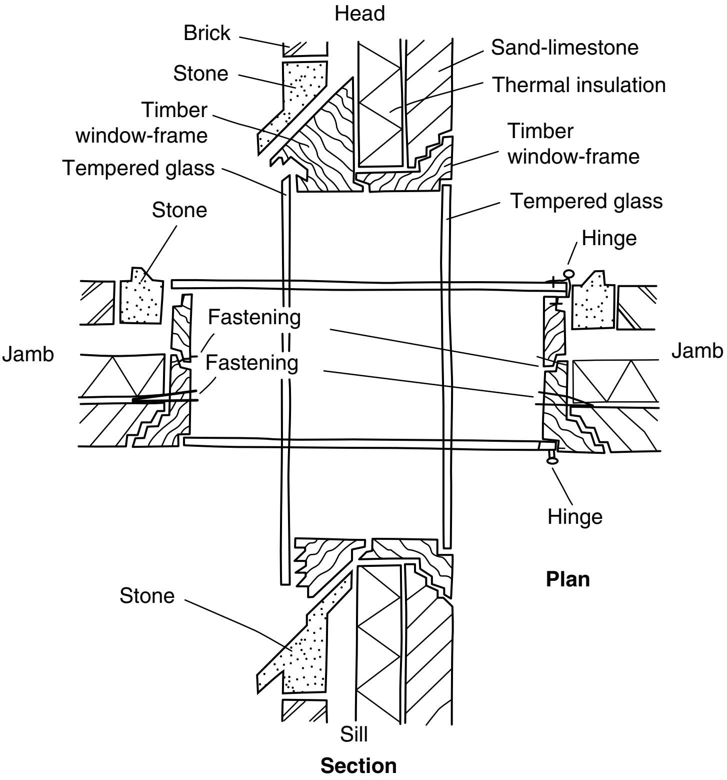


Figure B.10 Step 9 + 1.

(Figure B.10). We also determine additional fixing parts. In the end there is another criterion for sustainable details: *Experiencing the details/joints should give us knowledge about the relationship between the performance of controlling the passage of … (Mediator) and the way the detail/joint is made (Creator).*

Knowing/understanding your built environment is essential to achieve an attitude of care.

Prototyping

Having the intention of approaching the building market I needed something more substantial than a story and drawings. I told a model maker (Sjoerd Hiemstra) I usually work with for the making of building mock-ups about my window frame. He was so enthusiastic about it that he offered to make it on a scale of 1:10 (Figure B.11); he even made two of them using high density polyurethane (PU) foam, which behaves like wood when sawing and sanding. This turned out to be very useful for communication and conviction.

At one of the Detail Design in Architecture (DDiA) conferences in Velp, The Netherlands, I had invited a young building contractor to attend (Ruben de Gelder)

Figure B.11 Model scale 1:10 of the window in a cavity wall.

Figure B.12 Prototype window scale 1:1 made of pine wood, without the glass panes, showing the outer and inner window component separately.

who had a special degree in carpentry, especially windows. After listening to me about my window principle and seeing my 1:10 prototype, he offered to make a full size prototype (1:1) (Figure B.12). We both talked to his main carpenter (Theo) and I noticed that he had quite a struggle to get rid of his ‘schemata’ of the standard window, but it was amazing how quickly he grasped the essentials. I interpreted this as recognition of an 'obvious' quality of the principle. In the window I added a mullion and a jamb to complete the collection of standard joint situations in windows.

The testing

I had stated a list of advantages of this window principle, looking at each factor separately under the sustainability criterion: Mediator, Creator and Informator.

Mediator (pragmatic)

(Vitruvius talks about 'utility', Allen and Rand about 'function'.)

As a Mediator the boundary/joints should control the passage of the factors below in an optimal way, also taking into consideration change of circumstances and/or requirements, especially in the case of simultaneousness.

Moisture

The outer single tempered glass pane prohibits passage of precipitation. In extreme conditions the inside of the outer glass pane might get wet, but the seam of 6 mm prohibits water getting further inside, because a seam of 6 mm is too large to effectuate capillary forces. Water vapour can pass quite freely from inside to outside and vice versa, depending on pressure differences (we have a vapour-open construction here).

Air

Deliberately we have an air-open construction here. The seams are the ventilation system; the length of the seams can be calculated specifically in relation to the space behind the window.

Sound

The size of the airspace/cavity between the single pane on the outside and the double pane on the inside is crucial for the performance of prohibiting passage of sound.

However, controlling specifically the passage of the song of birds but prohibiting the sound of traffic is more challenging (the situation of simul taneousness).

Warmth

This double-window principle has triple glazing just as in the Passiv-Haus concept. This principle is comparable to the second skin principle with double glazing on the inside and single glazing on the outside (second skin). The ventilation air coming in is first warmed in the cavity space before entering the interior space (we are talking about cold conditions outside and daylight). To lessen the build-up of warmth we can apply sun-shading in the cavity. Another aspect is the thermal insulation value of the whole window: what is the *R*-value? We can increase the *R*-value by applying an insulation layer in the cavity.

Light

Because tempered glass is used there is no obstruction of light by window profiles.

By making the inner side surfaces of the cavity light in colour we can maximize the amount of indirect daylight because of the high reflection factor. In the cavity we can apply various kinds of screens and filters to achieve all kinds of qualities of light.

View

Comparable to light there are no obstructions for view. We can make the inner side surfaces of the cavity from mirrors to enlarge the field of view.

Minerals–plants–animals

To control the passage of dust, pollen and insects we can apply a filter or filters in the cavity. The cavity could even be a ‘home’ for certain plants and animals.

People

In order to prohibit passage of people two locked layers has its advantages.

Creator (syntactic)

(Vitruvius talks about ‘strength’, Allen and Rand about ‘constructability’.)

Using the least number of jointing parts such as flashings, gaskets, foams and sealants (which are the least desirable considering their material characteristics) supports achieving sustainable details/joints. We try to achieve the performance of sealing by the morphology of the joint faces of the main components and jointing parts.

Execution

The chosen materials achieve their shapes, sizes and positions by certain methods. A special aspect is the sequence of assembly and disassembly of parts in the factory and/or on site.

Durability

The expected lifetimes of building components depends on the chosen materials and how components and the jointing parts are put together in the detail/joint situation.

Maintenance

We achieve the extension of lifetimes by cleaning, protecting (coatings) and replacing parts. Accessibility and disassembly possibilities are important aspects in this sense.

Informator (semantic)

(Vitruvius talks about ‘aesthetics’, Allen and Rand also about ‘aesthetics’.)

To have an understanding and appreciation of our built environment we must be able to ‘read’ our environment. To achieve this we must be able to experience the relationship between the Mediator and Creator aspect in general and those of details/joints in particular.

Material

Here we mean the texture (visual and tactile) and colour (visual) of materials.

Image

The morphology triggers associations, based on knowledge, analogous thinking and experience.

Control

Change of material and morphology through our own intervention supports understanding of our built environment. We are then sensors and then following through by adapting Creator in order to achieve an improved performance of the building, component, joint as Mediator.

The next step was to team up with a manufacturer dealing with window frames and windows, especially applying tempered glass. There was a choice of two. I happened to meet up with a salesman of BUVA and the connection felt right, so we proceeded. BUVA had just built a new extension to their assembly hall and had installed their new testing facilities (see Figure B.13), approved in accordance with European regulations.

The tests

The original prototype measured 306 mm deep; as the testing facility could hold only a window profile of up to 240 mm, we had to adjust the size of the prototype.

The surroundings (the wall) of the window frame are part of this window frame system. Dutch regulations demand closure (the rectangle sealed space in which the artificial climate of rain and wind pressures is simulated) on the outer face of the window frame. The Joint Origin window frame does not have an outer face (at that point there is a tempered glass layer). With BUVA we agreed to make a mock-up of the surrounding of the window frame (being the cavity wall with its specific shapes) and position the closure on the surrounding. The glass infill was simulated by using sheets of board (masonite). Once this was completed the following tests were conducted.

Water tightness

Within the closure water is sprayed and air pressure is increased.

Figure B.13 Positioning the window in the testing facility, showing Arjan Verheul and Max de Vries (now a pensioner), the R&D people at BUVA.

Air tightness

Within the closure air pressure is increased in steps and air tightness is measured using specific computer software, complying with Dutch regulations.

Sound insulation (Peutz)

One of our best sound engineering companies Peutz, and specifically Remco Allan, was willing to value my window frame by using their software calculations and their references of other window frame systems available on the Dutch market.

The test results

Water tightness

Especially one weakness that was revealed when the air pressure was high was the creep of water on the surface of the head, jambs and middle sill.

Air tightness (with 100% gasket filling between the interior window and the window frame)

Because closure was on the outer leaf of the wall, air escaped through the wall cavity by way of the (quite large) seam between the window frame and the outer leaf. This would comply with actual performance in my opinion, but the head of

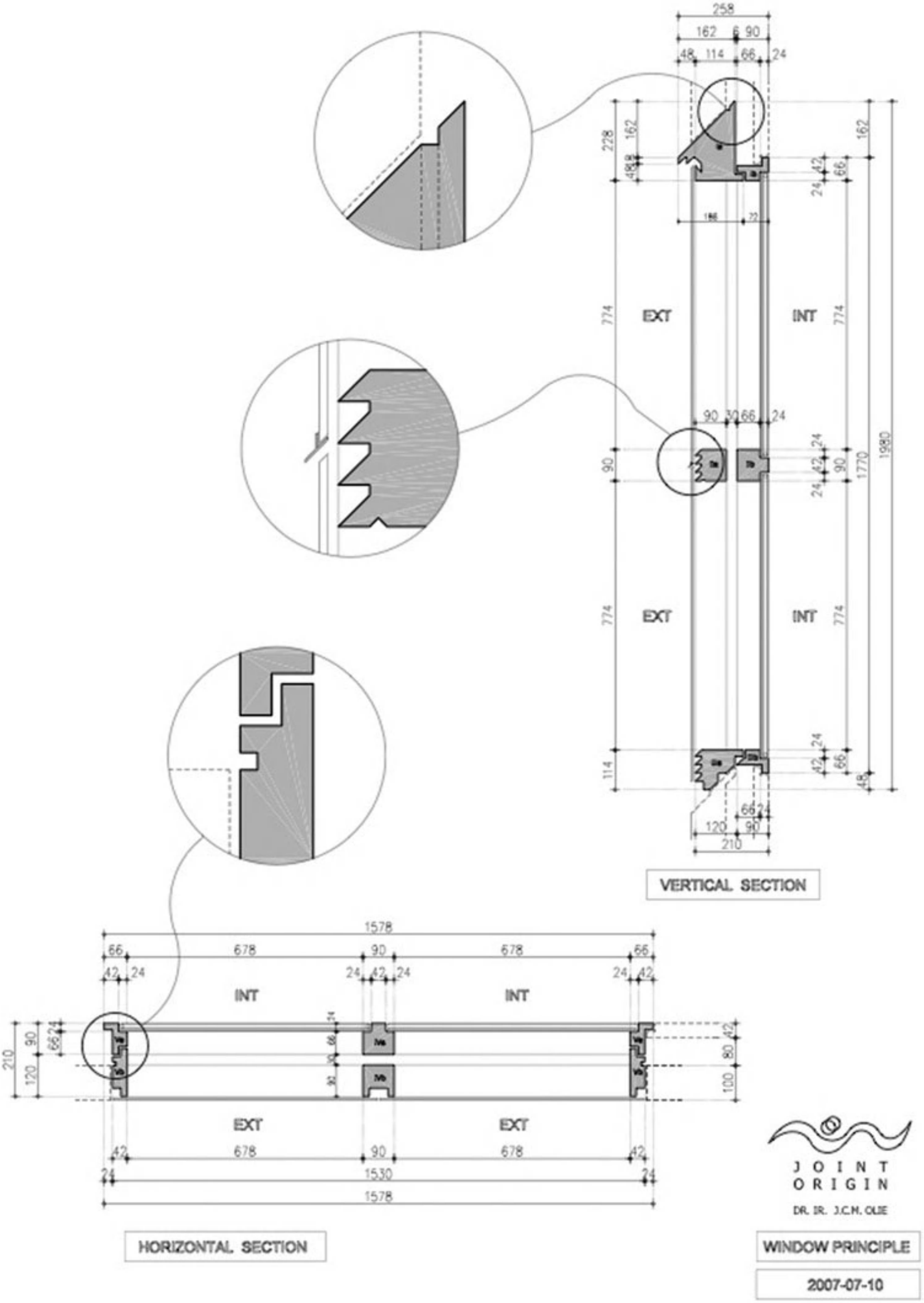


Figure B.14 Horizontal and vertical sections of the window principle, showing adjustments in the design after the testing of water tightness.

R&D of BUVA, Arjan Verheul, did not quite agree. Air flows would have to be measured specifically in the cavity of the wall and the cavity of the window; this test was not set up for that.

Sound insulation (calculations by Peutz)
The advantage due to the large cavity is considerable. The sound insulation with 100% gasket filling (inner window) is Ra = 48 dB. The sound insulation without gasket filling is Ra = 30 dB. Without a gasket filling there may be an outside noise level of 63 dB (high traffic noise) still resulting in a noise level of 35 dB on the inside, which is the legal maximum. (A 'normal' Dutch window, being a single sash window, with a standard vent may take 53 dB).

Evaluation

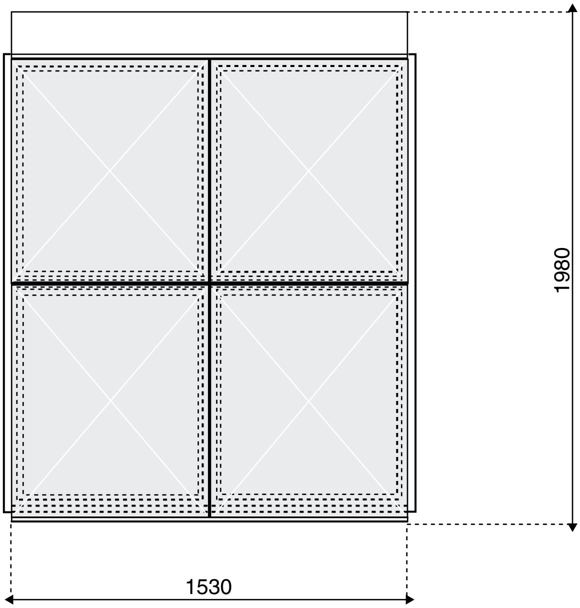
Water tightness
Applying a groove in the head and the jambs should solve the problem of water creep. In the middle sill, besides applying a similar groove, it might be advisable to add a profile at the bottom of the top glass panes in order to protect the seam (see Figure B.14).

Air tightness
There is discussion about the test conditions as such, but this is only a formal test regulation issue. The intention was not to accomplish air tightness but to use the seams for ventilation. Peutz declares that it is possible to calculate the quantity of open seams in relation to the space inside for fresh air intake, balanced with the used air exhaust ratio (see Figure B.15). The cavity is also responsible for preheating the incoming air, working as a mini greenhouse in the cold periods.

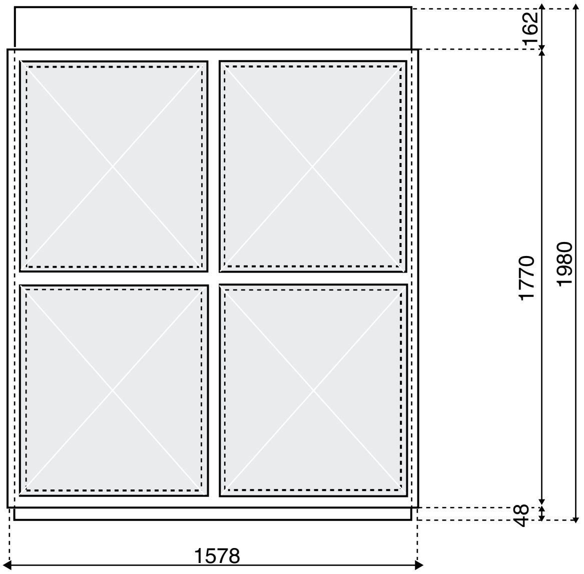
*Sound insulation (*Peutz)
In combination with ventilation possibilities, sound insulation performance is very promising. Performance can easily be improved, if necessary, by applying absorption material on the side surfaces in the cavity.

Conferences

For years nothing further happened except participating in the Detail Design in Architecture conferences, initiated by Professor Stephen Emmitt and partly organised by myself when hosting in The Netherlands. The conferences gained recognition and attracted a diverse group of researchers, educators and (still too few) practitioners. The conference went from an Anglo/Dutch event to an international event in 2011, with the conference in Istanbul, Turkey and then Taiwan in 2013. The signal was clear: joints and details were becoming more and more an item in architecture and the conferences were showing richness in approaches to the various themes.



Exterior image



Interior image

J O I N T
O R I G I N
DR. DR. J.C.H. OLDE

Window principle

2007-07-10

Figure B.15 The interior and exterior images of the window.

At one of the DDiA conferences it was striking when two presentations were given about alternative building systems by Professor Tom Wolley about hemp-lime construction (Bevan and Wolley, 2010) and Craig White about the wood and strawbale Modcell components system (Roberts *et al.*, 2010). Both hardly paid attention to the 'holes' in the wall, applying very regular standard windows. I was the next presenter to show my double window principle for the 'holes' in the outer walls (Olie, 2009; Olie and Hermsen, 2010). Afterwards both admitted that getting our heads together to share knowledge would be a good thing. Modcell and I have stayed in contact, although this is taking time because of further development of floor and roof components at Modcell.

The greatest advantage for me as a practitioner by attending these conferences is the fact that the 'outside' market world and the 'inside' academic world meet each other. One side finds out what is worthwhile researching and the other side finds out what is worthwhile knowing or getting to know. In a world in which sustainable development (meaning lean, green, smart, healthy, social and inspiring) is so important we have to work together, support and encourage each other. In the joint not only do components meet but so also do all the parties behind the components or in front of the components and their joints such as the users (being us all). Conferences should be the essential events in time and place where these parties meet and communicate and set out the direction of development – a sustainable development.

A manufacturer and further specific development

A few years ago I designed the new office building for the firm JAZO in Zevenaar, The Netherlands. JAZO specialises in aluminium components for the building industry. Last year they celebrated their 50th anniversary, inviting participants at the event to come up with suggestions for the development of products for the future in order to strengthen the market position of JAZO.

I filled in 'climate windows' on the suggestion slip (without my name). A few days later I was called by the young director, Axel Jansen. He had the paper slip in his hand and he made the guess that it was mine. He invited me to tell him more about my ideas. The meeting was held together with two R&D persons and again a few days later Axel told me they had decided to choose the 'Climate Window' for further development. He asked me if I was alright with aluminium profiles instead of wooden ones. I said that I would always prefer wood as a sustainable material. The morphology of the profiles is essential to abide to the criterion of Creator, avoiding use of more unsustainable jointing parts. In this sense with aluminium we can achieve the same morphology of the profiles. A young master's student in Architecture, Lion Schreven, will spend four days a week for a year on this project named 'IntegRaam' (integral window).

Further development will require more calculations and tests. Marcel van Uffelen of Peutz bv has made the following calculations:

1. The U-value/the R_c-value.
2. Warmth of the ventilation air coming in, accumulating in the cavity.

3. The *g*-factor of solar radiation on the window, incorporating sunshading in the cavity.
4. The effect of IntegRaam on the annual energy consumption for a home or office, comparing this with a conventional window type with triple glazing as required for a Passiv-Haus level of performance (as yet to be calculated).

In Marcel's own words the outcomes are the following: for Joint Origin and JAZO of Zevenaar, Peutz Ltd of Mook, the Netherlands, has studied the thermal performance of the IntegRaam window system. The thermal properties that have been studied are the thermal transmission, *U*-value, and the solar gain, *g*-value. Both properties have been computed using computational fluid dynamics(CFD), employing a three-dimensional time varying (transient) numerical model of an IntegRaam, including a three-dimensional surface-to-surface radiation model. Upon modelling the *U*-value, the transmission heat recovery effect of the ventilation air entering through the cavity between the inner and outer window panes has been computed as well. This means that ventilation air flowing through the cavity picks up the heat that flows from the dwelling through the inner glass pane to the cavity, heat that otherwise would be lost. The *U*-value has been depicted in the graph in Figure B.16, together with the *effective* *U*-value, U_{eff}, i.e. including

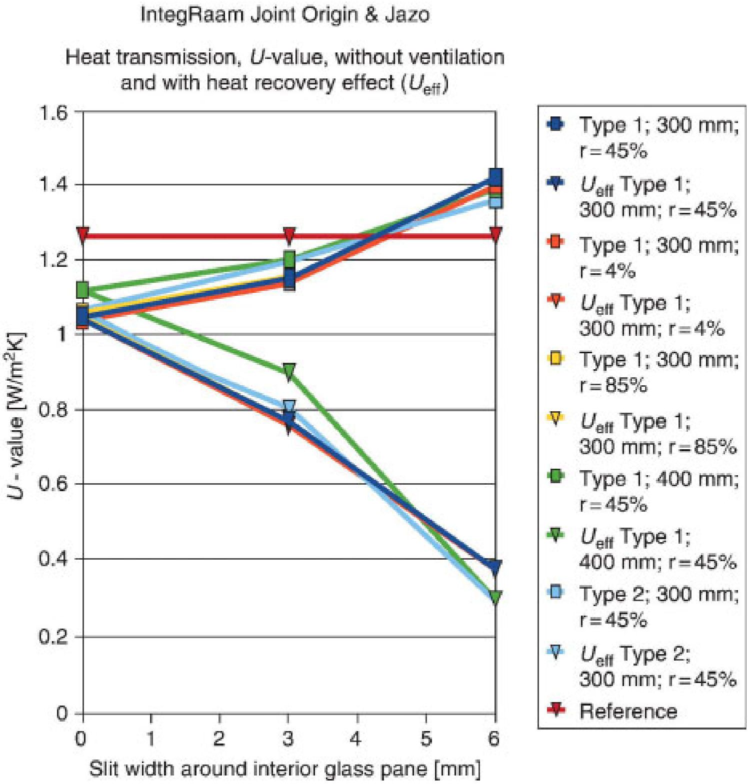


Figure B.16 Diagram showing the *U*-values and U_{eff}-values of the regular window and the IntegRaam window in combination with variation of slit widths.

the heat recovery effect of the cavity. The lowest predicted value of U_{eff} amounts to 0.3 W/m^2 K approximately for the case with a ventilation rate of 17 m^3/h (slit width 6 mm) versus a value of 1.15 W/m^2 K for the transmission heat loss excluding the heat recovery effect (the case without ventilation) and 1.26 W/m^2 K for a traditional window with triple glazing. The difference between the traditional window and the IntegRaam without ventilation is due to the favourable abandonment of a ventilation grill in the latter, since such a grill has poor heat insulation even when it is closed, as well as the fact that the window frame of the IntegRaam is more effectively shielded by the exterior glass pane.

Figures B.17, B.18 and B.19 show a solution principle for renovation of windows in existing buildings. Renovation will be one of the biggest markets in the near future.

Application in projects

Axel Jansen of JAZO commissioned me to replace one of the windows in his home.

He said that the wooden version would be advisable in order not to have to wait for the whole development of the aluminium version. Here we are dealing with a renovation challenge, also giving us the chance to monitor performance (see Figure B.20). A programme will have to be written for this.

At the moment I am designing/developing a small project of four houses for a developer, Wim van Keulen. We want to do this together with the participants/buyers, of which my wife and I are also part. Wim is very enthusiastic about the goals of the Passive House concept, but we have yet to agree on the building system and the application of my double-window principle (no question about my own house). Various plans are shown in Figures B.21 and B.22.

Looking back and looking ahead

Looking back I have, on one hand, wasted too much time considering the development of my window principle towards a tested product in the building market.

You must have the courage, discipline and money to follow your own path and pace, not being bothered by existing regulations, the usual pace of the building industry and the doubts of building agents. However, the funny thing is that in (that too long) time the general development, the focus, the change of attitude is supporting more and more the approach represented by my opinion of sustainable joints/details in general and by my window principle in particular. Recently I have visited several housing corporations explaining my window principle, aiming especially at the renovation potential. All key managers were very interested and even happy that this kind of innovation might work well for them. They all did say that they would first wait until all calculations and tests were carried out.

Like the saying goes: ‘there is a time and a place for everything’. It appears that especially the timing is quite right at the moment for developments such as my

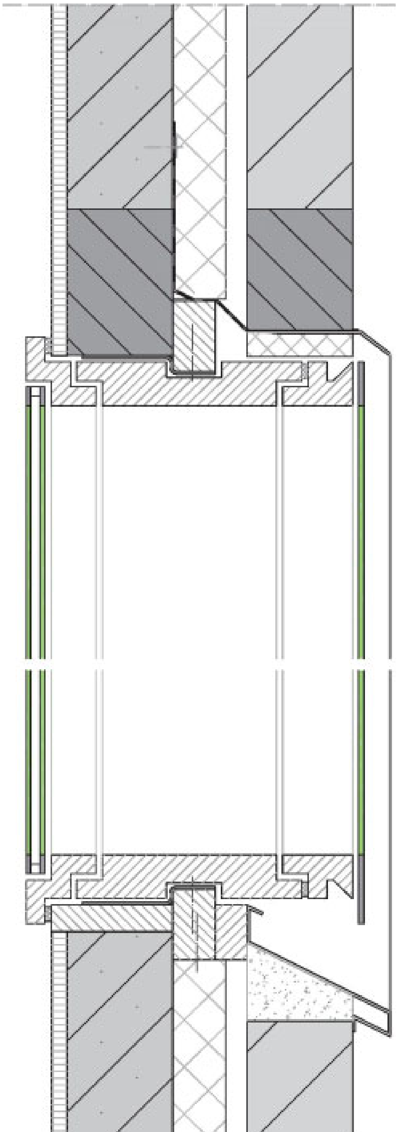


Figure B.17 Vertical section of the test window.

window principle, that now carries the name IntegRaam. Looking ahead I now have a manufacturer (Axel Jansen, JAZO) who believes in the potential of IntegRaam, a young architecture student (Lion Schreven) who understands and is working part-time on IntegRaam, a physics engineer (Marcel van Uffelen, Peutz)

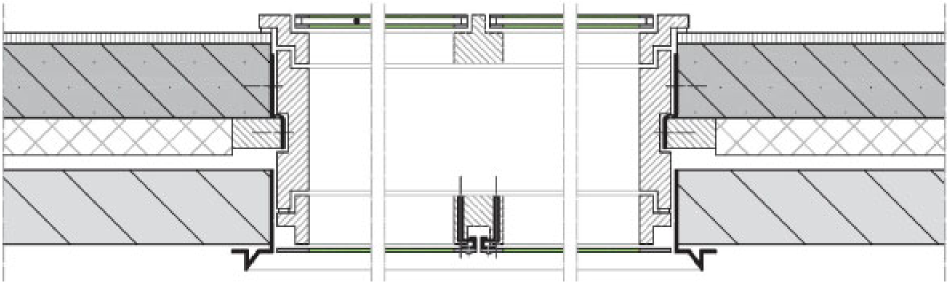


Figure B.18 Horizontal section of the test window.

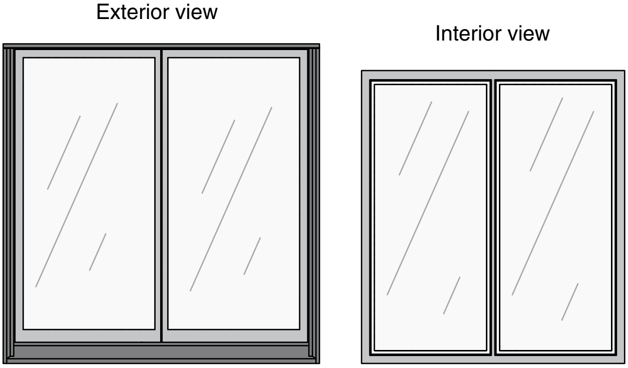


Figure B.19 Exterior and interior views of the test window.

Figure B.20 Three-dimensional impression of the renovation window.

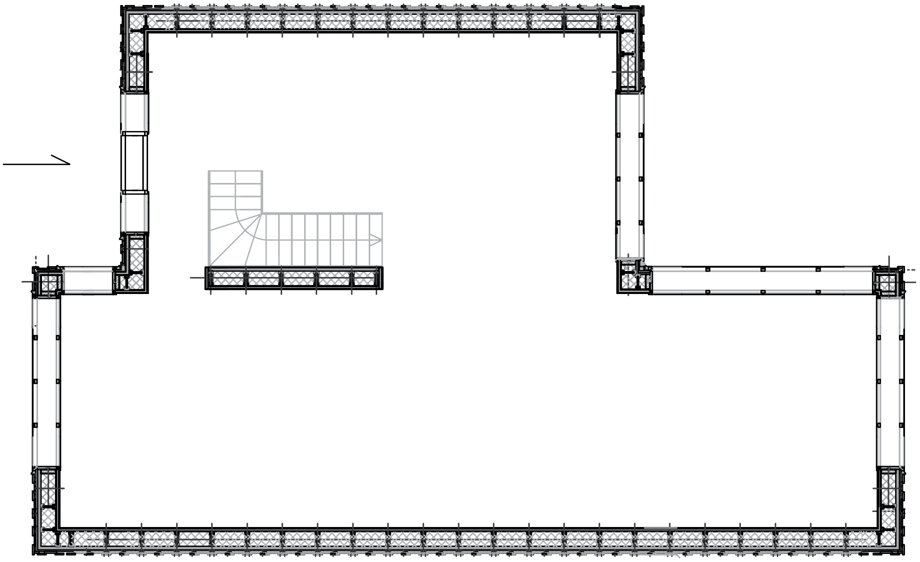


Figure B.21 Ground floor plan variant of the house design showing application of the IntegRaam window.

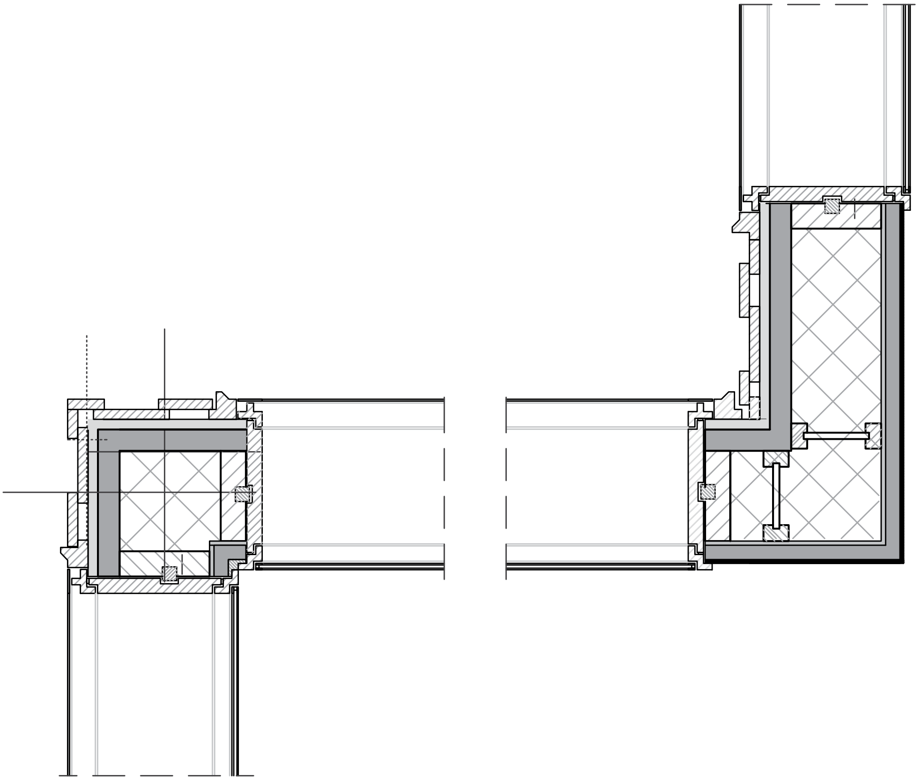


Figure B.22 Details of the horizontal section of this timber building system showing the IntegRaam windows.

who believes in the principles of IntegRaam and a principal (Wim van Keulen) who might dare to apply my windows in his housing project.

When writing this article I was invited to attend a lecture given by Wubbo Ockels, Netherlands' first astronaut (while our second astronaut Andre Kuipers was in space).

He is now professor of Space Aviation and Innovation at the Technical University of Delft. When you hear him talk about 'spaceship Earth' and the necessary direction of sustainable development we should be taking, you feel ashamed of how little we have achieved as yet in building/architecture, but on the other hand how inspiring the thought is that there are so many exciting things to be done.

Ockels has developed solar cars, solar boats, solar buses, solar houses together with students and young people, even talking to and with primary school children. The future is actually developing, making, prototyping, testing new components, building systems and their joints/details, being adaptive, responsive, for an ever changing future, the future of the young generation, a sustainable future that is positive, exciting and rewarding.

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Chapter Three

Sustainable Design Analysis and BIM Integration

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In this chapter the purpose of sustainable design analysis (SDA) in the building design process is addressed – its principles, integration, implementation, advantages and pitfalls. The benefits of full integration of SDA with building information modelling (BIM) is also explored, with the author reflecting on interoperability and uptake issues. There is no attempt to propose alterations to the nature of the design process in its journey from conception to completion, nor to pose an argument as to what merits good architecture, sustainable or not. Instead the author explores the need for, and the role of, sustainable design analysis within the design process as it is, arguing for an approach that favours a true iterative cycle of sustainable design. A case study demonstrates the integration of SDA in the design process and highlights its benefits. Although the term 'sustainable design analysis' is used within the text, the primary focus of this chapter will be on the environmental aspects of sustainability.

Introduction

> *Get the habit of analysis – analysis will in time enable synthesis to become your habit of mind.*
>
> Frank Lloyd Wright (1867–1959)

Too often at the early design stages clients are presented with sketch proposals of proposed sustainable design strategies and subsequent services integration. Two or three dimensional, these are illustrated with vivid colour schemes, arrows and legends, demonstrating a plethora of proposed 'fabric first' passive and active approaches. The meeting with the client begins; images and drawings are presented with knowledge, passion and conviction. While all may agree on the

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merit of the proposals and appreciate the amount of creative problem solving undertaken, clients are often exasperated when trying to get the designers to quantify their thinking. Thus, the uncomfortable questioning starts:

What would be the difference in the passive solar gains if we are to rotate the building 15 degrees from its current axis? What is the impact of a 10% decrease in the percentage of south facing fenestration? What are the changes in heat gains/losses if the amount or type of insulation is changed? What is the PV potential and payback period for our site and the building? How effective would be the use of natural ventilation if we install wind catchers or mechanical ventilation heat recovery (MVHR)? What would be the exact impact on the visibility and the right to light if we are to increase building massing by adding an additional floor? Have we got any costs versus environmental impact analysis in place? What is the payback period in terms of energy savings on our initial investment?

Questions of this kind can go on forever. Clients are investing considerable sums of money and they expect quantifiable answers, not just drawings, however informative they might be. Practitioners, on the other hand, are often left with the frustrations and fears of 'promising numbers' at the early stages of the design, which they later might regret. Therefore the financial case often fails before the green case ever gets a real chance. However, such fear is often unfounded, as most clients understand what is or is not possible to quantify at early stages of any investment, and to what degree. They are quite happy to discuss estimates and ballpark figures, rather than accurate guarantees. After all, most of them in their professional lives are used to making decisions based on similar type of forecasts, be that marketing potential, estimated projected turnover, predicted revenue and profits, risk analysis or others.

Herein lies the great potential of integrating sustainable design analysis within early stages of the design process. It offers practitioners power to enhance environmental aspects of their design proposals by investigating a multitude of 'what if' sustainable scenarios and design alternatives. It further gives ammunition to support proposals with quantifiable data, backing up and challenging design thinking in preparation for a meeting with the client. Of course, we could always argue that sustainable design only ever happens if it can be afforded, but this argument cannot hide the fact that the benefits of correct sustainable design decisions made early in the design process by far exceed investment required to make them in the first place.

There are quite a few leading architectural and multidisciplinary practices at the cutting edge of this way of thinking, with a fully integrated BIM and sustainable design analysis processes and protocols in place. These are constantly updated and refined as new lessons are learned on each and every project, with money invested in the knowledge, software and training (or employment) of in-house sustainable design specialists. However, most of the small to medium size practices are currently at the stage of still considering the move from a traditional two-dimensional computer aided design (CAD) platform to BIM, not to mention integrating sustainable design analysis as well. Their sustainable design approach is too often based on a mere compliance with building regulations and codes of practice, reliant on the elemental *U*-values approach and dependent on their Part L approved assessors to 'sort it all out' at the end. Any changes required are thus often made very late in the design process, driven by the need to get Building Control approval, and quite often only weeks before construction is scheduled to commence.

The consequences are clear. While there is a high percentage of Part L passes, too many of them represent minimum compliance. It is hard to envisage this approach standing the test of proposed changes in Part L, requiring a stringent 44% reduction on Part L 2006 CO_2 emissions as early as 2013 – not to mention a journey towards zero carbon for new build homes by 2016 and for new build commercial buildings by 2019/20. These ambitious targets, at the time of writing, have not been abandoned or relaxed despite the economic recession. A shift in design management and procurement approach is needed, one that brings knowledge and expertise of early sustainable design analysis into the design office. Its aim would be to maximise the impact on the life cycle costs at early stages of design when they are at their most beneficial.

Sustainable design analysis does not need to, but should ideally, be integrated with BIM as the design progresses, leading seamlessly to the Part L assessment at the compliance stages of a project. For it to be really effective the shift needs to be coupled with an investment in training and, eventually, full BIM integration.

What is sustainable design analysis?

If we are to consider the environmental impact of buildings through the use of energy and materials during their life cycle, from design, through construction, use, adaption, re-use and finally demolition and materials recovery, then their environmental performance could be defined as the actual building's ability to make best use of the natural resources available throughout its functional life. Minimising the detrimental effect and demands that buildings can have on both local and greater environments is a key to the environmental aspects of sustainable design. Of course, sustainable design could and should be interpreted in its wider context, one that considers not only environmental but also economic, social, ecological, technological and, arguably, governmental sustainability. As such it represents a joint and is often a complex effort of several disciplines coming together to achieve a harmonious outcome.

Sustainable design analysis in this context could be defined as a rapid and quantifiable feedback on different sustainable scenarios and *what if* questions posed by a design team during early stages of the project. Its core purpose is to address predominantly environmental and ecological issues, such as building materials and technologies, energy use, energy sources, water management, waste and pollution management. However, other issues are inherently correlated and thus considered, such as a functional (constructional, operational), human (safety and security, health, comfort, wellbeing), sociocultural (social and cultural context, aesthetics) and economical (profit, environmental cost benefit analysis, life cycle cost, etc.). To provide all of this feedback, the help of specialist software and knowledge of how to use it and interpret the results is needed.

There are quite a few energy analysis programmes on the market, such as Ecotect, IES<VE>, eQuest, Energy Plus, Design Builder, HEED, etc., that have been used to study the energy performance of buildings. Without favouring one over another, it should be noted that they differ in terms of the accuracy of results, visual representation, the knowledge required to use them and interpret the results, the type of input and output, Part L compliance and so on. Programmes range from simple, user friendly, free tools to extensive, sophisticated software that need expert knowledge and are used by specialist building engineering consultants. The range of applications includes site and PV potential analysis, visibility and right-to-light analysis, heating and cooling load calculations, thermal, solar analysis and shading design, lighting, acoustic, ventilation, air flow computational fluid dynamics (CFD) analysis, as well as a host of other functions. Deciding which one to buy and understanding how it integrates with current office practice is one of the biggest challenges (McGraw-Hill, 2010).

These programmes are often misinterpreted as another CAD protocol to be implemented with its routine training – something to do with computers and drafting, not designing. This, of course, could not be further from the truth. A sustainable design analysis expert is a key to the whole implementation process. He or she should ideally be an architecturally educated practitioner, someone with a strong understanding and appreciation of the design process and its creative, technical and regulatory aspects. It should be someone capable of being involved in a design process from its conception to completion; someone with strong knowledge and understanding of the theories and principles of environmental design, sustainable services integration and means of its assessment (such as the Code for Sustainable Homes, BREEAM, PassivHaus, etc.). Arguably, it should also be someone capable of advising on and designing out any potential health impacts that living in a low carbon environment might pose, suggesting more benign materials and specifications, while protecting thermal (or other) building performance requirements. Finally, wherever required, he or she should advise and liaise with the specialist contractors on site regarding post-construction building monitoring, in relation to both an indoor environmental health/comfort and actual building performance.

Krygeil and Nies (2008) suggest a holistic appraisal of the design sequence, a sustainable design chronology that considers the following aspects:

- Understanding climate, culture and place.
- Understanding the building typology.
- Reducing the resource consumption need.
- Using free local resources and natural systems.
- Using efficient man-made systems.
- Applying renewable energy generation systems.
- Offsetting negative impacts.

Low energy design analysis falls into two broad phases: conceptualisation and calculation. Each of these phases requires different design approaches and serves a different purpose for a distinct outcome. Conceptualisation is about challenging, questioning and problem solving, understanding broader creative and rational issues, the macro scale and the directional decisions. The calculation stage is then focused on quantities over direction, aiming to measure qualitative directional decisions and compare alternatives for different 'what if' scenarios.

The different site and building parameters are varied and assessed in different scenarios: climate of location, wind parameters, surrounding surfaces, landscaping and topology, building envelope, massing and orientation, building shape, fenestration placement and percentage, zoning, day-lighting, heating and cooling loads, required air change rate, occupant behaviour, services and allowed indoor climate variation range. This of course is not an exhaustive list and nor should it be considered in isolation from the design process itself. Each and every design must be a unique response to the site and client brief, fully taking account of the whole life cycle, including construction, operation, maintenance and end-of-life costs.

Commercial realities

> *Early decisions are usually based upon one of two fundamentally flawed processes; what did we do in the last project and what we learned a long time ago.*
>
> Haynes (2009)

Professionals are being challenged to consider energy usage analysis from the very onset of the design process, with owners looking at their total cost of ownership, including the cost to own and maintain the building throughout the projected life cycle.

At early stages the cost of design changes is at its lowest, but the capacity to impact the overall project costs is at its highest. This capacity diminishes as the design progress, while its costs increase. Therefore, the ability to control the project costs and costs of design changes are inversely proportionate, that is to say that as the design progress while from its feasibility to a tender (and eventually to the construction stage), so does the cost impact of changes in the design diminish. Hence, the ability to control costs and the effort required to make changes is at its most beneficial at early stages of design. It follows then that the opposite is also true, i.e. the cost of design changes increases as it progresses to its later stages. Most clients know this and thus are keen to explore changes at the earliest opportunity (Autodesk, 2010). However, current practice in many small to medium practices is not geared up to meet the client challenge, encouraging linear over the iterative process (see Figure 3.1).

The opportunities, however, tend to present themselves at the time of greatest challenges. Winston (2011), in her article, states that the chief construction adviser Paul Morell (2011) has indicated that 'Building Information Modelling (BIM) will be rolled out to all public projects by 2016, becoming a key part of the procurement of public buildings'. It appears that this statement alone has made many

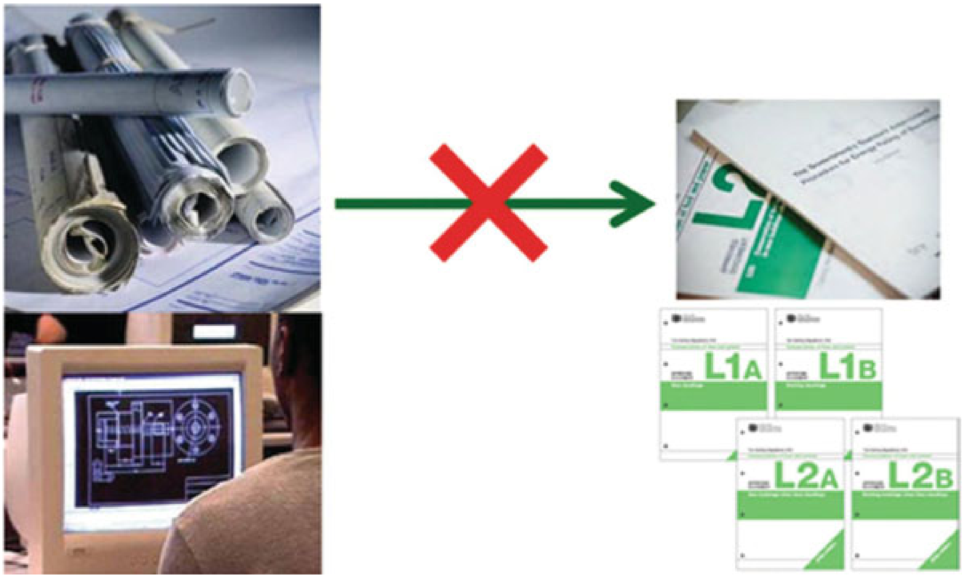


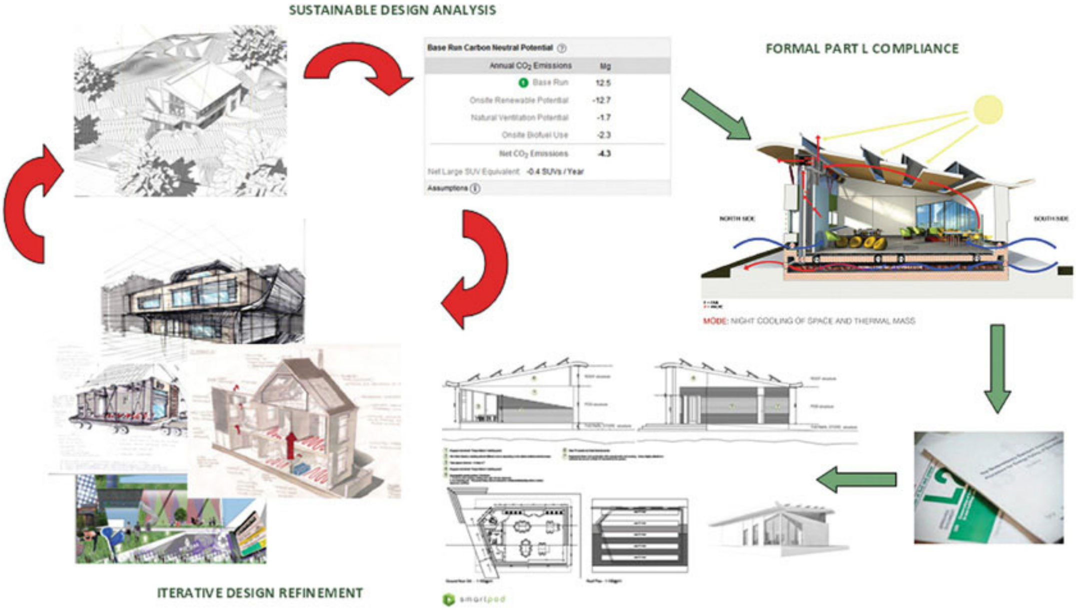
Figure 3.1 Current process.

companies seriously consider implementation of BIM in their office practice. Integrating sustainable design analysis at the same time would make things more efficient, but it remains to be seen as to whether this will be another example of a missed opportunity.

True cycle of sustainable design

According to Haynes (2009) 'the benefit of an iterative design process is the ability to review design decisions and make appropriate modifications to the design prior to design solidification. Iteration can bring refinement, a better design'. Haynes continues with an example of design iteration in relation to solar access and sunshading, posing a scenario where due to the shading from parts of the building, or other buildings, analysis has proven that sunshading is not necessary. This design iteration would bring about design refinement, in other words a better building. The point being made is that a fundamental part of the design process is being able to take the design, test it, analyse the findings and then take those findings back into the design process as part of the ongoing design iteration. Figure 3.2 encapsulates this philosophy in a true cycle of sustainable design, emphasising its iterative nature over the linear approach.

At the feasibility stages of the design process early building massing models are created based on the conceptual drawings and sketch schemes. The sustainable potential of the site is analysed to determine an optimal location, shape and orientation of a building, based on the adopted concept and environmental



Base Run Carbon Neutral Potential

Annual CO_2 Emissions	Mg
Base Run	12.5
Onsite Renewable Potential	-12.7
Natural Ventilation Potential	-1.7
Onsite Biofuel Use	-2.3
Net CO_2 Emissions	-4.3

Net Large SUV Equivalent: -0.4 SUVs / Year

Assumptions

Figure 3.2 True cycle of sustainable design.

factors. To gain rapid feedback at this stage an initial thermal analysis and energy use calculations are based on a selection of not actual but limited choice of predefined building construction specifications. The idea is to create a fast set of alternatives and assess their performance, without having to commit to any given building envelope/services specification.

By the next stage the conceptual design evolves to consider whole building energy, costs, water and carbon analysis. As the design progresses further and the elements that define a building's thermal zones are established (the layout of the walls, windows, roofs, floors and interior partitions), the model can be used for room-based calculations such as average daylight factors, reverberation times and portions of the floor area with direct views outside (Autodesk, 2009).

At the final stage, fundamental design parameters such as services and zone thermal templates are established and software can be used to produce an initial thermal performance analysis, to rearrange rooms and zones, to size and shape individual apertures, to design custom shading devices or to choose specific materials. It is at this stage, after analysing different scenarios, that the design is 'fixed', detailed drawings are produced and a full drawings package with the performance specification is sent to Part L assessors for compliance calculations (see www.cadalyst.com).

Sustainable BIM integration

Posing a case for BIM, Weygant (2011) states:

> While there is nothing wrong with the way the design, construction and procurement teams work today, building information modelling forces the industry to rethink how projects are delivered. In a traditional project delivery method, there is little collaboration among the parties. *The owner works with the architect. The architect works with the contractor. The contractor works with the subcontractor. The project is designed and built.* Linguistically, the last four sentences are disjointed, and while there is nothing wrong with each sentence independently, when read together, they do not flow. The same is true of any type of project; the more collaboration that occurs, the better the flow, and the faster it happens. In a collaborative environment, we may read something like this: *The owner, architect, contractor and subcontractor collaborate and the project is designed and built.*

BIM generates fully coordinated project drawing information and manages not just graphics but also textual and numerical project information. This ultimately leads to improved team collaboration throughout the building life cycle, from its conception to the demolition and materials recovery stage. At the design stage it includes visualisation and connection to other analysis systems, such as structural, energy calculation, cost estimates, conflict detection, etc. During the construction phase, wherever required, the design model supports computer controlled prefabrication, construction planning and logistics, and in-use building management systems, facilities management, renovation, adaptation and eventual demolition (Autodesk, 2011).

For some time BIM has been praised as a methodology for the future and the work that has gone into both its establishment and collaboration with other disciplines since its inception is considerable (see, for example, Eastman *et al.*, 2008, and Suermann and Issa, 2009). That said, while the work done on the interoperability between BIM and sustainable design analysis software is technically accomplished and no longer in its infancy, the practice is still relatively new. Thus, given that interoperability is technically possible (Griloa and Jardim-Goncalvesb, 2010), how well can it be adopted, what benefits can it bring and can it prove itself over the conventional stand-alone approach?

In his work on interoperability between BIM and energy analysis programmes Kumar (2008) suggests that the advantages of interoperability could be to 'streamline' the transfer of information between design and analysis software, which results in significant reductions in the amount of effort, time and cost. Indeed, the removal of duplication and redundancy of data would be a major benefit, helping to bring about better energy conscious designs via closer collaboration of building specialists. The basis of interoperability is the file sharing/data transfer between programmes. These file formats encompass the differing translation methods of data exchange, with DXF, gbXML and IFC file formats being some of the main formats of data exchange.

In summary, sustainable design analysis (SDA) and building information modelling (BIM) interoperability can and does work. While it is not without its difficulties, it is being improved and implemented at each and every edition (Autodesk, 2005). When is it likely to happen in everyday practice? It must be recognised that for interoperability to occur in the first place, an organisation must have chosen to adopt BIM. Interest in SDA in the UK is more popular than its implementation, so despite the sustainable drivers, its uptake by small and medium sized enterprises is likely to be sometime in the future and is likely to 'piggy-back' BIM implementation.

The relatively mature software that supports SDA and BIM are not the same, nor are they fully integrated. It is primarily their differences that can lead to the incorrect interpretation of data and the failure of interoperability. For good interoperability in the future the following is needed:

- A full solution to the problems of zone surface and volume recognition so that SDA and BIM software is able to differentiate between them.
- Improvement of bidirectional linkages. Poor bidirectional linkages between models are leading to 'modelling twice', which should not be necessary as changes introduced in the SDA model should directly be updated in the BIM.
- Performance degradation (Lee *et al.*, 2006). Too many parameters/too much of geometric data/constraints attempted to be interoperable, thus affecting performance.
- Resolution of the manner in which the SDA software overcomplicates interpretation of BIM elements during the import, including any loss of parametric object intelligence.

- Market research suggests that the software is somewhat US orientated, in particular in its links to the codes for sustainable assessment, i.e. LEED versus BREEAM. Future developments should provide a more UK customised approach to enable easier usability, assessment and compliance.

Case Study –SMARTPOD (S– sustainable, M– modular, A– autonomous, R– reusable, T– transportable) building system

Designed to address the challenges of a sustainable future and the financial difficulties facing schools, SmartPOD is a unique and innovative project that provides an alternative to traditional classroom planning. Modular in design, flexible in set-up and self-sustaining in use, SmartPOD is a modern solution to the needs of today's schools. In addition to its original use, consultation with a consortium of external stakeholders highlighted the potential of additional markets, such as retail, medical, disaster relief, business incubation, military, tourism, sport,

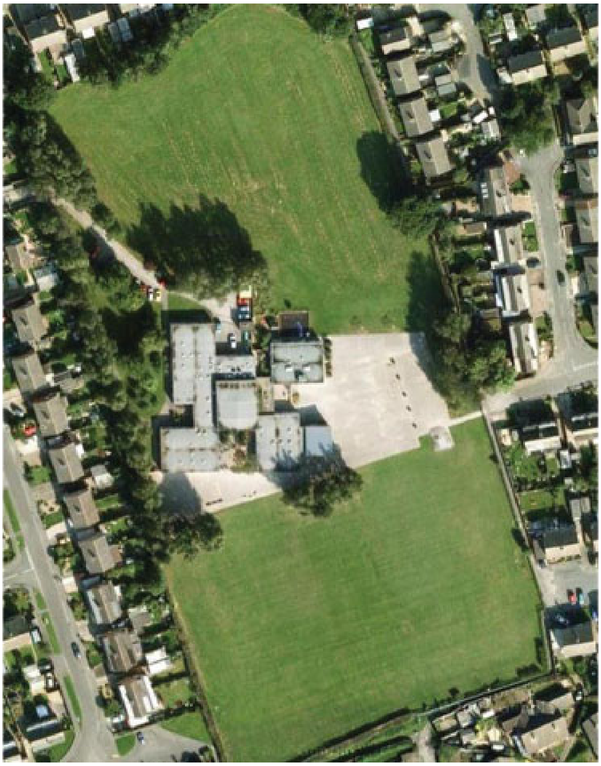


Figure 3.3 North view of site. Reproduced by the joined permission of UoD, EKV, T4 Sustainability, DMU and Silverhill Primary School.

community spaces and festivals. The project is still in progress at the time of writing, with the case study on the site below demonstrating benefits of sustainable design analysis at early stages of design development. The case study was undertaken in May/June 2011.

Silverhill Primary School is located in Mickleover, Derby. It opened in April 1971 and caters for children aged between four and eleven. It is situated in the middle of a residential area, on a spacious site with playing fields adjacent to the building (see Figures 3.3 and 3.4).

The site has latitude of 52.9119 and longitude of –1.5520. The proposed development of the school included the use of SmartPODs (see Figures 3.5 and 3.6). In its single pod set-up, these have a classroom floor area of 70 m^2, which includes one classroom with an integrated chill-out area and optional library zone and separate store room (the preferred option for Year 1 and Year 2). The electricity cost was £0.12/kWh (the assumed national average) and the fuel cost was £0.59/therm (the assumed national average at the time when the case study was undertaken; 1 therm = 29.3 kWh). The analysis was conducted in the schematic stage of the project. The green building goal was BREEAM 'outstanding', with the results given below for both 'favourable' and 'unfavourable' site conditions (see Figure 3.8).

Figure 3.4 South view of site. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Figure 3.5 SmartPOD concepts. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Figures 3.5, 3.6 and 3.7 summarise SmartPOD proposal development, as a visual reference, from initial sketches to a final proposed solution.

The objectives of this part of the research reported in the case study were to:

- Conduct an analysis of estimated energy use of two adjacent SmartPOD classrooms situated at the Silverhill Primary School site (see Figure 3.6) and
- Explore the energy saving potential via design alternatives and renewables.

Use of the Green Building Studio (GBS)

The Green Building Studio is a Web-based energy analysis service that enables evaluation of the energy profiles and carbon footprints of their buildings in the early stages of the design process. Indications of the buildings electricity and water use are given, along with the potential outcomes of renewable energy use, e.g. wind and photovoltaic electricity generation, with the latter specifying the installation cost and payback period.

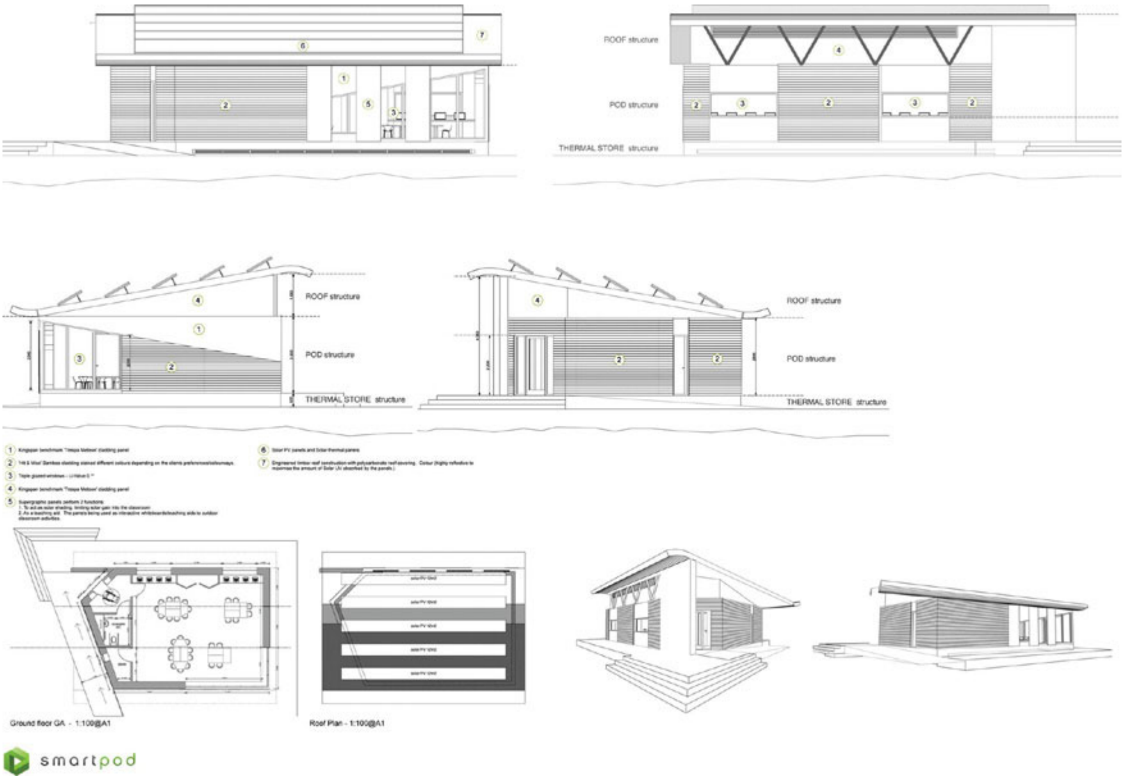


Figure 3.6 Plans and elevations. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

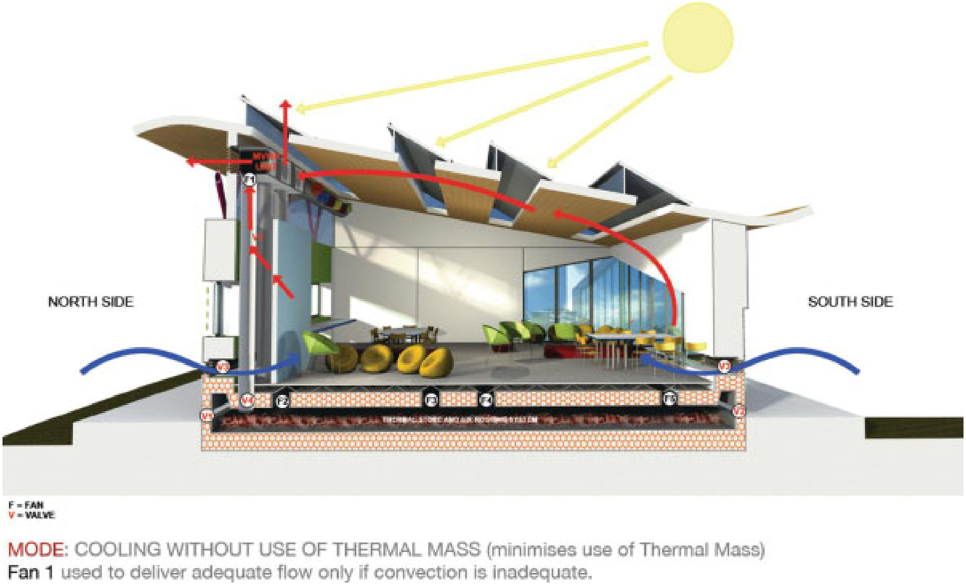


Figure 3.7 SmartPOD – example of one of the eight building management system (BMS) modes established for the sustainable services integration. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

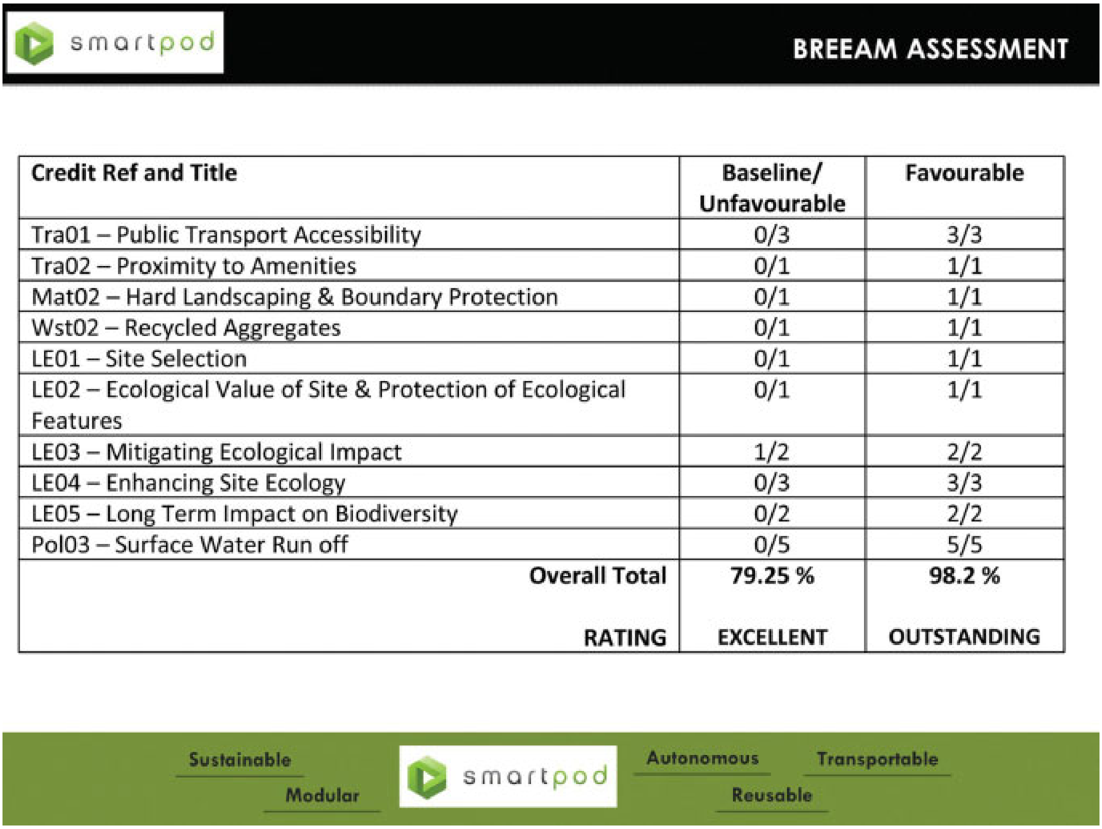
A building's carbon emissions include the following:

- Estimated energy cost summaries.
- Carbon reduction potential.
- Water usage and costs.
- Electricity and fuel costs.
- Photovoltaic potential.
- Wind potential.
- Natural ventilation potential.

Based on the building's size, type and location, the Web service determines the appropriate material, construction, HVAC system and equipment defaults by using regional building standards and codes to make intelligent assumptions (i.e. similar to the notional building in the SBEM). These assumptions inform the calculation of electricity and water use costs. The case study building was initially modelled using Ecotect to enable analysis in the Green Building Studio via a gbXML file format.

Base run – project results

The initial analysis results are based upon the default assumptions made by the Green Building Studio, as explained above, in order to form the base run. The subsequent analyses through design alternatives and search for improvement were driven by simulating the SmartPOD performance specification (see below), brainstormed and outlined by the design team.



BREEAM ASSESSMENT

Credit Ref and Title	Baseline/ Unfavourable	Favourable
Tra01 – Public Transport Accessibility	0/3	3/3
Tra02 – Proximity to Amenities	0/1	1/1
Mat02 – Hard Landscaping & Boundary Protection	0/1	1/1
Wst02 – Recycled Aggregates	0/1	1/1
LE01 – Site Selection	0/1	1/1
LE02 – Ecological Value of Site & Protection of Ecological Features	0/1	1/1
LE03 – Mitigating Ecological Impact	1/2	2/2
LE04 – Enhancing Site Ecology	0/3	3/3
LE05 – Long Term Impact on Biodiversity	0/2	2/2
Pol03 – Surface Water Run off	0/5	5/5
Overall Total	79.25 %	98.2 %
RATING	EXCELLENT	OUTSTANDING

Figure 3.8 BREEAM assessment (as designed). Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Smartpod Performance Specification Outline

Building envelope U-values ($W/m^2 K$)

All opaque surfaces = 0.1–0.12 $W/m^2 K$ (*U*-values for external walls = 0.1–0.12 $W/m^2 K$, floor = 0.1–0.12 $W/m^2 K$, roof = 0.1–0.12 $W/m^2 K$)
Windows 0.7–0.75 $W/m^2 K$

Renewable energy

Roof mounted solar electricity PV (photovoltaic) panels

Passive strategies

Innovative concept of 'thermal capacity on demand'

Ventilation

Natural ventilation
MVHR (mechanical ventilation heat recovery) system. To be specified from the manufacturer as per required efficiency below:

MVHR efficiency

≥ 90%
QH ≤25 kWh/m^2 a

Air tightness

≤ 3–4 $m^3/h\,m^2$ @ 50 Pa (or ≤ 0.6 ACH @ 50 Pa)

Heat distribution

MVHR distribution warm air system

Heating load

<15 kWh/m^2 pa
≤10 W/m^2

Overheating

<10% over 25 °C

Electrical appliances

A+++ equivalent

Limiting solar gains in summer

MVHR cooling with the 'summer bypass'
Solar shading/glazing specification
Natural cooling and purge ventilation

Thermal bridging

Bespoke and accredited robust construction details. 'Thermal bridge free design' with the thermal bridging coefficient limiting value set at 0.01 W/m K

Lighting

Energy efficient low energy lighting, dual occupancy/light levels control

Performance monitoring and energy efficient operation

Building management system (BMS) – number of established modes of operation = 8
Monitoring equipment, data collection
Log book and data monitoring sheets
Inc. TER, BER 'on-construction' Energy Performance Certificate (EPC)

Estimated energy and cost summary

The estimated energy and cost summary for the single classroom pod (see Table 3.1) indicates an annual energy cost of £1497. Of this amount the annual electricity cost is £1233, which equates to 10.1 metric tons (or Mg) of CO_2 emissions with the remaining £263 in heating fuel costs, 2.3 metric tons of CO_2 emissions. The overall amount in CO_2 emissions is 12.5 metric tons, an equivalent of 1.2 large sport utility vehicles (SUVs).[1]

Initial analysis signifies that the annual electricity cost is significantly greater than the annual fuel cost. The Green Building Studio assumed a breakdown of electricity and fuel cost and consumption in this building type is given in Figure 3.9a and b.

Carbon reduction potential

The carbon neutral potential suggests where reductions in CO_2 emissions could be made. By utilising the building's carbon neutral potential the net CO_2 emissions could be reduced from the initial 12.5 metric tons to –4.3 metric tons, if onsite renewables, fuel and natural ventilation potential are fully exploited (see Table 3.2). Onsite renewables include wind energy and the potential of photovoltaic panels. Thus, the building has potential not only to be carbon neutral but actually carbon negative. (In this context the phrase 'carbon negative' refers to the scenario where the building produces less CO_2 emissions than renewable energy generation displaces by reducing consumption of electricity generated from fossil fuels.)

Photovoltaic potential

Exploiting the maximum onsite renewable potential using PV (102 m^2 of roof) at an installed panel cost of £1.40[2] per watt and an applied electricity cost of £0.31 per kW h[3] gives a maximum payback period of 6 years,[4] annual energy production

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[1] An SUV is a heavy high performance four-wheel drive car, travelling approximately 15 000 miles per year. These are typically built on a truck chassis and are high in fuel consumption.
[2] The average installed panel cost per watt for a commercial building as per figures supplied by the project collaborator, at the time of case study.
[3] Assumed PV installation size of 10–100 kW.
[4] Standard PV warrant of 25 years.

Energy, carbon and cost summary	
Annual energy cost	£1497
Life cycle cost	£20 387
Annual CO_2 emissions	
Electric	10.1 Mg
Onsite fuel	2.3 Mg
Large SUV equivalent	1.2 SUVs/yr
Annual energy	
Electric	10 279 kWh
Fuel	47 091 MJ
Annual peak demand	4.2 kW
Life cycle energy	
Electric	308 366 kW
Fuel	1 412 741 MJ

Table 3.1 Base run – estimated energy and cost summary. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

of 10 338 kW h and cost savings of £3205 per year. Carbon emissions reduction is 10.2 metric tons (12.7–2.5 metric tons wind potential). The equivalent to large SUVs has been reduced from the initial +1.2 to –0.4 SUV. Tariff levels shown in Table 3.3 are prior to the 31 March 2012 FIT (Feed-in Tariff) scheme reduction. After that date a reduction close to 50% was introduced, bringing the cost saving to around £1603 per year.

A summary of the maximum PV potential is shown in Table 3.4. It is estimated that the total installed panel cost is £19 643, which covers an area of approx 102 m^2 and suggests an annual energy saving of 10 338 kW/h at a nominated rated power of 14 kW. It is important to note that this potential saving is generated using the roof area only and that the estimated energy savings are greater than the estimated annual electricity use of 10 269 kW h. The Green Building Studio uses a maximum roof plane area that is equal to 102 m^2, for which it predicts cost savings of £3205 per year[5] Since the annual energy cost of the base run is £1497, this presents the school with the opportunity to 'earn' £1708 annually through the FIT scheme. If we are to use 75 m^2 the annual cost saving would be £2357. If we are to use 50 m^2, the cost saving would be £1571 de facto paying off all of the annual energy costs. The annual electricity savings due to PV generation are net sum, i.e. not calculated as a future value with interest rate taken into account. The assumed costs of £1.40 per watt energy do not include mounting, installation and control equipment costs. Thus the payback period would be more likely to be in the region of eight years.

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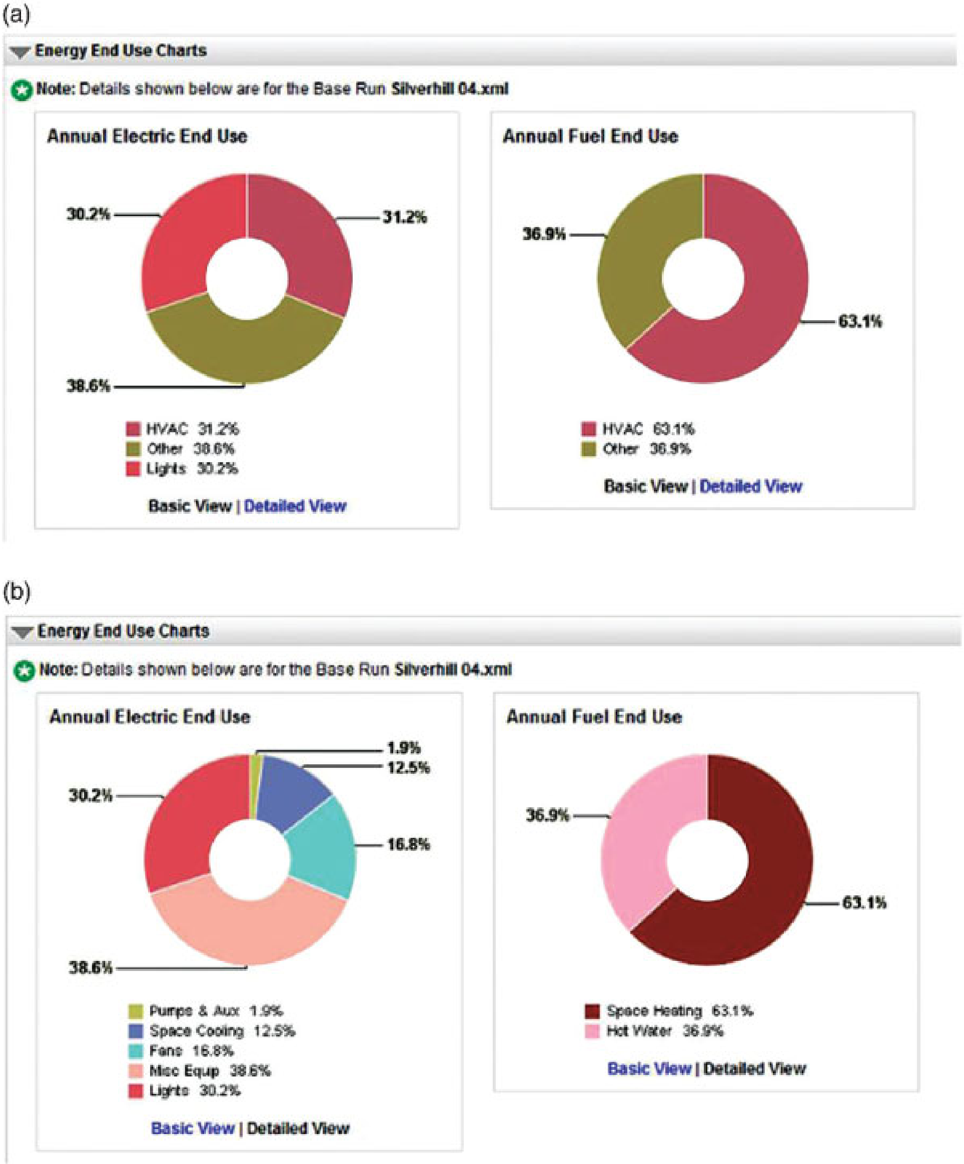
[5] Recalculation is needed for the post 31 March 2012 FIT scheme reduction, in the region of 50%.



Note: Details shown below are for the Base Run **Silverhill 04.xml**

Note: Details shown below are for the Base Run **Silverhill 04.xml**

Figure 3.9 (a) Energy end use breakdown and (b) breakdown of electric end use for different services/equipment. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Design alternatives

The design alternatives feature allows the base case assumptions to be modified and then a simulation is run in order to estimate the impact of these modifications on energy efficiency. Three design alternatives were run through the analysis to

Base run carbon neutral potential (?)	
Annual CO_2 emissions	Mg
❶ Base run	12.5
Onside renewable potential	–12.7
Natural ventilation potential	–1.7
Onsite biofuel use[1]	–2.3
Net CO_2 emissions	–4.3
Net large SUV equivalent	–0.4 SUV/yr

[1] Not considered for deployment in the current version of SmartPOD

Table 3.2 Base run – carbon neutral potential. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Type/size	**Installed before 31 March 2012**	**Installed after 1 April 2012**
PV <4 kW (retrofit)	41.3p	37.8p
PV <4 kW (new build)	36.1p	33.0p
PV 4–10 kW	36.1p	33.0p
PV 10–100 kW	31.4p	28.7p
PV 100 kW–5 MW	29.3p	26.8p
PV stand-alone system	29.3p	26.8p
Export rate	3p	3p

Table 3.3 Feed-in tariff level (p/kWh) for new installations in the period prior to 31 March 2012. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Photovoltaic Potential	
Annual Energy Savings	10,338 kWh
Total Installed Panel Cost	£19,643
Nominal Rated Power	14 kW
Total Panel Area	102 m^2
Maximum Payback Period	6 years @ £0.31 / kWh
Wind Energy Potential	
Annual Electric Generation	2,586 kWh

Table 3.4 Base run – photovoltaic and wind energy potential. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

illustrate the effects that simple alterations can have on the energy efficiency of the building.

Design Alternative 1 – improving the building envelope

This design alternative considers improving the building envelope with a very high insulation and triple glazing and its potential effect on the CO_2 emissions and cost reduction. The external wall construction was modified to analyse the effects of various construction types. Structural insulated panels (SIPs) resulted in higher energy and cost savings. Due to their credentials, which include excellent thermal performance, high structural performance (strong, lightweight panels), construction time and costs savings, and a low impact on the environment (zero ozone depletion potential (ODP insulation core, faces made from sustainable forest resources), this type of construction might be a preferred method for SmartPOD, or at least one of the concept alternatives. Heavily insulated SIP panels were added to the building envelope with clear low-e triple glazing to the south and west elevations where fenestration is present. A certain amount of east elevation fenestration would be beneficial for passive heat gains early in the day and will be explored in the scheme design proposal.

Estimated energy and cost summary

The estimated energy and cost summary (Table 3.5) indicates an annual energy cost of £1420, an annual reduction of £77 from the initial base run. This excludes savings generated by maximum PV installation (£3205).

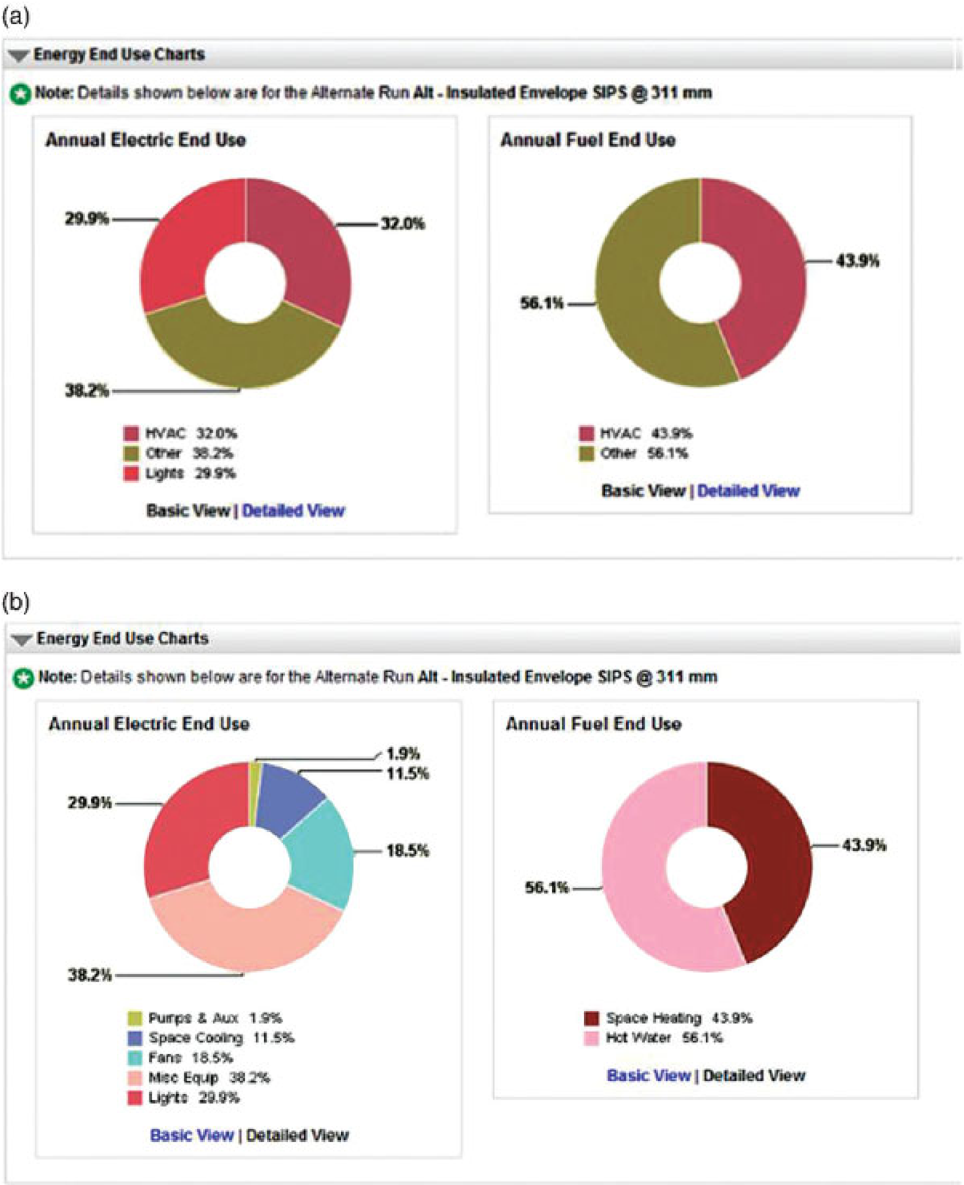
The annual CO_2 emissions of onsite fuel (e.g. gas) see the most significant savings. Highly insulating the building envelope reduces the demand for space heating, thus savings are made. In the initial base run an estimated 63.1% demand for space heating was noted, compared with a 43.9% demand estimated from this run, a reduction of 19.2% (see Figure 3.10b).

Carbon neutral potential

The carbon neutral potential (Table 3.6) suggests that the net CO_2 emissions could be reduced from the initial 12.5 metric tons to –4.1 metric tons if the potential

Estimated energy and cost summary	
Annual energy cost	£1420
Life cycle cost	£19 338
Annual CO_2 emissions	
Electric	10.2 Mg
Onsite fuel	1.5 Mg
Large SUV equivalent	1.2 SUVs/yr
Annual energy	
Electric	10 390 kWh
Fuel	30 942 MJ
Annual peak demand	4.5 kW
Life cycle energy	
Electric	311 697 kW
Fuel	928 245 MJ

Table 3.5 Design alternative – estimated energy and cost summary. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.



(a)

Energy End Use Charts

Note: Details shown below are for the Alternate Run Alt - Insulated Envelope SIPS @ 311 mm

(b)

Energy End Use Charts

Note: Details shown below are for the Alternate Run Alt - Insulated Envelope SIPS @ 311 mm

Figure 3.10 (a) Energy end use breakdown and (b) breakdown of electric end use for different services/equipment. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

of onsite renewables, fuel and natural ventilation are fully exploited; 10.2 metric tons of the onsite renewable potential is generated using the maximum PV potential generated by exploiting the roof area.

Alternate run carbon neutral potential ?	
Annual CO_2 emissions	Mg
① Base run	12.5
❷ Alternate run	11.8
Onsite renewable potential	–12.7
Natural ventilation potential	–1.6
Onside biofuel use	–1.5
Net CO_2 emissions	–4.1
Net large SUV equivalent	–0.4 SUV/yr

Table 3.6 Alternative run – carbon neutral potential. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Estimated energy and cost summary	
Annual energy cost	£1177
Life cycle cost	£16 026
Annual CO_2 emissions	
Electric	8.1 Mg
Onsite fuel	1.7 Mg
Large SUV equivalent	1.0 SUV/yr
Annual energy	
Electric	8261 kWh
Fuel	33 123 MJ
Annual peak demand	3.8 kW
Life cycle energy	
Electric	247 842 kW
Fuel	993 697 MJ

Table 3.7 Alternative run – estimated energy and cost summary. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Design Alternative 2 – improving the building envelope and lighting control

Taking simple steps, such as incorporating daylight/occupancy lighting sensors and dimmable efficient lighting, a significant difference to the overall CO_2 emissions can be made.

Estimated energy and cost summary

The estimated energy and cost summary (Table 3.7) indicates an annual energy cost of £1177, an annual reduction of £320 from the initial base run. This excludes savings generated by the maximum PV installation (the maximum of the roof plane PV area is equal to 102 m^2 with cost savings of £3205). If we were to use

75 m^2 the cost saving would be £2357. Considering this, the net savings would be –£1180, presenting a gain that the school could earn through the FIT scheme. If we were to use 38 m^2 the cost saving would be £1194, exceeding all of the annual energy costs.

An annual reduction in CO_2 emissions generated by electricity use can be seen. Improving the lighting efficiency and integrating daylight and occupancy sensors sees a 14.1% reduction in lighting demand, from the initial base run estimation of 30.2% to 16.1% in this run (see Figure 3.11b). This improvement also sees an annual reduction in CO_2 emissions of 2.1 metric tons (10.2–8.1 Mg).

Carbon reduction potential

The carbon reduction potential (Table 3.8) suggests that the net CO_2 emissions could be reduced from the initial 12.5 metric tons to –5.8 metric tons if onsite renewables, fuel and natural ventilation potential are fully exploited; 10.2 metric tons of reduction using onsite renewable potential is generated using the maximum PV roof area. Possible passive heat recovery, thermal capacity on demand and natural ventilation systems need to be discussed.

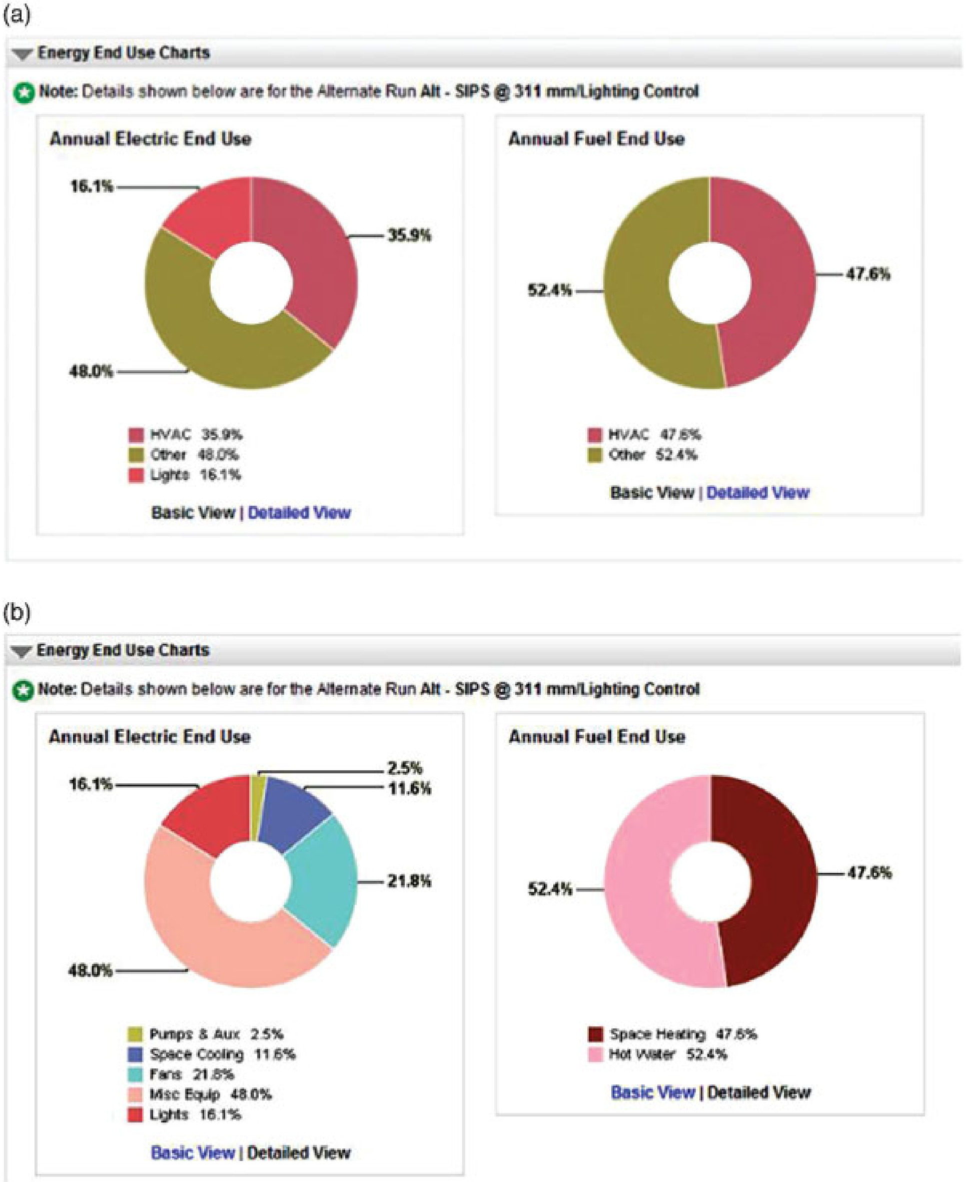
Furthermore, the lighting is using 16.4% of the overall 8.1 metric tons of electricity use. On the days in the year when sunpipes (northern light windows behind the PV panels) provide a sufficient daylight factor alone, the net CO_2 emissions would therefore be further reduced by 1.3 metric tons (0.161 × 8.1 with no artificial light used).

Design Alternative 3 – improving the building envelope, lighting control and HVAC

This design alternative uses a superinsulated envelope, energy efficient lighting, daylight/occupancy sensors and a heatpump, introduced to simulate a scenario similar to a PassivHaus standard. Fuel use for heating is 0% and the whole allocation of fuel use is now for the hot water alone (see Figure 3.12b). If the above is achievable without the active heatpump/exchanger, i.e. via means of thermal store (our concept of thermal capacity on demand) and the mechanical ventilation heat recovery (MVHR) system solely, then together with passive cooling it would satisfy one of the core criteria of the PassivHaus standard. Since it is impossible to specify above in the Green Building Studio, we have used a heatpump to simulate that scenario and arrive at the predicted results. Of course, it would be great if the same performance is achievable via passive means alone.

Estimated energy and cost summary

The estimated energy and cost summary (Table 3.9) indicates an annual energy cost of £1060. This excludes savings generated by a maximum PV installation. The estimated energy and cost summary indicates an annual reduction of £437 or 30% from the initial base run. If we were to use the full 102 m^2 of roof (cost savings of £3205), the net annual gain for the school would be £2145, which could be earned through the FIT scheme. If we were to use 34 m^2, the cost saving would be £1068, paying off all of the annual energy costs.



Note: Details shown below are for the Alternate Run Alt - SIPS @ 311 mm/Lighting Control

Note: Details shown below are for the Alternate Run Alt - SIPS @ 311 mm/Lighting Control

Figure 3.11 (a) Energy end use breakdown and (b) breakdown of electric end use for different services/equipment. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

However, 34 m^2 of PV generates approximately 3446 kWh and the SmartPOD at this stage requires 8114 kWh of electric energy to be autonomous. Further savings in energy consumption therefore need to be investigated.

Alternate run carbon neutral potential ?	
Annual CO_2 emissions	Mg
① Base run	12.5
❷ Alternate run	9.8
Onsite renewable potential	–12.7
Natural ventilation potential	–1.2
Onsite biofuel use	–1.7
Net CO_2 emissions	–5.8
Net large SUV equivalent	–0.6 SUV/yr

Table 3.8 Alternative run – carbon neutral potential. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Carbon neutral potential

The carbon neutral potential (Table 3.10) suggests that the net CO_2 emissions could be reduced from the initial 12.5 metric tons to –5.9 metric tons, if onsite renewables, fuel and natural ventilation potential are fully exploited; 10.2 metric tons of the onsite renewable potential is offset using the maximum PV potential generated by exploiting the roof area.

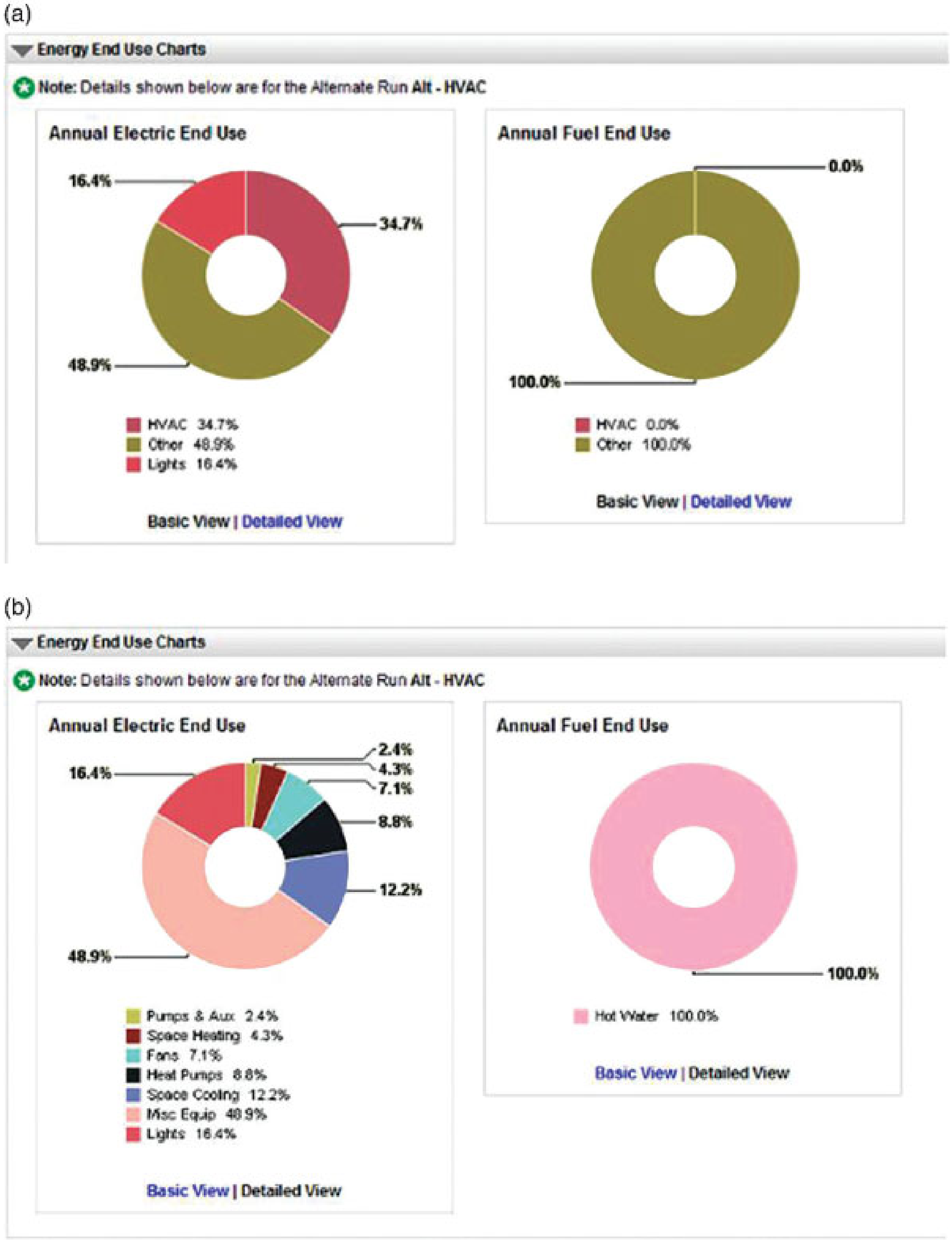
On the days where sunpipes (northern light windows behind the PV panels) alone would produce sufficient lux levels, a further 16.4% of 8.0 metric tons of CO_2 produced by electricity could be saved (1.31 Mg), resulting in the predicted net emissions being as low as –7.21 metric tons, if the full site potential is utilised. Furthermore, the following savings could be made if a full passive strategy is in place (e.g. keeping fans at 7.1% and auxillaries at 2.4% to account for the use of MHVR):

Space heating	4.3%
Space cooling	12.2%
No heat pump	8.8%
Total reduction	25.3%

This would reduce a further 2 metric tons of CO_2, resulting in the predicted net emissions being as low as –9.21 metric tons.

If we consider the PV and natural ventilation only (i.e. eliminate –2.5 metric tons for wind generation and –0.8 for the onsite bio fuel use), the predicted net emissions would rise to –5.91 metric tons of annual CO_2 emissions.

However, if we could reduce 48.9% of electric use allocated by the Green Building Studio to IT and other equipment even by half (and we should do a lot better with our classroom having the future ultra low energy tablet computers and interactive board scenario), then the further 25% of 8 metric tons could be reduced (= 2 metric tons), giving us a net carbon neutral potential of –7.91 metric tons. Finally, if the single POD scenario does not have toilet facilities (i.e. the



Note: Details shown below are for the Alternate Run Alt - HVAC

Note: Details shown below are for the Alternate Run Alt - HVAC

Figure 3.12 (a) Energy end use breakdown and (b) breakdown of electric end use for different services/equipment. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Estimated energy and cost summary	
Annual energy cost	£1060
Life cycle cost	£14 437
Annual CO_2 emissions	
Electric	8.0 Mg
Onsite fuel	0.8 Mg
Large SUV equivalent	0.9 SUV/yr
Annual energy	
Electric	8114 kWh
Fuel	15 434 MJ
Annual peak demand	16.7 kW
Life cycle energy	
Electric	243 421 kW
Fuel	463 016 MJ

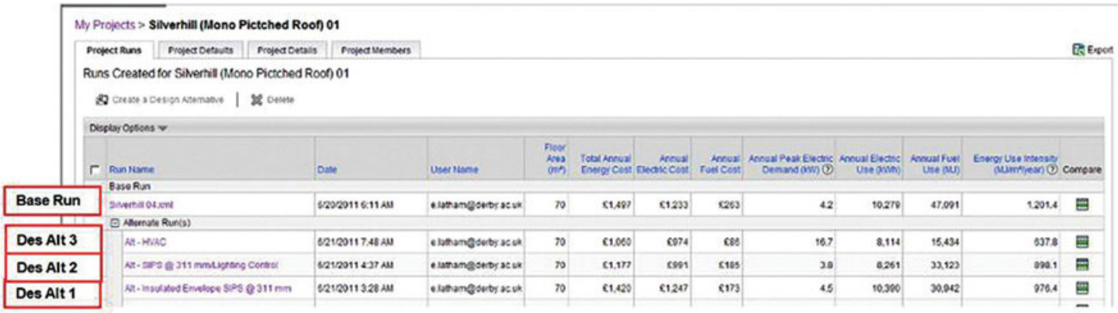
Table 3.9 Alternative run – estimated energy and cost summary. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

Alternate run carbon neutral potential (?)	
Annual CO_2 emissions	Mg
① Base run	12.5
❷ Alternate run	8.8
Onsite renewable potential	–12.7
Natural ventilation potential	–1.1
Onsite biofuel use	–0.8
Net CO_2 emissions	–5.9
Net large SUV equivalent	–0.6 SUVs/yr

Table 3.10 Alternative run – carbon neutral potential. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

children could use the main building) and therefore no need for hot water, a further 0.8 metric tons could be reduced, totalling –8.71 metric tons of CO_2 carbon negative performance. This is equivalent to taking out nearly one SUV, a high performance four-wheel drive car, travelling approximately 15 000 miles per year on the road (for a single classroom POD).

Cost savings would amount to –£86 in fuel costs (heating and hot water – see Figure 3.13) and 25.3% (space heating 4.3%, space cooling 12.2%, no heatpump 8.8%) plus 25% in estimated equipment demand reduction. This gives 50.3% reduction in electricity costs (saving £490 of a total of £974). Overall, for this design alternative £484 (£1060 – £490 – £86) is the annual estimated energy costs for the single POD.



My Projects > Silverhill (Mono Pictched Roof) 01

Runs Created for Silverhill (Mono Pictched Roof) 01

☐	Run Name	Date	User Name	Floor Area (m²)	Total Annual Energy Cost	Annual Electric Cost	Annual Fuel Cost	Annual Peak Electric Demand (kW)	Annual Electric Use (kWh)	Annual Fuel Use (MJ)	Energy Use Intensity (MJ/m²/year)	Compare
	Base Run											
	Silverhill 04.xml	6/20/2011 6:11 AM	e.latham@derby.ac.uk	70	€1,497	€1,233	€263	4.2	10,279	47,091	1,201.4	▤
	⊟ Alternate Run(s)											
	Alt - HVAC	6/21/2011 7:48 AM	e.latham@derby.ac.uk	70	€1,060	€974	€86	16.7	8,114	15,434	637.8	▤
	Alt - SIPS @ 311 mm/Lighting Control	6/21/2011 4:37 AM	e.latham@derby.ac.uk	70	€1,177	€991	€185	3.8	8,261	33,123	898.1	▤
	Alt - Insulated Envelope SIPS @ 311 mm	6/21/2011 3:28 AM	e.latham@derby.ac.uk	70	€1,420	€1,247	€173	4.5	10,390	30,942	976.4	▤

Figure 3.13 Design alternatives – summary. Reproduced by the joined permission of UoD, EKV, T4S, DMU and Silverhill Primary School.

However, what about electrical energy? Will the POD still be able to be autonomous, i.e. generate enough energy to cover its demand? As a reminder, 34 m^2 of PV generates 3470 kWh and the POD requires 8114 kWh. Applying the 50.3% reduction in energy demand mentioned above, the following is arrived at: $8114 - 0.53 \times 8114 = 3814$ kWh.

This excludes any savings made on the sunpipes (northern light windows) as the Green Building Studio allocates 16.4% of electric energy consumption to the artificial lighting alone. If sunpipes are to contribute only 4% (and for sure they will contribute more), the reduction in electricity demand would be 325 kWh, which gives the overall electricity energy requirement for the POD as 3489 kWh (3814–325 kWh), the amount that can be generated by 34 m^2 of PV panels. Therefore, the POD has the potential to be autonomous in terms of the overall electrical demand, but possibly would not be able to meet all peak demands through renewables alone.

Summary

Some of the results are based on savings that assume a maximum site PV/wind potential and natural ventilation generation. It is obviously reasonable to consider any 'in-between' options. It is also important to point out that the results are based on average assumed electricity and fuel costs and a breakdown of energy use that the Green Building Studio assumes for this building type. Therefore, more accurate analysis is possible if exact costs are available. Furthermore, due to the Green Building Studio being an initial sustainable design analysis software, it is important to note that Design Alternative 1 does not use the precise construction material specification, but a generic superinsulated scenario instead. Hence, it is only fair to conclude that all of the above results have to be treated as ballpark figures rather than exact results and are intended to be used to explore 'what if' scenarios rather than to arrive at accurate conclusions.

The energy consumption could possibly be further improved by using energy efficient equipment (e.g. an A+++ equivalent). It is not possible at this stage to determine precise electrical consumption costs, but by specifying and finding the exact consumption of IT and other equipment we could easily calculate more accurate electricity cost savings.

Finally, it has to be noted that figures given by the Green Building Studio refers to the annual energy performance and thus hide peaks and troughs throughout the year. It is obvious that PV efficiency will be lower during the winter period, when coincidentally the demand load will be at its highest. Therefore, it is beneficial and sustainable for the school scenarios to connect to the main electricity grid (via an easy to install 'plug and play' connection). This will act as a back-up system when peak demands cannot be met entirely by renewables. However, and more importantly, it is right in terms of a sustainable ethos to return electricity generated over the summer to the grid, rather than waste it by 'dumping it' on the site. This will be the period when PVs will generate a lot of the energy and the POD will be largely unused due to the summer holidays.

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Case Study C

Applying Research in Practice: Developing a Specialist Service in the Analysis of Thermal Bridging

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This case study focuses on the commercial application of thermal modelling to analyse the thermal bridging attributes of junction details. It is based on a project undertaken by the architectural technology practice Studio A Consulting Limited. The practice offers professional services in the design and management of buildings and thermal modelling is one of the specialist services provided. The case study was developed to demonstrate to potential clients the effect that thermal bridging has on the overall thermal performance of the building envelope. It was also intended to use the case study to create an opportunity to experiment and to extend the practice's depth of experience and knowledge in the different options for dealing with thermal bridging, hence helping to secure future commissions. Providing the information to prospective clients as a case study allowed the practice to compare the potential options for addressing thermal bridging in a manner that would not be available through a normal commission. The case study also provided an opportunity to demonstrate the practice's technical capability in developing junction details and undertaking thermal modelling.

Introduction

The environmental agenda and successive changes to the Building Regulations (Department of the Environment and the Welsh Office, 1995; Office of the Deputy Prime Minister (ODPM), 2002, 2006; HM Government, 2010) have driven thermal improvements to the design of the building envelope. Initially the focus has been on the main building elements (plane elements), for example floors, walls, roofs, windows and doors. As the performance requirements of the plane elements have increased, the impact of heat loss at junctions where different elements interface has become a greater concern. This has resulted in the need for the

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additional heat losses caused by thermal bridging at these junctions to be properly addressed and accounted for. Those undertaking energy performance and carbon dioxide (CO_2) emissions calculations are obliged by the UK Building Regulations (HM Government, 2010) to quantify the extent of thermal bridging and to demonstrate where the input parameters have been sourced.

This case study focuses on the commercial application of thermal modelling to analyse the thermal bridging attributes of junction details. This numerical modelling technique is used to obtain the linear thermal transmittance (Ψ-value) and temperature factor (f_{Rsi}) of junctions as outlined by the conventions in BR 497 (Ward and Sanders, 2007). These parameters are required to quantify heat loss and assess the risk of surface condensation and mould growth. The case study is based on a project undertaken by the architectural technology practice Studio A Consulting Limited. The practice offers professional services in the design and management of buildings and thermal modelling is one of the specialist services provided. The case study was developed to demonstrate to potential clients the effect that thermal bridging has on the overall thermal performance of the building envelope. The case study compares the Building Regulation default Ψ-values (Department of Energy and Climate Change (DECC), 2011), the Accredited Construction Details (DECC, 2011) and the Enhanced Construction Details (Energy Savings Trust (EST), 2008, 2009) against construction details designed and thermally modelled by the practice. The effect on the overall thermal performance of a dwelling is measured using a base model building in the Government's Standard Assessment Procedure (SAP) for Energy Rating of Dwellings (DECC, 2011). The potential to earn credits under Category 1: Energy and Carbon Dioxide Emissions of the Code for Sustainable Homes (CSH) (Department for Communities and Local Government (DCLG), 2010) is also investigated to establish any possible benefit that could be gained from employing thermal modelling to inform and assess the design of construction details.

It was also intended to use the case study to create an opportunity to experiment. It was hoped to extend the practice's depth of experience and knowledge in the different options for dealing with thermal bridging to assist in securing future commissions. Providing the information to prospective clients as a case study allowed the practice to compare the potential options for addressing thermal bridging in a manner that would not be available through a normal commission. The case study also provided an opportunity to demonstrate the practice's technical capability in developing junction details and undertaking thermal modelling.

Background

Under the UK Building Regulations (HM Government, 2010) there are three permitted approaches to demonstrate the thermal compliance of junction details. These are: the use of Accredited Construction Details (DCLG, 2007) (including Enhanced Construction Details (EST, 2008, 2009)), thermal modelling and nonspecific quantification. The Department for Communities and Local Government (2007) published the Accredited Construction Details (ACD) to assist the construction industry in complying with the performance requirements of Building Regulations Part L (ODPM, 2006) and these continue to apply to the revised Regulations (HM Government, 2010). These illustrate standard junction details, state the thermal performance values that can be utilised, prescribe minimum requirements and provide a quality checklist to contractors. The ACD can also be applied individually to junctions in combination with bespoke designs for junction details where the performance is known. The Energy Saving Trust (2008, 2009) published the Enhanced Construction Details (ECD) to improve upon the worst performing ACD and permit designers, contractors and developers to gain credit for reducing thermal bridging in energy performance and CO_2 emissions calculations. When the ECD lintel, gable and ground floor are included in calculations, the ACD are applied to all other junctions if the standard detail approach is being followed.

Bespoke designs for construction details that do not conform to the ACD or ECD can be thermally modelled to ascertain their thermal performance and obtain values for regulatory purposes. There are well established standards and conventions for the thermal modelling of construction details. BR 497 (Ward and Sanders, 2007) forms the UK conventions for calculating the linear thermal transmittance and temperature factors of junction details. BR 497 (Ward and Sanders, 2007) is based on BS EN ISO 10211 (British Standards Institution, 2007b); however, the international standard offers additional options for assessing certain junction types such as ground floors with a slab on ground. IP 1/06 (Ward, 2006) deals with assessing the effects of thermal bridging and stipulates the minimum performance standards. BR 497 (Ward and Sanders, 2007) and IP 1/06 (Ward, 2006) are both named as third party documents to Part L of the Building Regulations (HM Government, 2010). The standard BS EN ISO 6946 (British Standards Institution, 2007a) describes the conventions for calculating the thermal properties of airspaces and voids. BS EN 12524 (British Standards Institution, 2000) and BR 443 (Anderson, 2006) provides the thermal properties of typical construction materials for use in fabric heat loss calculations.

The Building Regulations (HM Government, 2010) require the thermal modelling of junction details to be undertaken by a person with suitable expertise and experience. In order to be qualified to assess thermal bridges professionals (which could include the architectural technologist) must be competent in the application of the standards and conventions and be able to use the appropriate software. This requires investment in training and development. Organisations will need to commit resources to finance the undertaking of a structured training programme and support the following period while individuals continue to develop their skills and apply the technique to real-world projects for the first time. Financial investment is also required in order to purchase the appropriate software to create thermal models.

Appendix K of SAP (DECC, 2011) stipulates the Building Regulation default Ψ-values that are to be used in cases of nonspecific quantification of heat losses attributed to junction details. This is where junction details do not follow officially approved thermal design standards and have not been assessed by numerical modelling (thermal modelling). The default values penalise projects for not paying attention to construction detailing by imposing significantly high thermal bridging parameters for use in energy and CO_2 emissions calculations. The default values listed in SAP Appendix K (DECC, 2011) are twice the heat loss of the ACD values.

Guidance on very high performing detail designs has been produced by authors such as Pokorny *et al*. (2009) and the Association for Environment Conscious Building (2009). These provide junction details with stated thermal performance values for incorporation into designs following Passivhaus principles (Passivhaus Trust, 2012). However, projects using construction methods of Passivhaus standard are currently a minority within the UK construction industry. Between 1996 and 2012 only circa 30 000 Passivhaus buildings had been completed worldwide (Passivhaus Trust, 2012). By comparison 118 000 conventional homes were completed in England during the 12 month period up to March 2012 (DCLG, 2012).

Technical literature supplied by product manufacturers such as Keystone Lintels (2011) or Kingspan (2010) often contain information on thermal bridging for construction details incorporating their products. By its very nature this type of literature is construction detail and manufacturer specific. Therefore, care must be taken in its application as it is likely that the contribution of other companies will be required in order to create a design solution where products manufactured by different companies interface with each other and (one hopes) perform as intended as a whole.

Practitioners such as Clarke and Yeats (2011) publish illustrated articles in professional journals that describe junction details applied to specific projects. These occasionally report upon the levels of thermal performance achieved. These types of articles also often convey the associated issues encountered during the design and construction processes. Information of this nature is easily accessible to the architectural technologist in practice. Similarly, researchers from academic institutions publish the findings of research projects, such as Wingfield *et al*. (2008) and Hopper *et al*. (2012). This type of literature is sometimes made readily available to the practitioner via the Internet. Literature reporting the performance of junction details for completed projects provides a feedback mechanism to designers beyond the experiences gained through their own projects. Successful approaches can be adopted to expand the architectural technologist's repertoire of junction details and failures can potentially be avoided.

Housing developments take thermal bridging into account using SAP (DECC, 2011) and its outputs inform CSH (DCLG, 2010) assessments. SAP is the UK Government's chosen method for assessing the energy performance and CO_2 emissions of dwellings. Its methodology is compliant with the European Union (2010) Energy Performance of Buildings Directive (2010/31/EU) and the calculation requires the input of thermal bridging values. There are a number of outputs from SAP, but the two of importance to this case study are the Dwelling CO_2 Emissions Rate (DER) and the Fabric Energy Efficiency (FEE). The DER is the predicted annual CO_2 emissions per unit floor area attributed to the space heating, water heating, ventilation and lighting expressed as kg/m^2yr for the design. The Target CO_2 Emission Rate (TER) is the maximum calculated CO_2 emissions deemed permissible under the Building Regulations (HM Government, 2010) for the design. The DER must be lower than the TER in order to achieve compliance (DECC, 2011). The FEE is the space heating and cooling energy demand expressed as kWh/m^2yr (DCLG, 2010). The Code for Sustainable Homes (CSH) is a national environmental assessment method for new dwellings (DCLG, 2010). The design and construction of dwellings is rated using a credit scoring system. The nine categories assessed are diverse and range from water use to ecology. It is Category 1: Energy and Carbon Dioxide Emissions that is of particular interest to this case study. This uses the DER and FEE produced by SAP to assign credits. Category 1 is heavily weighted, potentially making its credits highly sought after by developers. Therefore, it is considered by Studio Consulting that any significant gain to be made in Category 1 of CSH could generate demand for the thermal modelling services offered by the practice.

It was recognised that the practice needed to promote the business and the thermal modelling services offered. In this commercial context it was considered that ownership of design information and thermal modelling data was paramount for the creation of marketing material. Therefore, it was decided to develop a case study to demonstrate the thermal modelling of bespoke designs of junction details and illustrate any benefits achieved. In order to maximise the potential use of the output, the project would focus on traditional masonry construction since its use is very common within the UK construction industry.

Method

The case study is based on the design of a four bedroom detached property shown in Figures C.1, C.2 and C.3. The case study was undertaken between September 2011 and December 2011 and the design had to conform to the threshold standards of Building Regulations Part L 2010 (HM Government, 2010). The key parameters of the base property are given in Table C.1. The house design was created by the practice specifically for the case study to provide a base model to which four different approaches to thermal bridging could be applied. The thermal bridging options investigated were:

- Building Regulations defaults values listed in SAP Appendix K (DECC, 2011).
- Accredited Construction Details also listed in SAP Appendix K (DECC, 2011).
- Enhanced Construction Details (EST, 2008).
- Thermal modelling of bespoke designs of junction details produced by the practice.

Each scenario was entered separately into SAP to perform the energy performance and CO_2 emissions calculations. Reference was made to the CSH technical data (DCLG, 2010) using the DER and FEE from the SAP calculations to identify how each of the thermal bridging scenarios affected the credits that could be claimed from Category 1: Energy and CO_2 Emissions. Direct comparison was

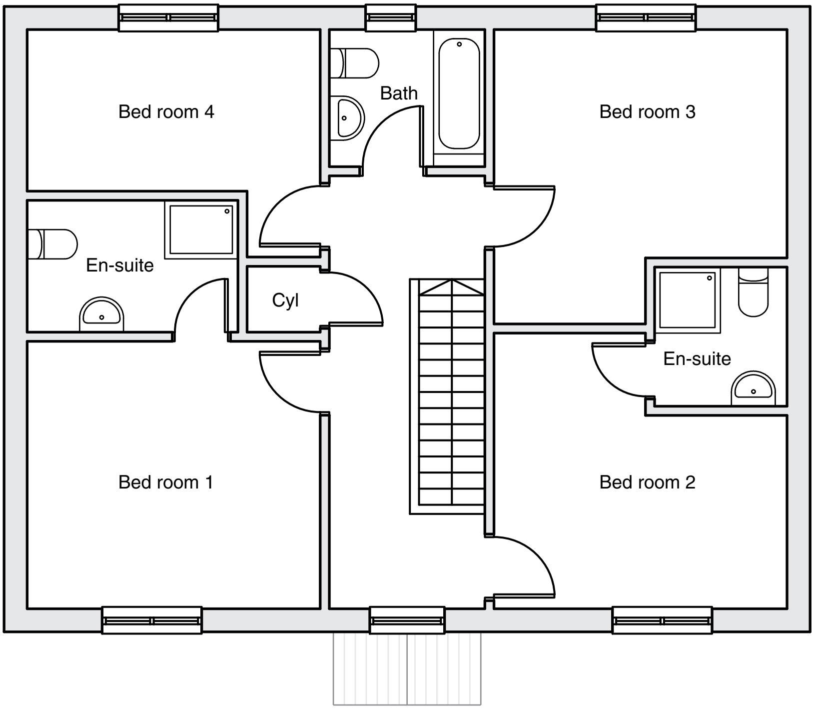

Figure C.1 First floor plan.

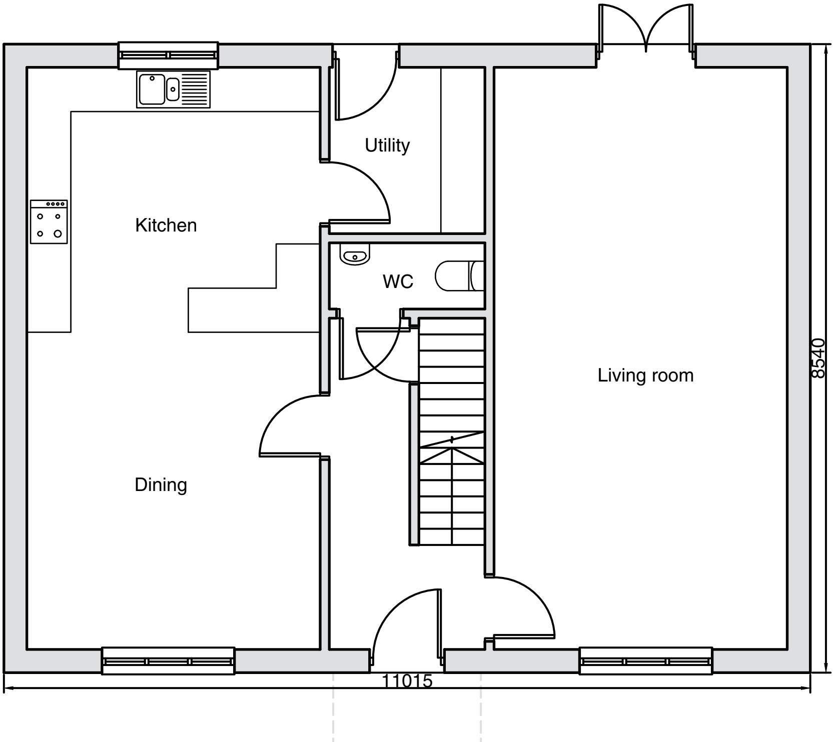

Figure C.2 Ground floor plan.

Figure C.3 Front elevation.

made between the different options based on the SAP and CSH results. A diagram illustrating the method is shown in Figure C.4.

The thermally modelled construction details used the ACD as a base, but a number of changes were made informed by the experience of the practice, current at the time of the case study. These sought to improve the thermal performance of the junction details while reflecting designs commonly used in traditional masonry construction that were familiar to the practice. All details were thermally modelled using Physibel TRISCO version 12.0w software (Physibel, 2010) to establish the linear thermal transmittance (Ψ-value) and temperature factor (f_{Rsi}) for each. The conventions for the thermal modelling of construction junction details given in BR 497 (Ward and Sanders, 2007) and BS EN ISO 10211 (British Standards Institution, 2007b) were followed throughout. The equivalent thermal conductivities for all airspaces and voids were calculated in accordance with BS EN ISO 6946 (BSI, 2007). Material conductivities were sourced from manufacturers' literature where possible to represent those widely commercially available in the UK. In instances where these could not be obtained, suitable values were sourced from BS EN 12524 (British Standards Institution, 2000) or calculated following guidance from BR 443 (Anderson, 2006). Table C.2 shows the conductivities of the materials used in the thermal models.

Stroma FSAP 2009 software (Stroma Certification, 2010) was used to perform the SAP calculations for the base model dwelling employing the four different

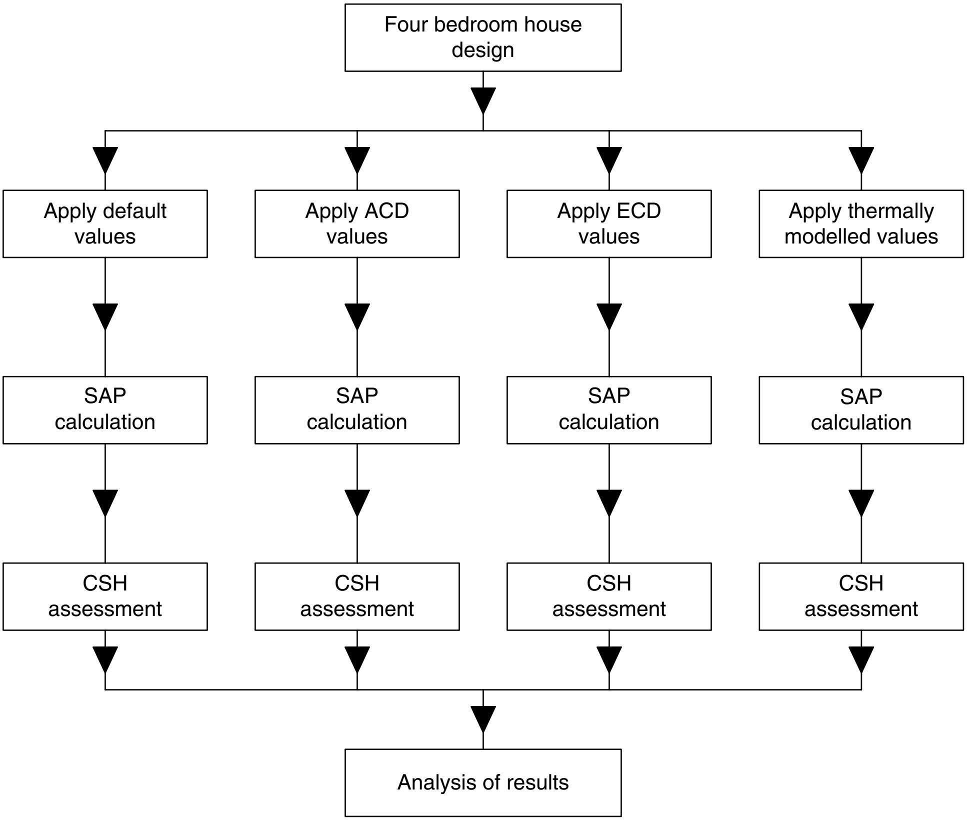

Figure C.4 Method diagram.

Item	Performance
Air permeability rate	5 $m^3/h\,m^2$ @ 50 Pa
Condensing boiler with time and temperature zone control	89.8%
Ground floor	0.14 W/m^2K
Natural ventilation with fans to kitchen, WC and wet rooms	
Roof	0.15 W/m^2K
Walls	0.29 W/m^2K
Windows fully opening	1.4 W/m^2K
210 litre cylinder with 80 mm factory fitted insulation	

Table C.1 Design parameters.

thermal bridging options separately. The data output from SAP was entered into a spreadsheet to facilitate analysis and enable comparisons to be drawn and the output is shown in Tables C.3 to C.6.

Material	λ (W/m K)	Source
Aircrete blocks	0.110	Manufacturer (H + H, n.d.)
Brickwork (outer leaves)	0.770	BR 443 (Anderson, 2006)
Cavity closer flexible	0.040	Manufacturer (Cavity Trays, n.d.)
Cavity closer rigid insulation core	0.022	Manufacturer (Kingspan, 2010)
Foundation blocks	0.250	Manufacturer (H + H, n.d.)
Hardcore	2.000	BS EN 12524 (BSI, 2000)
Insulation acoustic	0.044	Manufacturer (Knauf, 2009)
Insulation floor	0.020	Manufacturer (Kingspan, 2011a)
Insulation roof	0.040	Manufacturer (Euroform Products, 2008)
Insulation wall	0.020	Manufacturer (Kingspan, 2011b)
Medium density fibreboard (MDF)	0.140	BS EN 12524 (BSI, 2000)
Mortar (inner leaves)	0.880	BR 443 (Anderson, 2006)
Mortar (outer leaves)	0.940	BR 443 (Anderson, 2006)
Plaster	0.400	BS EN 12524 (BSI, 2000)
Plasterboard	0.250	BR 443 (Anderson, 2006)
Polyvinyl chloride (PVC)	0.170	BS EN 12524 (BSI, 2000)
Reinforced concrete	2.300	BS EN 12524 (BSI, 2000)
Sand	2.000	BS EN 12524 (BSI, 2000)
Soil	2.000	BR 497 (Ward and Sanders, 2007)
Steel	50.000	BR 443 (Anderson, 2006)
Timber	0.130	BR 443 (Anderson, 2006)
50 mm low-E wall cavity	0.114	BR 443 (Anderson, 2006)

Table C.2 Material conductivities.

	Ψ-value (W/m K)			
Detail	**Default**	**ACD**	**ECD**	**TM**
Corner (normal)	0.180	0.090		0.052
Eaves	0.120	0.060		0.051
Gable	0.480	0.240	0.040	0.098
Ground floor	0.320	0.160	0.043	0.025
Intermediate floor (average)	0.140	0.070		–0.007
Jamb	0.100	0.050		0.005
Lintel	1.000	0.500	0.004	0.264
Sill	0.080	0.040		0.003

Table C.3 Ψ-values.

Considerations

In order to develop a case study where the results could be used to market the thermal modelling services to the largest number of organisations, it was decided to base the project on a house type representative of those constructed by many house builders. Attempts were made to obtain house designs from a number of national house builders. However, this proved to be fraught with difficulties.

Detail	Improvement over default	Improvement over ACD	Improvement over ECD
Corner (normal)	71%	42%	NA
Eaves	58%	15%	NA
Gable	80%	59%	0%
Ground floor	92%	85%	43%
Intermediate floor (average)	105%	109%	NA
Jamb	95%	91%	NA
Lintel	74%	47%	0%
Sill	96%	92%	NA

Table C.4 Comparison of improvements.

	H_{TB}	DER	FEE (1 d.p. as CSH)
Default	52.635	17.77	61.9
ACD	28.072	16.29	54.5
ECD	14.036	15.42	50.1
TM	8.626	15.07	48.31

Table C.5 Effect of thermal bridges.

Detail	f_{Rsi}
Corner (normal)	0.957
Eaves	0.931
Gable	0.911
Ground floor	0.941
Intermediate floor joists perpendicular	0.955
Intermediate floor joists parallel	0.951
Jamb	0.957
Lintel	0.833
Sill	0.959

Table C.6 Temperature factors obtained.

Multiple organisations contribute to the design of house types for national developers and this leads to the formation of technology clusters often containing a number of the same discipline. Decision making in this type of environment became subjected to political motives during the case study, preventing the timely release of information. Therefore, an alternative approach was required to obtain a base design. It was decided to use experience gained by the practice on residential projects to develop a design that represented those built by house builders. It was also deemed beneficial to create a design that characterised those often prepared by architectural practices as single houses for individual clients. This approach ensured full ownership of the design and thermal modelling data, permitting unrestricted use of it for research and marketing purposes.

During the research phase the builders merchant Travis Perkins (Jackson, 2011) announced the Sustainable Building Solutions New Build Fabric project comparing the Building Regulations Part L (HM Government, 2010) default Ψ-values (DECC, 2011) with those obtained from the thermal modelling of junction details with prescriptively specified products. The project had been undertaken in collaboration with an advisory panel consisting of the Building Research Establishment (BRE), Local Authority Building Control (LABC), GreenSpec, Salford University and a number of anonymous national house builders. Thermal modelling had been carried out for designs of a two bedroom terrace property in both mid and end terrace situations, as well as a three bedroom detached dwelling house. The designs of these buildings were created specifically for the Travis Perkins project. The construction incorporated brick and blockwork masonry walls, beam and block suspended ground floors, timber intermediate floors and trussed rafter roof construction. Alternative solutions using other construction methods such as a timber frame were planned for development at a later stage in the project. Significant improvements on the Building Regulations Part L (HM Government, 2010) default Ψ-values (DECC, 2011) were reported. These were input to an undisclosed SAP software program to perform energy performance and CO_2 emissions calculations for the dwelling designs, which resulted in tangible benefits in the predicted performance. Travis Perkins (Jackson, 2011) stated that the dwellings were all given a southwest orientation to ensure the process was robust. Travis Perkins (Jackson, 2011) went on to demonstrate the financial incentives for developers when adopting their building fabric solutions. This was shown by adding a solar thermal system to the SAP calculation applying the default Ψ-values to make the building achieve a pass in SAP. The favourable cost difference of £1800 between the options was then reported. The ability to gain points under a CSH assessment based on the FEE was also briefly explained. This work formed part of a marketing strategy to demonstrate the use and benefits of particular products. The premise was to supply ready-made solutions to common building situations. Travis Perkins has an inherent commercial interest to portray their building fabric solutions in a positive manner and have not published any negative findings or commented on their absence. The publication of the supporting data for this project is incomplete, preventing full independent analysis of the results or exact replication of the project. This reduces the robustness of their claims, but the limited release of information could be deliberate in an attempt to prevent competitors using their work. Travis Perkins (Jackson, 2011) stated that their results had been independently verified by the BRE and LABC.

Publication of the work by Travis Perkins (Jackson, 2011) potentially threatened this project. The availability of information produced by a nationwide organisation that presents ready-made solutions for addressing thermal bridging could provide a cheaper alternative to the services offered by the practice. However, the solutions presented by Travis Perkins (Jackson, 2011) constrained designers, contractors and developers to fixed detailing and specific products. This has a similar effect as when applying the ACD to a building design, albeit with enhanced Ψ-values. It is considered that this approach presents some major limitations. Designers have been found to develop a palette of favourite products (Emmitt and Yeomans, 2008) and often resist pressure to adopt unfamiliar alternatives. They are not alone in their repeated use of familiar items. Research conducted by

Barbour Index (1995, 2003) indicates that clients who stipulate the use of particular items in their developments tend to make a selection from approved lists. In circumstances when contractors have an influence on a project specification, research (Barbour Index, 1994, 2004) shows that they may also operate using a palette. A further consideration is that standard designs for junction details cannot always be applied and bespoke solutions often need to be developed to meet project specific criteria. This is where employing thermal modelling techniques in the analysis of thermal bridging plays a particularly important role.

The announcement by Travis Perkins (Jackson, 2011) impacted upon the case study as the design of the base building had to be altered to avoid close similarity with those created by Travis Perkins. The resulting design shown in Figures C.1, C.2 and C.3 is admittedly a large property having four bedrooms, but this was not thought to be a problem for the investigation of thermal bridging solutions. In addition to clients from the residential sector, it was also intended to target designers, contractors and developers of commercial buildings in the marketing of services. With this in mind, it was considered that a house design was simple to understand regardless of sector experience.

At the outset of the case study it was considered feasible that no benefit could be gained from the thermally modelled junction details over the ACD solutions. This was deemed a low risk as the ACD values were considered robust so that a wide selection of materials and products could be accommodated. It was anticipated that a definitive performance specification for each material and component would yield more favourable results.

The case study represents an investment in time that initially does not generate fee income. However, the purpose of the exercise was to gain a greater understanding of the service currently offered and produce information that could be used to attract additional work. SAP and CSH are widely used assessment tools within the industry. Therefore, any benefit that could be gained under these was potentially seen by the practice as a major factor influencing the decision on which approach to take when dealing with thermal bridging. Most companies undertake business development activity and this type of project was deemed appropriate for a practice that specialises in the thermal modelling of junction details.

Results and analysis

The Ψ-values obtained from the Architectural Technology Practice's thermally modelled junction details are shown in Table C.3. The Building Regulation default (DECC, 2011), ACD (DECC, 2011) and ECD (Energy Savings Trust, 2008) values are also included for comparative purposes. Table C.4 shows the improvements made over the default, ACD and ECD Ψ-values by the thermally modelled approach.

The smallest enhancement of 15% over the ACD was achieved by the eaves detail. The design shown in Figure C.5 is very similar to the ACD. The decrease in predicted heat loss is thought to be mainly a result of applying a fixed specification to the thermally modelled solution.

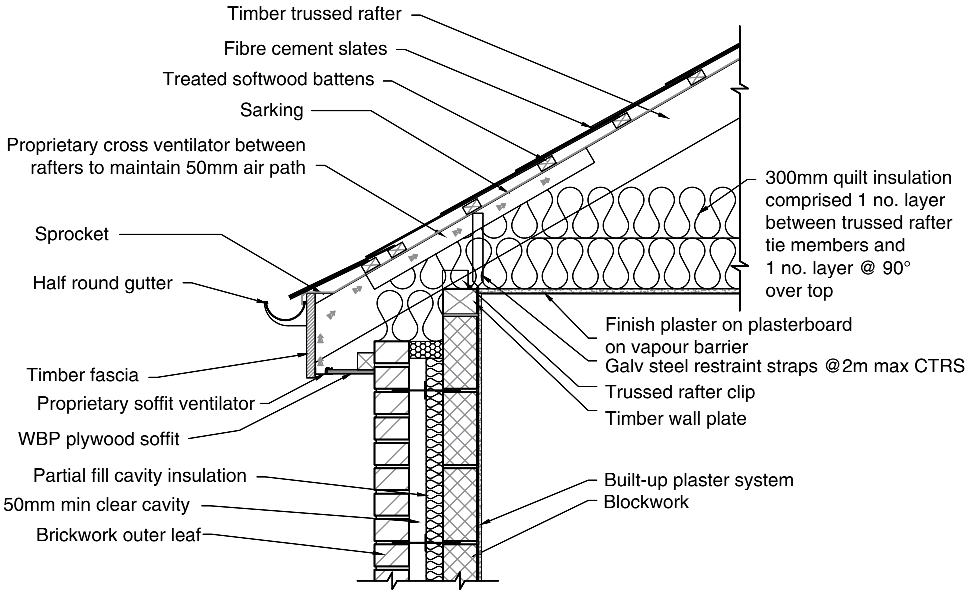

Figure C.5 Eaves detail.

The largest improvement of 109% over the ACD was made by the intermediate floor detail and resulted in a negative Ψ-value. The –0.007 W/m K Ψ-value is an average derived from the thermal modelling of details with joists perpendicular to the external walls and with the joists parallel to the walls. The negative value obtained does not mean that heat is gained through the junction. It is believed that the acoustic insulation to the ceiling shown in Figure C.6 improves the *U*-value of the wall locally to the floor. The thermal model takes the effect of the insulation in the floor into account. However, the *U*-value of the wall (U_w) subtracted in the following equation (the intermediate floor Ψ-value) is higher because it represents the flanking elements:

$$\Psi = L^{2D} - \ell_w \times U_w \tag{C.1}$$

The acoustic insulation is actually part of the floor but affects the performance of the wall. Mathematically the negative Ψ-value avoids the double counting of heat losses. Acoustic insulation is not shown in the ACD but would need to be included in order to meet the requirements of Building Regulations Part E (HM Government, 2003).

The ACD lintel detail is the worst performing of the default and ACD values. The thermally modelled detail adopted a profiled steel lintel with a solid full-fill insulation core and a perforated base plate, as shown in Figure C.7, to achieve a 47% improvement over the ACD Ψ-value. The use of aircrete blockwork with a thermal conductivity of 0.11 W/m K to form the inner leaf of the external wall was also considered a substantial contributor in reducing the Ψ-value of the lintel junction detail. The thermal performance could have been improved further by

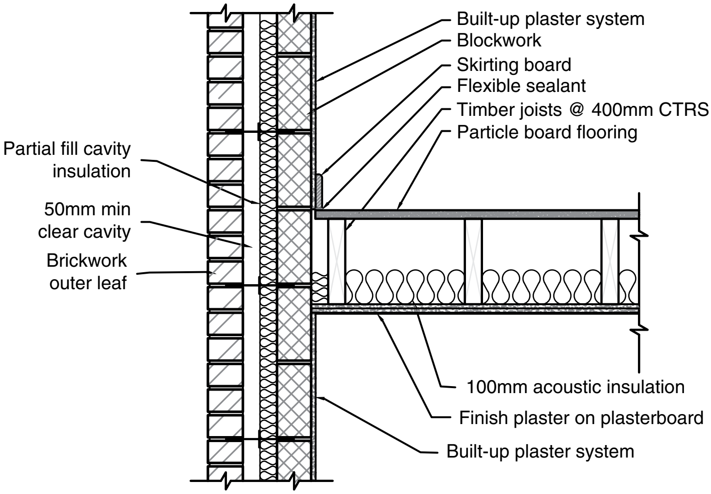

Figure C.6 Intermediate floor detail.

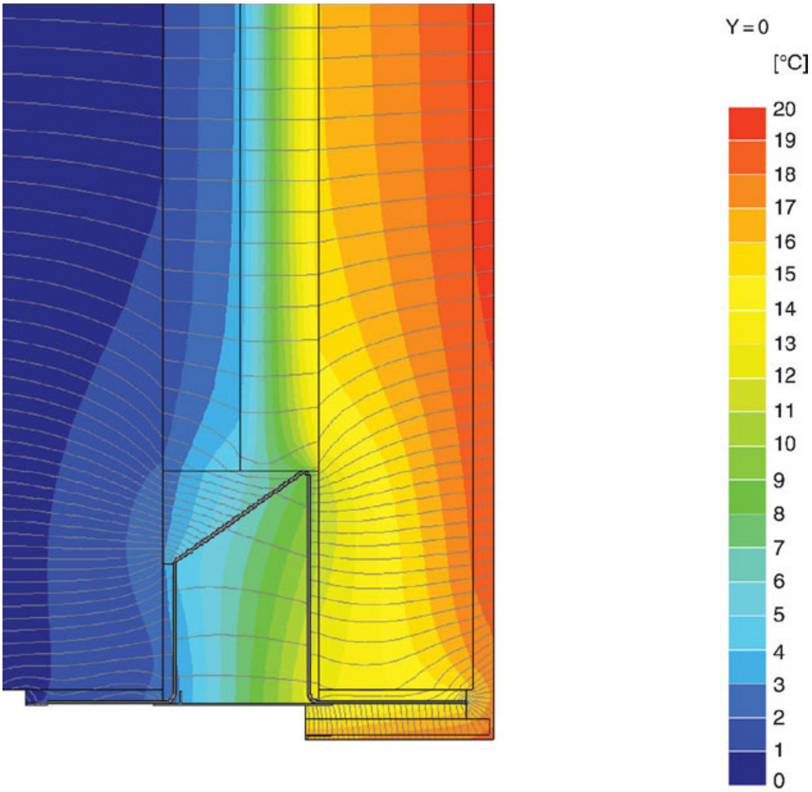

Figure C.7 Lintel temperature distribution.

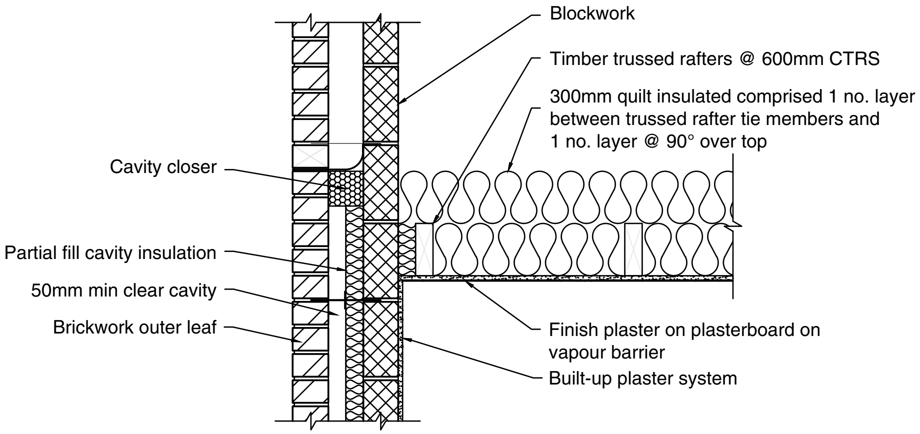

Figure C.8 Gable detail.

specifying split lintels or a composite lintel with different materials supporting the inner and outer leaves of the external wall. These alternative lintel options would remove or reduce the constructional thermal bridge by eliminating the steel that would otherwise span the external wall cavity, providing a direct path for heat to flow between the two leaves of the wall. The Keystone Lintels (2011) Hi-therm is an example of a composite lintel where steel is used to support the inner leaf and glass reinforced plastic (GRP) is used to support the outer leaf. Both materials are connected to form a single lintel. The ECD lintel detail outperforms the thermally modelled solution. This detail uses an inner concrete lintel and a completely separate steel outer lintel. The inner leaf of the wall is also fitted with thermal laminate plasterboard. Together these are considered to be the reasons for the reduced heat flow. The cost of the ECD is likely to be the highest because it incorporates two lintels and additional wall treatment. This may discourage its use by contractors and developers.

The gable junction has the second worst default and ACD Ψ-value applicable to the case study. A 59% improvement over the ACD Ψ-value was made using low conductivity aircrete blockwork to reduce the effect of the constructional thermal bridge created by the inner leaf of the external wall. The detail and associated temperature distribution are shown in Figures C.8 and C.9. The ECD gable outperforms all the other solutions. The improvement is believed to be provided by the fitting of thermal laminate plasterboard to the inner leaf of the external wall and rigid insulation under the rafters. Similar to the ECD lintel, the ECD gable detail gains extra thermal performance by adding materials and this potentially reduces its appeal to developers and contractors because of the likely additional material and labour costs.

The thermally modelled (TM) ground floor junction detail shown in Figures C.10 and C.11 achieved an 85% enhancement on the ACD Ψ-value. This detail also achieved the only improvement (43%) over the ECD Ψ-values. The thermally modelled detail shown in Figure C.10 was developed by the practice as a bespoke solution to

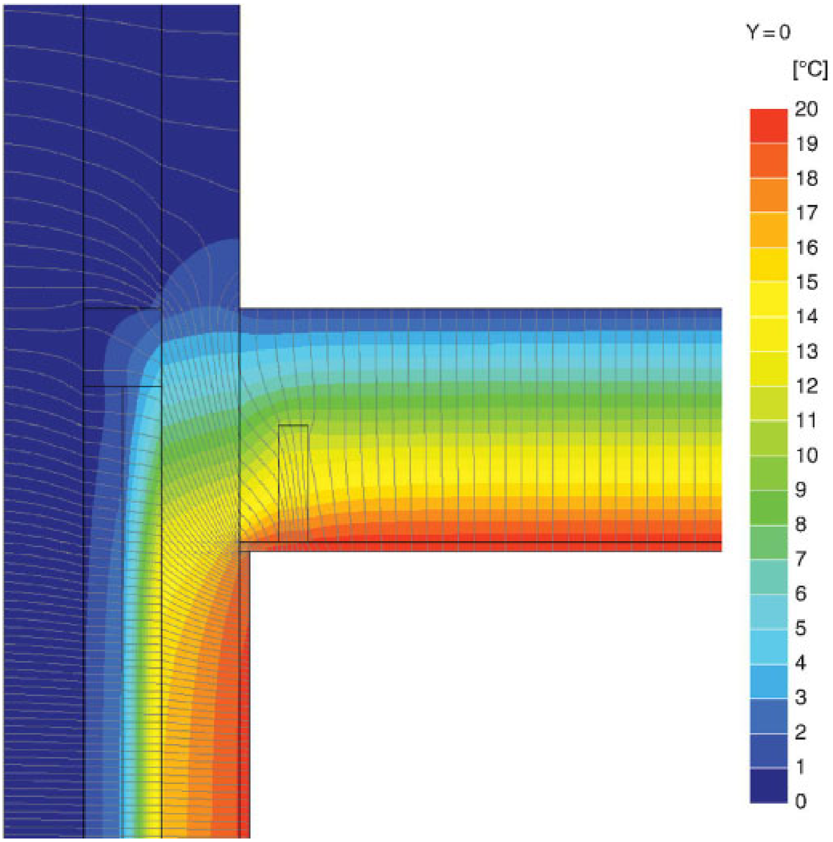

Figure C.9 Gable temperature distribution.

the ground floor to wall junction. It incorporates low thermal conductivity foundation blocks and low thermal conductivity blocks to form the inner leaf of the external wall. These components reduce the constructional thermal bridging created by the inner leaf of the external wall and the substructure supporting the wall.

The case study building had a total surface heat loss area of 350.900 m^2 generating a heat flow of 101.088 W/K for the plane elements. The heat loss attributed to thermal bridging (H_{TB}) is shown in Table C.5 for each of the options. The ACD provide a 47% improvement on the defaults. The ECD improve upon the defaults by 73% and 50% on the ACD. The thermally modelled details achieve improvements of 84% over the default values, 69% over the ACD and 39% over the ECD values. Adding the H_{TB} to the heat flow through the plane elements creates heat transmission coefficients of 153.723 W/K, 129.160 W/K, 115.124 W/K and 109.714 W/K for the default, ACD, ECD and thermally modelled options respectively. This means that the H_{TB} for the defaults represents 34% of the total fabric heat loss. This is reduced to 22% for the ACD and 12% for the ECD. A further reduction to 8% is achieved for the thermally modelled solution.

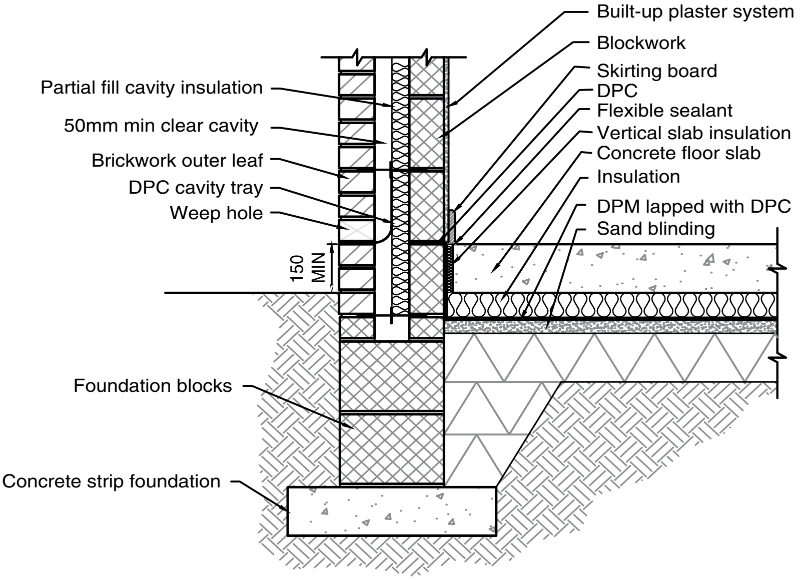

Figure C.10 Ground floor detail.

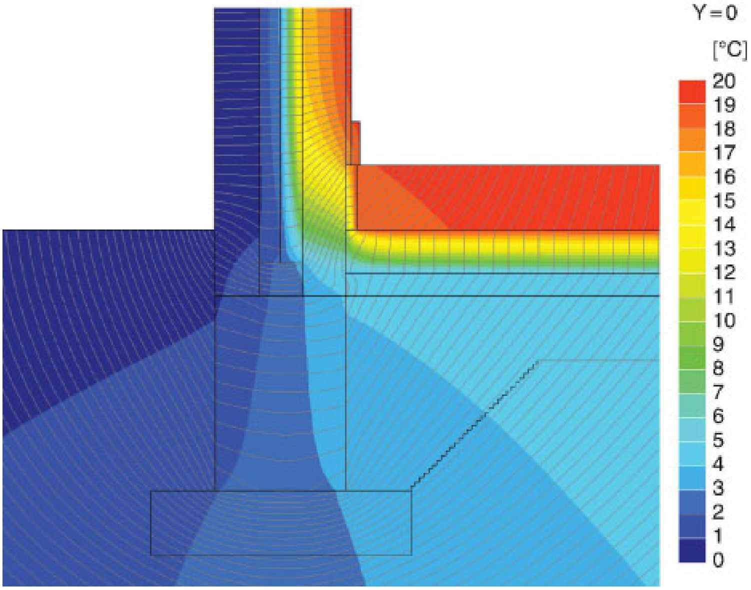

Figure C.11 Ground floor temperature distribution.

There are many parameters that can affect the DER obtained under SAP; however, with a consistent base model the method employed in this case study does allow comparisons to be drawn for the four options of addressing thermal bridging. A TER of 16.39 kg/m^2 was calculated for the building. The resulting DER obtained for each approach can be seen in Table C.5. Using the default values meant that the building failed by –8% in SAP under Part L 2010 of the Building Regulations (HM Government, 2010). Entering the H_{TB} for the ACD created an 8% improvement in the DER when compared to the defaults. This result bettered the TER by 1% and achieved a pass under SAP. The ECD surpassed the TER by 6% with a DER 13% better than the defaults and 5% better than the ACD. The H_{TB} for the thermally modelled details generated DER improvements of 15% compared to the defaults, 7% over the ACD and 2% better than the ECD result. The thermally modelled solution passed SAP with an 8% DER improvement on the TER. This is just within the lower CSH limit of ≥8% to gain one credit.

Table C.5 also shows the FEE returned from SAP for the four thermal bridging solutions. It is acknowledged that the performance standard of the plane elements also affects the FEE, but, once again, a consistent base model allows comparisons to be made between the thermal bridging solutions. It can be seen that the effect of thermal bridging is significant on the FEE calculated. The model using the H_{TB} from the default values resulted in a FEE above the 60 kWh/m^{2}yr CSH upper limit. The ACD produced a FEE that could gain four credits while the ECD is able to claim five. The thermally modelled solution performed best, scoring six credits.

The temperature factor (f_{Rsi}) for each of the thermally modelled details is shown in Table C.6. All the values obtained are above the critical temperature factor (f_{CRsi}) of 0.75 stated in IP 1/06 (Ward, 2006) for dwellings to avoid mould growth.

Conclusion

A number of conclusions can be drawn from the research conducted for this case study. The thermal modelling of bespoke designs for junction details with defined material specifications can yield results that improve upon the thermal performance of standard junction design solutions. The employment of thermal modelling to quantify the thermal performance of bespoke junction designs could prove a useful tool for the architectural technologist or other design professional seeking to develop construction details from first principles. In addition, the project has demonstrated that the thermal modelling of construction details can benefit designers, contractors and developers when seeking to achieve a pass in SAP or score CSH credits.

During the research phase the practice discovered similar work that had been undertaken by the builders merchant Travis Perkins (Jackson, 2011), which caused a redesign of the research reported in this case study chapter. The underlying research created junction designs and thermal modelling data that have been utilised by the practice for promotional purposes in discussions with prospective clients. The research has also advanced the practice’s understanding of the issues associated with the thermal modelling of junction details. These are deeply beneficial to a commercial organisation and have already contributed to an increase in thermal modelling commissions for the practice. To this end the research informing the case study is deemed to have been a success.

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Chapter Four
Testing the Thermal Performance of New Dwellings during Construction

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Architectural technologists play a key role in the construction sector and have an important role to play in improving the thermal performance of buildings. In this chapter some of the drivers for developing low and zero carbon dwellings are discussed before turning attention to testing the thermal performance of new dwellings while they are being constructed. This can identify thermal bridging and air leakage while dwellings are being built, which is seen as novel and a cost effective method of improving build quality and performance prior to occupation. The reasons for the increased interest in monitoring buildings is discussed and the rationale why building testing and monitoring could lead to new areas of operation and fee earning ability for architectural technologists. Results from two case studies help to further illustrate the potential of the approach adopted.

Introduction

Architectural technologists play an important role in ensuring that the low carbon design of buildings for the thermal envelope (walls, windows and doors, floors, ceiling and roof) is translated into the low carbon construction and operation of buildings, such as dwellings. An efficient thermal envelope minimises heat loss during the heating season, typically October to April in the UK, and minimises heat gain in the other months of the year (Lechner, 2001). However, Littlewood *et al*. (2011b) and Taylor *et al*. (2012) argue that low carbon design of dwellings does not always lead to low carbon construction of new dwellings. Szokolay (2008) argues that many buildings designed to be sustainable are far from sustainable when complete and that 'green

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wash' can occur, i.e. claims to improve environmental performance are not realised on site or by building occupants. Baird (2010) discusses that building designers do not systematically evaluate their projects for their own practices and neither do they determine what the users think about the buildings they use for work, leisure and shelter. Baird (2010) goes on to suggest that building evaluation is not very common as defects in design and construction may be highlighted. Hopper *et al.* (2011) argue that low carbon intervention measures for existing dwellings aimed at increasing the energy efficiency of exterior walls by retrofitting insulation is not always executed as per the manufacturer's recommendations and best practice.

Architectural technologists already undertake a crucial role in the appraisal of building performance in use (see Chartered Institute of Architectural Technologists, 2012a). By enhancing their services, architectural technologists could win more commissions with residential developers as sustainability experts. Indeed, Littlewood and Geens (2002) argued in their paper 'A new multidisciplinary team for the UK's 21st century homes' of the need for residential developers to commission external consultants to join their design teams who can provide specialist sustainability advice using dynamic thermal simulation to ensure compliance with Approved Document L of the Building Regulations. The novelty suggested by Littlewood and Geens (2002) was for residential design teams to use dynamic thermal simulation, a tool in 2002 then normally associated with complex and commercial property projects, such as hospitals and schools. More than ten years later the author of this chapter is promoting the use of thermography as an everyday site inspection tool for new and existing dwellings (Hopper *et al.*, 2012a, 2012b; Littlewood *et al.*, 2011b; Taylor *et al.*, 2012).

UK policy and strategic targets for low and zero carbon dwellings

Since 2011 there has been a rise in the number of low and zero carbon dwellings built in the UK. There were just over 1800 low carbon, 100 zero carbon and 10 carbon neutral homes built by 2011 (Zero Carbon Hub, 2011a). The Climate Change Act 2008 commits the UK to legally binding targets for greenhouse gas (GHG) emissions reductions of at least 34% by 2020 and 80% by 2050 against a 1990 baseline (Office of Public Sector Information, 2008). The UK residential stock accounts for approximately 25% of total UK GHG emissions by the end-use sector (National Statistics, 2010). Of this 25%, 58% is related to space heating (Rooze, 2011). Achieving deep GHG emissions reductions from the residential sector is very important if the above targets are to be achieved (Boardman, 2007). New dwellings is one of easiest sectors of the economy to implement emissions reductions cost-effectively and in 2007 the UK Government announced its intention for all new homes to be built to a zero carbon standard from 2016 (Levine and Vorsatz, 2007; Department for Communities and Local Government (DCLG), 2007).

The performance targets of the zero carbon standard are to be implemented through progressive strengthening of the requirements of Approved Document L1A 'Conservation of fuel and power in new dwellings' (ADL1A) of the Building

Regulations (CLG, 2010). One of the mechanims used to ensure that new dwellings meet low and zero carbon targets was through the introduction of the Code for Sustainable Homes (CfSH) in 2007. Initially the CfSH was an optional environmental assessment tool for developers. However, as the CfSH is tied into proposed changes to Approved Document L of the Building Regulations, of which the 2010 change has already occurred, there are further enhancements planned in 2013 and 2016 (Zero Carbon Hub, 2012a). The CfSH includes six levels, where level four is deemed as low carbon, level five is deemed as zero carbon (and the limit in Wales) and level six as carbon neutral. Since, 2011 and in Wales, developers in both the public and the private sectors have not been able to obtain planning permission for new dwellings unless they design the dwellings to meet CfSH level three plus (the plus refers to targets meetings level four for the energy category of the CfSH) (Welsh Assembly Government, 2011). The mandatory requirement to develop to code level four will come about with the implementation of the revisions in 2013 to ADL1a.

To achieve zero carbon, the Zero Carbon Hub (2011a) states the starting point for all new dwellings is to focus on a very well performing fabric, followed by the inclusion of low and zero carbon technologies. A working group from the Zero Carbon Hub accepts that homes may not perform as designed even before occupants are involved. Thus, there is a consensus that more evidence is required to establish the scale of the issue and members of the group support more on-site assessment and monitoring of the dwelling fabric and services (Zero Carbon Hub, 2011a).

Further development of the definition for zero carbon homes came in early 2011 in the UK Government budget, where it was announced that zero carbon would be redefined to only require zero emissions from regulated energy use (i.e. the energy required to heat and cool a home and to provide hot water and lighting) (NHBC Foundation, 2011). Zero emissions from regulated energy is still a very challenging target for mainstream delivery, which requires considerable innovation over and above current practice and, typically, the need for measures (Allowable Solutions) that mitigate the emissions that cannot normally be achieved by the design of the home. The new UK definition is now much closer to the requirements set out by the European Energy Performance of Buildings Directive (NHBC Foundation, 2011). Furthermore, the zero carbon standard refers to as-built performance and not as-designed performance (Zero Carbon Hub, 2011b). This means that there will be a requirement by stakeholders involved in the design and construction of dwellings to ensure that designed performance is translated into construction performance. Littlewood *et al*. (Littlewood, 2011a; Littlewood *et al*., 2011b) argue that the reasoning behind this shift from measuring designed performance to actual performance is to try and eradicate the differences between predicted and designed performance of a building with that of the actual completed building energy performance. There are many case studies that highlight buildings that do not perform as designed once they are completed, even before they are occupied.

The Zero Carbon Hub (2010) highlights the fact that focusing on the 'as-built performance' of buildings will lead to the need to test the performance and compliance during the production of buildings, or as Littlewood *et al*. (2011b) and Taylor *et al*. (2012) discuss, during the construction process through a series of in-construction tests (iCT). The as-built performance emissions from new homes constructed from 2016 should not exceed: 10 kg $CO_{2(eq)}/m^2$ yr for detached houses, 11 kg $CO_{2(eq)}/m^2$ yr for other houses and 14 kg $CO_{2(eq)}/m^2$ yr for low rise apartment blocks (Zero Carbon Hub 2011c). Since the Carbon Compliance Standards apply to built performance, the recommendations cannot be directly compared with current standards. The percentage improvements on the 2006 standard would be: 60% for detached houses, 56% for other houses and 44% for low rise apartment blocks. Carbon compliance is the overall contribution to achieving zero carbon that can be attained on-site – combining good building fabric performance and use of on-site low and zero carbon energy technologies such as photovoltaic cells and connected heat (community heating networks) to reduce emissions (Zero Carbon Hub, 2009, 2011c). Controlling the heat flow through the building fabric is essential to minimise the energy expended in meeting these requirements (King, 2010). Heat flows by several mechanisms, including conduction, transport by air or water and radiation. Building designs must include a range of measures, such as insulation, physical barriers and conduits, to control its flow, whether natural or induced, such as in a radiator heating system (King, 2010). Therefore, any assessment and monitoring procedure to determine that buildings meet an as-built performance will have to be robust and needs development through rigorous testing; particularly if these tests are to be undertaken during the ‘production’ or in-construction of buildings.

The need to test the thermal performance of new low carbon dwellings during construction

With the increase in drivers for low and zero carbon dwellings and schemes to increase the thermal performance and thereby energy efficiency of existing dwellings in the UK, there is an increased need to test and monitor whether design solutions have been translated into good quality construction solutions. Indeed, one of the most pressing needs in the construction industry in the UK is for reliable information on the actual energy and carbon performance of recently constructed or refurbished buildings (King, 2010). This information is essential for the establishment of benchmarks and standards, for the validation of new designs and techniques, for the development of robust UK national policy and for the development of up to date and authoritative teaching materials for the current and next generation of architectural technologists.

Furthermore, Zero Carbon Hub in 2011 (2011a) accepts that many new low and zero carbon homes may not perform as designed, even before occupants are involved. There is thus a consensus that more evidence is required to establish the scale of the possible problems in thermal performance being affected by poor build quality and more on-site testing for fabric and services is required. Lowe and Oreszczyn (2008) argue that it will be essential to monitor and evaluate the energy and carbon performance of new dwellings in the UK on order to appraise the impact and success of policy implementation for zero carbon homes.

Further drivers for monitoring the performance of new dwellings are identified by Littlewood *et al*. (2011a, 2011b) and Taylor *et al*. (2010):

- Supporting product and process innovation for new design and construction methods and technologies.
- Developing knowledge and expertise in the development of low carbon dwellings through providing feedback to the clients and design and construction teams.
- Informing the development of design standards and regulatory instruments and thus connecting policy aims with practice.

Testing the thermal performance of buildings to compare as-designed performance with performance in use of dwellings is not a new idea, as commented by Littlewood *et al*. (2011b) and Taylor *et al*. (2012). Furthermore, the Technology Strategy Board (TSB) launched the 'Building Performance Evaluation' (BPE) funded scheme in 2010, which runs until 2014 as a means of 'funding the costs of building performance evaluation studies on domestic and non-domestic buildings', in the UK (TSB, 2012). The main weakness of the TSB's BPE call is that there is no assessment or test of performance during the construction stages of building. Littlewood *et al*. (2011b) and Taylor *et al*. (2012) argue that an iCT methodology is essential to assess whether low carbon design is translated into low carbon construction and that thermal performance targets are actually met during construction, and ultimately during the occupancy phase of buildings. Indeed, one advantage of iCT is that if problems in performance (including thermal, but also acoustic and fire) are discovered at the construction stage then it could more cost effective to clients, funders and design teams to provide a solution to these problems than if the problems were found at the post-occupancy stage. The first Ecological Built Environment Research and Enterprise (EBERE) iCT test is to use iCT thermography (iCT:Th) to assess the thermal performance of buildings, during site inspections, prior to occupancy. The iCT:Th test is part of research being developed by the EBERE group at Cardiff Metropolitan University, including Work Package Six (WP6) of the Low Carbon Built Environment (LCBE) project (Anon, 2010) and a doctorate project. WP6 of the LCBE project is discussed in more detail below, as is the EBERE iCT methodology using thermography for new dwellings.

The projects within the EBERE group at Cardiff Metropolitan University aim to address the general lack of of detailed empirical evidence of the performance of low carbon dwellings in Wales and the UK (Lowe and Oreszczyn, 2008). Furthermore, these projects are developing and testing methodologies and a series of protocols for assessing and monitoring the environmental performance of new and existing dwellings. The EBERE research builds upon recent research work in the UK for developing monitoring protocols for low carbon dwellings (Energy Saving Trust, 2008).

Thermography

Thermography is 'the science of acquisition and analysis of thermal information from non-contact thermal imaging devices' (Infrared Training Center, 2010). Thermal 'information' is captured by an infrared (IR) camera, by measuring the intensity of IR radiation emitted from the surface of the object under observation. An IR camera is adjusted by the operator to convert the measured intensity of infrared radiation emitted by an object into a surface temperature (these adjustments compensate for the material and surface properties of the object and the environmental conditions in which it is observed). Hence, the resulting thermal image provides a two-dimensional map of temperature difference over the surface of the object (Infrared Training Center, 2010). Thermography is an established technique within the construction industry for checking the continuity of insulation, identifying sources of air leakage, thermal bridging, workmanship, detecting and mapping moisture in a building (Hart, 1991; Pearson, 2002; Goodhew, 2006). The output when using an IR thermal camera is a thermogram, which illustrates hot and cold areas as different colours (Hart, 1991; Lechner, 2001; Infrared Training Center, 2010). When interpreting thermograms it is necessary to have a thorough understanding of building physics, and thus the surface characteristics of the materials being viewed, in terms of their emissivity and reflectivity (Infrared Training Center, 2010). Materials with high emissivity values have a low reflectivity and materials with low emissivity have a high reflectivity (Infrared Training Center, 2010). When conducting thermography tests, only materials with high emissivity provide reliable readings, since materials with low emissivity tend to reflect the temperature of surrounding objects and materials (Snell and Spring, 2002; Lo and Choi, 2004; Infrared Training Center, 2010). Thus, materials with low emissivity can produce misleading results, which can have disastrous consequences when reporting on what appears to be poor quality (Infrared Training Center, 2010; Hopper *et al.*, 2012a). It is therefore recommended that any architectural technologist considering using EBERE's iCT:Th test should undertake level I thermography training, such as that provided by the Infrared Training Centre, in the UK (Infrared Training Center, 2010).

Infrared thermography can be used to undertake both qualitative and quantitative surveys of buildings, but other methods should be adopted to quantify heat loss from a building (Hopper *et al.*, 2012a, 2012b; Littlewood *et al.*, 2011b; Pearson, 2002; Taylor *et al.*, 2012; TSB, 2012). In most instances qualitative thermographic building surveys provide sufficient information, for example, to identify: sufficient, correctly installed and thereby continuity of insulation; occurrences of thermal bridges; sources of air-leakage, particularly at critical construction junctions; moisture and damp within an element; hidden components, such as pipes and wall ties; and electrical faults (Hart, 1991; Hopper *et al.*, 2012a, 2012b; Littlewood *et al.*, 2011b; Pearson, 2002; Taylor *et al.*, 2012; Thomsen and Rose, 2009; TSB, 2011).

The advantage of using thermography during the construction process is that it can be an easier and less costly option to a client, contractor and design team to rectify any problems identified in build quality that can affect thermal performance, energy use and carbon emissions, than if it were undertaken post-completion and occupation of the building.

Methodology

Thermography was used to test fabric build quality and the effect of poorly executed construction on the thermal performance of dwellings in two case studies. The first case study is a new low carbon dwelling, part of an apartment block completed in December 2011, which is one of several case studies associated with Cardiff Metropolitan's research for WP6 of the LCBE project (see Tweed and Littlewood, 2010a, Littlewood *et al.*, 2011b, Nooraei *et al.*, 2013 and Taylor *et al.*, 2012). The second case study discussed is a relatively new semi-detached dwelling, completed in 2009, before EBERE's iCT:Th test was developed. In this case thermography has been used following similar procedures used by Hopper *et al.* (2012a, 2012b) and recommended by several experts in the field (Air Pressure Testing (APT), n.d.; Hart, 1991; Pearson, 2002; TSB, 2011).

The inspiration

While working as a Building Surveyor and a Project Manager for a housing charity in the 1990s and for Swansea Housing Association (now Coastal Housing Group) between 2007 and 2008 the author experienced the difficulty of assessing the accuracy of construction to meet design details. To the naked eye it is very difficult and almost impossible to assess that the fabric of a building has been constructed correctly so as to meet designed and regulatory performance standards, particularly since the fabric of a building (interior or exterior) can be made up of several layers. In 2007, during the assessment of the fabric of the Palace of Westminster to investigate the thermal performance of the building's fabric (as part of a team of Sustainability Consultants from Building Design Partnership), the author was able to fully appreciate the potential of thermography, which helped to identify inadequate fabric performance and significant heat loss (Littlewood, 2011b). Lechner (2001) points out that occupants of buildings may seek to improve the thermal performance of the fabric if they can visibly see and understand the consequences of a poorly performing building fabric.

An invitation by the Welsh School of Architecture at Cardiff University in February 2009 to contribute to writing a collaborative research bid entitled 'Low Carbon Built Environment (LCBE)' gave the author the opportunity to investigate the development of a methodology for monitoring the thermal performance of dwellings during construction. The author also won a collaborative grant with Coastal Housing Group in 2009 from the European Social Fund to support a doctoral scholarship to complement the research to be undertaken (see Tweed and Littlewood, 2010; Taylor *et al.*, 2010, 2012). Working on WP6 of the project enabled the author to become a qualified Level One certified thermographer.

Monitoring the performance of low carbon buildings and technologies

The aim of WP6 ('Monitoring the performance of low carbon buildings and technologies in Wales') is to assess progress towards the delivery of low carbon buildings in Wales and to develop guidelines for evaluating the performance of the delivery process at key stages. The research is centred on the sequence of design–build–operate stages shown in Figure 4.1.

The research is investigating the application of current theories, standards, models of best practice and advanced technologies that aim to reduce the carbon

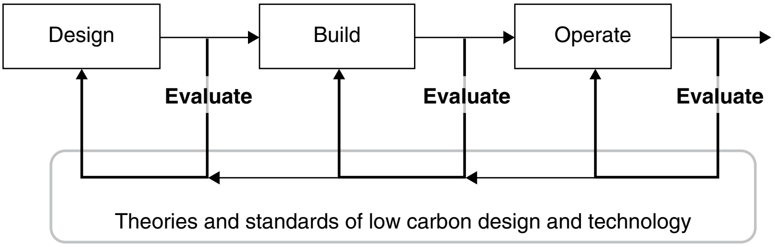

Figure 4.1 Simplified model of the deployment of low carbon design and technology (Source: Tweed and Littlewood, 2010a, 2010b).

emissions from buildings. The EBERE group at Cardiff Metropolitan University are focusing their research on dwellings (apartments and houses) in collaboration with Coastal Housing Group in Swansea, UK. In particular, EBERE researchers are examining the second and third phases of deployment (as illustrated in Figure 4.1) to build a rich picture of how low carbon dwellings are constructed and operated. At the construction stage, the research team is assessing and monitoring the implementation of specific low carbon design features and the installation of low carbon technologies in a number of case studies in Swansea (Littlewood, 2011a, 2011b; Littlewood *et al.*, 2011b). At the operation stage, the performance of dwellings from case study one is to be monitored and the findings will be related to the client, the design team and manufacturers of low carbon products (Nooraei *et al.*, 2013; Tweed and Littlewood, 2010a, 2010b). One of the main outputs is to develop guidelines for monitoring performance at all three stages, indicated in Figure 4.1.

The results from monitoring each of the stages is being presented to the stakeholders involved in the previous stages as well as those directly involved in that stage. For example, the results of assessing and monitoring the thermal performance of apartments in construction has been presented in October 2011 to the developer, the design team as well as the contractors for one of the case studies for WP6 (also part of a doctorate project). Similarly, the results of monitoring the performance in use of the dwellings will be fed back to the developer, contractors, manufacturers and the design team as well as the occupants (Nooraei *et al.*, 2013). Second, the final stage of the research will develop guidelines to help occupants and tenant or community groups to conduct their own monitoring activities to increase stakeholder involvement in the process (Tweed and Littlewood, 2010a, 2010b). This will build upon research undertaken by the author of this chapter with United Welsh Housing Association, to develop a monitoring strategy for this organisation, which includes educating tenants about low carbon renewable energy systems (Littlewood *et al.*, 2011a).

Research from the EBERE group at Cardiff Metropolitan University for WP6 aims to produce comprehensive advice on what and how to monitor low carbon dwellings, to determine if they are delivering expected performance as well as how to embed performance monitoring in the design and construction process. The results are already helping Coastal Housing Group decide how to monitor the build quality and execution of construction processes in construction (Littlewood, 2011b; Littlewood *et al.*, 2011b; Nooraei *et al.*, 2013).

The research from WP6 recognises that in a period of rapid technological change the buildings that rely on emerging technologies are effectively 'experiments'. It is therefore crucial that this is acknowledged during the design, construction and after the building has entered the operational phase. Monitoring of performance will provide an important tool for learning how to design and construct better buildings in the future, and so monitoring of key technologies will be part of the low carbon learning process.

Modus operandi for the EBERE iCT:Th test

A series of climatic and internal (to the building) conditions that needs to be verified and reached, prior to a iCT:Th test being undertaken, are set out in Table 4.1. In meeting the conditions it is suggested that the measured data will be more accurate (Hart, 1991; Hopper *et al.*, 2012a; Littlewood *et al.*, 2011b; Pearson, 2002; APT, n.d.; Taylor *et al.*, 2012). However, as indicated in Table 4.1, there is disagreement amongst experts on the environmental conditions that need to be met prior to a thermography survey being undertaken (APT, n.d.; Hart, 1991; Pearson, 2002). Indeed, the TSB (2011) adds further differences by stating that the wind speed should 8 m/s and that the building surfaces being examined should be dry with no rain during the survey (illustrated in points five and six in Table 4.1). In using the EBERE iCT:Th test for Case Study One, Pearson's (2002) recommendations were adhered to in order to produce the results illustrated. However, for Case Study Two it was decided to follow all Pearson's (2002) recommendations, apart from the required 10 °C difference in internal and external air temperatures, for the preceding 24 hours before a thermography test is undertaken. This is because Hopper *et al.* (2012b) have demonstrated that when undertaking qualitative thermography tests APT's (n.d.) recommendations for air temperatures being at least 5 °C different between internal and external temperatures, and only for the preceding four hours before and during the test, produce robust results.

As part of the ongoing development of the iCT:Th test researchers from the EBERE group are investigating which of the recommendations from Table 4.1 can be challenged, particularly as only qualitative tests are being used. Quantifying heat loss will be investigated through other EBERE iCT tests. Quantifying heat loss through thermography is not recommended by Pearson (2002). To achieve the test conditions illustrated in Table 4.1, the EBERE iCT:Th test is developing a modus operandi with a pre-test procedure, an on-test procedure and a post-test procedure, as illustrated in Table 4.2. The EBERE iCT:Th test modus operandi is a further development of the thermography protocol discussed in Littlewood *et al.* (2011b). Further information on the initial development of a test procedure for the iCT of the thermal performance of dwellings using thermography is illustrated in Taylor *et al.* (2012).

Pearson (2002)	Hart (1991)	APT (n.d)
1. No direct solar radiation on the surfaces to be inspected in the preceding hour.	1. The façade of the building should not be exposed to sufficient solar radiation that would affect the results, during and for at least 12 hours prior to the survey.	1. No recommendation.
2. A temperature difference of at least 10 °C across the building envelope for ideal test conditions, i.e. between the internal rooms in the building and the external climate.	2. A temperature difference of at least 10 °C across the building envelope for ideal test conditions, i.e. between the internal rooms in the building and the external climate.	2. A temperature difference of at least 5 °C across the building envelope for ideal test conditions, i.e. between the internal rooms in the building and the external climate.
3. The difference in internal and external air temperatures should be at least 10 °C in the preceding 24 hours (±5 °C for 'lightweight' structures).	3. The difference in internal and external air temperatures should be at least 10 °C in the preceding 24 hours.	3. The difference in internal and external air temperatures should be at least 5 °C in the preceding 4 hours and during the test.
4. The external air temperature should not exceed ±3 °C during the test hour itself.	4. No recommendation.	4. No recommendation.
5. All surfaces to be inspected must be dry with no precipitation 24 hours and immediately prior to or during the survey (including mist and fog).	5. All surfaces to be inspected must be dry at and during the survey.	5. All surfaces to be inspected must be dry at and during the survey.
6. Wind speeds not to exceed 10 m/s during the survey.	6. No recommendation.	6. Wind speeds not to exceed 6 m/s during the survey.
7. Surveys should be undertaken in darkness to minimise effects from solar radiation.	7. Surveys can be undertaken on cold and overcast days.	7. No recommendation.

Table 4.1 Recommended environmental conditions, before and during thermography surveys (Source: information from Hart, 1991, Pearson, 2002 and APT, n.d.).

1.0 EBERE iCT:Th pre-test procedures		
Step	**Period before test**	**Tasks and responsibilities**
1.1	***14 days prior to test***	Agree dwelling/s to be tested with client, design team and contractor's representative, preferably including the site manager. Conduct briefing to discuss the procedures that will be conducted prior to and during the test and the responsibilities of the testers, client and contractor. In brief the responsibilities are laid out here: ***Tester responsibilities***: ■ Obtain in writing, permission from client and contractor (latterly if required due to procurement contract, used for build) to attend site and undertake test. ■ Provide equipment for test, calibrated and with valid Portable Appliance Testing (PAT) tests, to include: ■ Thermal camera, with a minimum resolution of 320 × 240 pixels and a full colour spectrum (TSB, 2011), such as a FLIR B365 or FLIR Eb60 (FLIR, 2012a, 2012b); □ Environment meter with thermometer, hygrometer and anemometer functions, such as a Kestrel 3000 pocket meter (Kestrel, 2012); □ Extension leads appropriate for 110 volt appliances and length between heater/s and transformer; □ 110 volt transformer/s for the heaters used during the test; □ Head torch for each tester; □ Site safety clothing for each tester. ■ Determine climatic conditions and agree appropriate day/s for the test. ■ Inspect dwelling before test commences to ensure minimum environmental conditions are met within the dwelling. ■ Determine climatic and internal conditions prior to and during the test. ■ If the tester's 110 volt electrical heaters are used, one 20 metre extension cable per heater should also be brought to the test. Also, all electrical equipment should have valid PAT certificates and be tested at least 14 days before the test. ■ Collect visual images in daylight hours before the test. ■ Collect thermograms during the test. ■ Analyse the collected data. ■ Prepare a report, illustrating and discussing anomalies found and recommend potential solutions and further tests to validate observations. ***Client responsibilities***: ■ Provide permission in writing to the tester that they can undertake the test and that personal liability insurance will be provided to the assessors. Also, facilitate access to appropriate personnel within the client's team and the design team that the test can be organised and undertaken.

Table 4.2 The modus operandi to conduct an EBERE iCT:Th test.

1.0 EBERE iCT:Th pre-test procedures

Step	Period before test	Tasks and responsibilities
		Contractor's responsibilities: ■ Provide permission in writing to the testers that they can undertake the test and that personal liability insurance will be provided to the assessors. Also, facilitate access to appropriate personnel within the contractor's team that the test can be organised and undertaken. ■ To provide the necessary insurance cover to allow the test to be undertaken on a live construction site. ■ To induct the testers in site safety procedures before access to the site and the test procedures begins. ■ To provide personnel to accompany the testers to and from the test dwelling/test areas, prior to the test beginning and during the test. ■ To provide sufficient power and transformers (latterly if required) for the test to be undertaken. ■ If the contractor is providing the 110 volt electrical heaters, sufficient extension cables per heater should also be brought to the test. Also, all heaters and electrical appliances should have valid PAT certificates and be tested at least 14 days before the test. ■ To ensure the test dwelling/s is/are secure 48 hours prior to and during the test and that no site personnel can conduct works to these dwelling/s 24 hours before the test is undertaken, during and until the test is complete. ■ To ensure that the minimum conditions are met within the dwelling 24 hours prior to the test commencing. ■ To allow access to the testers at least 48 hours prior to the test to inspect the dwelling and route-way, which will be travelled (walking and other transport if necessary) to the dwelling, across the construction site. ■ To provide power to the dwelling and 110 volt transfer with sufficient sockets for the heaters to be used during the test. ■ To ensure external and internal safety lighting is de-activated in the immediate vicinity of the test dwelling/s, prior to the test and during the test, as this could cause problems for the thermal cameras being used for the test. ■ Conduct a risk assessment, as iCT:Th tests will almost always be undertaken in the dark at night or early morning before sunrise, depending on the weather conditions prior to the test.
1.2	***7 days prior to test***	■ Testers to verify weather conditions and select appropriate days that meet the minimum environmental conditions set out in Table 4.1 above and inform the client's representative and contractor's site manager. ■ Test all equipment to ensure that it is suitable for use during the test. ■ Determine the number of 110 volt electrical fan heaters, extension leads, transformers and power source requirements to be used during the test.

Table 4.2

1.0 EBERE iCT:Th pre-test procedures		
Step	**Period before test**	**Tasks and responsibilities**
		■ The power output and number of heaters required will depend upon the configuration of the building, since the test dwelling will be zoned to ensure that a relatively even temperature profile is achieved throughout. In addition, the placement of circulation fans in locations appropriate to encourage air movement may assist with achieving a more even temperature distribution within the test dwelling.
1.3	***3 days prior to test***	■ Tester to re-check the climatic conditions on the selected test day and re-select days if necessary. ■ Tester to check with the client and contractor that test dwelling/s will be ready for test and 48 hour checks. ■ Collect written permissions to undertake the test if not already provided.
1.4	***48 hours prior to the test***	■ Inspect the dwelling before the test commences to ensure minimum environmental conditions are met within the dwelling. ■ If the tester's 110 volt electrical heaters are used, one 20 metre extension cable per heater should also be brought to the test. ■ Collect visual images in daylight hours before the test. ■ Undertake risk assessment and site safety induction with the contractor, if not already completed.
1.5	***24 hours prior to the test***	■ Activate heaters, check power supply to each heater, ensure windows, vents and doors are closed and internal doors are opened within the test dwelling. ■ Ensure signs are displayed to ensure no site personnel enter the test dwelling prior to/during the test. ■ Walk the route from the site compound to the test dwelling/s, noting any hazards along the route and re-check site safety procedures. ■ Re-check all equipment for the test, ensuring batteries are charged where necessary. ■ Print an EBERE thermography building survey proforma to record information during the test: date, time, location, property type, construction type, orientation, environmental conditions, identification for each image and description. ■ Check external climatic conditions for the test; abort and re-select day if not appropriate or confirm test with the contractor and client's representative. ■ If a meteorological station is located in close proximity to the test dwelling then local climatic conditions during the 24 hours preceding the survey can be recorded.
1.6	***At the start of the morning (for an evening test) or at the end of the afternoon (for a test the next morning)***	■ Contact contractor and client to ensure everything is in place for the test. ■ Re-visit the site to check internal heating is in place and all windows and vents are closed. ■ Ensure all testers will be wearing appropriate clothing for the test including personal safety high visibility vest, hard hat and appropriate footwear.

Table 4.2 (Cont'd)

2.0 EBERE iCT:Th on-test procedures		
Step	**Period before test**	**Tasks and responsibilities**
2.1	***4 hours before test***	■ Test environmental conditions internal and external to the test dwelling meet the conditions set out in Table 4.1 above.
2.2	***1 hour prior to test***	■ Re-check environmental conditions internal and external to the test dwelling meet the conditions set out in Table 4.1 above. These measurements should be repeated at the end of the survey. ■ If conditions are not met, abort the test.
2.3	***Immediately before commencing test***	■ Repeat recordings of environmental conditions. ■ Inspect surfaces internal to and external to the dwelling/s being tested; particular note should be taken of window and any junctions/details in the construction (e.g. wall-ceiling, wall-floor, wall-opening junctions and void spaces, such as roofs). Any areas that appear unusual and any suspected performance anomalies that could affect thermal, acoustic or fire performance should be assessed in detail with close-up images captured with both the thermal camera and a digital camera (unnecessary images can be deleted later).
2.4	***During the test***	■ Commence the test (minimum of two testers – one to record the thermograms and one to record the manual information on the EBERE thermography building survey proforma and to highlight hazards to tester using camera) outside the building and re-record the environmental conditions using the same suitably calibrated environment meter, as one hour prior to the test beginning, noting any changes. ■ Thermal patterns (qualitative) should be examined using a thermal camera, on all surfaces of the external façade of the test dwelling and inside the test dwelling. Note, the thermal camera used should have a minimum resolution of 320 × 240 pixels and a full colour spectrum (TSB, 2011), such as a FLIR B365 or FLIR Eb60 (FLIR, 2012a, 2012b). ■ Collect both thermograms and visual images and pay particular attention to focusing each image (both thermograms and visual) on the external fabric of the test dwelling. ■ Particular note should be taken of window and any junctions/details in the construction (e.g. wall-ceiling, wall-floor, wall-opening junctions and void spaces, such as roofs). Any areas that appear unusual and any suspected performance anomalies that could affect thermal, acoustic or fire performance should be assessed in detail with close-up images captured with both the thermal camera and a digital camera (unnecessary images can be deleted later). ■ The thermal camera, or other infrared sensing device, should be adjusted to compensate for the material and surface properties of the area of the test dwelling under observation and the environmental conditions in which it is observed as per the manufacturer's instructions.

Table 4.2

2.0 EBERE iCT:Th on-test procedures

Step	Period before test	Tasks and responsibilities
		■ Written or audio notes should be taken to accompany each image recorded during the EBERE iCT:Th test to aid interpretation and identification of the image within/external to the building, the surface, the orientation and the potential anomaly identified on site. ■ Re-record the environmental conditions using the same suitably calibrated environment meter, as indicated above in Table 4.1, noting any changes. ■ De-activate all heaters, disconnect from all extensions, transformers and power supply – if supplied by the testers, remove from the test dwelling and store in the site compound (or other appropriate secure storage). ■ Sign-out of the site.

3.0 EBERE iCT:Th post-test procedures

Step	Period after test	Tasks and responsibilities
3.1	***Immediately after the test and either in the site compound or in another secure location***	■ Download the images immediately following the test.
3.2	***1 day after test***	■ Collect any heaters or other equipment from site. ■ Thermally tune images in the appropriate software supplied by the thermal camera manufacturer. ■ Analyse and interpret anomalies and determine requirements for further testing and/or potential solutions.
3.3	***2 days after tests***	■ The results of the EBERE iCT:Th test should be presented in a report including a description and interpretation of the thermograms and visual images recorded prior to and during the survey, identifying anomalies and potential causes and also recommendations for further investigation using the EBERE iCT:T and also other tests, such as opening up the fabric and conducting inspections using an endoscope, fitted with a digital camera and illumination. The report should follow recommendations set out in British Standards Institute (1999) and Pearson (2002).
3.4	***Up to 5 days after test***	■ Meet with the client's representative and contractor's representative to discuss the results and arrange any additional testing.

Table 4.2 (Cont'd)

Case Study One

Images 4.2 to 4.11 (see Table 4.6 later) show Case Study One, which is one apartment in a block of apartments on a split level site, developed by Coastal Housing Group (CHG) in Swansea. There are 69 two bedroom apartments on five floors, situated above a basement, which is at street level at the rear of the building, but below street level at the front. All apartments are designed and have been constructed to level four of the CfSH and were completed and commenced occupation in December 2011. The apartments are part of the Welsh Government's Pathfinder scheme of 400 dwellings across Wales (Welsh Assembly Government, 2009). The aim of the Pathfinder scheme was to promote new design and construction methods and technologies, and also develop expertise in Wales for the delivery of low carbon dwellings. The Welsh Government (formerly Welsh Assembly Government) provided additional funding within the Registered Social Landlord (RSL) Development programme in 2008 to pilot 22 'Pathfinder' housing schemes built to levels four and five of the CfSH. However, resources were not allocated within the RSL Development programme to investigate the impact of the CfSH on the development process, or to measure and report on the environmental performance of the dwellings in use, curtailing an essential element of the feedback and learning process for clients and the design and construction teams involved (Taylor *et al.*, 2010).

The apartment where the EBERE iCT:Th test was undertaken was deemed suitable for thermal performance testing during the construction process, albeit at the latter part of the second fix, by the contractor's site manager and CHG's project manager. This was to provide confidence that the low carbon design strategy had been translated into a low carbon construction method and therefore achieve the design targets for thermal performance. The targets for Case Study One included a design air permeability of 3 $m^3/h\,m^2$ at 50 Pa, but following a pressurisation test conducted on 8 December 2010, achieved an air permeability of 1.09 $m^3/h\,m^2$ at 50 Pa (Taylor *et al.*, 2012). Table 4.3 below illustrates the *U*-values of the fabric of Case Study One.

Building component	*U*-value (W/m² °C)
Interior door	1.80
Window	1.80
Exterior wall	0.20
Separating floor	0.26
Roof	0.20
Separating wall	0.26

Table 4.3 *U*-values for key construction components at Case Study One.

Case Study Two

Images 4.12 to 4.21 (see Table 4.6 later) show Case Study Two, which is one dwelling in a pair of semi-detached houses, owned by another housing association (not CHG). Case Study Two was constructed by one of the UK major residential developers and the second housing association and is situated in Caerphilly, UK. Case Study Two was completed in 2009 and was designed and built to level three of the CfSH.

Case Study Two was chosen for documentation in this chapter since it provides an example of a dwelling, which did not have an EBERE iCT:Th test undertaken during the construction process, since it had not been developed at the time of construction. Table 4.4 illustrates the *U*-values of the fabric of Case Study Two. Unfortunately, the results of the pressurisation test have not been made available to the author. Case Study Two was also chosen because the occupants of the dwelling had expressed concerns about their internal comfort conditions, in at least two of the rooms of the house, in terms of internal temperatures being below their perceived comfort.

Building component	*U*-value (W/m^2 °C)
Exterior door	1.80
Window	1.80
Exterior wall	0.28
Ground floor	0.16
Roof	0.13

Table 4.4 *U*-values for key construction components at Case Study Two.

Results

The environmental conditions recorded during the tests on 31 January 2011 (Case Study One) and on 29 February 2012 (Case Study Two) are shown in Table 4.5. All environmental data was recorded using a Kestrel 3000 pocket weather meter (Kestrel, 2012). It should be noted that the external conditions recorded at the Case Study One test should have been recorded immediately prior to the test beginning at 18.30, in addition to the recording at 16.30. The reason why the conditions were not re-tested at 18.30 is because the environmental conditions meeting Pearson's recommendations (from Table 4.1) had been met at 16.30. However, if the modus operandi for an EBERE iCT:Th is to be adhered to, the environmental conditions should have been re-tested immediately prior to the test (see step 2.3 in Table 4.2).

Thermograms and visual pictures captured at Case Study One and Case Study Two, on 31 January 2011 and 29 February, are shown in Table 4.6.

Environmental conditions	**Case Study One January 2011**	**Case Study Two February 2012**
Sunset	17.02[a]	17.52[b]
External air temperature	4.0 °C at 16.30[c]	11.2 °C at 19.15
External relative humidity	69.0% at 16:30[c]	76.3% at 19.15
Internal air temperature	30.0 °C at 18:30[d]	23.0 °C at 19.15
Internal relative humidity	61.0% at 18:30[c]	57.3% at 19.15
Wind speed	0.0 m/s (sheltered site)	0.0 m/s

[a] Time and Date (2011).

[b] The Weather Channel (2012).

[c] City and County of Swansea (2011).

[d] Taylor *et al.* (2012).

Table 4.5 Environmental conditions for Case Study One and Case Study Two thermography tests.

Case Study One, January 2011 (in construction of new dwelling)

Figure 4.2 External view of the building.

Table 4.6 Results from thermography tests for Case Study One and Case Study Two.

Case Study One, January 2011 (in construction of new dwelling)

Figure 4.3 External view of the apartment.

Figure 4.4 Internal view of the apartment.

Table 4.6 (Cont'd)

Case Study One, January 2011 (in construction of new dwelling)

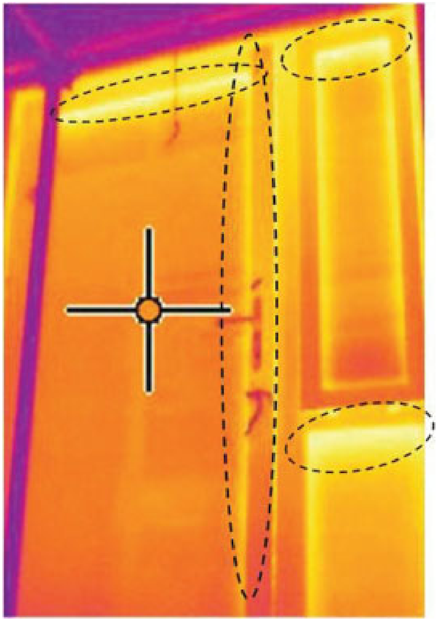

Figure 4.5 External thermogram of door (i) and window (i). Reproduced by permission of Steve Goodhew.

Figure 4.6 Interior view of door (ii) and window (ii).

Table 4.6 (Cont'd)

Case Study One, January 2011 (in construction of new dwelling)

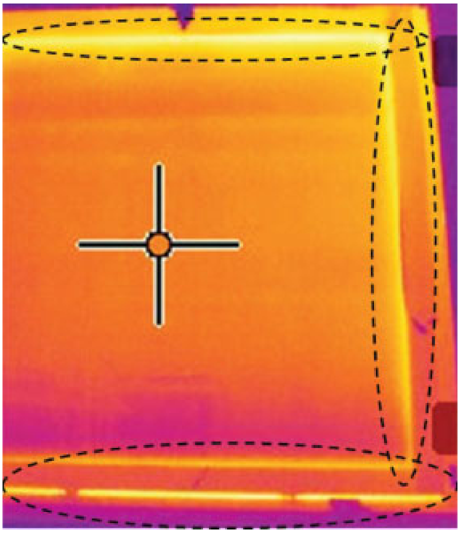

Figure 4.7 External thermogram of window (iii). Reproduced by permission of Steve Goodhew.

Figure 4.8 External view of window (iii) (there is a reflection on the external pane of the window).

Table 4.6 (Cont'd)

Case Study One, January 2011 (in construction of new dwelling)

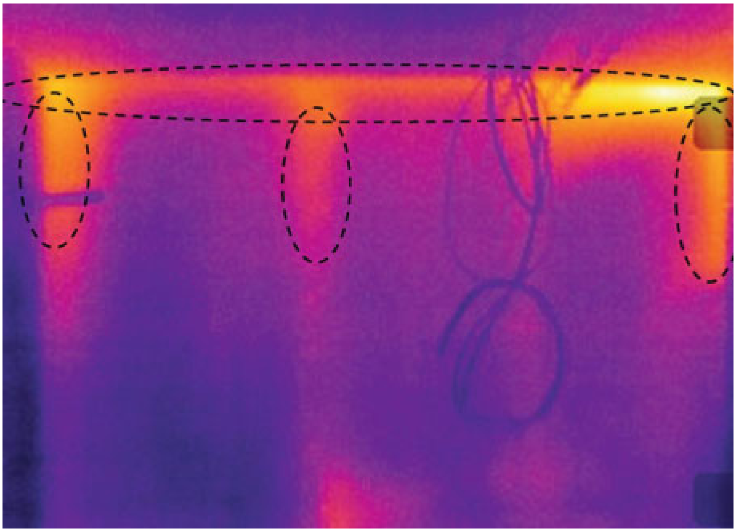

Figure 4.9 Internal thermogram of the apartment separating wall. Reproduced by permission of Steve Goodhew.

Figure 4.10 Internal view of (top right) the apartment separating wall.

Table 4.6 (Cont'd)

Case Study One, January 2011 (in construction of new dwelling)

Figure 4.11 External view of the apartment building at practical completion and undergoing occupation (February 2012).

Case study Two, February 2012 (in-occupancy of new dwelling)

Figure 4.12 External view of the house.

Table 4.6 (Cont’d)

Case Study Two, February 2012 (in-occupancy of new dwelling)

Figure 4.13 External thermogram of the entire house (excluding annex).

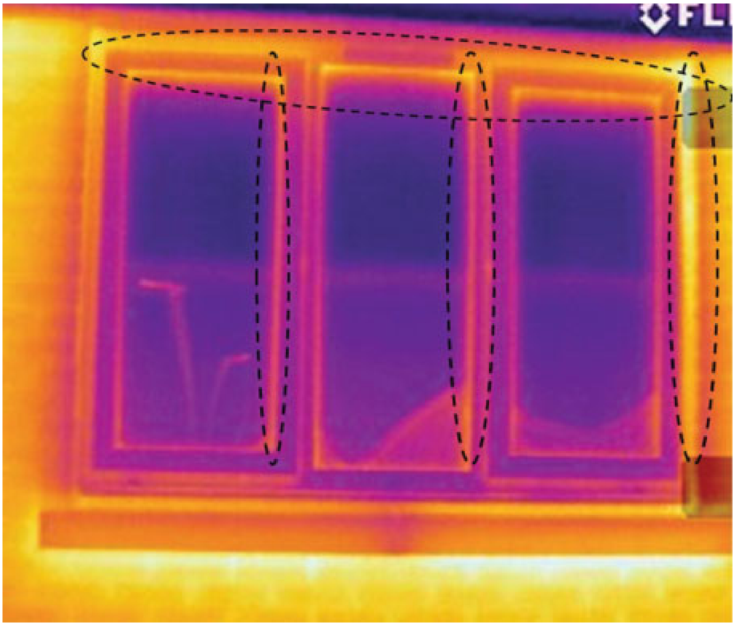

Figure 4.14 External thermogram of window (iv).

Table 4.6 (Cont'd)

Case Study Two, February 2012 (in-occupancy of new dwelling)

Figure 4.15 External view of window (iv).

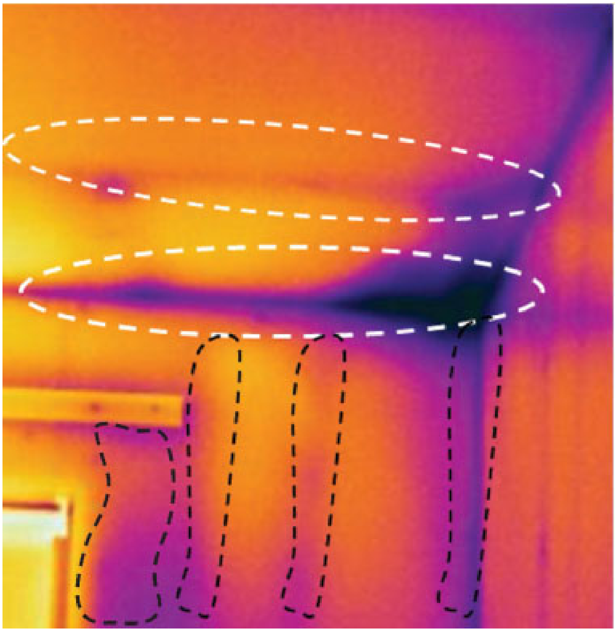

Figure 4.16 Internal thermogram of the exterior wall and ceiling interface.

Table 4.6 (Cont'd)

Case Study Two, February 2012 (in-occupancy of new dwelling)

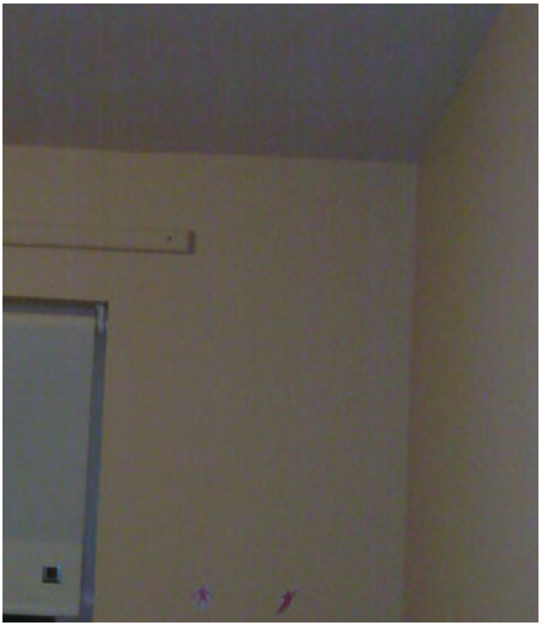

Figure 4.17 Internal view of the exterior wall and ceiling interface.

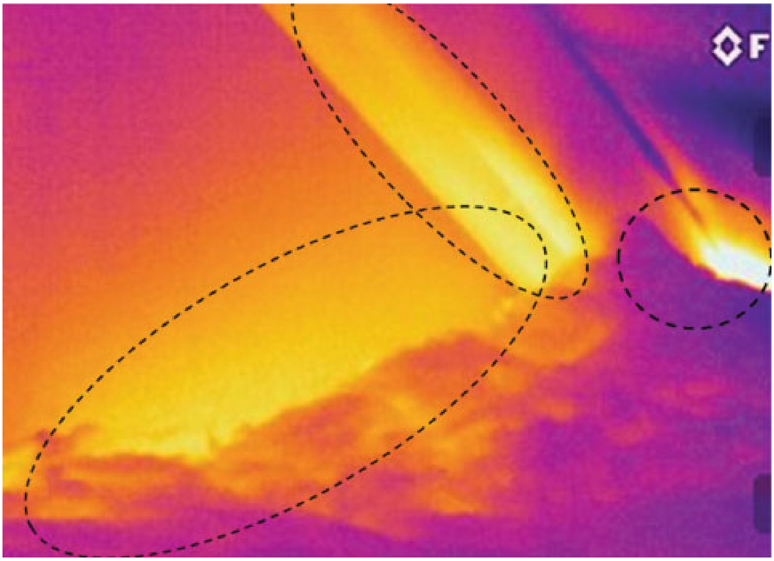

Figure 4.18 Internal thermogram of the roof space with exterior wall and ceiling interface facing the rear elevation of the house.

Table 4.6 (Cont'd)

Case Study Two, February 2012 (in-occupancy of new dwelling)

Figure 4.19 Internal view of the roof space with exterior wall and ceiling interface facing the rear elevation of the house.

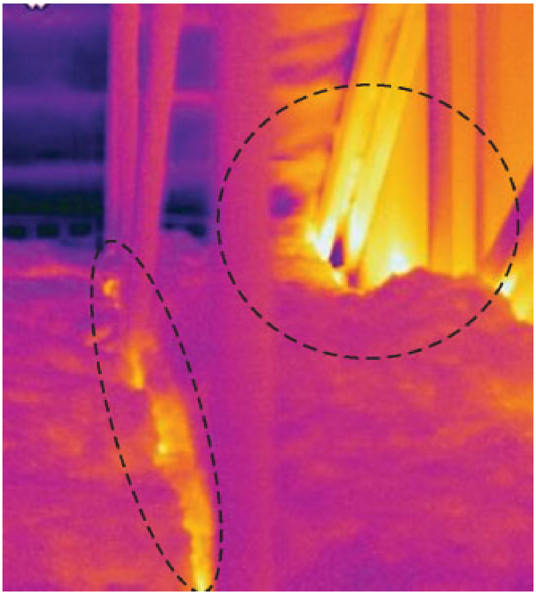

Figure 4.20 Internal thermogram of the roof space with exterior wall and ceiling interface facing the front elevation of the house.

Table 4.6 (Cont'd)

Case Study Two, February 2012 (in-occupancy of new dwelling)

Figure 4.21 Internal visual picture of the roof space with exterior wall and ceiling interface facing the front elevation of the house.

Table 4.6 Results from thermography tests for Case Study One and Case Study Two.

In each of the thermal images in Table 4.6 there appears to be a number of potential problems (highlighted by the dashed lines on each thermogram) that could affect thermal performance and potentially acoustic performance and fire performance of the dwellings. In each image, when viewing a heated space from an unheated space, such as outside the buildings, flat or in the loft space lighter shading illustrates greater heat loss and darker shading towards blue shows lower heat loss. When inside a heated space, however, such as in the building or flat, darker shading illustrates greater heat loss. If the thermograms were in colour then lighter colours would be towards range and yellow and darker colours would be towards blue. The potential problems include heat loss pathways at/in close proximity of:

(i) window sill level (Figures 4.7, 4.13 and 4.14);
(ii) in window frames where the glazing is fixed into the frame (Figures 4.5, 4.7, 4.13 and 4.14);
(iii) in door frames where the glazing is fixed into the frame (Figure 4.5);
(iv) at the interface between the ceiling and the timber frame stud partition, which is the separating wall between apartments (Figure 4.9 is taken in the

unheated apartment facing Case Study One, which has been heated prior to and during the test);

(v) the exterior wall (Figure 4.13 is taken outside facing the front elevation of Case Study Two);

(vi) unheated roof space on the ceiling joists (Figures 4.16, 4.18 and 4.20);

(vii) the junction of the ceiling with the exterior wall of the two storey house (Figures 4.18 and 4.20 are taken in the unheated roof space of the single storey annex);

(viii) thermal bridging on the timber frame joists, in the external walls and at the window and door reveals.

The possible causes of the potential problems include:

- poor design detailing (potential problems i, iv, v, vii and viii);
- poor workmanship, which could include poor translation of low carbon design into low carbon construction (potential problems i, iv, v, vii and viii);
- faulty components (potential problems ii and iii);
- poor inspection of completed works (all images);
- apparent uneven distribution of heat loss across the exterior wall (potential problem v);
- how the thermal camera sees emissivity of materials, such as where the edge of the glazing meets the frame in windows and doors (potential problems ii and iii).

Particular caution should be taken in respect of the window and door reveals and the eaves due to the higher thermal resistance of the brickwork that surrounds the openings and the highly reflective material of the unplasticised polyvinyl chloride (uPVC) windows and fascia boards respectively.

Unfortunately, it was not possible to undertake any further tests using the modus operandi for the EBERE iCT:Th or indeed other investigative tests to identify the causes of the problems at Case Study One, illustrated in Figures 4.5, 4. 7 and 4.9. Post completion thermography tests, similar to those that had been undertaken at Case Study Two, are to be undertaken as part of WP6 in December 2012. Additional tests have been recommended at Case Study Two using an endoscope and digital camera to investigate further the potential problems illustrated in Figures 4.13, 4.14, 4.16, 4.18 and 4.20. Furthermore, there is an opportunity to undertake additional tests on five other houses that have the same construction configuration as Case Study Two and where it is known that some of their occupants have experienced similar comfort conditions to the occupants of Case Study Two. It is anticipated that the housing association will be discussing the anomalies with the house builder who constructed the houses in 2008 and 2009.

Discussion

The results from the use of the EBERE iCT:Th test modus operandi at Case Study One have illustrated a number of potential problems. In addition, the results from a thermography study at Case Study Two where the EBERE iCT:Th testing modus operandi was not used during the construction process has illustrated significantly more problems than at Case Study One. All these problems could affect the thermal performance of the dwellings. Figures 4.9, 4.13 and 4.16 illustrate problems that could also affect acoustic performance, between dwellings and between the internal and external environments. Of particular concern is that the design strategy for Case Study One is one of a low carbon approach (level four of the Code for Sustainable Homes) and was one of the case studies included in the WG Pathfinder scheme. Poorly performing window frames and separating walls between apartments could undermine the low carbon strategy.

The results from Case Study Two illustrate that if the modus operandi for the EBERE iCT:Th test had been undertaken during the construction process (by the house builder's site manager) the identified potential problems may have been identified before the house was completed and therefore rectified before occupancy. In addition, if the problems had been rectified before occupancy, the finished dwelling's thermal performance should not have been compromised and neither should the comfort conditions of the occupants and resulting raised space heating costs have occurred.

The results are starting to address the general lack of detailed empirical evidence of the performance of low carbon dwellings during construction in the UK. This evidence combined with the results from Case Study Two is further justification for using iCT, particularly with thermography, i.e. the EBERE iCT:Th test. One of the outputs of WP6 will include protocols to enable guidance to be dissemintaed to Registered Social Landlord (RSL) and residential developers, on the assessment and monitoring of the thermal performance of dwellings. This builds upon recent research work in the UK for developing monitoring protocols for low carbon dwellings (EST, 2008; Littlewood, 2011a; Littlewood *et al.*, 2011a, 2011b; Taylor *et al.*, 2012).

Finally, the results from the use of the EBERE iCT:Th test at Case Study One and the use of thermography post construction in a dwelling where the EBERE iCT:Th test was not used, demonstrate that the modus operandi is an effective methodological approach for capturing qualitative data for built environment professionals engaged in the assessment of the thermal performance of dwellings, during the construction process and post construction. Similar findings of the use of thermography are observed by Hopper *et al*. (2012a), Pearson and Seaman (2003) and Thomsen and Rose (2009).

On-going research

As part of WP6 of the LCBE project, the EBERE group at Cardiff Metropolitan University are further developing the modus operandi for the EBERE iCT:Th test to include using it at the first fix level of other low carbon dwelling case studies. This testing will include determining the earliest starting point at the first fix and how frequently EBERE iCT:Th tests can be used throughout first and second fix construction; which other iCT tests can be used with the iCT:Th test, such as smoke generator tests and air-tightness testing; and challenging the minimum environmental conditions summarised in Table 4.1. This on-going research is being undertaken in collaboration with CHG. Furthermore, at Case Study One a weather station and internal sensors (in three apartments) will be installed to record internal temperatures, relative humidity and energy use of the occupants. Interviewing the occupants from the 69 apartments and spot measurements of air temperature, relative humidity (RH), CO_2 emissions, daylight levels and solar radiation will also be undertaken. For more information of the interview and spot measurement results to date see Nooraei *et al*. (2013).

Concluding thoughts

Architectural technologists are specialists in the science and technology of building design and construction. Architectural technologists are, arguably, best placed to address anomalies with poor design detailing, poor workmanship and poor build quality, and thus poor translation of low carbon design to low carbon construction and ultimately low carbon operation. The author of this chapter (an Associate Member of the Chartered Institute of Architectural Technologists (CIAT) since 2003) strongly believes, and is practising, that architectural technologists are the key built environment profession to test and monitor the thermal performance of dwellings. Research has shown that architectural technologists could use the iCT tests as part of their routine site inspections of current building projects. This could be an enhancement to the site inspection services that architectural technologists already provide or be a new service and consequently a new fee generator.

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Case Study D
Assessing Retrofitted External Wall Insulation

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Assessing the performance of retrofitted external wall insulation to existing properties is the theme of this case study chapter. The work draws on applied research conducted on existing houses in South Wales. The background and context to the research is described, followed by an exploration of the issues relevant to the insulation of solid external walls of existing dwelling houses. This is followed by the methodology, findings and discussion, and conclusion, which includes recommendations and implications for research by architectural technologists.

Introduction

Within this chapter the author demonstrates the significance of the architectural technologist's knowledge and skills for undertaking applied research. The author is an architectural technologist and winner of the CIAT Student Award for Technical Excellence in 2010 (CIAT, 2011). The award winning submission was based on the final year design project from the author's first degree, which was from the Cardiff School of Art and Design within Cardiff Metropolitan University (formerly the University of Wales Institute Cardiff). Following graduation the author successfully applied to study for a PhD through applied research within the same school. The aim of the research is to evaluate the implementation of retrofitted external wall insulation (EWI) and the resultant impact on energy use, carbon emissions and fuel poverty. EWI was installed through the first phase of the Welsh Government's Arbed funding scheme at a selection of Swansea's hard-to-treat dwellings. One of the funding criteria was that monitoring and evaluation should be undertaken to demonstrate the effectiveness of the energy efficiency improvements. However, there was no methodology in place and very limited funding for

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these assessments; therefore the doctoral research project was designed by a housing association based in Swansea in conjunction with Cardiff Metropolitan University, with the aim of meeting the requirements.

One of the objectives of the research is to examine the technical solutions used to retrofit the EWI and determine the effects on the quality of installations. The methodology adopted includes site visits to discuss the retrofit process with the housing association and to undertake field observations (during and after installations), along with pre-retrofit and post-retrofit thermographic surveys. The key findings comprise evidence of potential thermal bridging as a result of an incomplete covering of insulation, which was due to either: inadequate preliminary surveys; the omission of appropriate technical details at the design stage; poor execution and insufficient quality control on-site during installations; or a combination of these issues. These findings could have implications for stakeholders involved in EWI retrofit projects, in particular for phase two of the Welsh Government's Arbed scheme and the UK Government's forthcoming Green Deal initiative.

Background and context

The UK Government has set a legally binding target to reduce greenhouse gas (GHG) emissions by 80% by 2050. However, if this target is to be realised then the reduction in GHG emissions resulting from energy use in existing dwellings needs to be prevalent. With over 66% of the current housing stock expected to still be in use in 2050 (Department for Communities and Local Government (DCLG), 2008), thermally improving existing dwellings is becoming a priority. The challenge of undertaking these improvements is equally important, as the UK has a substantial number of older and poor quality dwellings. Around 15% of approximately 26 million existing dwellings in the UK were built before 1919 and 40% have a Standard Assessment Procedure (SAP) rating of 41 or below, which correlates to an F or G rating on an Energy Performance Certificate (EPC) (DCLG, 2006).

All G rated and many F rated dwellings have an SAP rating of 30 or below, which indicates they have very poor thermal and fuel efficiency (Boardman, 2007; DCLG, 2006). These dwellings also qualify as a Category One Hazard for Excess Cold under the Housing, Health and Safety Rating System, which means they pose a risk to the health of occupants (Boardman, 2007). The majority of these dwellings are also classified as 'hard-to-treat', which denotes that they are either of solid wall construction, of nontraditional construction, not on the mains gas network, do not have a loft space, are part of high rise block or are not suitable for standard efficiency measures for technical reasons (National Energy Action, 2008; Housing Energy Advisor, 2011). According to National Energy Action (2008), over 50% of hard-to-treat dwellings are of solid wall construction.

In Wales approximately 21% of existing dwellings have solid walls (King, 2012a). In recognition of the requirement to thermally improve these and other poor quality existing dwellings the Welsh Government implemented the Arbed funding scheme in 2009. The purpose of the scheme is to take a community-based and whole-street approach to the reduction of energy use, carbon emissions and fuel poverty. For phase one of Arbed, local authorities and social housing providers were able to bid for a share in the funding to upgrade both public and privately owned dwellings in the most deprived areas across Wales. Approximately 30% of the £60 million funding was invested in insulating solid walls at nearly 3000 hard-to-treat dwellings across Wales (Welsh Government, 2011). These figures suggest an average cost of £6000 per dwelling, which is around 50% less than for an isolated installation. These reduced costs were achieved due to the application of economies of scale (Welsh Government, 2011). EWI costs at this level are comparable to levels of funding that are expected to be available through the Green Deal, which is estimated to be up to £10 000 (AECB, 2011).

Insulating solid walls

Solid walls can either be insulated internally or externally. As documented in Hopper *et al*. (2012a), the advantages of retrofitting EWI over internal wall insulation include: reduced risks from unavoidable thermal bridging caused by an incomplete covering of insulation, for example at partition wall and floor junctions; airtightness is improved; thermal mass is retained on the inside of the building, thus aiding control of the internal environment; minimal disruption to occupants; internal floor area is retained; and internal fittings and fixtures do not have to be relocated or restricted to predetermined locations. The main advantage of EWI is that it provides a thermal and waterproof layer for the entire envelope of the building (King, 2012b). However, retrofitting EWI can present technical challenges to ensure a complete covering is achieved.

Where EWI is not continuous, avoidable thermal bridging can occur. This poses a risk of internal and interstitial condensation, which can lead to damp and mould growth, and compromise reductions in heat loss (Hopper *et al*., 2011, 2012a; English Heritage, 2010; Energy Saving Trust (EST), 2006; Immendorfer *et al*., 2008). According to King and Weeks (2010), approximately 30% of heat loss from a building can be attributed to thermal bridging between thermal elements and around openings. Furthermore, Burberry (1997) states that the greater the level of insulation in buildings, the more significant thermal bridging becomes in terms of the overall thermal performance. To minimise thermal bridging when retrofitting EWI, and thus increase overall thermal performance, preliminary surveys should be undertaken to inform the production of appropriate technical details at the design stage (Energy Solutions, n.d.). Particular attention is required when designing details for window and door openings, wall to roof junctions, window sills and any projections, such as porches and conservatories (Construction Products Association, 2010; English Heritage, 2010; EST, 2006; Immendorfer *et al*., 2008; Hopper *et al*., 2012a). These design intentions then need to be executed accurately on site, to ensure overall thermal performance is not undermined by poor workmanship (Immendorfer *et al*., 2008; Hopper *et al*., 2012a).

Methodology

The focus of this study is to assess EWI installations at some of the Arbed phase one case study dwellings in Swansea. The purpose of these assessments is to examine the technical solutions implemented on site and determine the effects on the quality of the EWI installations. Based on the literature review the most significant issue that could affect the overall quality of the EWI's physical performance is that of thermal bridging, and the subsequent consequences related to possible condensation. Using established building performance evaluation techniques for data collection, the methodological approach decided upon includes: site visits, which involved meeting with the housing association and undertaking field observations at the dwellings to record methods of installation; and pre-retrofit and post-retrofit thermographic surveys to assess before and after heat loss. Collectively, these methods should allow for the identification and causes of potential thermal bridging.

Site visits

During the site visits regular meetings were undertaken with the housing association and information was collected to inform the process used to implement retrofitting the EWI at their allocated Arbed dwellings. Site visits also involved field observations, where the main method of data collection was photography. Photographs were taken before, during and after EWI installations, which allowed a record to be kept for the different stages of the retrofit process. Through field observations, the technical details that were implemented on site were also recorded. These technical details were then drawn in CAD software, using a combination of the photographs, observations made by the author, and generic details and specifications obtained from the manufacturers of the EWI systems.

Thermographic surveys

Pre-retrofit and post-retrofit thermographic surveys were undertaken to qualitatively assess external wall insulation that has been installed at a small sample of the Arbed case study dwellings in Swansea. The qualitative thermographic survey images display thermal patterns that indicate the possible locations of increased heat loss and thus potential thermal bridging. Due to the environmental conditions recommended to undertake a thermographic survey, the initial challenge was to determine a day with a suitable weather forecast, both before and during the planned survey. The recommendations include: no solar radiation for at least the preceding hour before the survey; no precipitation during the survey and for the preceding 24 hours to ensure the fabric is completely dry; and maximum wind speeds of 10 metres per second. Furthermore, a 10 °C temperature difference between the inside and the outside of the building during the survey is recommended.

Once a suitable date and time for each survey was determined, occupants were contacted, either by telephone or in person, to explain the purpose of the survey and to establish their availability. If the occupant was available, they were: advised of the names of the thermographers; requested to activate their heating at least four hours prior to the survey; requested that all windows and doors are kept shut before and during the survey; asked for permission to take photographs of their home, as well as take the thermal images; and permission was requested to enter their home at the time of the survey to record internal temperature and relative humidity readings. Photographs were taken the day preceding the surveys for the purposes of aiding interpretation of the thermal images.

Results from one Arbed dwelling in Swansea are described for the pre-retrofit and post-retrofit thermographic surveys. These results represent common findings displayed at many of the Arbed dwellings in Swansea.

Findings and discussion

The housing association worked with an external project manager and engaged a design and build contract with a principal contractor to oversee and undertake the retrofitting works. The contractor employed subcontractors to install the EWI. Although the principal contractor was responsible for the preliminary surveys and the resultant technical details for the various types of junctions, there is little evidence that these were undertaken. Lack of evidence is demonstrated by some of the methods used to install the EWI, confirmed in the field observations. Furthermore, the housing association only received copies of generic technical details and specifications, which were produced by manufacturers.

Time constraints imposed by one of the Arbed funding criteria may have restricted the level of preliminary work that could reasonably be undertaken. This criterion was that works had to be completed by the end of March 2011, which was less than 12 months after confirmation that the funds were to be awarded. Much of this time was spent engaging with occupants of dwellings and undertaking procurement for the works. Installations of the EWI commenced in late December 2010. This meant that much of the work had to be undertaken in poor weather conditions, despite the manufacturers' recommendations that the EWI is not to be installed in such circumstances.

Field observations

Figure D.1 is an example of a completely sealed external junction at the eaves, which demonstrates that despite the challenges of retrofitting EWI, relatively good detailing can be achieved in practice. Nevertheless, there is likely to be a thermal bridge created at the eaves due to the insulation stopping below the fascia board, as demonstrated later in Figure D.4. This is the technical solution recommended by the manufacturer for buildings with no roof overhang at the eaves and verge junctions, which is the form of roof construction at the case study dwellings.

Figure D.1 Example of a well planned and executed junction detail.

Figure D.2 is an example of poor execution on site, a direct contrast to Figure D.1, in that it appears that not enough thought and consideration has gone into how to achieve a satisfactory technical solution. The new fascia board, which was installed as part of the works, does not extend to the new outside edge of the gable wall, resulting in an unsatisfactory finish. There is a gap between the edge of the fascia board and the insulation board that has been fixed to the gable wall, which could allow rainwater to enter and penetrate the insulation, as well as exacerbating the potential thermal bridge at the eaves. The capping that is covering the top of the insulation on the gable wall has been cut too short and therefore does not provide complete protection from rainwater penetration. Furthermore, the gutter does not extend to the external edge of the roof tiles and therefore rainwater can run down into the top of the unprotected insulation board fixed to the gable wall. Where rainwater can penetrate the insulation, the likely consequence is that the overall thermal performance will be impaired.

Figure D.3 demonstrates the lack of a preliminary survey that should have identified the obstruction the insulation will cause for opening the window. As a result, an area of the wall has been left uninsulated and has created a thermal bridge. Had a preliminary survey been undertaken, a more appropriate technical solution for the junction may have been ascertained. This particular issue was relatively common in the Arbed case study dwellings in Swansea and in each situation where this was encountered, an area of the wall had to be left without any insulation.

Figure D.2 Example of a poorly planned and executed junction detail.

Figure D.3 Example of the lack of a preliminary survey and appropriate technical detail.

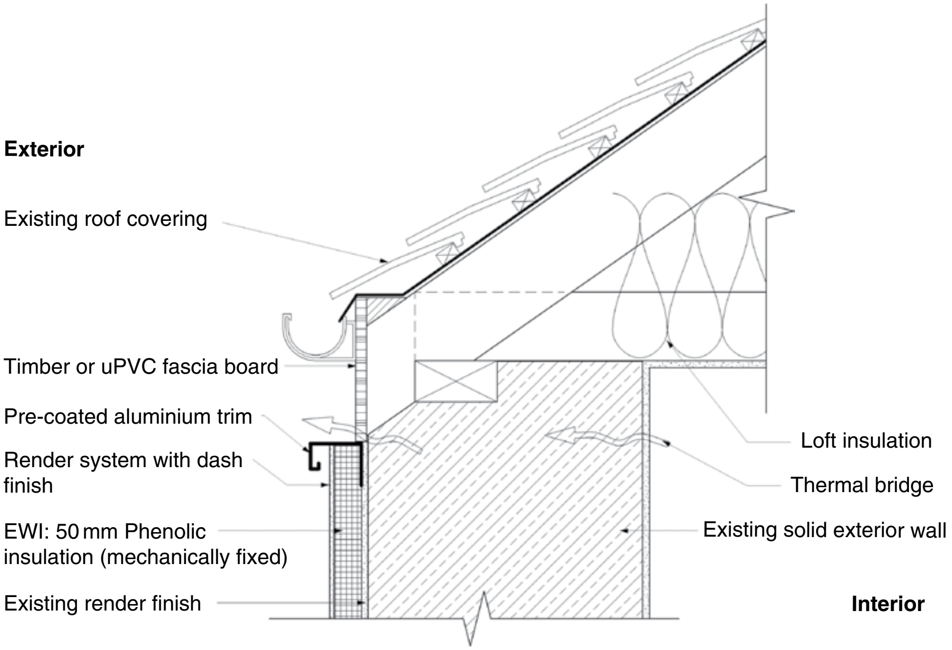

Figure D.4 Eaves detail as observed on site (Source: Hopper *et al.*, 2012b).

Figures D.4 to D.6 (which are not to scale) illustrate the technical solutions implemented on site at the eaves, window sills and pavement to external wall junctions. These details have been produced based on observations from sites and have provided a valuable link between photographic and thermographic data for assessing some of the potential issues. Figure D.4 demonstrates the use of the pre-coated aluminium trim to cap the top of the insulation, which can be seen in Figures D.1 and D.2. This detail identifies the potential path of a thermal bridge at the eaves, resulting from the insulation stopping below the fascia board. As discussed above, this is the manufacturer's recommended technical solution for protecting the top of the insulation at buildings that do not have a roof overhang.

However, it would appear that a more satisfactory solution should be explored to reduce the potential risks posed by this method of installation. If there is a thermal bridge in the location indicated, there is a risk of interstitial and internal condensation. This could lead to the rotting of timber and thus jeopardise the structural integrity of the roof construction, and also lead to damp and mould growth on the internal surface of the walls and ceiling, which could affect the health of the occupants.

Figure D.5 illustrates the method of installing the EWI system at the window sill junctions. To maintain the window projection, insulation was fixed to the front of the existing stone sills. The rationale for this method does not appear to be for the purpose of minimising heat loss at this junction because there is the potential

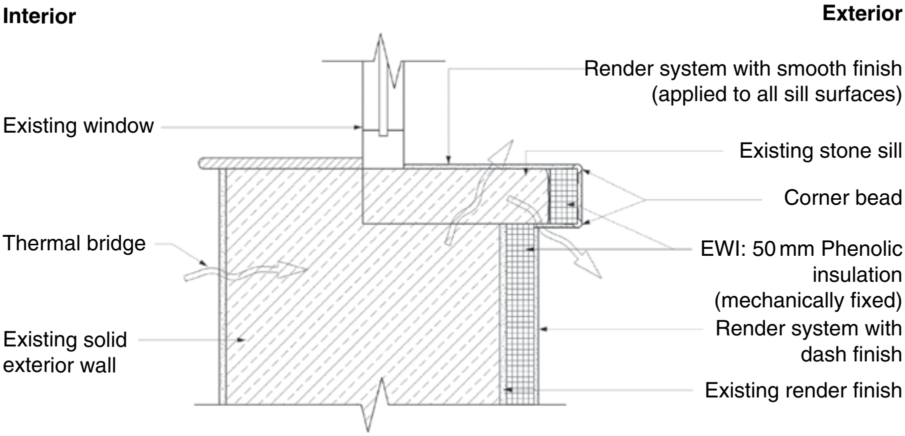

Figure D.5 Window sill detail as observed on site (Source: Hopper *et al.*, 2012b).

for thermal bridging through and below the existing stone sill. This could result in damp and mould growth occurring below the window sill on the internal surface of the wall. A more satisfactory solution could have been to insulate above and below the window sill and thus provide a continuous covering. This could be improved further by ensuring that future window replacements incorporate frames with a thermal break.

Figure D.6 shows the method used to insulate the base of the external wall at the junction with the pavement. There are two variations in the methods of installation recommended by the manufacturer in their generic details. One method is that extruded polystyrene (XPS) is installed below the phenolic insulation, which is used above the damp proof course (DPC) level. With this method the manufacturer's recommendations also illustrate that the XPS should be installed below ground level. The other method is for no insulation to be installed below the DPC level. Instead, with this method, the plinth area of the external wall can be painted with silicone paint. While an attempt has been made at the Arbed case study dwellings in Swansea to improve the thermal performance by insulating the plinth of the external wall, unless the first method is used there remains the potential for thermal bridging at ground level (as shown in Figure D.6). Due to the age of the dwellings it is predicted that most of them have suspended timber ground floor constructions. If condensation occurs due to the thermal bridging, there is a risk that the floor structure could get damp and thus rot. In addition, damp and mould growth could occur at the base of the internal surface of the external wall.

Thermographic surveys

Figures D.7 to D.11 show an Arbed case study dwelling in Swansea before and after the work took place. Figures D.7 and D.9 aid interpretation of the thermal images (Figures D.8, D.10 and D.11). The comparison between Figures D.8 and D.10

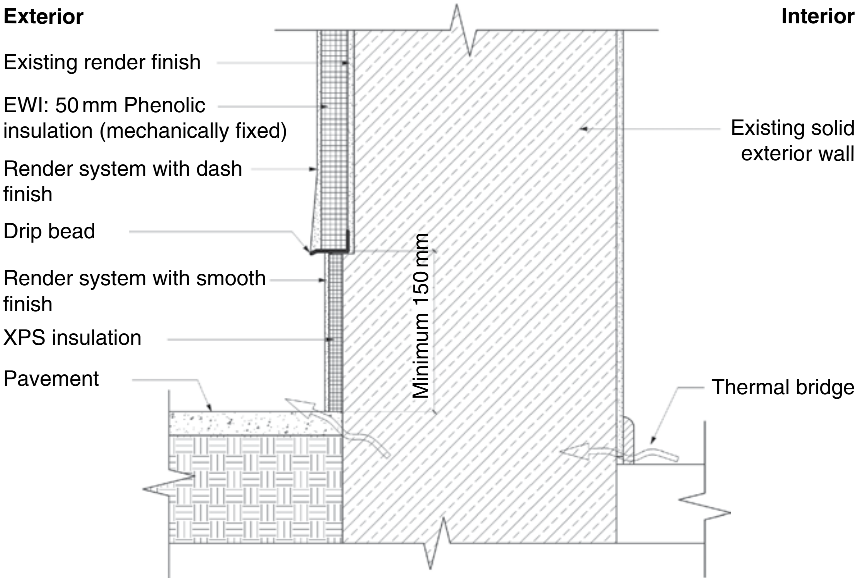

Figure D.6 Pavement to external wall junction detail as observed on site (Source: Hopper *et al.*, 2012b).

Figure D.7 Photograph of an Arbed case study dwelling before retrofitted EWI was installed.

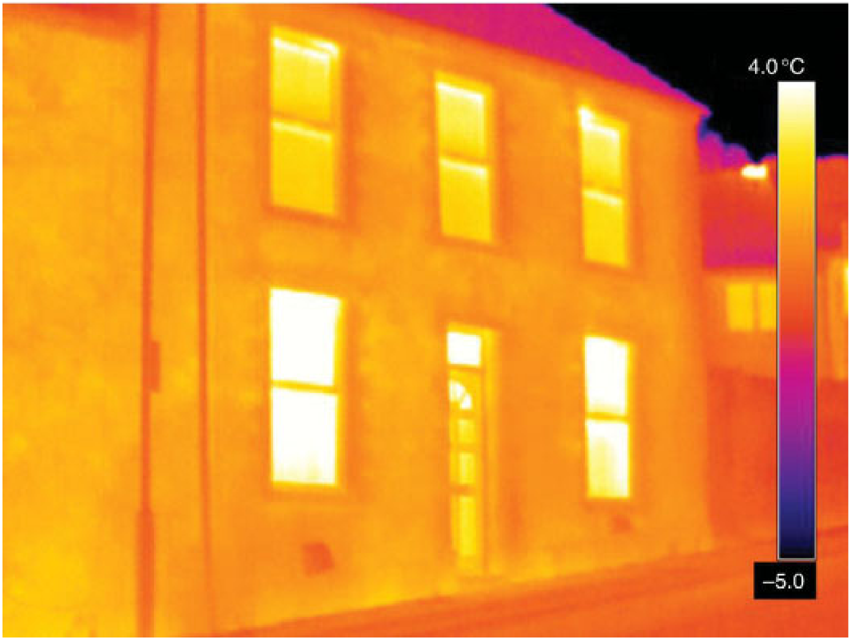

Figure D.8 Thermal image of an Arbed case study dwelling before retrofitted EWI was installed.

Figure D.9 Photograph of an Arbed case study dwelling after retrofitted EWI was installed.

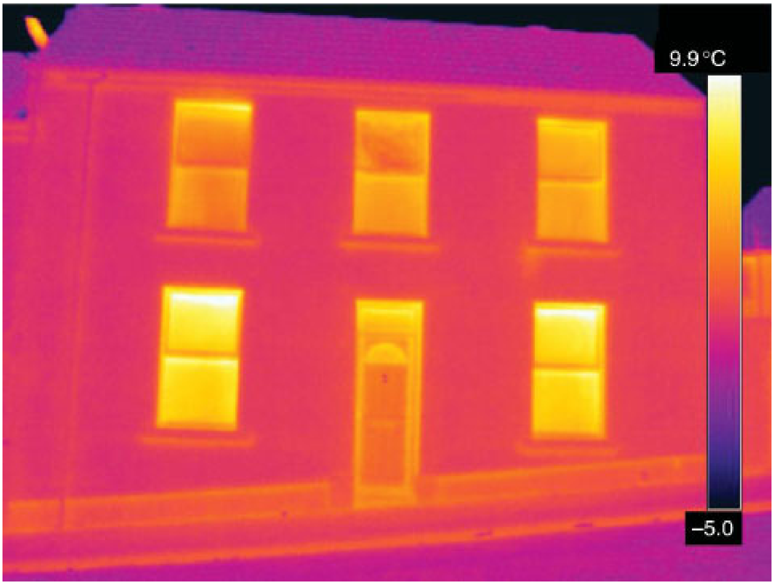

Figure D.10 Thermal image of an Arbed case study dwelling after retrofitted EWI was installed.

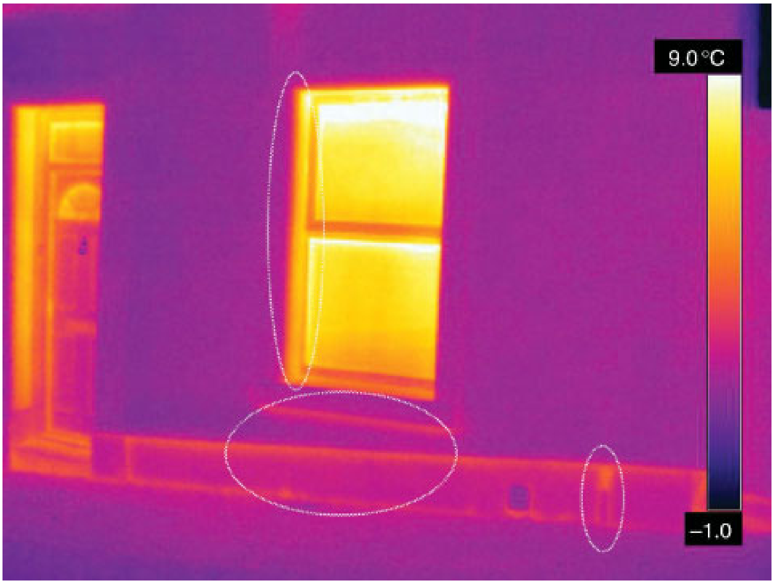

Figure D.11 Thermal image showing a small area of external wall after retrofitted EWI was installed.

appears to demonstrate an overall reduction in heat loss through the external walls, which could be used to promote the installation of EWI. However, Figures D.10 and D.11 appear to illustrate that thermal bridging has occurred at the eaves, under the window sills, at the reveals for window and door openings, between the XPS covering the plinth of the external wall and the phenolic insulation covering the remainder of the external wall above, at the junction between the pavement and external wall and where services enter the dwelling, for example the gas pipe. While the field observations suggested that these thermal bridges could occur, the thermal images appear to confirm that they do.

As discussed by King and Weeks (2010), English Heritage (2010) and Hopper *et al*. (2012b), not only could thermal bridges undermine reductions in heat loss, they also present a potential risk to both the dwelling structure and health of occupants due to interstitial and internal surface condensation. If the illustrated methods for implementing EWI were to be used for the Green Deal, there could be implications for litigation as a result of this induced condensation. In order to reduce the risk to the health of occupants posed by consequential damp and mould growth, the internal air temperature needs to be increased to raise the internal surface temperature above the dew point temperature of the air. The alternative is that the dew point temperature of the air is reduced to below the dew point temperature of the internal surface by increasing the rate of ventilation. With either, or a combination of these approaches, energy use will be increased, which will undermine the overall effectiveness and thus the purpose of the EWI. Furthermore, insufficient reductions in energy use will result in the principles of the Green Deal not working for EWI and achieving the 2050 target could be jeopardised.

Conclusion

The findings have demonstrated that thermal bridging can result from a lack of preliminary surveys and appropriate design details for the individual dwellings at the design stage, along with poor execution and a lack of appropriate quality control on site during the installations. These findings could have implications for future EWI installations, in particular proposals through the second phase of Arbed and the forthcoming Green Deal initiative. It is recommended that further research is undertaken to investigate the occurrence of interstitial and internal condensation in the locations identified, for example at the eaves, under window sills and external wall to ground floor junctions, any resultant affects on the structure of the dwellings and health of occupants and alternative technical solutions to prevent thermal bridging at a range of critical junctions, which are commonplace at existing dwellings.

This case study has also helped to demonstrate the value of the skills and knowledge of an architectural technologist for undertaking applied research. In the author's opinion architectural technologists are suitably qualified with the technical and scientific knowledge and skills to:

- Assess existing dwellings for suitability for retrofitting EWI through undertaking preliminary surveys.
- Identify and produce appropriate technical details to overcome thermal bridging at some of the problematic and nonstandard junctions that are encountered

at existing dwellings, particularly those that are older and unique in their original construction.

- Recommend appropriate materials for the wide variety of constructions used to build existing dwellings in the UK.
- Undertake on-site quality control checks (for example using field observations and thermographic surveys) and make impulsive decisions on how to overcome unidentified issues that are encountered during the retrofit process.
- Monitor and evaluate the implementation and execution of retrofit projects to ensure that lessons learnt are acted upon during decision making of future projects.
- Assist manufacturers with developing new products to overcome nonstandard junctions to avoid thermal bridging.
- Undertake Green Deal assessments to reduce the potential for future litigation that could result from inappropriate advice and recommendations from a lesser qualified assessor.

Acknowledgements

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Chapter Five

Exploring Links between Education, Research and Practice in Architectural Technology

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Within this chapter the authors explore the links between education, research and practice. The findings of a research project, which used questionnaires and interviews to collect data from architectural technologists, are presented and discussed within this context. The research provides insights based on current perceptions of architectural technology course leaders and academics as well as practitioners.

Introduction

Before we embark on an exploration of the relationship between education, research and practice in architectural technology it would be helpful to briefly consider these terms individually.

The word education is derived from the Latin *educatio* – a bringing up, a rearing. Education is normally interpreted in a narrow sense as a structured process of imparting knowledge and skills. It is often assumed that education is limited to institutionalised centres such as schools, colleges and universities. This is not necessarily the case since we can learn in other spheres beginning in the domestic setting. In many instances the educational process can also be informal and experimental. A broader definition of education regards it as the transmission of customs, beliefs, skills, truths, knowledge, etc., from generation to generation. Another notable point that will be developed later is that learning is as important as teaching in the educational process.

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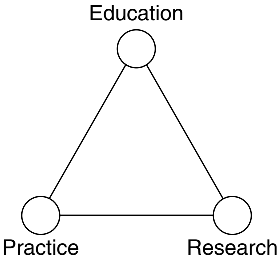

Figure 5.1 The simple relationship between education, research and practice.

Research is an intriguing word, being a noun and a verb at the same time. As a noun it denotes the gathering of facts, information and data. As a verb it signifies the process of asking questions in the pursuit of answers. Some definitions of research combine these two concepts, arguing that the accumulation of information allows questions to be answered. Research is frequently perceived as being abstract, merely academic and without relevance in practice. It may be argued that the value of some research is questionable. However, in many cases research has practical outcomes that really do benefit society at large. Research in the formal sense normally appears in the form of published data but less formal types of research do exist. For example, when information is gathered and analysed and new material is generated then this knowledge can be applied in the design process. This type of research has been called 'design research' (Augustin and Coleman, 2012).

Practice is often confused with practise. Several definitions associated with each word are closely linked, leading to misuse of both words in the English language. The difference is clear if you remember that 'practice' is a noun and 'practise' is a verb. The sense of practice that we need to consider is the exercise of a profession, as in architectural practice or medical practice. It clearly relates to activity that is undertaken in fulfilling employment responsibilities. Practice in this sense is normally associated with a place of work, though not always. The Chartered Institute of Architectural Technologists (CIAT) maintains a register of architectural technology practices. It identifies businesses in the UK, Ireland, Hong Kong and other countries that offer and provide services of Chartered architectural technologists.

From this brief consideration of education, research and practice it is apparent that each term is open to different interpretations. A simple relationship between education, research and practice is appealing (as seen in Figure 5.1) but the complex nature of the three elements means that the relationship between the three is even more complicated. In recent years those in academic circles have recognised that the relationship between teaching and research is tangled (Scott, 2005, cited in Macdonald, 2010). There has also been healthy debate about how research should be embedded into teaching. On the other hand, the relationship of education and practice is frequently dominated by graduate employability needs and the incorporation of work based learning in programmes of study. The link between research and practice is less obvious in many discipline areas. Architectural technology as a professional discipline and a research discipline is relatively young. Fertile ground exists where the interplay between education, research and practice can be explored.

At this juncture the specific context of architectural technology in the UK is worthy of consideration. The Society of Architectural and Associated Technicians (SAAT) was founded in 1965 (Endacott, 2005). Following the transition to the British Institute of Architectural Technicians (BIAT) in 1986, it was recognised that the discipline had evolved and the qualification of technologist was necessary in 1994. In 2001 the professional qualified architectural technician was reintroduced as it was recognised as a separate discipline in its own right. In 2005 the Institute was incorporated under Royal Charter and the Institute became the Chartered Institute of Architectural Technologists (CIAT). The profile of Chartered architectural technologists, together with those practising and studying the discipline of architectural technology, has been steadily rising over this period.

From its formative years the Institute has recognised the importance of the education of its members. The Institute has been involved in various educational developments as early as 1966 with the development of the Higher Syllabus. In 1994 the first three CIAT (then BIAT) accredited honours degrees in architectural technology were awarded: Luton University, South Bank University and the University of Ulster (Endacott, 2005). Other pioneering educational institutions to offer early architectural technology programmes were Edinburgh Napier, Leeds Metropolitan and Sheffield Hallam Universities (Mason, 1999, cited in Emmitt, 2002). At the time of writing CIAT accredits 34 honours degrees in architectural technology throughout the UK and Ireland. Other educational institutions also offer architectural technology degrees but are not currently accredited. In recent years CIAT has moved to recognise Foundation level degrees and Masters level degrees relating to architectural technology. There is growing appreciation of architectural technology as a discipline internationally and it is anticipated that CIAT will soon accredit programmes outside the UK and Ireland.

Architectural technology education integrates research and practice elements. Work based learning is a popular option on undergraduate architectural technology degrees. This allows the application of theory in practice. Architectural technology degrees also incorporate a dissertation or a technical report. Students therefore have a responsibility to undertake research during their education. Structured investigation, information analysis and critical thinking are just some of the skills required in such research. These skills can be applied in different ways in architectural practice. Much informal research continues to be carried out in practice but there is increasing opportunity for a more formalised approach to be used.

An early stimulus in architectural technology research was the formation of CIAT's Innovation and Research Committee in 1995 (now known as the Research Group). This book is just one of the ways in which the Research Group promotes research from the discipline. The numerous Detail Design in Architecture (DDiA) conferences since 1996 have raised the reputation of architectural technology research. The recent establishment of The International Congress in Architectural Technology (ICAT) provides another outlet for architectural technology research in a wider sphere. All these developments highlight the growing importance of research in architectural technology and demonstrate that the complex relationship between education, research and practice in architectural technology warrants detailed investigation.

Aim and objectives

The aim of this research was to explore links between education, research and practice in the discipline of architectural technology, predominantly in the UK context. The research investigated current perceptions of the relationship between the three and helped to define what architectural technology research is. At the outset it was also anticipated that the research findings will help to highlight ways in which the links can be developed in the future. The objectives of this research were:

- To investigate the current perceptions of education, research and practice in architectural technology in the UK context.
- To identify strengths and weaknesses in the existing relationship between education, research and practice associated with architectural technology.
- To help define what architectural technology research is.
- To identify opportunities where the links between education, research and practice in architectural technology can be developed in the future.

Literature review

As previously noted, it is difficult to define the terms research, practice and education. Let us first consider education, remembering that there is a vast body of information surrounding the subject. We shall take the perspective that education is the transmission of information. Learning, teaching and assessment are key concepts associated with education (Race, 2007). Teaching and learning are often confused and seen as synonymous when in reality they are not. Learning can be described as a process leading to the acquisition of knowledge or skill. Teaching emphasises the delivery of information and the methods and techniques employed to encourage learning. Assessment is any process that attempts to quantify the progress of learning, skills and understanding achieved.

Leaving aside the complexity and debate concerning teaching and assessment, let us focus on learning. The significant increase of research related to learning in higher education has changed the thinking and practices of academics. There is growing recognition that learning is more important than teaching (Fry *et al.*, 2003). Further to this point is the realisation that the process of learning is as important as what is actually learned. Higher education should effectively equip us with the ability to learn for ourselves.

Within the academic sphere, course programmes are designed to ensure that a minimum level of learning is reached by students during their course of studies. Built environment courses including architectural technology programmes are designed to meet the needs of the industry and profession (Quality Assurance Agency, 2007). Course curricula and programme specifications detail the learning outcomes achieved by successful graduates of a course. The key reference points for architectural technology curricula in the UK include the ‘QAA Benchmark Statement for Architectural Technology’ and the ‘CIAT Accreditation Guidelines’. All successful graduates must satisfy a minimum level across the learning outcomes but students who have excelled in their studies will obviously have attained a higher level of skill and understanding.

Learning is not limited to the academic sphere. We began learning a long time before we reached school. Formalised education does give us a broad platform on which we continue to build knowledge and experience throughout our lives. However, the academic setting is not conducive for learning certain things, while the workplace environment is full of opportunities to learn. Learning is an ongoing process that only ends in death. There is never a state that we can reach as humans that means learning is redundant (Illeris, 2007). The inquisitive nature of the mind always drives us to learn more.

As we focus on the workplace setting we can accept that a good grounding in academic principles will be beneficial. At the same time we must recognise that academic studies often simplify the realities of the workplace environment. There are many aspects of professional practice that do not easily transfer to the academic setting. Therefore good practical experience must follow on from academic studies. For this reason many built environment courses, including architectural technology, provide opportunity for work based learning to consolidate student learning. This is one way in which the relationship between education and practice is already clear to see. Most built environment courses will also give students the opportunity for site visits during their studies, exposing them to real world examples. There are many benefits in site visits, but there are also many complications, such as health and safety, planning and costs (Ashford and Mills, 2006). For these reasons some academics are using video technology to bring site practices to the students (Comiskey and McCartan, 2011) (see Figure 5.2). Such technology is readily available and if used correctly it has a positive influence on student learning. Such innovation in teaching shows the potential to enhance links between education and practice.

Another significant point is that many built environment institutes, including CIAT and RIBA (Royal Institute of British Architects), require graduates to complete postgraduate experience before Chartered status can be attained. A large number of professional institutes also place an obligation on their members to maintain Continuing Professional Development (CPD) activity on an annual basis. Professional institutes therefore recognise that learning must continue in practice. CPD activity closely parallels the academic notion of lifelong learning. Many educational establishments deliver CPD activity to professionals. This proves they are committed to providing lifelong learning. Many graduate professionals also return to study postgraduate courses or undertake a PhD on a part-time basis.

The Latham Report (Latham, 1994) and Egan Report (Egan, 1998) uncovered the need for radical changes in construction industry practice to provide clients with better service. This led to the agenda for change in the construction industry

Figure 5.2 'Construct Online' (2012). Reproduced by permission of David Comiskey.

and the formation of Constructing Excellence, the organisation tasked with driving the changes set forth. Higher Education (HE) has played a key role in driving the change, but there is still opportunity for more collaboration between industry and HE as highlighted in The Lambert Review (Lambert, 2003) and the Department for Education and Science (DfES) White Paper on 'The Future of Higher Education' (2003).

Various studies have been undertaken that identify the benefits of collaboration between industry and higher education in the built environment context (Gibb, 2005; Wood and Oxley 2007; Heesom *et al.*, 2008). There is mutual benefit for students, academics and practitioners. Such collaboration is often sporadic in nature and frequently there is no coordinated approach. As we look to the future there is so much potential for collaboration to address the lifelong learning needs of construction. Collaboration can lead to the development of CPD activity and Knowledge Transfer Partnerships as experienced at the University of Wolverhampton (Figure 5.3).

How does research fit into the picture? Research is more readily associated with education than it is with practice. Does research relate to architectural technologists in practice? If we accept a broad definition of research, it is a vital ingredient in many of the key activities of architectural technologists. Trade literature, certification tests, information papers and case studies all give practitioners access to certain types of research. In the built environment context there is an abundance of reports and papers that are presented as research. It must be acknowledged that many are innovative and at the cutting edge. However, in reality a sizeable number of reports and papers are little more than marketing tools with a commercial focus. We do well to access such information with caution and healthy scepticism. In contrast, we must also accept the vital contribution of formal research in areas such as fire testing that has resulted in changes to the Building Regulations.

Figure 5.3 Building Information Modelling CPD event at the University of Wolverhampton, April 2012.

Much research directly related to architectural technology is done by universities. Academics are constantly being encouraged to incorporate this research into their teaching. One example where links are being made is the use of the research houses at the University of Ulster. The recently constructed houses have been built as part of ground breaking research into energy efficiency and are intended to assist with reducing fuel poverty. At a simple level, first year architectural technology students have been granted access to undertake measurements of the properties (see Figure 5.4). As the research progresses the findings will be disseminated to students in a number of modules through the course. The findings will also be shared with the local construction industry through Construction Excellence Northern Ireland (CENI), which is based at the University of Ulster.

Architectural technology as a professional discipline is well established in the UK. As a research discipline the position is less definitive. Yet there is a wealth of research that is closely associated with architectural technology (Emmitt, 2002). Building Information Modelling (BIM), sustainable construction, fire engineering, thermal bridging and health and safety are among the relevant areas that can be researched in the architectural technology context. Many of these topics and others are investigated for dissertations and technical reports at undergraduate level. The rigors of research at MSc and PhD level build on these principles. As architectural

Figure 5.4 Architectural technology students at the University of Ulster undertaking a measurement survey of the research houses.

technology emerges in its own right as a research discipline the development of research theory and methodology is paramount.

Whether we realise it or not, research forms an integral part of the design process. Design research is a recognised field of study (Augustin and Coleman, 2012) and designers carry out a range of activities that are very similar to the processes used in research. Designers analyse an ever increasing amount of information. They choose which information is relevant for a given project. Designers generate a lot of new information and material in reaching appropriate solutions. Significantly, design research is often ahead of published research.

There are further striking similarities between design in practice and the employment of research methodology. Design and research are processes that constantly evolve. Both processes pose questions and problems that require answers and solutions. Both necessitate correlation and production of information in an efficient manner. This overlap between the two raises opportunity for designers to learn from the structured and systematic approach used in research. Designers are increasingly pushed for time and anything that can give them a competitive edge in terms of efficiency and innovation is good. One easily discernible comparison is between empirical research and the use of observational skills by designers. Designers learn so much from what they see. By watching how people respond to their environment designers can improve their designs. Empirical research relies heavily on interpreting what is observed to gain knowledge. Researchers tend to be more systematic in their approach. Design research therefore has the potential to be really enhanced through the application of the planning, testing and evaluation processes that are commonly used in scientific research.

It has become apparent that for architectural technology the relationship between education, research and practice is complex. There are many similarities and differences between the three and there are many questions that need to be answered. Do practitioners see the relevance of research in what they do? Can practice activities be enhanced by applying research methodologies in appropriate scenarios? Can innovation and enterprising activity help to raise the profile of architectural technologists?

Research method and data collection

The literature review provides data from a variety of sources to help address each of the objectives. First hand data will also be required to gain a more comprehensive insight into the perceptions of individuals relating to the research. Various methodologies, such as observational studies and focus groups, have been discounted by the authors due to their inappropriateness in gathering the opinions of individuals. Questionnaires will be employed to generate quantitative data. If the response rate is good then a reasonable cross section of opinions should be recorded. Since questionnaires are notoriously unreliable and perception is subjective in nature, structured interviews will also be used. This will provide qualitative data and allow cross checking of the findings. The structured interviews will be carried out after the questionnaire process is completed to allow the structured interviews to be suitably tailored.

At the outset of the investigation the intention was to target three major groupings for their opinions, namely practitioners, academics and students. Upon reflection it was decided that the research should focus on the opinions of practitioners and academics. The first reason for this decision was that practitioners and academics, in general, are in a better position to have informed opinions related to the study focus. Secondly, obtaining dependable student opinion is not easy and if qualitative methods were used there is the likelihood the data collected would be overwhelming if the response rate was high. Thirdly, it was viewed that excluding students from this study would simplify the ethical issues to be dealt with. Maintaining two target groups does at least preserve some triangulation in the study as the perceptions may be compared and contrasted.

Since the two target groups are quite different in some respects, two different questionnaires were created. They were carefully designed with consideration given to the questionnaire length and structure and how the questions were sequenced. General questions came first to give some appreciation of each recipients' background. A fixed set of responses were used for these questions. Specific questions focusing on education or practice followed in each respective questionnaire. The questions were a mix of fixed response and open ended questions. The key questions surrounding the research investigation came towards the end of the survey. To enable good data analysis the Likert scale was employed in the responses for these questions. A free response question was used at the end to allow respondents the opportunity to add additional comments and include their contact details if they were willing to take part in the structured interviews.

Due to the nature of the academic questionnaire, CIAT administrative staff suggested that it be limited to the course leaders of each accredited university. They agreed that the questionnaire for practitioners should only be distributed to those on the register of architectural technology practices. The surveys were not piloted; however, the questionnaires were circulated to a select number of academics and professionals who were not in the target groups. These individuals were able to give constructive feedback to help us ensure the questionnaires were sufficiently well designed.

A short note was included at the start of each questionnaire outlining the purpose of the survey and informing participants that a parallel questionnaire was also being run for the corresponding group. The note also promised to disseminate the results – a summary of the findings will be submitted for inclusion in the CIAT quarterly magazine *Architectural Technology*, a publication that all of the potential participants should receive. Questionnaires were hosted on surveymonkey.com to enable wide circulation and easy access. To encourage a good response rate, a CIAT staff member circulated an email invitation. This gave a short explanation of the research being undertaken and indicated an estimated length of time required to complete the questionnaire. It also noted the closing date of the survey. Unfortunately some recipients reported having difficulty accessing the surveys. A minor issue was subsequently identified, so to minimise the impact on the response rate a second set of email invites was sent out quite quickly. A reminder email was also sent out a couple of days prior to the survey end date.

Structured interviews followed the completion of the survey process. From the results of the surveys we were able to identify the individual participants who indicated they would be willing to be interviewed. We were also able to identify a number of issues that required investigation. To keep the process manageable it was decided to interview six educators and six practitioners. Each of the interviews was structured in similar fashion and built on the responses each participant had given in the questionnaires. Individuals were questioned on their opinions in an effort to understand why certain responses had been given.

Data analysis

Accredited course leader questionnaires

Questionnaires were sent out to all 32 CIAT Accredited Universities, of which 23 responded, equating to a 72% return. While this was a high response rate, it is important to remember that the survey results only indicate perceptions at a point in time. The questions at the start of the survey related to the individual courses. From the responses we derived the name of the academic institutions and the exact title of each programme. This enabled us to clearly identify which universities had responded. It is reassuring to note that 22 out of 23 undergraduate programmes had 'architectural technology' in their title. Interestingly, only two universities out of those that responded offer a Bachelor of Arts degree in

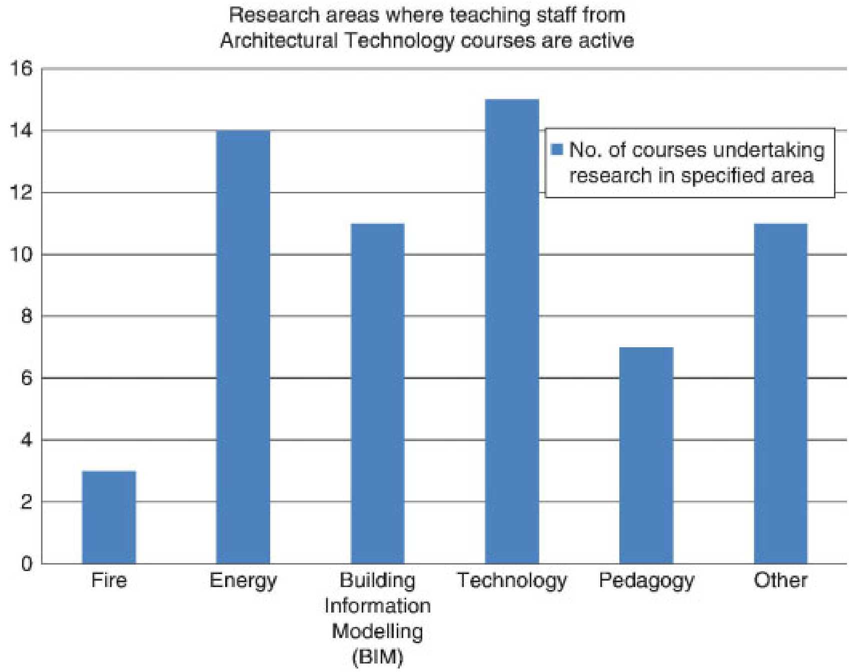

Figure 5.5 Bar chart of responses to Course Leaders question 12.

architectural technology, while the remaining universities offer a Bachelor of Science degree in architectural technology. All of the 23 courses last a minimum of three years, with five courses lasting four years. Seven of the institutions do not offer placement while only two courses stipulate that placement is compulsory. Generally, student numbers on the courses are encouraging with ten institutions having 100 or more students across all years of the programme. Hopefully, this bodes well for architectural technology as a discipline, despite the challenging economic circumstances currently facing us.

The number of teaching staff who contribute to the core teaching of the architectural technology programmes at the 23 respondent institutions ranged from 3 to 19 with a mix of full time and part time staff; 18 institutions indicated they have RIBA members, while 17 institutions have CIAT members (whether Associate or Chartered members). Only eight (35%) of the respondents indicated two or more staff are CIAT members. All universities have staff members who are members of related built environment Institutes, such as RICS, CIOB, CIBSE, etc. The main areas of research were identified as technology, energy and building information modelling (BIM) (see Figure 5.5). Some specialist areas like fire and sustainability were also highlighted. Eight institutions have staff who research teaching practices (pedagogy).

From the responses in Figure 5.6 it can be seen that 62% felt that research is well embedded into the teaching on their architectural technology programme. Residential design, specialist consultancy and innovation/related academic

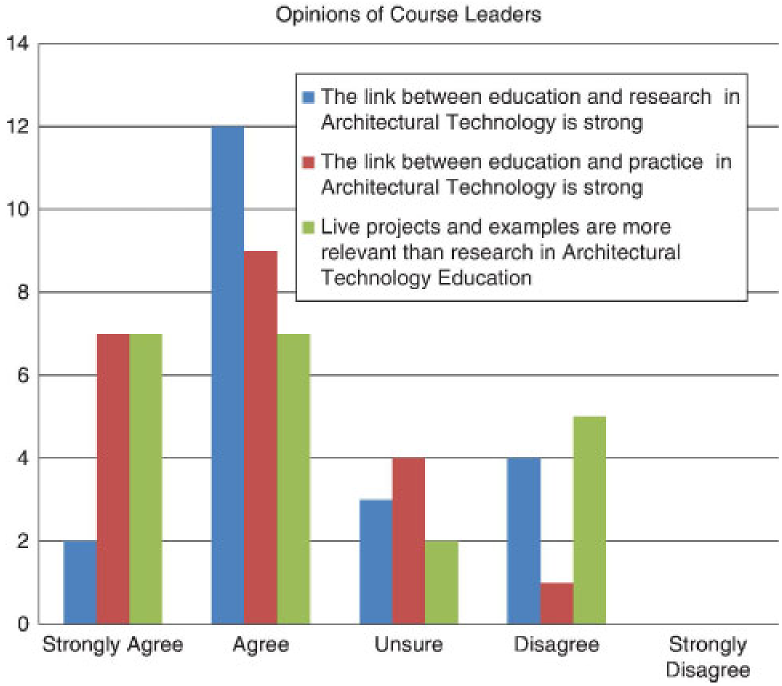

Figure 5.6 Bar chart of responses to Course Leaders questions 17, 18 and 19.

enterprise were indicated as the main areas of consultancy and practice type work being undertaken by staff at various institutions. Only one institution was identified where live projects or examples are not important in teaching key aspects of their course, but 67% used this approach regularly. Of the responses, 67% also agreed there is a strong link between education and research in the discipline of architectural technology and 76% agreed there is a strong link between education and practice in the discipline; 67% agreed that it is more relevant to use live projects and examples in architectural technology education than it is to embed research into the curriculum. This was reinforced with statements such as: 'Research informs the live projects of the future', 'Application of knowledge is essential' and 'Research is the most important element of any academic work'; 19% felt both were equally important, one stating 'a practical approach to technology gives the student a greater understanding and allows the topic to be put into context'. The data collected identified that research was being undertaken in the area of embedding research into the curriculum.

Accredited course leader interviews

Structured interviews focusing on research and practice areas were conducted with six of the respondents. All six were from an architectural background: two were Associate members of CIAT and two would like to progress to Chartered membership via an academic route. All those interviewed acknowledged that the links between education, research and practice are crucial in the discipline of architectural technology. Varying definitions of research were given from the view of published and scientific research through to general CPD type activity commonly recognised in practice. All had come from practice into education, with half of the sample still practising in the field of architecture as consultants or practitioners. Residential design and specialist consultancy were the two main areas of work undertaken.

All those interviewed considered live projects or project simulation as a key component of their teaching. All agreed it is critical to have contacts with those in industry to incorporate such projects. In some cases, partnerships with local organisations provided access to projects, without formal contracts or issues of design liability. Three believed that it is more relevant to use live projects and examples in architectural technology education than it is to embed research into the curriculum. These three had moved to academia in recent years and some were still significantly engaged in practice activity. This obviously affects their opinion in various ways. Five felt that education was driven by research and this was the reason for the emergence of the discipline of architectural technology over the last ten years. All agreed the links between education and practice need to be widened to reflect the specialist skills required over and above the general skills of the discipline.

Registered practice questionnaires

Out of 1566 practices that the 'Practice Questionnaire' was circulated to, 315 responded. This equates to a 20.1% response rate, so again care must be taken in the analysis of results as the individual opinions are only indicative. The questions at the start of the survey related to the individual practices. The responses revealed that 117 (37%) of practices had been established 15 years or more and a further 104 (33%) practices were established between 6 and 15 years ago. The remaining 94 (30%) have been established in the last 5 years. The profile of the respondent practices was 196 (62%) sole practitioners with another 92 (30%) with 2–5 employees. The academic qualifications held ranged from 44.4% (140) holding degrees, 28% (89) subdegrees, 9% (28) holding Master's and 2% (6) holding a Doctorate. Over the last 5 years only 66 (21%) had been in the position to offer placement opportunities and only 57 (18%) had engaged with their local accredited architectural technology programme.

The term research was interpreted as being very much related to projects and not to scientific research of any nature. A few examples are quoted:

- 'Investigating, and learning about a particular subject to improve and expand your knowledge on that subject.'
- 'To search for knowledge of a given subject.'
- 'In my case keeping up with ever changing requirements for building laws, and standard requirements.'

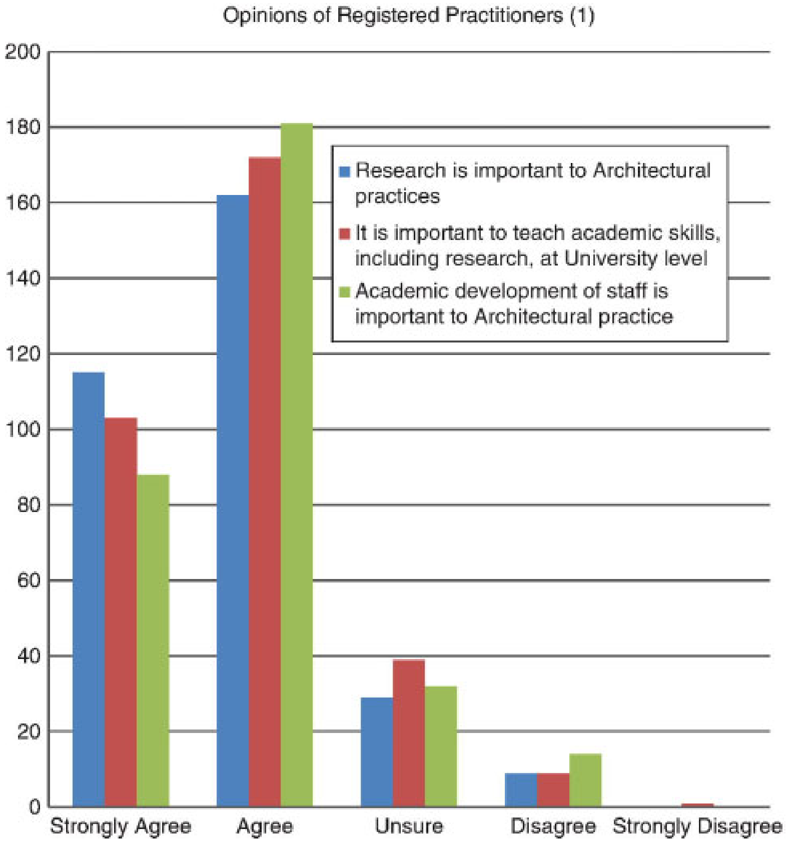

Figure 5.7 Bar chart of responses to Registered Practice questions 9, 10 and 11.

Others described research as:

- 'Investigation into new technology.'
- 'Gathering information and evidence including testing, using, etc., about a given topic or subject and formulating results and possibly recommendations based on the information and evidence gathered.'
- 'Studying new and past designs and best practices.'
- 'Research to me is an ongoing learning activity.'

In the responses in Figure 5.7, 277 (88%) practitioners agreed that research was important to architectural practices. A similar number of 275 (87%) agreed that research should be one of the academic skills taught at universities. The majority also felt that academic development of their own staff was important. Of those asked, 304 (97%) thought that architectural practices should support the development of professional qualifications, e.g. progression to Chartered membership of CIAT.

In the responses in Figure 5.8, 290 (92%) respondents felt that it was important to use live projects as examples at university level. However, the number who felt

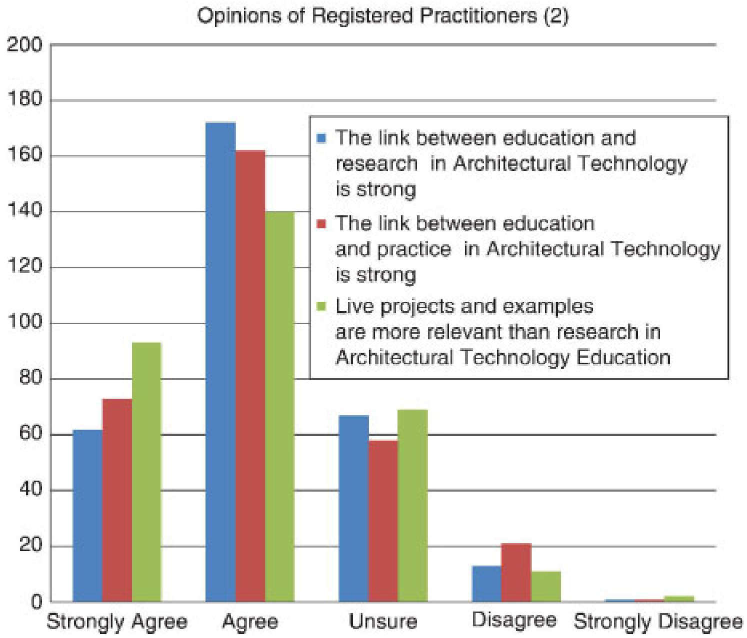

Figure 5.8 Bar chart of responses to Registered Practice questions 14, 15 and 16.

there was a strong link between education and research in the discipline dropped to 234 (74%), with a similar number, 235 (75%), agreeing that there is a strong link between education and practice. This perception continues to be evident with 233 (74%) agreeing that it was more relevant to use live projects and project examples in architectural technology education than it is to embed research in to the curriculum.

Fewer than half the respondents provided additional comment or were prepared to participate in the structured interviews. Some examples of how the links between education, research and practice in architectural technology are interpreted were:

- ‘Research in universities should be far ahead of current industrial practices.’
- ‘Surely investigating and analysing existing or live projects can be deemed as research?’
- ‘Ideal that education, research and practice are intrinsically linked. However, I do not believe that universities and practices are taking this approach to the discipline.’

Registered practice interviews

Structured interviews were conducted with six of the respondents. They represented the spread of categories identified from the questionnaires: three were sole practitioners, two senior partners/directors working alongside architects and one employed in the Estates Department of an academic institution. Academic qualifications ranged from subdegree to Masters level. Only one of the interviewee's had been in the position to employ a placement student in the last five years. The others were restricted due to the current economic downturn.

All of the interviewees viewed 'research' as central to their role. They described research as specific information gathering, career progression and practice development. The general consensus was that updates in legislation and government policies required research. Research they undertake on a day to day basis ranged from engagement with product libraries and manufacturers' web sites to formal research as part of postgraduate studies. All agreed that their business would cease to exist without research – that is how important it is to their architectural practice. There was 100% agreement that research should be one of the academic skills taught at university relevant to the discipline. Five of the six feel that academic development was important to the practice. The other argued there is no substitute to having experience. There was 100% agreement to supporting professional qualification, with each stating it was the baseline by which they are judged by their clients.

Half of those interviewed were involved with local programmes in architectural technology through regional membership of the professional body (CIAT). Additionally, one of these three acts as an external examiner for one of the CIAT accredited courses. They all like the idea of project simulation being used in teaching but the majority agreed that live projects should be used as much as possible. Half of those interviewed felt that the research in the curriculum was not really relevant to the real world. To quote one practitioner, 'I've never done a survey in all my years of practice. Who would pay me even if I had the time?' However, there was general interest concerning how research can be applied outside of education.

Conclusion

There was general recognition of the links between the three areas by those academics and practitioners who took part in the research. Participants from both target groups held similar views about architectural technology, education, research and practice. A higher proportion of academics placed more value in research, which is understandable given their employment setting. Most practitioners were aware that links exist between practice and universities in the form of placements and CPD activity. However, many claimed not to be aware of other opportunities that exist.

Some educational establishments do appear to have very strong links with industry in the context of architectural technology. Some universities are able to engage well with industry by using live projects, guest lecturers, CPD activity, etc. This modest study cannot conclude that such practice is widespread, but it does suggest that the strength of links depends on the individuals involved. There is still opportunity to develop additional links for live projects, collaborative projects, innovation and consultancy. As research momentum in architectural technology

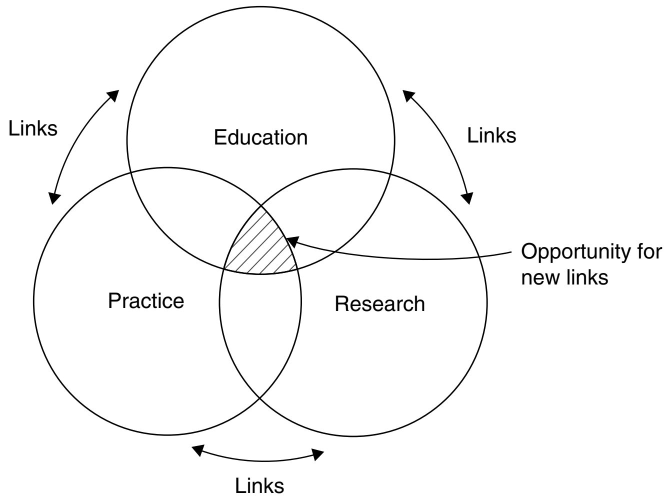

Figure 5.9 The overlapping relationship of education, research and practice.

builds, there should be opportunity given to research within the practice setting. Indeed, there should also be occasion for practitioners to learn from the methods that researchers use. Practically, this could be through Masters and PhD study.

The survey and interview findings have shown that there is a lot of confusion among practitioners about what research really is. Academics generally have a clearer understanding of what research is, but some still have misconceptions. Two general definitions prevail: research in the scientific sense (that is publishable) and research in the general sense (that relates to work practice and CPD activity). It must be conceded that 'research' as a noun is a process and this is possibly where the greatest opportunity lies for practices to benefit from researchers. However, attention should also be given to researching how practices work, where efficiency gains could be made and how enterprising activity can give practitioners the competitive edge.

Research related to architectural technology is being carried out in areas such as fire, energy, BIM, technology and sustainability. Research seems to be clearly linked to building performance, which is a key area of interest for those in practice as well. Some excellent research has been encountered in the course of this study, but further research would need to be undertaken to appreciate the extent of research being carried out in the area of architectural technology. Few seem to realise that innovative work in architectural practice is often ahead of published research. There appears to be a healthy interest in pedagogic research within the architectural technology area. This is encouraging and there is room for development.

It has become clear that a simple model representing the links between education, practice and research as shown in Figure 5.1 is inadequate. To an extent that model represents the current situation, but it does not reflect the potential that we should aspire to achieve. An interlinking model, as proposed in Figure 5.9, needs to be developed and put into practice. This investigation has found decent research relating to architectural technology and shows there is potential for further research in areas such as practice operation and management, building performance and pedagogical issues. While academics regularly share research through conferences, journals, etc., architectural technology practitioners generally miss out on this research. One natural step that could combat this would be the inclusion of a regular research article in CIAT's magazine *Architectural Technology*. Academics and practitioners should also look to develop links via collaborative projects, CPD activity and knowledge transfer partnerships (KTPs). Current opportunities to move towards the proposed model should not be missed – all architectural technology professionals have a role to play.

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Case Study E

BIM Collaboration in Student Architectural Technologist Learning

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This chapter is the result of a qualitative case study that investigated the influence of building information modelling (BIM) collaboration on the learning of student architectural technologists based around a studio group project. The purpose of the chapter is to disseminate knowledge gained into a new learning environment facilitated by the collaborative properties of a BIM application. A qualitative case study approach has been used to undertake the examination of the learners' experiences during the project. This approach allowed the author to map the complex interaction between the participants during the stages of the collaborative design project. The chapter provides evidence of a new learning environment created in the studio setting. This learning is facilitated by the collaboration tools and work-set methodology of the BIM application. This case study will support higher education institutions proposing to introduce collaborative BIM applications into a built environment curriculum and also may act as a catalyst to encourage educators to adopt a similar approach to teaching in a range of other professions. This research supports a need in higher education to provide for transition from theory to workplace practice and identifies a potential for higher level learning facilitated by collaborative BIM technologies and methodologies.

Introduction

There is a growing demand for closer collaboration within the built environment. This demand needs to be reflected back into the teaching and learning practices of students in the disciplines of design and construction. Penttila and Elger (2006) suggest that diverse multidisciplinary understanding and knowledge about various factors of design and construction will be essential in the near future architectural design profile and so, to provide for industry, it will be incumbent on

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higher education institutions to break down silos of built environment education and provide opportunities for the development of collaborative skills for students poised to enter into the design and construction industry. A catalyst to bring about this change is the robust platform provided by building information modelling (BIM) technologies and the collaborative design opportunities it promotes. Bedrick and Rinella, cited in Becerik-Gerber *et al*. (2006), suggest that building information modelling technologies and methodologies are poised to revolutionise the construction industry because of its potential to radically improve collaboration among the wide-ranging expertise needed to design and construct a building and to increase efficiency.

If collaboration processes are reflected back into built environment education, a legitimate question arises as to the potential benefits for collaborative learning for the students whose disciplines fall within the design and construction industry. This research explores one case scenario that involved the collaboration of student architectural technologists with a practising architect using a BIM digital building model as the vehicle for the collaborative design process and as the delivery application for project documentation – a role previously achieved by group work using a two-dimensional computer aided design application.

Architectural technology is an emerging profession in the built environment. The role of the architectural technologist has changed and developed as building design and construction have become more specialised. The Royal Institute of Architects Ireland (2010, p. 4) regards 'the professional Architectural Technologist as a technical designer, skilled in the application and integration of construction technologies in the building design practice. Harty and Lang (2010, p. 558) conclude that 'Architectural Technologists are trained to know what each profession does and to know what each project needs from the other professionals. Architectural Technologists are equipped to adopt the role of manager in an integrated design and construction process.' Their core education is technical design and this gives them a skill set that allows them to communicate effectively with the other design disciplines to in effect provide a central point of coordination for building information. The Dublin Institute of Technology Programme in Architectural Technology was established in 1963 and is the oldest programme of its kind in Ireland. Harty and Laing (2010, p. 548) refer to the Department of Architectural Technology *ab initio* Level 8 BSc (Hons) in Architectural Technology addressing the educational needs of the professional architectural technologist. The new course had its first intake of students in September 2010.

Building upon a model of a constructivist learning environment proposed in a paper 'Designing constructivist learning environments', Jonassen (1999, pp. 215–239) set out to observe and record a collaborative design project taught in the Department of Architectural Technology, in the Dublin Institute of Technology (DIT). Jonassen's model design puts the emphasis on providing learning experiences that facilitate knowledge construction and in meaning making. During the collaborative design process it became apparent that a strong learning dynamic had evolved, fostered by the collaboration tools of the BIM application. Using a single exploratory case study approach, the researcher has examined the strong learning dynamic and provided evidence of a new learning environment.

Background

Building information modelling (BIM)

The term building information modelling (BIM) is an extensive, wide-ranging term that covers technologies and methodologies based around the creation and coordination of digital building data that are visually represented in three dimensions on a computer screen. The subject is extensively reviewed in the *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors* (Eastman *et al.*, 2008). BIM technologies and methodologies are central to integrated project delivery (IPD). The American Institute of Architects (2007, p. 1) defines IPD as 'a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harness the talents and insights of all project participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction'. A global information service provider, McGraw-Hill Company, produced a report in 2008 and followed this up in 2009, published the results of a state-wide survey in North America charting the rise of BIM in the architecture engineering and construction (AEC) industry. A similar survey was conducted in Europe in 2010 focusing on the UK, France and Germany, finding that the level of implementation might be higher in North America but that Western European companies that have adopted BIM show a deeper commitment to BIM processes. These three reports appear to indicate that BIM is on a rising trajectory in its use by AEC companies on both continents (McGraw-Hill Construction, 2008, 2009, 2010). As a result BIM applications and methodologies are being increasingly taught in third level colleges across architectural, engineering, computer graphics and construction management courses (see Barison and Santos, 2010, pp. 1–10) and Becerik-Gerber *et al.*, 2011, pp. 411–432). 'Over the last 5 years there has been a rapid movement from computer aided design (CAD) to building information modelling (BIM) by professional architects, engineers and construction managers and this has created several challenges and opportunities for AEC educational programmes' (Becerik-Gerber *et al.*, 2011, pp. 411–432). However, teaching BIM is not as simple as introducing the application within a module. BIM needs to be part of a holistic approach within a technical design studio. Christenson (2006, pp. 55–62) concludes that 'the act of creating a parametric building model in Autodesk Revit, a BIM application, requires that a designer be able to intelligently define relationships between and within building elements'. Christenson also says that the successful user of Revit, in addition to understanding how the software works, must understand construction technology sufficiently well in order to define such relationships intelligently. The growing number of architectural engineering courses in AEC education is testament to a need for a professional group to have a skill set to marry the conceptual and practical. The development of the architectural technologist as a collaborative technical designer makes the professional architectural technologist ideally placed to fulfil this role.

Learning with BIM

Fioravanti (2008, p. 3) proposes 'collaborative design as being the design method best suited to the challenges of our times'. He suggests that the 'fundamental components of these design problems lie in a low and selfish collaboration among actors', and to overcome this limitation he suggests that 'higher education needs to deal with the lack of suitable education in cross-disciplinary collaboration and the lack of suitable ICT tools enabling collaboration to be practiced in the design of complex buildings'. Denzer and Hedges (2008, pp. 1–11) investigated BIM in various classroom conditions and argue that BIM enhances group based classroom management approaches of team learning. They use Bloom's Taxonomy (Bloom *et al*., 1956) as a benchmark to assess the student performance in a Design Studio Course. They conclude that BIM allows the students to reach the evaluation level of Bloom's Taxonomy in terms of cognitive skills development (cited in Barison and Santos, 2010, p. 6). Lonely BIM is a term used to describe a process where a BIM user works without collaboration deriving set benefits from this, but not achieving the full potential from the process. Becerik-Gerber *et al*. (2011) say that BIM implemented into the curricula will facilitate a multidisciplinary approach that consolidates effort and enables more efficient collaboration and can also provide a platform for exploring new team structures and collaborations and realising improved student outcomes. Harty and Laing (2010, p. 548) refer to the 'need to address the educational needs of the professional architectural technologist'. In his authoritative work *Architectural Technology*, Emmitt (2002) states that 'the technologist forms the link between conceptual design and production, translating design intent into physical reality'. It is this 'link' role that has the potential within a BIM process to elevate the architectural technologist into being the creator and curator of the digital model. The link being not only with the architect, the architectural technologist needs to develop the ability to collaborate with all the stakeholders in the design and construction process.

Learning spaces

The studio has always been part of the educational experience of the student architectural technologist in the DIT. The crucial difference between traditional classrooms and studios lies in the distinction between 'learning about' and 'learning to be' (Brown, 2006, p. 5). The pedagogy of student-centred learning is well catered for in the open plan studio setting. Indeed, this style of learning is rated highly in a paper 'Designing new learning environments to support 21st century skills' (Pearlman, 2010, pp. 123, 124). The open plan design is equipped with work tables on the inside allowing workspace for sketching, model making and study. In the Department of Architectural Technology in the DIT, where this research study was undertaken, personal computers were introduced into the studio in early 2000. This was facilitated by fixing benching to the exterior studio walls upon which the hardware was mounted and networked. The idea of keeping the personal computer within the studio and not relegating it to a separate lab has made the integration of information communication technology into the associated architectural technology course a smooth transition for the students. It is the replacement of the drawing board by the personal computer in the architectural technology studio as a main deliverable in terms of a learning tool, coupled with the collaborative methodologies of BIM applications, that have led to the creation of a new learning environment, which is explored within this case study.

Cognitive learning in architectural technology

The role of the architectural technologist is to solve technical problems within the process of delivering the architectural intent while conforming to statutory legislation. Emmitt (2002, pp. 32, 33) states that 'creativity still takes place in the detailed design. This is a complex process full of reasoning about constraints, exploring fixes, resolving conflicts and searching for alternatives.' Jonassen (2011, p. 143) states, 'constraints are rarely, if ever, identified completely at the beginning of the design process, as implied by the analysis phase at the beginning of the ADDIE model (the ADDIE model being a generic term for the five-phase instructional design model consisting of Analysis, Design, Development, Implementation, and Evaluation), rather the beliefs and constraints emerge during each cycle in the design process' . Designers make decisions based on the constraints as they emerge (see Figure E.1).

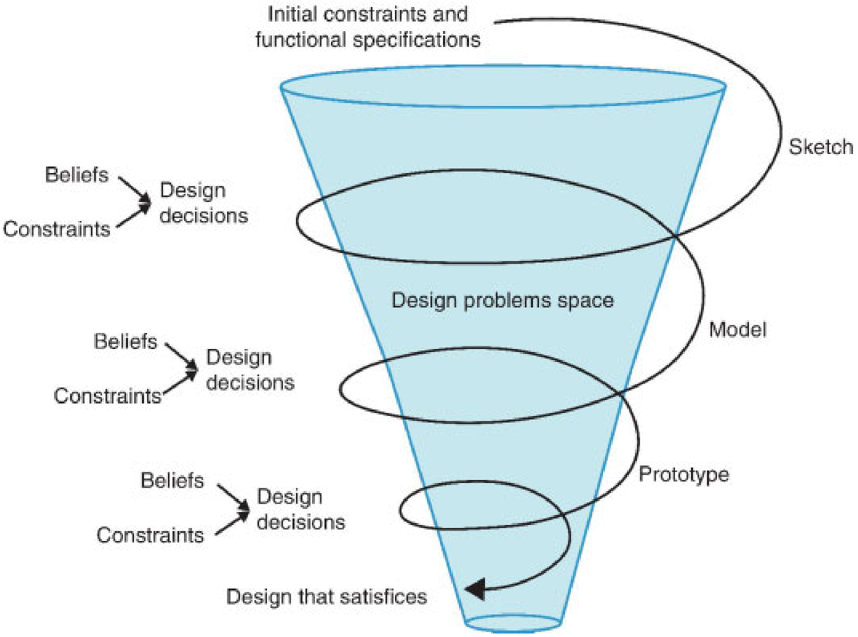

Figure E.1 Iterative design process model (Source: Jonassen, 2011, p. 144).

This iterative design process model aligns with the decision making process the architectural technologist faces when designing a technical solution to a design problem. Emmitt (2002, pp. 24, 25) suggests that 'It would be easy to conclude from the design methods literature that the conceptual design stage is where the creativity takes place, ceasing at the detail design'. For Emmitt (2002) this assumption would, however, be wrong as 'creativity still takes place – indeed the best detailers can come up with creative solutions to very difficult technical problems – it just has to be constrained'. The BIM model contributes to this iterative design process model and can identify design problems in a way that working in two dimensions does not. BIM prompts students to ask questions about structures, material assemblies and detailing that requires the instructors to be relatively more agile in their ability to respond (Becerik-Gerber *et al.*, 2011, p 9). These processes are also highly motivational to students as they engage collaboratively within their groups and with the architect on the design problem. The participation of the professional architect has the effect of providing scaffolding support to the students in this learning environment and helps to bridge the gap between student learning and professional practice. This enables the students to explore and learn the professional language of the industry and to communicate in the design collaboration.

A new learning environment for problem solving

There has been considerable research around the creation of or what constitutes a learning environment (see, for example, Hannafin *et al.*, 1999, and Wilson, 1995). 'The case studio, studio team, studio group and problem based scenario are the main components of a Constructivist learning environment' (Ng, 2005, cited in Barison and Santos, 2010, p. 4). This aligns with Jonassen (1999, pp. 215–239) who proposes a model for designing a learning environment that has four aligned components. The first component is a problem, question or project that would be the focus of the environment. This is the goal that will drive the learning process. To provide a live brief for a project would sufficiently map Jonassen's (1999) three major components in the design of the problem. The brief must have context and it should provide a description of the physical, organisational and sociocultural elements of the problem. In this case study, the research is based around a brief to provide a new third-age centre and refurbish an existing senior citizens' housing complex at Verschoyle Court in Dublin City centre. The live brief is therefore authentic and represents the same cognitive challenges as those in a real world setting. The real life setting is a challenge to the student and can be considered a meaningful and mindful activity where the manipulation of space, in this case, the digital environment, will visualise the students' argument to support their proposed solutions to the problem.

The second component from the model is related cases, representing a set of related experience. By the time the student architectural technologist has reached the fourth year, they have completed an intense three year programme in building technology, environment, structures and materials aligned to their studio projects. The students are then encouraged to seek summer work in design practices. The third component from the model is information resources. This is well provided for as the student has access to the college library, the world wide web via the Internet on the networked college personal computers. The final component is cognitive tools; Jonassen (1999) states that 'cognitive tools are computer tools that help visualise, organise, automate, or supplant thinking skills'. A BIM application Autodesk, Revit, was introduced into the course in 2008 providing the innovative cognitive tool completing the four elements of Jonassen's model. In my observations of the collaborative design meetings and as outlined in this chapter, it appears as though the collaborative properties of a BIM application, the studio setting, and a group project based around a live building brief have combined to create the conditions for a new learning environment.

Research methodology

The aim of this research was to explore potential benefits for learning to students through the use of collaborative learning supported by a BIM application. The author observed and recorded a studio based design and construction project that partnered a professional architect with six student architectural technologists. A qualitative case study methodology has been used to examine the learner's experiences during the project as 'a hallmark of case study research is the use of multiple sources, a strategy which also enhances data credibility (Patton, 1990; Yin, 2003, cited in Baxter and Jack, 2008, p. 554). Potential data sources may include, but are not limited to, 'documentation, archival records, interviews, physical artefacts, direct observations and participant observation' (Baxter and Jack, 2008, p. 544). The author used six methods to capture data from the project, observation of the group collaborative design meetings, observation of the students working in the studio environment, reflective writing by the author, on-line blogging by the students, students formative assessment from the project brief and project end interviews of the individual students. The research sample was drawn from a fourth year group of 18 students. The class are separated into groups at the start of the first semester; they then work within these groups. The studio project is based around a live brief provided by a client, in this case Dublin City Council Architectural Department. The student groups are each assigned a practising architect with whom they will work in a collaborative design process for twelve weeks. The group the author used for research had decided from the outset to use BIM technologies as the main deliverable for their project. Their assigned architect was not familiar with BIM applications. The student group would be working collaboratively on the digital model using a BIM application in this case Autodesk Revit. The collaborative design process was observed by the author from start to finish over the period of 12 weeks.

The researcher selected Unit Four because of their commitment to work with a BIM application. Unit Four consisted of six students, where five of the students had, the previous academic year, completed the NQAI Level 7 BSc in Architectural Technology. The sixth student had received his award the previous year. The six students had also completed two BIM projects as part of the Studio CAD element of their Technical Design Studio module and had a mixed ability from intermediate to proficient level of competence in Revit. The fourth year studio work in this study is based on the idea of a small architectural practice in the technical design studio module. A dateline for formative assessment of the group work and presentation of the design proposals to the client was set by the fourth year head of the course. The group had their first meeting with their architect in week two; the architect had received the brief the previous week. The architect had decided to take one typical building block consisting of eight senior citizens' apartments on two levels with a space to the east gable end for a proposed tower block six stories high. The existing apartments are to be refurbished to meet current standards for accessibility, energy consumption and fire regulations.

The case study methodology allowed the author to capture information through a range of data sources including the following.

Observation of group collaborative design meetings

Four formal meetings were held with the design architect over the twelve week period. The author sat in on the meetings but did not contribute in any way, to avoid distorting the process. The first observed collaborative design meeting took place in week 2. The second observed collaborative design meeting took place in week 5, the hand in of completed general arrangement drawings was in week 7 and the final observed collaborative design meeting was in week 9. Presentation to the client of group work took place in week 12. The author took notes on his observations and photographed the group. This provided an insight into the thinking of the group. The author was able to observe the interaction, conversation and thought processes. It provided a timeline in the progress of the project.

Observation of students working in a studio environment

The author set up the file based collaborative network and was in a position to observe the students working in the studio environment. The author took notes of the interaction between the students and saw the Revit collaborative application working.

Reflective writing by the author

The author kept a reflective writing journal during the project and used this to put a rational remark on the different information coming from the data sets.

On-line blogging by the students

The author set up an on line blog to which the students had access. This allowed the students to voice their thoughts during the project. The author prompted the students with open ended questions. The response to the blog questions by the students was excellent and provided valuable insights to both the problems encountered and the type of learning the collaboration was promoting.

Student's formative assessment from the project brief

The students work was assessed as a group. They were to deliver a set of general arrangement drawings for the building project. This involved proposals for interventions into an existing block of apartments and a new build tower block. Unit Four received the highest mark of the class for the work. The author made an assessment of the project work and concluded that the collaboration had been a great success in terms of meeting the project brief.

Project end interviews of the individual students

These oral interviews were carried out after the collaborative project was completed. The author set three open ended questions designed to get the students to reflect on the experience of working in a collaborative group using BIM technologies. The author observed in each case a positive reaction to the collaborative working on the digital model.

Analysis of the data sets was carried out at the project end. The data sets were mapped along a time line of the project and were compared, criticised and reflected upon. The data collected provided statements on the value of the new learning environment to the collaborative design process and the collaboration process on the learning of the students in Unit Four.

Findings

The author took notes of his observations during the collaborative design sessions. In each of these sessions the group sat around a large table in the studio where each member had a view of each other and were in a position to contribute verbally to the discussion. On the table was a large selection of hand sketches done in pencil and pen on light transparency paper. In the early discussions the researcher noticed that all the plans and elevations of the concept by the architect were in hard-line sketch format. The discussion was mostly initiated by the architect and covered an area of the project that required an intervention of an existing building. The student architectural technologists contributed as 'problem solvers' at this initial phase. Information contributed to the collaborative design process(CDP) blog by the students indicated that they were already taking the architect's two-dimensional sketches and making three-dimensional massing models. One of the group members who was more advanced in Revit started to lay down a grid line and level framework to model the existing senior citizens' block in preparation for the proposed refurbishment plans of the design architect. This was the start of the Revit model being used by the students to address the design problem (see Figures E.2 and E.3).

In the next stage the architect continued a methodology of designing the concept solution through the use of hard-line sketches on butter paper (light transparency paper). The author noticed that when the architect was explaining an idea in relation to a portion of the building he used his hands to

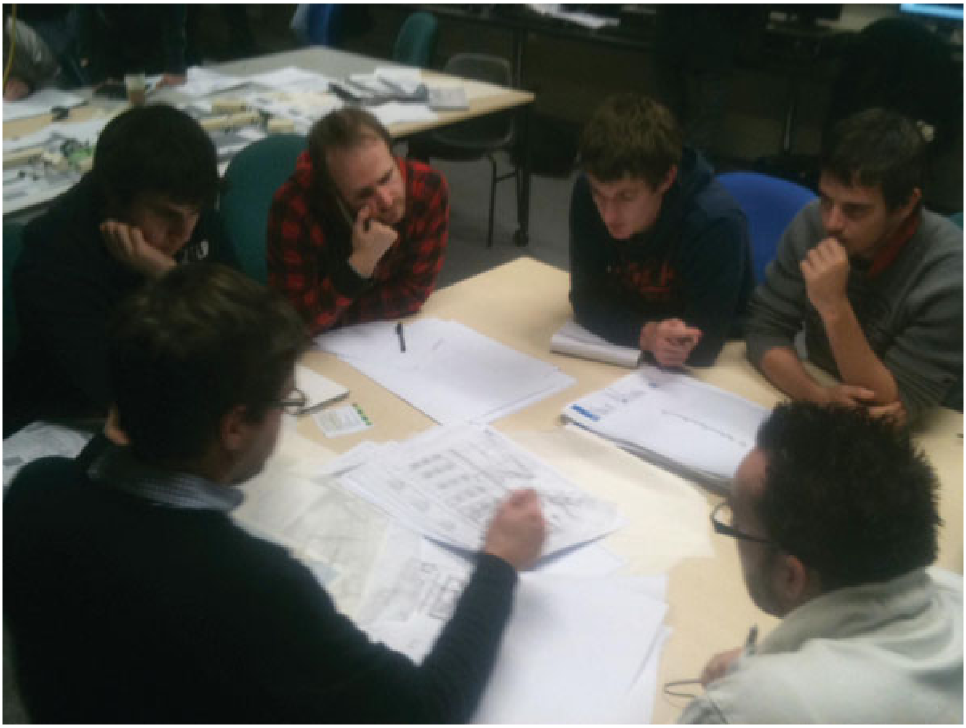

Figure E.2 Early stage CDP.

form three-dimensional shapes and volumes to give expression to the idea and to make it easier to understand and visualise. He also made use of overlays to coordinate rooms sited directly above and below the four storey building, in effect simulating three dimensions. As the volume of sketches increased, problems started to occur in coordinating the information between plans, elevations and sections. Also, locating sketches became difficult as the group had to shuffle through pieces of paper to locate a referred to layout. The author observed that the architect liked loose sketches at this early stage of the design as they allow for reflection and possible alternatives to come from this reflective process. The student group in these early sessions were also formulating technical questions as the design collaboration process continued. This had the effect of challenging their decision making skills and formulating their collaborative skills. They were also developing confidence through higher levels of involvement with the project.

By the end of week 4 the student group were contributing as collaborators in the design process with their increased commitment to and involvement with the project. They were representing the design information to the architect with hard copies drawn from computer aided design formats. The architect continued investigating design changes through the use of transparency paper

Figure E.3 Mid stage CDP.

overlays and pencil sketching. It was noticeable, however, that the student group were taking ownership of the project as their involvement intensified and different areas of technical design work were delegated out to individual students by group decision. These areas of responsibility were used later to form the Revit work-sets. Work-sets are a selected collection of building elements in the BIM model.

Although there were areas of the design still not fully resolved the students had a submission deadline for the end of week 7 to submit general arrangement drawings for formative assessment on their project and the students decided it was time to initiate the BIM model. The students were set up with a shared drive space on the institutional network and each of the group needed access to this network storage area. One student had the basic framework of the Revit model constructed, so this was set up as the master copy. The building elements were grouped into work-sets with each student taking responsibility for a set. Unit Four needed to work as a collaborative group, in order to make the deadline, as they had five days to produce the general arrangement drawings – a task that would take possibly three to four weeks working alone on a conventional two-dimensional computer aided design application. The general arrangement drawings were handed in on time and following formative assessment by the fourth year studio staff; Unit Four received the highest mark in class for their work.

The final collaborative design meeting took place on week 9 and Unit Four presented the BIM model projected from a personal computer on to a screen to the architect. His reaction was surprise followed by acceptance that this digital model was what he had envisioned. He also commented to the group that this was not far off from his intended design. For the rest of the meeting the BIM model was used for design visualisation references. It was observed that the architect's designer instincts almost immediately came into play as he initiated a discussion related to the external material of the lower two storeys of the tower block, and how these could be altered to give a 'base' to the tower. This interaction and many other subsequent design decisions were all taken prompted by the visual observation of the BIM model.

The blog to which the student group contributed confirmed the facilitating role of the BIM model and the benefits to the project derived not only in terms of collaborative decision making but also in terms of improved decision making by the individual student. Student 4 states 'that I learned in a different way. I learned through both individual research and group discussions.' The BIM (model) also improved communication between all members of the design team. All the implications of design decisions were picked up on through the work-sharing feature and discussed before the project moved on. Student 1 responded that he 'found the group did communicate much better while working in the collaboration mode of BIM, any important decisions to be made required us to discuss it as a group'. Student 3 said 'my decision making skills may have improved, but more so making decisions based on talking with others'. The author has reflected on the timing of introducing the BIM model into the design process and concluded that this needs to be carefully considered. The model carries a strong visual representation, perhaps too strong for the architect in the early stages of the conceptual design, in that it could unduly interfere in the architect's reflective thought process (see Figures E.4 and E.5).

Discussion

The collaborative process involves creating a master copy of the model. This is housed on a networked server. The master copy is divided up into work-sets. These work-sets are elements of the building, for instance the external envelope, the internal walls, the stair core and the floors; each of the students agreed to take ownership for an element and worked on this. The users synchronised with the master copy on a regular basis. Each time a synchronising happened all elements are updated and communicated to the group. This instant communication facilitated and prompted discussion amongst the students about the technical design proposal. The students were drawn into a conversation about the building elements and they would critically examine each other's work. Therefore, the BIM model provided enormous value in visualising the technical proposals and further enhancing the conversation. As a result of this, work was often revised and re-visualised. The students were also teaching each other and

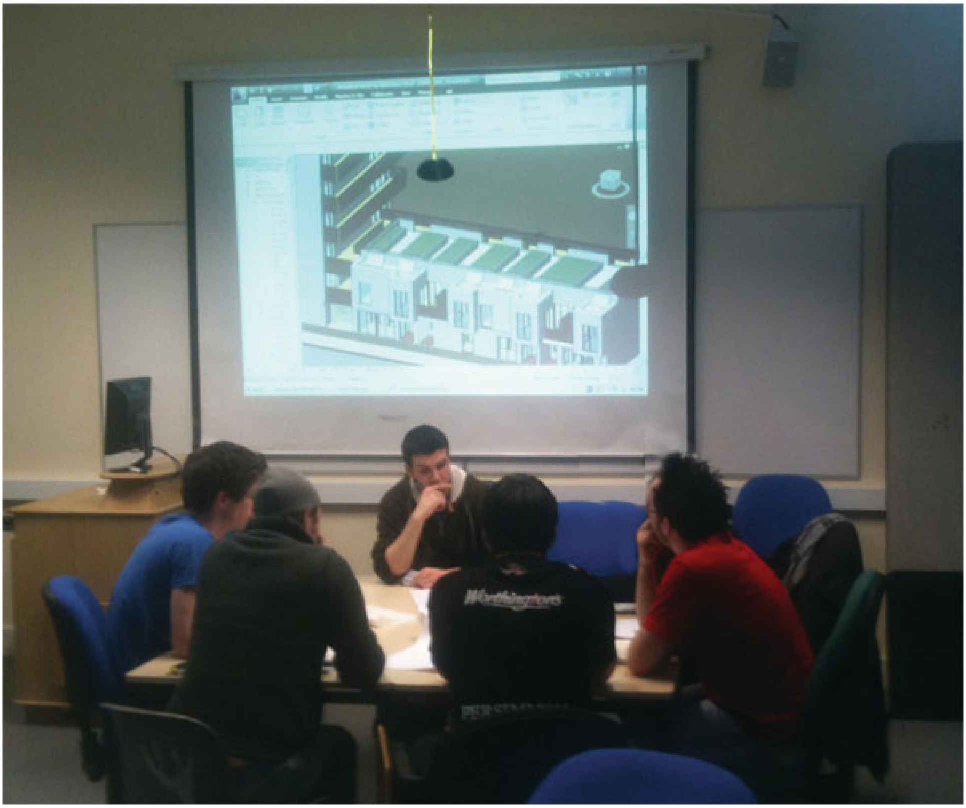

Figure E.4 CDP using the BIM model.

seeing the immediate results through the three-dimensional visualisation of the BIM model. This was confirmed in interviews conducted with the students after the group part of the project had finished. The feedback received included the following statements:

Student 1. 'Problem issues were much easier to see in the BIM model.'
Student 2. 'The use of BIM works well because you are not just drawing, you are building.'
Student 3. 'The model makes you think more of things on a macro scale.'
Student 4. 'It was a totally different way of working.'
Student 4. 'The model showed where things clashed; where you are drawing constantly in two dimensions you don't see these clashes.'
Student 5. 'Working on the model has changed the way one would think.'
Student 1. 'The model pushes you to collaborate more than one might do otherwise.'
Student 6. 'You will see what's wrong sooner when working on a BIM model.'

The learning pyramid developed by the NTL Institute for Applied Behavioural Science ranks average retention rates against learning styles. The three highest

Figure E.5 Early concept sketch.

rated learning styles on the pyramid are: discussion group, practice by doing and teach others with immediate use. The collaborative learning facilitated by BIM encompasses all three of these learning styles, culminating in a new rich learning experience for the student group. This echoes Denzer and Hedges's (2008, pp. 1–11) use of Bloom's Taxonomy as a benchmark to assess the student performance, confirming that BIM allows the students to reach the peak of Bloom's Taxonomy in terms of intellectual behaviour, 'the evaluation level'. From my observations, the work-set methodology further developed the collaborative process and contributed to a higher level of learning. For example, for a building element to interact with another from a different work-set, permission must be sought by the person wanting access to the element and permission must be granted by the owner of the work-set. This procedure facilitates a one on one conversation on how the elements will interact, resulting in a constant validation of the proposed technical design solution (see Figures E.6 and E.7).

The author observed continuous conversations during week 7 while students were working on the BIM model and this resulted in solutions to technical design problems with deeper understanding of the technical detail as the problems were teased out by the group working in collaboration.

Figure E.6 BIM render of elevation 1.

Figure E.7 BIM render of elevation 2.

Conclusion

It is likely that the problems of the future, in this case building design, will have a cross-disciplinary approach that encompasses multiple areas of expertise and the ways of knowing will have to become the norm. People, in this case the stakeholders in the design and construction of buildings, will need to be able to work in cross-disciplinary teams (Brown, 2006). The DIT architectural technologist, who is not burdened with the heavy weight of conceptual design, can concentrate their learning on developing an understanding of the other disciplines in the design and construction of a building – not to become the expert in these roles but to have the ability to be the creator and coordinator of the BIM and facilitate problem solving within the collaborative process. The complexities of modern design and construction lead the author to conclude that no one profession has all the answers to all the design questions. As new processes bring new responsibilities, the degree of specialised expertise that goes into a modern building expands constantly. This new collaborative learning environment simulated through working with BIM has the potential to prepare and equip the student architectural technologist with the skill set to be at the centre of the problem solving collaborative process. Jonassen (2011, p. 146) also argues that the ability to solve problems or to develop a methodology to address complex problems is something that requires practice. The creation of problem solving learning environments will address this. The fact that groups of students can collaborate together simultaneously on a BIM model adhering to a well structured brief to propose a solution to a technical problem will give them practice that closely follows what they can expect in modern design construction workplaces. It is the author's opinion that this structured coordinated collaborative process is more efficient in terms of students reaching their deadlines for project delivery and also enables a higher level of learning and understanding of technical design for buildings. A modified version of this model could be introduced in the third year of the course. This would provide further scaffolding to the students. They would learn the practicalities of how the collaborative tools work and this would have the effect of enhancing the collaborative project in the fourth year, allowing more time to spend on collaborative technical design. There is a challenge to take this model and extend it beyond the architect/technologist collaboration and open it up to include the other design and construction students and this can lead to further exploratory research in this area.

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Chapter Six
Research Processes and Practicalities

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As already demonstrated in this book, there is a great deal of research that falls under the general heading of architectural technology. Because architectural technology spans extensive disciplines of design, manufacture, assembly, maintenance, disassembly and management, the opportunities are almost limitless. Fortunately, the characteristics of good research projects are constant; they include meticulous planning, clearly defined aims and objectives, and appropriate resourcing. It is also important that projects are designed and conducted in such a way that the findings have value and relevance to the target audience. This means that projects should have clearly defined parameters, have clear aims and realistic objectives, and be achievable within given constraints of resources (time, finance, people, access to data). Although this may sound relatively straightforward it is not uncommon for the research design to be a time consuming act, especially if some of the constraints and parameters are not easy to establish at the outset. The aim of this chapter is to provide an overview of research processes and outline some of the practical issues facing researchers working in the architectural technology domain.

Introduction: research fundamentals

There are numerous definitions and interpretations of the word ‘research’, ranging from a careful and considered investigation, to a voyage of discovery, to a learning process. A useful definition can be found in the Research Excellence Framework (REF), which states that research is a process of investigation that leads to new insights that are disseminated or shared effectively (Higher Education Funding Council for England). The message is that research

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is a process, essentially a series of steps, that results in new knowledge. All research projects, regardless of size and duration, must be carefully planned, designed and implemented to ensure the validity of both the process and the findings. Conducting research will help to inform our own learning, and the research outcomes should result in new (original) knowledge from which others can learn. Learning may take place in a very small circle of contacts if the research is deemed to be confidential, or conversely the learning may extend to an international audience if the findings are disseminated widely, read and acted on.

Research categories

Research is usually categorised on a scale from pure research at one end to applied research at the other, with exploratory, explanatory and interpretive research lying somewhere between these two extremes:

- Pure research (alternatively known as basic research) is concerned with the discovery of theory and principles, the outcome of which is a contribution to the body of knowledge. This body of knowledge should be used to inform and underpin more practical research investigations.
- Exploratory research seeks to explore aspects of theory, usually by testing a research hypothesis. It is here that 'visionary' research ideas may be tested through a series of hypothetical scenarios.
- Explanatory research seeks to explain a phenomenon, by collecting additional data.
- Interpretive research seeks to place research findings into a theoretical model or framework.
- Applied research is concerned with the practical application of research to solve a practical problem, the outcome of which will also provide insights that may contribute to the wider knowledge base by confirming or challenging theoretical constructs.

Deductive and inductive reasoning

Deductive research is concerned with theory testing. Deductive reasoning starts with the theory (accepted principles and laws derived from the literature review), from which research questions and/or research hypothesis are proposed. The subsequent empirical data collection and analysis provides material to answer the research questions and support or refute the hypothesis. This is sometimes referred to as a 'top down' approach.

Inductive research is concerned with theory generation. Inductive reasoning starts with specific observations drawn from empirical data, which can lead to patterns and the generation of tentative research hypothesis. These data will then be used to develop or contribute to theory. This is sometimes referred to as a 'bottom up' approach.

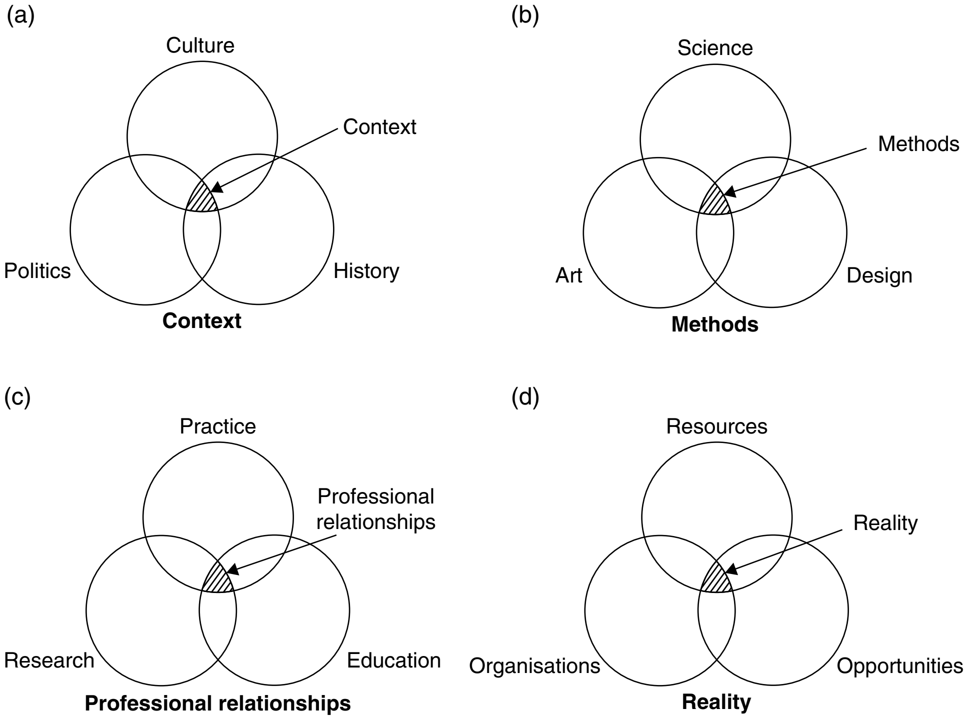

Figure 6.1 Research, practice and education (Source: Emmitt, 2002, p. 232).

Relationships

It is the relationship between context, methods, professional relationships and reality that will help to determine the success of individual research projects (Figure 6.1):

1. *Context*. Even the most rarefied piece of pure research is shaped by the social and physical environments in which it is conducted. Carrying out research ten years ago would be shaped by different social and economic factors compared to those existing today or compared to those that will exist ten years hence. In addition to time the context is also affected by the people involved in the research. This includes the funders, the individuals who conduct the research, and in many cases those subject to the research inquiry, and the target audience. Thus personal values, ethics, interests, experiences and desires will shape the research. Similarly, in carrying out research that aims to make a contribution to a specific discipline, in this case architectural technology, the research design will be influenced by the values of the profession or trade to which it is addressed.
2. *Methods*. Because the core characteristics of the architectural technology domain are design, technology and management, there are numerous

research methods that may be appropriate to a specific research investigation. This may range from the testing of materials, an enquiry into detailed design thinking, to implementing and monitoring a new managerial approach in a professional office – all of which demand different research techniques, knowledge and skills. Some of the methods that may be used have been described in the chapters in this book, although may more approaches can be found in publications outlining research methods (see, for example, Gill and Johnson, 2010).

3. *Professional relationships*. These revolve around the interaction and synergy between practice, research and education. Practitioners consume research, be it indirectly in the form of regulations, codes and standards, or directly through reading research reports, books and articles. Practice also provides researchers with a window on current techniques and procedures. Some daily practices may be well ahead of the published research, some will be similar to that reported in the literature, while some may be lagging behind. For researchers both ends of the spectrum can be fruitful areas to research, learning from the innovators and recommending improvements for the laggards. Education draws on practice and research, and the effective integration of research knowledge into the teaching of architectural technology is an important part of student learning (Emmitt, 2006).
4. *Reality (research practicalities)*. Issues of context, methods and professional relationships should be viewed from a pragmatic perspective. Resources, such as time and people, are often in short supply and all research projects need to be planned to make the best use of the available resources within a set budget. Balance is required between resources, opportunities and constraints, often necessitating some form of compromise and the identification of limitations on the scope of the research to make it achievable. Good research projects have clearly identified and articulated aims and objectives. This will help to establish the appropriate methods to be used and hence the amount of time required to conduct the research, the labour and equipment required, and hence the cost of the project.

Supervisors and advisors

It is prudent to have a supervisor or advisor to ensure maximum value can be derived from the research. Students following an educational programme will be given, or will choose, a supervisor for their dissertations and doctoral research. The relationship between supervisor and student is instrumental in helping to design, conduct and complete the research on time and to an appropriate standard. For practitioners it may be more of a challenge to find someone within their organisation to supervise or advise on a research project; this is especially so in a small professional office. It may be beneficial to enter into an agreement with an academic at a university to help guide the research to a successful conclusion. A number of programmes such as the TSB's Knowledge Transfer Partnerships and

Engineering Doctorate programmes are established routes; similarly, informal relationships between academics and practitioners can prove to be fruitful for both parties.

Research ethics

Research, by its very nature of enquiry, is invasive and care needs to be taken at all stages to ensure that the interests of those associated with the subject being researched are not compromised. The exact nature of the ethical issues will be related to the subject being investigated and the methodology employed. As a basic principle researchers must be open and honest with people and data.

In the competitive construction market a number of areas may be commercially sensitive and researchers must ensure that the people and processes involved are sufficiently well disguised to ensure anonymity. Some organisations may be keen to see their name or products in print and care must be taken to ensure that the research is not just an enhanced marketing exercise for those being researched. Research should be a balanced enquiry to have value to readers. It is ethical to:

- inform affected parties about the scope and nature of the research and the likely outcome before starting it;
- obtain consent to conduct the research and publish the findings (without caveats that would render the publication of results valueless);
- record all information accurately and systematically so that others could repeat the process;
- respect wishes for privacy and anonymity;
- thank people for their time and, if appropriate, offer to send a copy of the completed report.

Research – an iterative process

One widely held misconception is that research always follows a predetermined, well-planned route, from identifying the scope, to reviewing the literature, deciding on a methodology, collection of data, analysis of data, and finally the presentation of the findings. This may be the case with laboratory based materials testing, where researchers will follow tried and tested methods, but when we get into the realm of management and design research things are not always as straightforward. Experienced researchers will be familiar with a much more iterative process as they attempt to apply an appropriate way of working for a specific context. Whether we start with a title, or with access to some data, is largely a matter of individual preference and circumstance; what is important is not so much the order in which it is done but the rigour of the research approach and hence the validity of the findings.

Figure 6.2 indicates the main phases in a research project and their logical progression over time, during which the scope for uncertainty should decrease. This process is relatively generic and should cover the majority of research

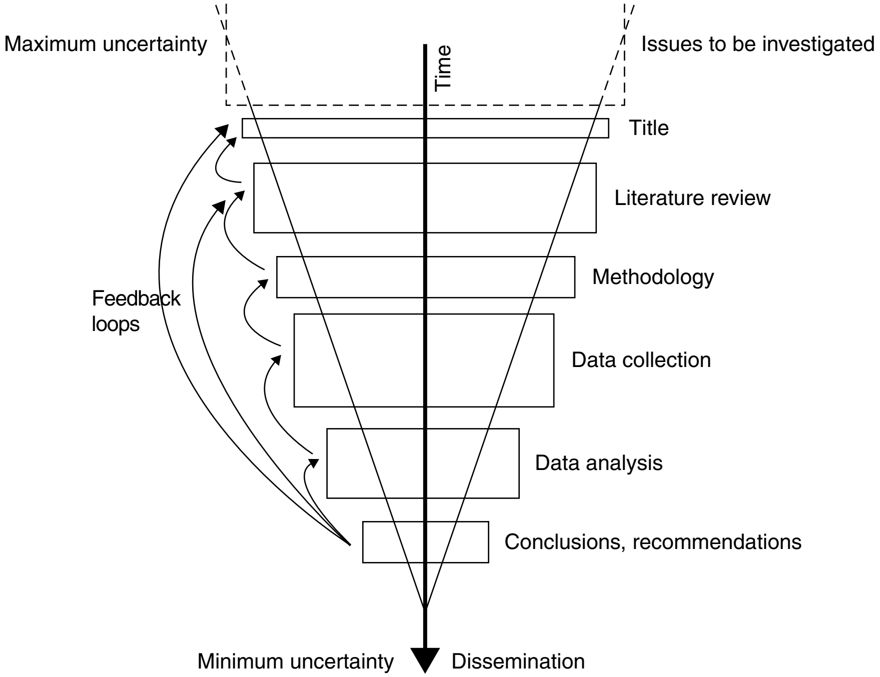

Figure 6.2 Research – an iterative process (Source: Emmitt, 2002, p. 236).

projects carried out by students and practitioners. The iterative process is represented by the feedback arrows in the figure.

Before proceeding too far it is usually necessary to develop an outline proposal. This will describe concisely the scope and the anticipated outcomes. Outline proposals are usually required for student projects and also for securing initial approval for developing more detailed research projects.

Title, scope and keywords

For reasons that should become clear from the discussion below, many projects start with a working title that broadly describes the research being undertaken. The final title may be revised once the research is complete, because more is known at the end of a project compared to the beginning. The final title should clearly indicate the scope of the research and give the reader a clear indication about the content. Good titles are usually concise and precise.

The scope of the project needs to be discussed and an outline proposal developed prior to addressing the literature review or methodological issues in depth. For undergraduate and postgraduate students the subject area and scope may be stimulated from personal interest, a specific module or related to a potential career direction. For practitioners, the subject area may be related to individual continuing professional development or related to a specific problem facing the individual in the workplace. Whatever our interests the research should aim to be meaningful and a catalyst for new work; it should be well organised and challenge perceived notions and/or question assumptions, thus helping to validate or question what has previously been published. In addition, of course, it should have some value to its intended audience.

It will be necessary to set out the aim of the research and a number of specific objectives when considering the scope of the project. Aims and objectives are fundamental drivers for all research projects, regardless of size and scope, and these will need to be reviewed and possibly adjusted as the research proceeds and more becomes known about the problem to hand. In addressing the aim and objectives it will be necessary to consider the resources required and in doing so it may be necessary to refine the scope of the project. It is not unusual to have unrealistic expectations at the outset that are tempered as practical constraints come into play.

Keywords are essential for helping others to find, and hence read, one's work. Reviewing the type and frequency of use of keywords by established researchers can be instrumental in helping to establish important themes and trends in the literature, which may also inform the research design.

Literature review

The primary aim of the literature review is to establish what we already know and by inference where the gaps in our knowledge may be. This means reviewing many sources, ranging from articles in peer reviewed journals to research reports, books, professional journals, peer reviewed conference papers and information placed on the Internet pages of respected institutions and organisations. All of this can consume a great amount of time. However, the temptation to cut corners must be avoided, because failure to conduct a rigorous literature review may result in abortive work and will certainly undermine the legitimacy of the findings.

A thorough literature review will help to identify trends, relevant theory, practice, the methods previously employed and the major authors in the field. This exercise needs to be carried out methodically, with each source fully referenced and reviewed without any bias on the part of the researcher. References must be recorded accurately, with each source listed consistently. Referencing conventions vary across subject areas, within universities and between peer reviewed journals; therefore it is essential to check the appropriate convention before starting the literature review. (The Harvard system has been used in this book.) It is essential to record the methodology underlying each literature source, since this will help to inform the researcher's own methodology. Reviewing what we already know, discovering what is unknown and establishing how knowledge was established provides a robust base from which to design a research project. At this stage it may be useful to reconsider the precise scope of the research and revisit the aims and objectives to ensure that they are still relevant.

No literature review can ever be exhaustive, nor can it ever be complete. Time pressures often make it impossible to cover every publication on a specific subject and so researchers may find themselves relying on concise reviews published by others. It is necessary to remain vigilant to ensure that new publications (new developments in the field) are surveyed for their relevance to the research project and of course to ensure that the findings are valid and have value to the intended audience. The outcome of the literature review should answer the following questions:

- What do we know?
- How was the knowledge derived? (What are the prevalent research methods?)
- Where are the gaps in our knowledge? (What don't we know?)

Methodology and method(s)

Once the literature review is complete, or substantively complete, it is possible to address the research methodology in greater detail and derive the method or methods to be used to collect data.

Methodology is a term used to describe a body of practices and rules used by others working in the discipline. In a research context the research methodology is a theoretical analysis of the research methods appropriate to a field of study. The purpose of the methodology section is to discuss theoretically the advantages and disadvantages of using different approaches. By analysing the theoretical and practical merits of the methods used in the field it is possible to design a research method that is specific to the aims and objectives of the project. This may involve the use of a previous method to allow direct comparisons with earlier published research or the design of a unique method to suit a specific research challenge.

Method describes how the data will be collected and how data will be analysed in a systematic way. In essence, the researcher is telling the reader how the research was conducted and how the data were analysed. The methods used must link to the aims and objectives of the research. This allows the reader to make an informed opinion on the data and should also allow other researchers to repeat the method at a future date. It is good practice to conduct a small trial (a pilot study) to test the design of the research method to see if it is feasible before embarking on the main data collection. Feedback from the trial will inform alterations and modifications to the research design to enhance its application and ease of use.

Data collection

Different methods have different protocols for recording information and it is important that the researcher(s) follow the established protocols to ensure the data are recorded accurately, legibly and consistently. Information on the protocols can be established through reviewing the work of others and consulting appropriate publications dedicated to specific research methods.

Data analysis and discussion

There are two approaches to the data analysis. The first approach is to complete the data collection phase and then analyse the findings as a separate task.

The second is an iterative approach, where data are collected and analysed as a series of predetermined steps, with the results of the intermediate analysis informing future data collection exercises. It is important that the adopted approach is explained in the research methods section.

Once the data have been analysed the findings will need to be described in the research report. Text will usually need to be balanced with graphics. Graphs, pie charts and diagrams are useful in helping to present the results clearly and concisely. It is at the discussion stage that the findings can be discussed in relation to previously published research findings (where appropriate), thus helping to identify the uniqueness and significance of the research. It is in the discussion section that the researcher's personal opinion may be introduced into the research, if appropriate to do so.

Conclusions and recommendations

Conclusions can be drawn once data collection and analysis are complete. This section of the report should include reflection on the strengths and limitations of the research methods used and appropriate recommendations. Conclusions must relate to the research aims and objectives, and it is good practice to discuss the conclusions against the stated aims and in relation to each objective or research hypothesis. Conclusions should flow logically from the data analysis and discussion section and should be discussed in relation to the magnitude of the research. This means that some conclusions may well be tentative due to the limitations of the study, while more extensive investigations may reveal conclusions that can be stated with more confidence. Conclusions should also relate to previously published work (identified in the literature review) to help demonstrate how the research has furthered our understanding in relation to the larger extant body of knowledge.

Discussing the strengths and limitations of the research methods allows other researchers to make an informed decision about the research findings. It also allows other researchers an insight into the practical application of specific research methods, which can help inform their own choice when considering methodological issues. The final step is to make recommendations for further research and, if appropriate, make practical recommendations for practitioners and educators.

List of references

The list of references at the end of the report or thesis is just that – a list of the sources cited in the body of the work. Every reference that has been cited must be included in the list of references, with page numbers if appropriate. Sometimes it may be appropriate to include a list of suggested further reading or a bibliography that contains a list of sources in addition to the references cited in the text.

Dissemination

The outcome of the research (the research deliverables) should be shared. There is little point in putting a lot of effort into a research project and then failing to address the findings to the target audience. For publicly funded research it is important to present the findings at appropriate conferences and publish the results in peer reviewed journals and, if appropriate, professional journals. Funding agencies will want to see value for money. In addition to any requirements for the formal reporting, sponsors will also want to see evidence of dissemination to a wider audience. Sponsors of publicly funded research, such as the Research Councils, will require a final report to be submitted that describes what has been done, the findings and the implications of those findings. This will be accompanied by a full financial report for the project. Research funded by private organisations may contain commercially sensitive findings and therefore it may not be appropriate to disseminate the work. Here the importance of dissemination within the organisation is crucial, which may be achieved by conducting seminars and writing short briefing papers. It may be possible, however, to release some of the findings to a wider audience, via conference presentations, articles and press releases, if some of the commercially sensitive material is not disclosed.

The main vehicle for disseminating work is the peer reviewed journal. Peer reviewed journals have a set layout for papers and articles, the style and content varying between journals and publishers; therefore it is important to send work to an appropriate outlet. This should be done before starting to write the paper so that it can be written in a style suited to the chosen journal. Once the article has been submitted it will be sent out for peer review by experts in the field. Reviews are ‘blind’, in that all author names are removed from the paper before it is sent to review. This helps to remove any professional or personal bias from the process and helps to ensure that the work is reviewed in a balanced manner. Reviewers are usually asked to review the manuscript against a set of parameters, which usually cover questions similar to:

- Is the research an original contribution to knowledge?
- Does the research add new insights and knowledge?
- Is it cutting edge research?
- Has the appropriate literature been reviewed and previous work acknowledged?
- Has the research been well designed and established protocols followed?
- Are the findings of interest to the journal’s (international) audience?
- Is the manuscript set out clearly, with clarity of structure and expression?
- Are there any omissions?
- Do the conclusions provide appropriate guidance?

Quantitative and qualitative methods

Choice of research methodology will depend upon a number of factors, such as the scope of the project and the available resources, so the choice of methodology is often a compromise. However, it is important to understand the differences between quantitative research and qualitative research.

Quantitative research

Quantitative research is based on the collection of data using scientific techniques, i.e. a numerical approach from which statistical analysis of the collected data allows conclusions to be drawn that may (or may not) be representative of the larger picture being studied. Engineering and materials science are examples of fields where quantitative methods are the principal investigative tool, essentially concerned with the world as it is (the measurables). There are two main research methods:

1. *Surveys*. Questionnaires administered by post, telephone or the Internet are a useful research tool for gathering information from a large, albeit remote, sample relatively cheaply and quickly. Although they are usually based on question design that requires answers that can be quantified, there is scope for asking and collecting a limited amount of qualitative data to support the quantitative responses. Typical questions require the respondent to check an answer to a question, ranging from a simple choice from Yes/Unsure/No to slightly more complex responses such as Strongly agree/Agree/Neither agree nor disagree/Disagree/Strongly disagree. Other questions may be designed that require the respondent to rank a list in order of preference, from 1 (first preference) to 10 (last preference). The better designed and better targeted the questionnaire, the more the likelihood of a good response rate. Surveys can be repeated relatively easily to gain comparative information.
2. *Experimental research*. Setting up a project under controlled conditions, e.g. in the laboratory, is relatively straightforward given a sound methodology, the correct equipment and accurate recording. Such experiments should be easy to replicate at a later date for verification of the findings. Again, the data generated are primarily numerical.

Qualitative research

Qualitative research is primarily concerned with individuals' perception of the world and is particularly well suited to research on management and design issues. Here the emphasis is on insights, using interviews, observational techniques and case studies. However, many other techniques are available, ranging from life histories and the use of stories, to qualitative research diaries and pictorial representation, to soft systems analysis and analytic induction (see Symon and Cassell, 1998).

1. *Interviews*. Interviewing people is an effective way of gaining opinion and perceptions and is widely used in research investigations. Care is required not to influence the interviewee deliberately by asking biased questions or by trying to direct their answers. Interviews are usually designed to be one of three types:
   - Structured. A set number of carefully designed questions are put to all interviewees.

- Semi-structured. Essentially a themed interview, where three or four main questions are put to the interviewee.
- Unstructured. The interviewee is asked to talk about a specific issue, with questions being asked by the interviewer for the sake of clarification.

A degree of caution is required because when professionals speak or write about their work they are portraying themselves as they wish to be seen – a professional image for public consumption (Ellis and Cuff, 1989). It is therefore prudent to use a second method of data collection to check that what people say they do is actually what they do (see ‘triangulation’ below).

2. *Observational research*. Observing the behaviour of people in their daily environment is potentially one of the most rewarding research techniques, but one difficult to conduct without influencing behaviour. It is also a technique that is difficult to repeat for the purpose of comparative study. Observational techniques involve varying degrees of participation, as identified by Gold (1958), where the researcher is:

- The complete participant. The true identity and purpose of the researcher are not revealed to those being researched. The intention here is not to affect behaviour.
- The participant as observer. This is where those being observed are overtly aware that they are being observed and by whom. This approach is likely to influence the behaviour of those being observed and permission will be required from all participants before the research can begin.
- The observer as participant. The researcher participates in daily activities alongside those being observed. This is a useful technique for part-time students who may be able to observe specific events within their professional offices, provided that everyone involved is happy and that all ethical concerns have been addressed.
- The complete observer. No social interaction takes place with those being observed by using hidden cameras or two-way mirrors. The intention here is not to affect behaviour and hence collect ‘pure’ data, although this raises ethical issues with secretly observing and recording people without their knowledge.

3. *Case studies*. Case studies are widely used in architecture, engineering and construction to help illustrate how designs are generated and buildings are realised. Emphasis is usually on context, processes and behaviour. For comparative purposes it is usually considered necessary to conduct multiple case studies to ensure a degree of validity to the research. However, one very detailed case study may help to illustrate some of the main issues being discussed without seeking to be representative of the larger population. In case studies a variety of data collection methods may be used to try and ensure that the main traits have been captured. These often include some form of observation and interviews.

Triangulation

It is a little unusual for researchers to rely entirely on one data collection method. When two or more methods are used it is possible to check, verify and validate the findings from each approach. Triangulation forms an important part of most research investigations, often involving the use of quantitative and qualitative research methods. An example of triangulation can be found in research into the behaviour of architects and architectural technologists (Emmitt and Yeomans, 2008). Quantitative data (questionnaire survey) and qualitative data (multiple case studies using observational research, interviews and analysis of project documentation) were used to develop a comprehensive insight into how professionals specified building products. It was only through the use of multiple methods that the main insights could be identified and verified.

Practical guidance for students

Undergraduate and postgraduate dissertation projects

Dissertations (or major projects) are an essential element of most undergraduate and postgraduate degree programmes. Dissertations allow students the chance to investigate a topic that they find of interest and that may help them to shape their career direction by, for example, focusing on a specific technology or managerial approach to develop knowledge. In some academic institutions the dissertation may take the form of a 'major project' with strong design and graphical content, although mostly it comprises a significant written component. For students that are more attuned to designing and working with graphical representation the prospect of producing a sizeable written document can be quite daunting. Fortunately, there are some simple rules to follow, which combined with adequate guidance from the dissertation supervisor, will help to ensure a successful piece of work within the available time (see, for example, Farrell, 2011, and/or Naoum, 2012) . The first step is to develop a research proposal, or project definition, which clearly and concisely describes what the research covers, some thoughts on how data are to be sourced and the intended outcomes of the research (as noted above). This is usually done in consultation with academic members of staff. Emphasis should be on practicalities and what can be achieved within a limited time and limited budget.

Doctoral research projects

A Doctor of Philosophy (PhD) is usually conducted over a three year period full-time or five years part-time. A Master of Philosophy is normally conducted over a two year period full-time and three years part-time. The aim of a PhD is to develop research skills and produce a thesis that contributes to knowledge. Students are required to undertake an oral examination (*viva voce*) where they are examined on the information contained within their thesis. The award of a PhD will be made to an individual who is in command of their field of study. Students are immersed within an academic culture, which facilitates the development of the literature review and the research design. Often the challenge is in getting access to industry to be able to collect sufficient data to satisfy the needs of the research. Ease of access to appropriate data sources needs to be given careful consideration when dealing with methodological issues to help ensure a successful piece of work.

Engineering doctorates

The engineering doctorate (EngD) differs from a PhD in that the student works within an industrial organisation. Sometimes known as 'industrial' PhDs they are conducted over a four year period. During this time the research engineers (the EngD students) will publish the results of their research in peer reviewed journals. These papers form an essential part of the final thesis, thus differing from a traditional PhD thesis. Similar to the PhD, all candidates undergo an oral examination. The benefit of the EngD over a PhD is that the student is embedded within an organisation and is surrounded by data, making collection of data relatively easy. The disadvantage is that it is sometimes difficult for the student to distance themselves sufficiently from the day to day activities of the business in order to analyse data critically and hence make sense of the world in which they work.

Practical guidance for practitioners

In many respects professionals remain perpetual 'students' of their subject throughout their careers, constantly asking questions about what they are doing and why. Practitioners will usually engage in some form of research in order to maintain their professional competences and to deliver projects to their clients. Continual professional development (CPD) or life-long learning are fundamental components of being a competent professional, and the busy practitioner has to decide which events and activities best suit his or her requirements, as well as satisfying the requirements of their employer. Many CPD events are short in duration, making it possible to fit learning into an already full schedule. However, there are times when CPD activities are either too general or simply not suitable to an individual or organisation, which can be the stimulus to engage in research. Changes to legislation and technologies may often provide the trigger to engage in modest research projects. Similarly, changes in market conditions may stimulate the need for a better way of delivering services. There are a number of recognised schemes to help organisations work with universities to develop new business capacity, one well known initiative being knowledge transfer partnerships.

Knowledge transfer partnerships (KTPs)

Knowledge transfer partnerships (KTPs) are part funded by the UK Government's Technology Strategy Board (TSB) and part by a commercial/business organisation. This allows a KTP Associate to be employed by the university to work as an agent for change within the organisation, applying knowledge to a practical challenge. Working alongside the organisation and university, the KTP Associate's role is to identify areas for improvement and make appropriate interventions, drawing on the knowledge and skills of the university to make informed decisions. The role of the university is to provide expertise and facilitate appropriate changes in the organisation. Typically a KTP will last for between 12 to 30 months, depending on the scale of the challenge to be addressed and available funding. The outcome of the KTP should be improved performance within the business and the generation of new knowledge.

Informal working relationships

In addition to formal projects it is sometimes advantageous for practitioners to enter into relatively informal working relationships with academics to deliver training, in-company learning events and research projects. Care should be taken to ensure all parties are aware of confidentiality issues and intellectual property rights, issues normally dealt with via a research contract.

Conclusion

To conclude, it is useful to re-emphasise the importance of research to the architectural technology knowledge domain. Sharing evidence based knowledge about good, and less good, practices will slowly but surely help to develop a unique area of knowledge that is specific to individuals working within the architectural technology field. Collectively, the knowledge derived from research projects will also help to reinforce and support the legitimacy of the architectural technology profession. It is useful to remember, however, that no matter how extensive and rigorous the research it only provides an indication of how things are at a particular point in time. Research does not prove a point beyond reasonable doubt.

Further reading

There are many books dedicated to specific research methods, and advice should be taken from supervisors on the most appropriate ones to read. The following publications deal with the essentials of conducting research from a construction perspective:

- Farrell, P. (2011) *Writing a Built Environment Dissertation: Practical Guidance and Examples*. Wiley-Blackwell, Chichester.
- Fellows, R. and Liu, A. (2008) *Research Methods for Construction*, third edition. Blackwell Publishing.
- Naoum, S.G. (2012) *Dissertation Research and Writing for Construction Students*, third edition. Routledge, Oxon.
- Phillips, E.M. and Pugh, D.S. (2010) *How to Get a PhD: A Handbook for Students and Their Supervisors*, fifth edition. Open University Press, Maidenhead.

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Emmitt, S. (2006) Investigating the synergy between teaching and research in a teaching led university: the case of an architectural technology undergraduate programme. *Architectural Engineering and Design Management* (Teaching and Learning Building Design and Construction, special issue), 2(1 and 2), 61–72.

Emmitt, S. and Yeomans, D.T. (2008) *Specifying Buildings: A Design Management Perspective*. Butterworth-Heinemann, Oxford.

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Gill, J. and Johnson, P. (2010) *Research Methods for Managers*, 4th edition. Sage Publications, London.

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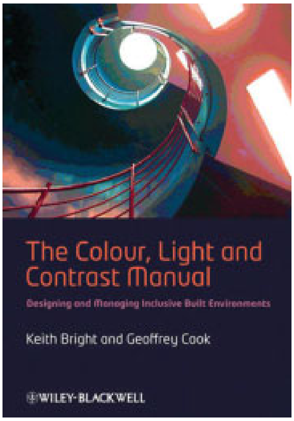

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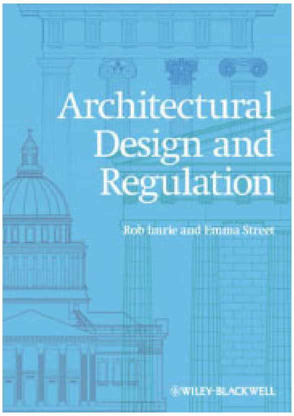

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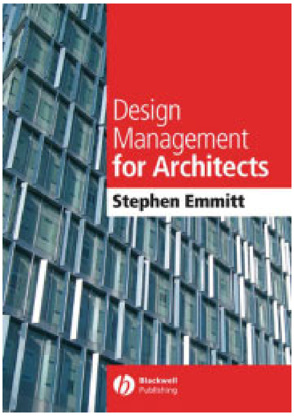

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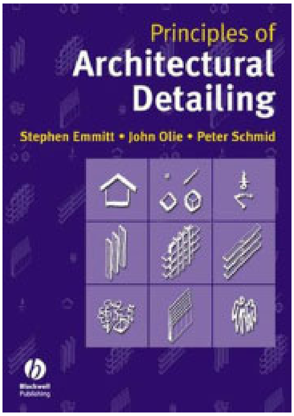

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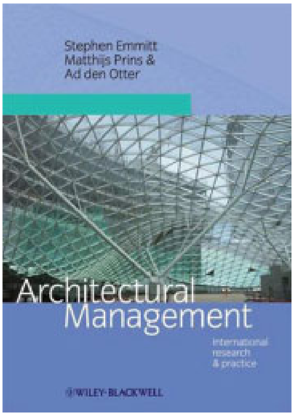

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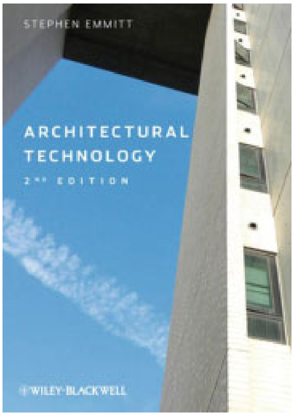

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