An investigation into the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales

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Summary of Thesis

The research aims to investigate the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales. There are three stages:

1) Literature review
This research starts with a review on low/ zero carbon design, architectural education, learning styles, and adult learning. The initial models of low/ zero carbon design and architects' learning preference are developed to reflect the initial understanding of the research topic.

2) Case studies
Three low/ zero carbon design training programmes are chosen as case studies with the acknowledgement of the limitations. The revised models are established with the feedback from the discussions and the survey results in the case studies to reflect architects' current perspectives.

3) Questionnaire survey
Based on the revised models, a nationwide questionnaire survey is conducted. Adding the survey results to the revised models, the final models are developed to inform the content and dissemination methods of low/ zero carbon design training programmes.

The final model of low/ zero carbon design reflects the iterative process and the holistic approach to achieve low/ zero carbon goal, identifies that the knowledge and skills that architects require are associated with new active technologies, the updated Building Regulations and standard, and tasks in construction, hand over and close out stages, and reveals the importance to raise architects' awareness of the importance of waste management, the legislation and regulations, and cost and value. The final model of architects' learning preference points out the importance of workplace follow-up sessions, indicates that architects prefer different learning styles and share the characteristics of adult learning except wanting to be involved in the planning of the future training programmes, and supports that presentational styles influence the knowledge transfer processes for architects.

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Chapter 1. Introduction

This chapter introduces background information regarding low/ zero carbon design in the building industry and explains the necessity to integrate low/ zero carbon design with training of architects. The research aim is then set and defined, with a comprehensive research plan developed. At the end of this chapter, the structure of the thesis is established and illustrated.

1.1 Background information

The Intergovernmental Panel on Climate Change (IPCC) published the Working Group I report for the Fifth Assessment Report which stated that the continued greenhouse gas emissions will cause further global warming and changes in all components of the climate system, and limiting climate change will require substantial and sustained reductions of greenhouse gas emissions (IPCC 2013). Since the IPCC First Assessment Report was published in 1990, the high greenhouse gas emissions resulting in an additional warming of the Earth's surface had attracted the world's attention. The United Nations Framework Convention on Climate Change (UNFCCC) was founded in 1992 and parties met annually in Conferences of the Parties (COP) to assess the progress made to mitigate climate change from 1995 (UNFCCC 2014a). The Kyoto protocol, established in 1997, was the first agreement between nations to mandate their reductions in greenhouse gas emissions (UN 1998). According to the agreements set by the Kyoto Protocol, the European Union committed to reduce the greenhouse gas emissions by 8% for the period 2008-2012 relative to the level in 1990, and 20% for a second commitment period 2012-2020 (EEA 2010). Accordingly, the European Energy 2020 strategy sets the targets to reduce the emission by 20% of the level in 1990 and to provide 20% of energy consumed from renewable energy systems by 2020. The European Climate Change Programme is developed to implement the EU legislation and policies, and the EU Energy Performance of Buildings Directive (EPBD) is the first move to reduce carbon emissions and energy consumption from buildings. In response to the EPBD, the UK Government puts forward the Energy White Paper and the UK Climate Change Programme. The Climate Change Bill was passed to be the Climate Change Act in 2008 which commits to reduce greenhouse gas emissions by at least 80% of 1990 levels by 2050 (Adeyeye 2007). In 2010, the Zero Carbon Britain 2030 report (ZCB2030) was published by the researchers from the Centre for Alternative Technologies to present how the UK can transit to a zero carbon society by

2030 with reduction of energy wastage, usage of renewable energy, and lifestyle and land use changes (Kemp 2010).

The construction industry globally is responsible for a large share of energy use and carbon emissions. Buildings use 32% of the world's resources in construction, and are responsible for around 40% of global energy use, and generate up to 30% of global greenhouse gas emissions (World Green Building Council 2010). In the UK, 50% of greenhouse gas emissions are from running buildings, while 30% of those emissions could be cut by cheap and simple measures; and 10% of UK emissions come from producing building materials (UK Green Building Council 2009). The first set of national building standards were introduced in the Building Regulations in 1965 (GOV.UK 2013). Since then, the UK construction industry has been in the transition to low/ zero energy buildings with incremental steps. However, with the intensified problems including climate change and fuel poverty, stringent building policies and regulations to reduce carbon dioxide emissions have been developed in the UK to respond to the international call to enforce the significant reduction of carbon emissions and energy consumption, such as the European Directive on the Energy Performance of Buildings. In response to the recommendations from the 2002 EPBD, the UK Government introduced performance based calculations for building energy consumption in 2006, moving away from prescriptive building regulations to standards where compliance is achieved by the performance of the end product (Hamza and Greenwood 2009). The advantage of the performance based approach is to overcome the inflexible enforcement of the prescriptive regulations. The 2010 version of Building Regulation Part L1A requires the Dwelling Emission Rate (DER) to achieve an addition 25% or more reduction of the Target Emission Rate (TER) compared with the 2006 version. By 2016, all new homes in England will be required to achieve zero net emissions of carbon dioxide from all energy use in the home (Department for Communities and Local Government 2006). Building regulation powers were devolved to Wales on 31

December 2011. Amendments had been made to the Approved Documents L for use in Wales to take into account of the recast of the EPBD, including: 1) Energy Performance Certificates came into force on 9th January 2013, 2) the analysis of high efficiency alternative systems for new buildings and existing buildings occupied by public authorities came into force on the 9th January 2013 and for all buildings on the 9th July 2013, and 3) all new buildings are expected to be nearly zero-energy by 2019 (The Welsh Government 2014).

However, how to implement these policies into practice presents a challenge for the current construction industry. Alkhaddar (2011) suggested that people are not educated as much as they should be regarding sustainability, and education is necessary to improve sustainability in the UK construction industry. The Construction Confederation Environmental Forum (CCEF) set one of its target to increase the environmental knowledge and skills of all who work in construction contracting (CCEF 2009).

1.2 The need for this research

Architects in practice are one of the keys to realize the above goals due to their leading role in the design process from the beginning of site planning to the later stages of material specification and construction. These fast tightening construction policies and rapid development of design theories and technologies drive significant changes/ challenges to the design process for architects in practice:

- The first change (challenge) is the additional consideration of building performance and energy efficiency to the original focus of function and form. Most architects in practice today are trained to deal with the function and aesthetic aspects of building design. Marsh (2008) stated that in order to achieve the high levels of efficiency and performance of the buildings, knowledge and understanding of building physics and energy flows through the buildings is needed which are not considered necessary for architects previously.
- The second challenge is to implement design strategies to reach the strict benchmarks which have never been set previously. There are general good practices and best practices to achieve energy efficiency in design. However, the introduction of performance based calculations for building energy consumption requires to identify sources of knowledge and tools to meet performance based regulations while considering current availability of materials and labour skill (Hazam and Greenwood 2009). Increasing the thickness of insulation and reducing the area of glazing cannot satisfy the Building Regulations any more. There are no existing, well-tested measures ensuring the achievement of the current energy consumption targets. The close collaboration between research and practice becomes important.

- The third challenge is to stay updated with policies and standards of low/ zero carbon design which have kept changing in order to respond to the situation. In response to the recommendations from the 2002 EPBD, the UK Building Regulations have been strengthened. Since then, the UK Building Regulations have been regularly updated with more stringent requirements every four years. For example, the Building Regulations 2013 has increased the requirements for fabric parameters comparing to the 2010 version, reduced the fuel factor for SAP calculations, and limited the effects of solar and other heating gains in summer (Allen 2012).

Therefore, in order to design buildings which can meet the targets set by the low/ zero carbon legislation and regulations, with reduced energy demand (by integrated passive design and efficient services) which may be supplied by renewable energy systems, architects need to learn. Hakkinen and Belloni (2011) carried out survey research and concluded that building professionals' level of knowledge of sustainable design should be improved significantly, and qualification systems are suggested. Therefore, low/ zero carbon design training programmes are necessary. Some organizations in the UK such as the Royal Institute of British Architects (RIBA), the Building Research Establishment (BRE), the Royal Society of Architects in Wales (RSAW), the UK Green Building Council, the Carbon Trust, the Low Carbon Research Institute (LCRI) and the Centre for Research in Built Environment (CRiBE) have started delivering lectures, workshops, seminars and surgeries of design to put architects through a process of 'raising the awareness and disseminating the knowledge of low/ zero carbon design' in order to get everyone in the construction industry on the same page from philosophical and technical standpoints.

The main reason for the conduction of this research is low/ zero carbon design training programmes are playing an important role in accomplishing the goals of reducing carbon emissions in the construction industry today. However, the training programmes would be of less value, if architects attended the low/ zero carbon design training programmes and could not bring the knowledge and skills they learnt to their projects. Newland et al. (1987) explained the reason why the well-established knowledge in built environment did not become manifest in architectural design, was that the strong belief systems and predispositions of practicing architects having any overriding effect on the transfer of technical information in architectural design. Ritter (1981) suggested that the information must reflect architects' personal perceptions and be relevant to them, in order to ensure the information to be successfully applied. Zapata-Poveda and Tweed (2014) suggested the necessity to address the knowledge gap and consider the type of training in order to enhance the practicalities of achieving carbon reductions. Thus, it would be necessary to carry out a systematic study to explore how to develop low/ zero carbon design training programmes to transfer the knowledge and skills to the architects in practice.

The development of low/ zero carbon design training programmes can be recognized as an attempt to integrate two themes: 1) low/ zero carbon design in architecture and 2) teaching and learning for architects. Models to inform the development of low/ zero carbon design training programmes for architects in practice in England and Wales will be established at the end of this research.

1.3 Research aim and research questions

The aim of this research is:

> To investigate the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales.

Two research questions are raised:

1. What knowledge and skills of low/ zero carbon design are required to be disseminated to the architects in practice?
2. How to disseminate the required knowledge and skills of low/ zero carbon design to architects in practice?

In order to make sure this research remains focused and accurate, three areas of focus are set on the research aim, related to the concept, profession, and region:

1. The research emphasizes the low/ zero carbon design within the sustainable design concept. The reason is that the current emphasis of building design regarding sustainability is to reduce energy consumption and minimize carbon dioxide emissions due to the global impact such as climate change and local impact such as fuel poverty.
2. This research focuses on architects, though a successful low/ zero carbon design is due to the efforts of a multi-disciplined design team. The reason is that architects are still in the leading position to integrate low/ zero carbon design strategies into projects from the very beginning of the design.
3. This research shows interest in England and Wales.

1.4 Research work flow and methods

1.4.1 Research work flow

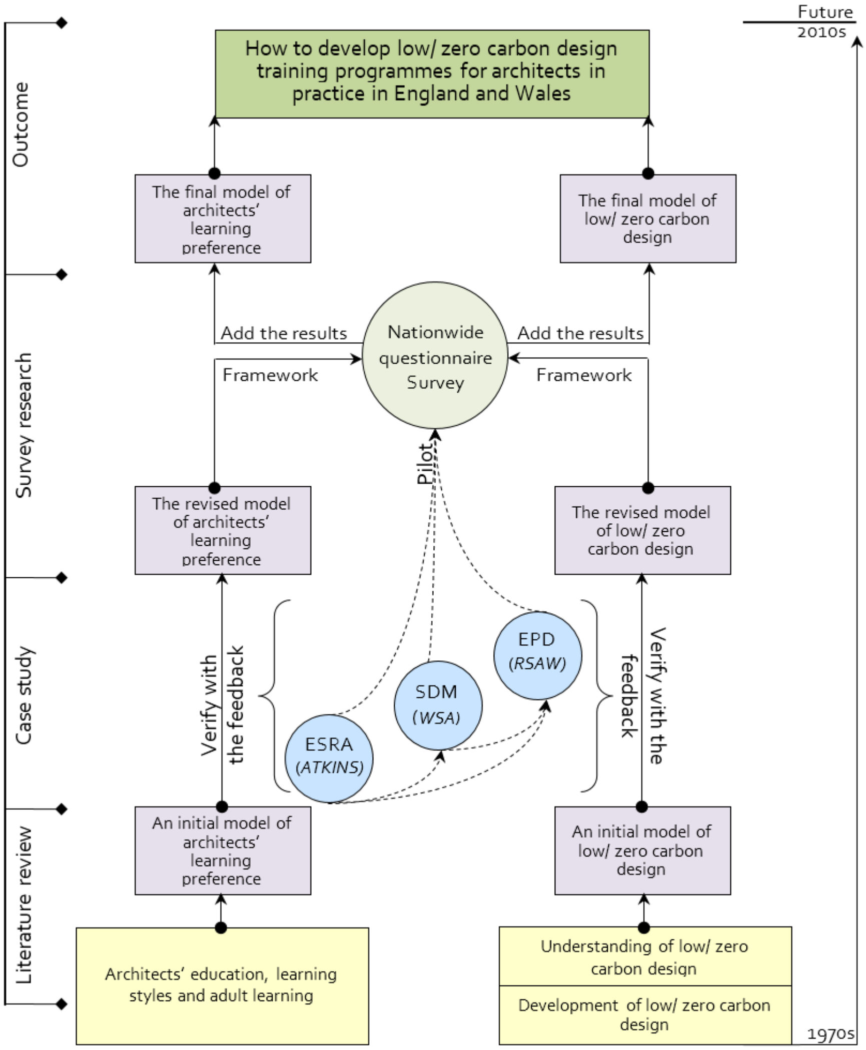
This research involves three main stages:

Stage 1: The research starts with a review regarding the movement towards low/ zero carbon design from the 1970s to the present in the construction industry, including the main drivers for low carbon commitment, and actions in architectural practice and education in the UK in response to the low carbon transition. This part of literature review is to explore how the construction industry in the UK moves towards low/ zero carbon design influenced by the worldwide movement to reduce carbon emissions due to the climate change and the fuel poverty. Then, a focused review on low/ zero carbon design regarding the definitions, the standards and assessment methods, and design process models is conducted. The review intends to establish an understanding of low/ zero carbon design, and identify the elements related to low/ zero carbon design. Next, a review of architectural education, learning styles, and adult learning is carried out to identify the elements influencing the knowledge dissemination to architects. Two initial models are developed based on the reviews: 1) an initial model of low/ zero carbon design, and 2) an initial model of architects' learning preference.

Stage 2: After the literature review, three representative case studies of low/ zero carbon design training programmes are chosen to 1) verify the initial models derived from the literature review to make sure the models reflect architects' current perspective, and 2) gather experience in questionnaire survey method. The three case studies include the 'Enable Sustainability— Raising Awareness' programme (ESRA) for ATKINS, the Sustainable Design Masters programme (SDM) by the Welsh School of Architecture (WSA), and the Environmental Professional Development pilot (EPD) by the Royal Society of Architects in Wales (RSAW). The relevant elements of the initial models are discussed with the participants during the three training programmes in the case studies. At the same time, one or two questionnaire surveys were carried out for each of the three training programmes, so lessons learnt regarding questionnaire survey will provide guidance to the nationwide questionnaire survey in the next stage. Taking into account the feedback from the discussions and the survey results, the revised models are generated at the end of the case studies in order to reflect architects' current perspectives on low/ zero carbon design and their learning preference.

Stage 3: A nationwide self-administered questionnaire survey for architects in practice in England and Wales is developed based on the revised model of low/ zero carbon design and the revised model of architects' learning preference. Lessons learnt in the case studies regarding questionnaire surveys are applied to the development of the questionnaire survey. The survey results are analysed and discussed. Adding the survey results to the revised models, the final models of low/ zero carbon design and architects' learning preference are developed.

At the end of the research, answers to the two research questions will be provided to inform 1) what knowledge and skills of low/ zero carbon design are required for dissemination, and 2) how to disseminate the required knowledge and skills of low/ zero carbon design to architects in practice in England and Wales. Figure 1-1 illustrates the research frame.



The three case studies:

ESRA: Enable Sustainability— Raising Awareness programme was a company internal staff training programme delivered by Cardiff University and the British University in Dubai for ATKINS' members in design teams

SDM: Sustainable Design Masters programme was a higher education programme delivered by the Welsh School of Architecture for candidates with various backgrounds, mainly architects and engineers

EPD: Environmental Professional Development pilot was a Continuous Professional Development programme delivered by the Royal Society of Architects in Wales for architects

Figure 1-1: Research frame

1.4.2 Research methods

Three main methods are employed to carry out this research, namely, the literature review, case study and survey research.

1: Literature review

A literature review is to review the critical points of current knowledge which have been published by accredited scholars and researchers on a particular topic (Ridley 2012). First, this research reviews the development of low/ zero carbon design in the construction industry in the UK from the 1970s to the present, and the concept of low/ zero carbon design including the definitions, standards and design process models to establish an understanding of low/ zero carbon design. Second, a review of learning and teaching in architecture, learning styles and adult learning is conducted to develop an understanding of the ways in which architects prefer to learn. Finally, the literatures about survey research regarding definition, characteristics, methods of survey research, the quality of survey research and ethical issues are reviewed, as well as the methodology for the analysis of the survey results.

2: Case study

According to Bouma and Atkinson (1995), a case study can provide answers to the question ‘what is going on?’. There are two types of case study: 1) exploratory study to ascertain the relevant variables for a particular area of the study, and 2) hypothesis tester to provide an initial test of a hypothesis (Bouma and Atkinson 1995). In this research, the case study serves both functions. First, the initial models are verified through the three typical case studies to reflect the architects’ current perspective (a hypothesis tester). Second, the issues regarding conducting successful questionnaire survey learnt from the literature can be tested, as well as the issues not mentioned in the literature can be explored through the questionnaire surveys carried out in these case studies (as an exploratory study).

3: Survey research

Survey research is one method of social research which is concerned with gathering data that can help to answer questions about various aspects of society and thus can enable us to understand society (Bailey 1994). The survey research method has been commonly applied to explore architectural students' and architects' learning preference, for example the questionnaire survey conducted by Newland et al. (1987) to explore architects' behaviour (learning styles and interpersonal communications). In order to find out the architects' opinion on low/ zero carbon design and the associated training programmes, a series of self-administered questionnaire surveys (one questionnaire survey for each of the first two case studies and two questionnaire surveys for the third case study) are carried out in the case studies, followed by a nationwide questionnaire survey regarding the required content and dissemination methods of low/ zero carbon design training programmes.

1.5 Thesis structure

The thesis consists of ten chapters. The following diagram (Figure 1-2) shows how each chapter is structured in the whole thesis.

Chapter one introduces the background information and the need for this research. It establishes the research aim and research questions, defines the research scope and finally draws the research plan. The aim of this study is to investigate the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales. The core of this thesis is to integrate two themes: 1) low/ zero carbon design, and 2) architects' learning preference. Chapter two explores the development of low/ zero carbon design in the construction industry, focusing on the time period from the 1970s to the present, in order to reflect the need for low/ zero carbon design. Chapter three reviews the current meaning of low/ zero carbon design in architecture, including the definitions, the assessment methods and the design process models. Chapter four goes through the literatures regarding architectural education, learning styles and adult learning. The literature review helps to link this research to the existing body of knowledge. At the end of the review, the initial models of low/ zero carbon design and architects' learning preference are generated. Chapter five describes the methodology applied in survey research. Chapter six introduces the case studies of three typical training programmes conducted to verify the initial models in order to establish the revised models to be applied as the framework to design the nationwide questionnaire survey, as well as to collect experience in conducting questionnaire survey. Chapter seven describes how the nationwide questionnaire survey is carried out to collect information on architects' opinion on low/ zero carbon design and the associated training programmes. The survey results are analysed and presented in Chapter eight, while Chapter nine discusses the survey results in relation to the existing body of knowledge and establish the final model of low/ zero carbon design and the final model of architects' learning preference. Chapter ten concludes the research.

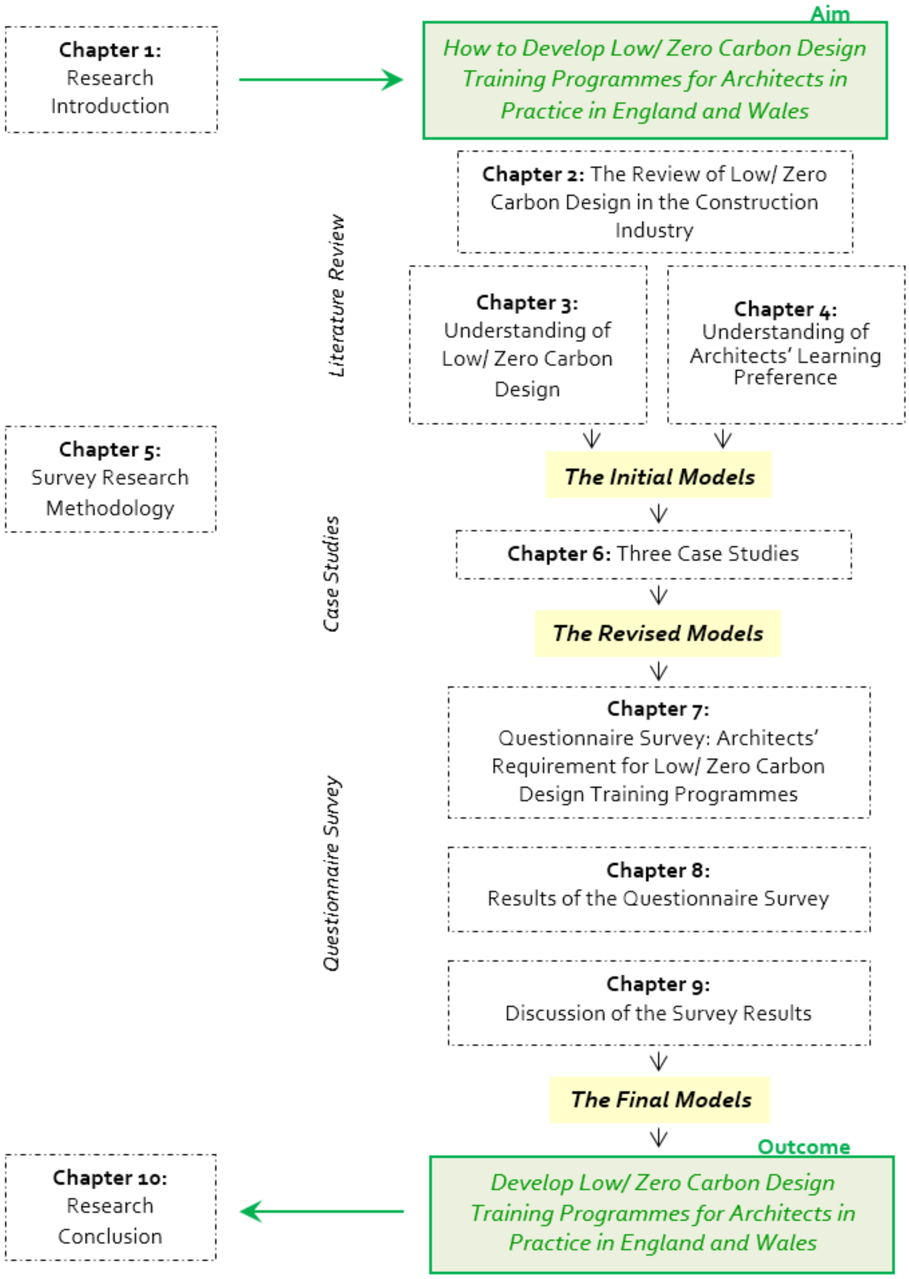


Figure 1-2: Thesis structure

1.6 Summary

In summary, this chapter introduced the context and the necessity of this research. The research aim was defined to investigate the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales. Two specific research questions were raised. A detailed research plan was developed in order to achieve the research aim.

Chapter 2. The development of low/ zero carbon design

This chapter explores the development of low/ zero carbon design in terms of the movement towards low/ zero carbon design in the construction industry from the 1970s to the present, the main drivers for the low carbon commitment, and actions in architectural practice and education in response to the low carbon transition. This chapter reviews the work conducted towards low/ zero carbon design in the past decades, reveals the requirement and actions to integrate low/ zero carbon design into the mainstream design of architecture, and identifies the need to develop training programmes to transfer the knowledge and skills to design low/ zero carbon buildings to architects in practice. A summary table of the development of low/ zero carbon design can be found in Appendix I, consisting of the international movements, the EU incentives and the UK policy statements and Building Regulations.

2.1 The worldwide movements towards low/ zero carbon design

2.1.1 Before the 1970s

Hoffman (2000) claimed that some concepts of sustainability are developments of the last decades; while many of the principles are old ideas, some of which are ancient understandings. A series of studies have been conducted to explore the development of sustainability in architectural design, including ‘The Critical Review of Ecological Architecture’ by Steele in 2005 and ‘The Philosophy of Sustainable Design’ by Mclennan in 2006. Steele (2005) reviewed the architectural history of the past century regarding the movement toward an ecological approach to architectural design with case studies of 26 architects. McLennan (2006) reviewed the evolutionary stages in the movement of sustainable design, and established the framework of sustainability in architecture with six principles of sustainable design from the respects for 1) the nature system, 2) people, 3) place, 4) the cycle of life, 5) energy and natural resources, and 6) process.

Sustainable design features can be found in the evolution of vernacular buildings built by builders without conscious design, but to make the best use of limited available resources to provide shelters to survive. Various designers and scholars conducted research to understand vernacular architecture. Rapoport published his book ‘House Form & Culture’ in 1969, and discussed the idea how culture ecology and interrelationships of sociocultural factors determine the character of the vernacular house form. Fathy (1986) explored the wisdom of vernacular architectural forms with dense brick walls and traditional courtyard forms to provide passive cooling, and offered a series of vernacular concepts to solve today’s critical housing situation facing millions in the Third World.

During a long span of time, architecture was designed purposely to promote the comfort and pleasure in spaces. Examples include natural lighting design in temples in ancient Egyptian time, passive solar design in city planning and house design in ancient Greek time as well as in thermal bathes and other public buildings in Roman time. In Renaissance time, Palladio contributed to architecture design with microclimate consideration and his treatise on architecture: Quattro Libri dell'Architettura (The Four Books on Architecture) which contained the application of thermal mass, window design with the consideration of both daylighting and thermal condition, heating and cooling techniques, and design with the sun (Palladio 1570).

The industrial revolution started in Britain in the late 18th century and then subsequently spread throughout Europe and North America. With new technologies, a break from the past in architectural design began. A number of architects around the world started developing new architectural solutions to interpret new technologies and materials, e.g. skyscrapers with elevators, well lit deep plan buildings with artificial lighting, and controllable indoor environment with heating and cooling equipment. However, some architects cherished traditional legacy. At the beginning of the 20th century, William Atkinson pioneered in the movement to rediscover passive solar design, and designed a 'solar house' based upon his own experiments with solar energy (Watson 1998). In 1912, he published his book 'The Orientation of Buildings or Planning for Sunlight'. An exemplary solar-heated building Annexe of St George's School Wallasey designed by Emslie Morgan was built in 1961 (Figure 2-1).

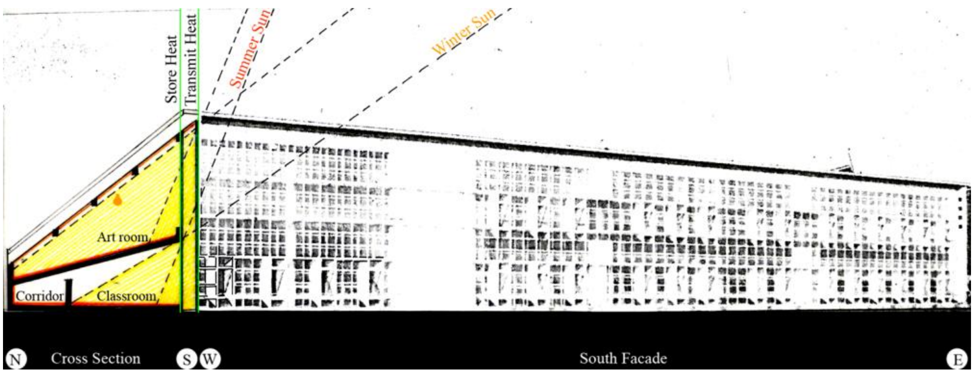


Figure 2-1: Annexe of St George's School Wallasey (Developed by researcher)

According to Watson (1998), climate responsive design was founded by the end of the 1940s. A number of architects were the pioneers in climate responsive design, including Frank Lloyd Wright, Tony Garnier, Le Corbusier, Marcel Breuer, Hannes Meyer, Alvar Aalto, and Olgyay Brothers. Frank Lloyd Wright started with Prairie Houses and tailored them specifically to local climatic conditions. He also designed the second Jacobs House (Solar Hemicycle) in 1944 which was an attempt at passive solar design. Le Corbusier's work showed environmental consciousness and design perceptions with collecting and analysing the environmental conditions and the requirements of the occupant s' comfort from the late 1940s. The villas and buildings he designed in Ahmadabad and Chandigarh in India were examples. Victor Olgyay and Aladar Olgyay published the book 'Design with Climate: Bioclimatic Approach to Architectural Regionalism' in 1963 to explore the relationship between buildings and their nature surroundings as well as the effects of climate on built environment. A new theory of the 'architectonic design' was developed to considerate orientation, shading, building form, air movements, site location, and effects of materials in order to solve the problems of shelter in different climates (Olgyay and Olgyay 1963).

In the 1960s and 1970s, a number of studies were carried out to understand general thermal comfort (Hawkes 1995). Fanger published 'Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation' to investigate the body's physiological processes in order to define the comfort equation in 1967. Also, Fanger (1970) developed the Predicted Mean Vote (PMV) model from laboratory and climate chamber studies.

The concern of the environment was raised as well. Rachael Carson's landmark book 'Silent Spring', first published in 1962, was written to alert the public to the abuse of chemical pesticides with little investigation of their effects on the environment and human beings. It caused a shift in public consciousness about the environment.

However, the low energy price and the development of heating and air conditioning equipment kept climatic responsive design from the main stream. In his book 'The Architecture of the Well-tempered Environment' in 1969, Banham recorded the increased energy consumption in buildings. Banham (1969) provided two approaches to the future: 1) the power operated mode, or 2) the conservative mode of environmental control. The impact of the energy crisis in early 1970s placed the favour towards the latter. An international focus was put on passive solar design and bioclimatic design in response to the increasing oil prices and the poor indoor health issues. In the 'The Environmental Tradition: Studies in the Architecture of Environment', Hawkes (1995) discussed environmental issues in a broader context in architecture, and outlined the evolution of the environmental design of architecture from the 1970s.

2.1.2 1970s: Energy conservation design

Earth Day, on the 22nd April 1970, was generally accepted to be the first consensus to arise out of the growing ecological concerns which began to be voiced in the 1960s (Steele 2005). In 1972, the United Nations Conference on the Human Environment was held in Stockholm, which was followed by the establishment of the UN Environment Programme (Sassi 2006). In 1974, an Ecumenical Study Conference on Science & Technology for Human Development was held by the World Council of Churches to respond to the developing world's objections to worry about the environment when human beings in many parts of the world suffer from poverty and deprivation (World Council of Churches 1974). According to Dresner (2002), this was the first time the concept of sustainability was close to its modern form.

Besides the attention on environmental issues, the first energy crisis started. In 1973, the escalating oil price alarmed the world and prompted governments to seek secure sources of energy and reduce dependency on imported fuel. As the decade went on, the second oil crisis happened in 1979.

The energy crises associated with the environment deterioration had a great influence on architectural design. In response to these crises, the buildings designed during this decade were looking at how to decrease the energy demand and use alternative energy. The common measures to reduce energy demand were the application of a higher level of insulation, smaller sized windows, and increased air tightness of the building envelope. This type of design can be categorised as the energy conservation design.

A series of research projects were set up to explore the effect of these measures to reduce energy demand. The Department of Environment: Housing Development Directive funded the ‘Abertridwr better insulated housing’ project from 1978 to 1984 to investigate the benefits of higher levels of thermal insulation together with reducing size of heating systems in housing (Jones 2005). The Pennylands project and Linford project were large scale housing projects developed by the joint venture between the Open University and Milton Keynes Development Corporation between 1976 and 1984 (Chapman et al. 1985). The overall aim of the two projects was to investigate potential energy savings that could be achieved through better house insulation and the incorporation of passive solar design features. These projects provided reliable data on a range of cost effective energy saving measures in houses with evidence for the benefits of insulation, low thermal capacity boilers, and measures to reduce infiltration rates, as well as detailed information on U-values, air change rates, patterns of occupancy behaviour together with a well calibrated passive solar model (Chapman et al. 1985).

British Gas (1980) introduced a series of technical publications 'Studies in Energy Efficiency in Buildings' during the International Energy Conservation Month (10/1979) as part of the industry's support of the Government Energy Initiatives. It aimed to contribute to the training and development of the professionals who concerned with the fuel efficiency of building design, and to assist the RIBA in its mid-career training programmes for architects.

The Gregory Bateson Building (1977-1979) designed by Sym Van Der Ryn is an exemplary project (Figure 2-2). The design features include passive heating (thermal mass storage), passive cooling (night time ventilation with reservoir), daylighting (atrium), as well as computer modelling of building thermal performance. Mike Reynolds, the garbage warrior, started using scraped tires, discarded beer cans and soda bottles to build his 'Earthship' to achieve tiny energy bills and surprisingly pleasing aesthetics.

Figure 2-2: Image of Gregory Bateson Building (Greatbuildings 2011)

2.1.3 1980s: Passive building design

By the 1980s, the price for oil began to go down (EIA 2014). However, the attention on energy did not totally fade away. In addition, the environmental and health issues became more relevant. In this decade, it was reported that human activities had negative effects on the environment and ecology, and these problems included water pollution, air pollution and land pollution, rapid ozone depletion, soil degradation, depletion of natural resources, extinction of plant and animal species, deforestation and destruction of natural habitats, waste production and fast population growth (Sassi 2006). Our society was under threat as well, due to population increase, poverty and inequality, urban sprawl, loss of quality of life, health deterioration and consumerism.

Several international programmes with those concerns in mind were carried out to improve the situation.

In 1980, World Conservation Strategy: Living Resources Conservation for Sustainable Development was commissioned by the International Union for Conservation of Nature and Natural Resources (IUCN), the United Nations Environment Programme (UNEP) together with the World Wildlife Fund (WWF) (Dresner 2008). In the document, the term sustainable development emerged, and the concept of sustainable development was put forward (IUCN 1980):

> *Sustainable development is the integration of conservation and development to ensure that modifications to the planet do indeed secure the survival and well-being of all people.*

In 1983, the United Nations World Commission on Environment and Development was convened by the United Nations. The commission was created to address the growing concern about the accelerating deterioration of the human environment and natural resources, as well as the consequences of the deterioration for economic and social development (Dresner 2008). In 1987, the report Our Common Future was published by the World Commission on Environment and Development when chaired by Brundtland, which provided the most cited definition of sustainable development (World Commission on Environment and Development 1987):

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*.

According to Dresner (2008), it was the right place at the right time to force governments and international agencies to start thinking and talking about the issue. Since then, the concept of sustainable development was quickly taken up.

In the construction industry, more projects were funded to explore the strategies for low energy buildings. The Energy World exhibition of low energy houses, organized by Milton Keynes Development Corporation (MKDC) and sponsored by Anglian Building in 1986, exhibited 51 energy efficient houses in the Shenley Lodge area of Milton Keynes (Horton 1987). It focused on energy efficient design in housing regarding the current and future technical and economic viability. It had a significant impact on the Government policy and within the national house-building industry. The Milton Keynes Energy Cost Index, an energy performance standard, was used to ensure dwellings have an energy performance significantly better than that required by the UK Building Regulations (Chapman 1990). Chapman (1990) continued that the UK's first national energy efficiency rating scheme for buildings, the National Home Energy Rating scheme launched in 1990, was based on the results and feedback from the Energy World, and it was replaced by the Standard Assessment Procedure (SAP) rating system in 1995.

Following the Energy World, Milton Keynes Energy Park was established with houses built following conventional housing design with higher standards of energy performance than the standards were required by the Building Regulations at that time in the late 1980s (UKERC-EDC 1990). From 1989 to 1991, 160 houses in Milton Keynes Energy Park were monitored for hourly energy consumption and a 28% reduction in energy consumption compared with the housing stock at the same time was concluded (Summerfield et al. 2007).

The Energy Performance Assessment (EPA) project was sponsored by the Energy Technology Support Unit on behalf of the Department of Energy in the late 1980s to accelerate the uptake of low energy and passive solar design of buildings (Palmer et al. 1991). 30 occupied low energy passive solar buildings of different types were studied to evaluate their energy, operating and cost performance.

Architects known for the quality of their design started to champion sustainable architecture, such as Thomas Herzog and Richard Rogers. Figure 2-3 shows Herzog's main work during this time, including Doppelwohnhaus in Pullach (1986-1989) which is a two-family house with 3.9 meter width to have access to winter sun and using translucent thermal mass with small holes set in front of the precast concrete external wall painted black with a gap; Guest Building for the Youth Education Centre in Windberg (1987-1991) which is positioned to expose the main function areas in the solar and daylight with transparent thermal mass to create even operational temperature and reduce heat loss, and Linz Design centre (1989-1993) which is known for its hybrid ventilation and space flexibility (From notes taken on a lecture given by Thomas Herzog in Tianjin on the 28th October 2013).

Figure 2.3: From left to right: Doppelwohnhaus in Pullach, Guest Building for the Youth Education Centre, and Linz Design centre (Herzog + Partner 2013)

Natural ventilation introducing fresh air and cooling effect was promoted during this period of time. There were two reasons. First, many of the buildings designed to conserve energy in the 1970s turned out to be sick buildings because the carbon dioxide and indoor pollutants from interior finishes and furnishings were built up due to the tight building envelopes and reduced air changes (Mclennan 2006). Second, data collected by the British Antarctic Survey showed that ozone levels had dropped to 10% below normal January levels in Antarctica (Farman et al. 1985). The reason for the depletion of the ozone layer was Chlorofluorocarbons (CFCs) which were used in air conditioning/ cooling units since CFCs were developed by Thomas Midgley in the 1920s. Natural ventilation was the alternative to cool spaces in buildings.

An exciting and innovative example of the application of natural ventilation is the School of Engineering, De Montfort University (1988-1993) by Short Ford & Associates (Figure 2-4). According to Steele (2005), the building is designed through an integral approach to link site layout, built form, materials, services and controls to the daily and seasonal patterns of occupants. The ventilation chimneys using stack effect with thermal mass are the main cooling strategy in the complex. Computer simulations indicate the size and position of the chimney openings. A carbon dioxide detector controlling automatic dampers in the stack is intended to prevent excess ventilation. Temperature sensors control the heating and can override the carbon dioxide detector to open the dampers when the space temperature rises over the comfortable zone (Steele 2005). Besides natural ventilation, other innovative design features include daylighting, building management system (BMS) and an efficient combined heat and power unit (CHP) (Thomas 2006). This building is designed to be naturally lighted and ventilated, passive heated and cooled spaces with the concern of healthy internal environment, which represents the era of passive design. The Contact Theatre in Manchester completed in 1999 and the Coventry University Library completed in 2000 are other examples of naturally ventilated buildings (Figure 2-5).

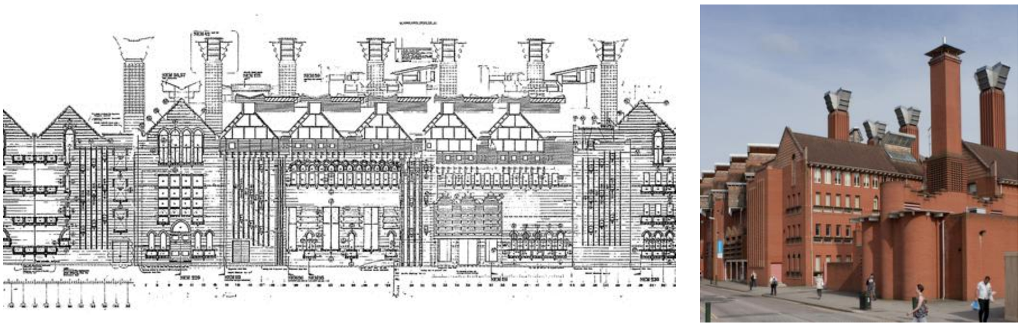


Figure 2-4: School of Engineering, De Montfort University (RIBA 2014)

The gateway 2 office building in Basingstoke designed by Arup Associates in 1983 is another example of naturally ventilated building (Figure 2-5). The atrium is a central social area of the building with a passive function: in winter, the warm air stored inside is recirculated down the atrium to partially supply the office area, and in summer the atrium sucks the warm air out from the office by stack effect (Allard 1998).

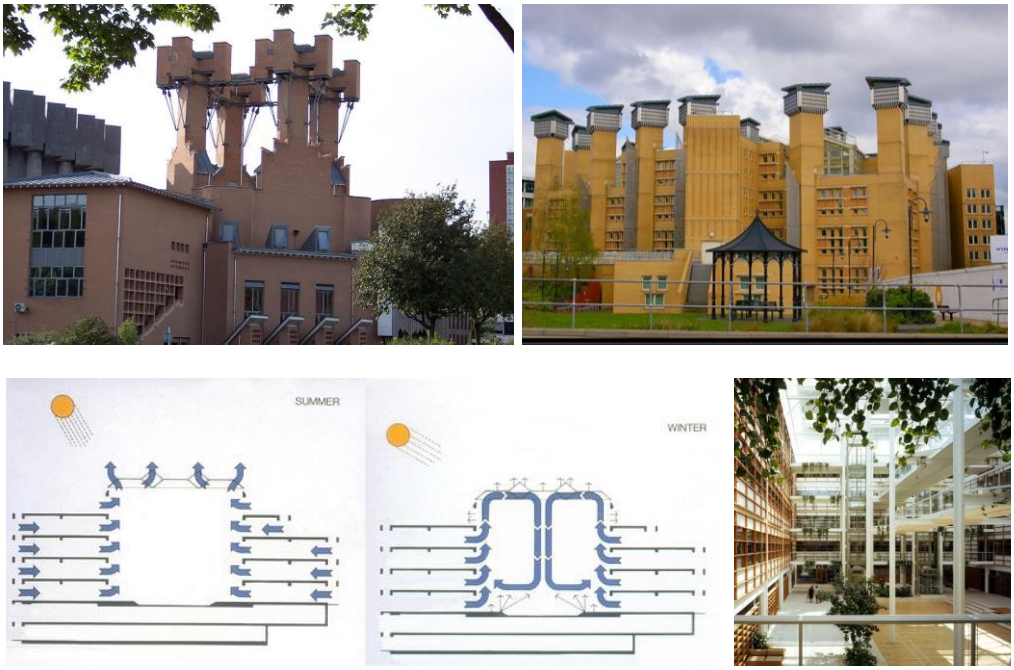


Figure 2-5: From left to right: Contact Theatre in Manchester (Wikipedia 2009), Coventry University Library (Wikipeidia 2012), The gateway 2 office building in Basingstoke (Arup Associates 1983)

2.1.4 1990s: Sustainable design

Following the First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) released in 1990, attention was drawn to the climate change. It was predicted that if carbon dioxide emissions continued to rise, a global average temperature rise of 1.5 to 4.5°C could be expected over the next century (IPCC 1990).There was an agreement among climate scientists worldwide that the present evidence suggested that climate change was 90% certain to be due to human activities, mainly through the burning of fossil fuels (Smith 2005). The Second Assessment Report of the Intergovernmental Panel on Climate Change was published in 1995, which suggested that the global warming had already been taking place, and the pattern of warming indicated that it was human-induced rather than nature (IPCC 1995). As global warming attracted more attention, international governments and societies began holding a series of urgent conferences to seek global solutions (Table 2-1).

Table 2-1 Events regarding global warming in the 1990s (Dresner 2008)

Year & Place	Event	Achievement
1990	IPCC	• The First Assessment Report of Intergovernmental Panel on Climate Change was published.
1992 Rio de Janeiro	The Earth Summit conference (United Nations Conference on Environment and Development or UNCED)	• The largest international conference held up to that time, including 172 governments participated with 108 at level of heads of State or Government. • The Framework Convention on Climate Change had been signed at Rio, which accepted that climate change was a serious problem and action could not wait for resolution of scientific uncertainties. • It accepted that industrialized countries should take the lead, and the first step would be Annex I countries to stabilize CO2 emissions at 1990 levels by the year 2000.
1995 Berlin	The first Conference of the Parties meeting (COP-1)	• It discussed a draft protocol proposed by the Alliance of Small Island State (AOSIS), calling for a 20% reduction in CO2 emissions from industrialized countries by 2005, which was suggested by the IPCC scientists as a first step towards a 60% reduction by 2040. • Since 1995, the parties at the convention had met annually in the Conferences of the Parties (COP) to assess progress in dealing with climate change.
1995	IPCC	• The Second Assessment Report of Intergovernmental Panel on Climate Change was published.
1996 Geneva	The second Conference of the Parties meeting (COP-2)	• The Clinton administration accepted the Second Assessment Report of IPCC. • Except Australia, all of the other JUSSCANNZ countries changed position to accept the principle of binding targets.
1997 New York	Earth Summit II	• It reviewed the progress towards the commitments made in Rio in 1992. • Most western countries were still increasing their carbon emissions despite their commitments in the Framework Convention on Climate Change to stabilize greenhouse gas emissions.
1997 Kyoto	The third Conference of the Parties meeting (COP-3)	• Kyoto Protocol, an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC), was finally agreed. • Smith (2005) viewed Kyoto Protocol as a first step on the path of serious CO_2 abatement. An agreement was signed by over 180 countries to cut CO_2 emissions by 5.2% globally based on 1990 level.
1998 Aires	The fourth conference of the Parties meeting (COP-4)	• It addressed the need to get down to the task of putting the Kyoto Protocol into effect with mechanisms that would provide flexibility in order to ensure credibility and promote sustainable development.

1999 Bonn	The fifth conference of the Parties meeting (COP-5)	• No major conclusions were reached.
Note 1: Annex I includes the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. (Dresner 2008)		

The Energy Saving Trust, a non-profit organization, was founded in1993. It aimed to tackle climate change by providing advice and information for people across the UK in order to promote the sustainable use of energy, energy conservation and to cut carbon dioxide emissions. The Best Practice programme managed by the Energy Technology Support Unit (ETSU) at Harwell and the Building Research Energy Conservation Support Unit (BRECSU) in Watford, was a major initiative by the Department of Environment Energy Efficiency Office (EEO) to help industry to improve the energy efficiency in the UK (Ahmad 1994). The programme supported projects of future practice, new practice, good practice or energy consumption guides, and opened to organisations in industry, commerce, building management, design and construction. The Fuel Efficiency Booklet series were part of the Best Practice programme.

More assessment methods to determine whether a building has good environmental performance were developed. For example, BRE Environmental Assessment Method (BREEAM) was established in 1990 as a voluntary measurement rating for the sustainability of new non-domestic buildings in the UK, while Leadership in Energy and Environmental Design (LEED) was launched in 1998 to help determine how green a particular building was in the US.

There were a series of environmentally advanced projects designed and built during the 1990s. The Menara Mesiniaga Tower in Selangor (1992) by the Malaysian architect Ken Yeang is a climate-responsive tower (Figure 2-6). It demonstrates Yeang's key principles for bioclimatic skyscraper design. In his book 'The Skyscraper, Bioclimatically Considered: A Design Primer', Yeang (Yeang 1996) defines the bioclimatic skyscraper as a tall building whose built form is configured by design, using passive low energy techniques to relate to the site's climate and meteorological data. The design results in a building that is environmentally interactive, low energy in embodiment and high quality in performance. Regarding the bioclimatic design approach, the first step and of the most importance is to achieve low energy through passive strategies, and then consider the use of mechanical systems to achieve the required indoor environment and enhance its low energy consumption as the secondary strategies to the passive ones.

British architect Bill Dunster founded the ZEDfactory in 1999 which specializes in zero-carbon design and development. The project Beddington Zero-fossil Energy Development (BedZED), is a community of 82 homes, 18 work/ live units and 1560m^2 of workspace and communal facilities built on a brown field from 1999 to 2002 (Ritchie and Thomas 2009) (Figure 2-6). It is a low energy housing scheme, aiming to create a prototype of how people should live to enjoy a sustainable future in Beddington (Smith 2005). The project won the 2003 Royal Institute of British Architects (RIBA) Sustainability Award. According to BRECSU (2002), BedZED's zero total energy strategy is achieved by: 1) energy efficient design of buildings, 2) energy efficient and hot water saving appliances to reduce demand, 3) use of renewable energy sources, and 4) a green transport plan. In addition, BedZED uses natural, recycled materials without volatile organic compounds, and products with a low embodied energy.

Another pioneering green project was the Inland Revenue Centre in Nottingham by Hopkins Architects in 1994 (Figure 2-6). The green design strategies consist of thermal mass and night time ventilation for cooling, buoyancy effect in glass block stair to drive the ventilation system, and fabric umbrellas on the tops of the towers to exhaust hot air or conserve heat.

Figure 2-6: From left to right: Menara Mesiniaga Tower by Yeang (Wikipedia 2011), BedZED by Dunster (Wikipedia 2007) and Inland Revenue Centre by Hopkins Architects (Hopkins Architects 1994)

Besides the emphasis on the reduction of greenhouse gas emissions and usage of fossil fuels in new built buildings, material selection and resource conservation (e.g. water saving) as well as waste management joined the circle. For example, the Environmental Resource Guide, published by the American Institute of Architects in 1996, was the first attempt to quantify the life cycle impacts of building materials (Mclennan 2006). At the same time, green practitioners began to research and test the link between health and the materials used in building construction. In addition, the scale of sustainable design was expanded to urban design and city planning. According to Van Der Ryn and Stuart (2007), the 1990s saw the emergence of the international eco cities movement which was working to create healthier and more resource efficient cities.

2.1.5 2000s to early 2010s: Low/zero carbon design

The trend of sustainable development at the beginning of the 21st century continued. The Royal Society of British Architects (RIBA) published RIBA Environmental Manifesto, committing to use its influence with government and the international communities, to endorse the principle of sustainable development and translate it into action (RIBA 2000). Sustainable development was defined as (RIBA 2000):

> *Development which raises the quality of life and serves the goal of achieving global equity in the distribution of the Earth's resources whilst conserving its*

natural capital and achieving significant and sustained reductions in all forms of pollution especially greenhouse gas emissions.

Events related to sustainable development are summarized in Table 2-2.

Table 2-2: Events regarding sustainable development in the 2000s (Dresner 2008; UNFCCC 2014b)

Year & Place	Event	Achievement
2000 Hague	The Sixth Conference of Parties meeting (COP-6)	• The Umbrella Group were keen to exploit a potential loophole in the Kyoto Protocol. • At the end of March 2001, the US president George Bush withdrew from the agreement and refused to accept a binding target for stabilizing carbon dioxide emissions. But, more than 200 cities in the US adopted the Kyoto Protocol in their own efforts to reduce greenhouse gas emissions.
2001 Marrakech	The Seventh Conference of Parties meeting (COP-7)	• The final rules for the Kyoto protocol were agreed with the European Union making concessions to demands for more flexibility from Japan and Russia.
2001	IPCC	• The Third Assessment Report of Intergovernmental Panel on Climate Change was published.
2002 New Deli	The Eighth Conference of Parties meeting (COP-8)	• It called for efforts from developed countries to reduce the impact of climate change. • Russia required more time to consider the related issues, which could delay the Kyoto Protocol entering into force.
2002 Johannesburg	The World Summit on Sustainable Development	• It was a ten-year-on sequel to UNCED. • It was supposed to be more about the development than the environment. • No new commitments were made.
2003 Milan	The ninth Conference of Parties meeting (COP-9)	• The parties agreed to use the Adaptation Fund primarily to support developing countries better adapt to climate change, and for capacity-building through technology transfer.
2004 Buenos Aires	The tenth Conference of Parties meeting (COP-10)	• The progress made since the first Conference of the Parties and its future challenges, with special emphasis on climate change mitigation and adaptation was reviewed. • The Buenos Aires Plan of Action was adopted to promote developing countries better adapt to climate change. • How to allocate emission reduction obligation when the first commitment period ends by 2012 was discussed.
2005 Montreal	The 11th Conference of Parties meeting (COP-11)	• It was a review of the working of the industrialized countries in the Kyoto Protocol.
2006 Nairobi	The 12th Conference of Parties meeting (COP-12)	• The parties developed a five-year plan of work to support developing countries to achieve climate change adaptation, and agreed on the procedures and modalities for the Adaptation Fund.
2006	The Stern Review on the Economics of Climate Change	• Released by economist, Lord Stern of Brentford, for the British government, it discussed the effect of climate change and global warming on the world economy. • In June 2008, Stern increased the estimate to 2% (previously 1%) of GDP to account for faster than expected climate change.

2007 Bali	The 13th Conference of Parties meeting (COP-13)	• Australia ratified the Kyoto Protocol. • The European Union committed itself unilaterally to a 20% emissions reduction below 1990 levels by 2020. • The US, Canada, Japan, and Russia accepted a reference to the need for 'deep cuts' in emissions. • China, India and other developing countries were persuaded to agree to do something to restrain their emissions rather than pledge actual emissions cuts.
2007	IPCC	• The Fourth Assessment Report of Intergovernmental Panel on Climate Change was published. • The IPCC won the Nobel Peace Prize, sharing the award with Al Gore for their work to raise awareness of climate change.
2008 Poznan	The 14th Conference of Parties meeting (COP-14)	• Principles for the financing of a fund to help the poorest nations cope with the effects of climate change were agreed, and a mechanism to protect forest to combat climate change was passed.
2009 Copenhag en	The 15th Conference of Parties meeting (COP-15)	• No binding agreement for long-term action was achieved as the goal set to establish a global climate agreement for the period from 2012 when the first commitment period under the Kyoto Protocol expires.
2010 Cancun	The 16th conference of the Parties meeting (COP-16)	• An agreement that called for Green Climate Fund, and a Climate Technology Centre and network was achieved. • The IPCC Fourth Assessment Report goal of a maximum 2 °C global warming was recognized.
2011 Durban	The 17th Conference of Parties meeting (COP-17)	• All countries agreed on a legally binding deal to be prepared by 2015, and to take effect in 2020 comprising. • The creation of a Green Climate Fund (GCF) was progressed.
2012 Doha	The 18th Conference of Parties meeting (COP-18)	• The Doha Climate Gateway was produced, which contained an amendment of the Kyoto Protocol, featuring a second commitment period running from 2012 until. • Little progress towards the funding of the Green Climate Fund was made during the conference.
2013 Warsaw	The 19th Conference of Parties meeting (COP-18)	• An agreement that all states would start cutting emissions as soon as possible, but preferably by the first quarter of 2015 was achieved. • The Warsaw Mechanism was proposed to aid developing nations to deal with loss and damage from such natural climate disasters.
2013	IPCC	• The Working Group I (WGI) contribution to the IPCC Fifth Assessment Report 'Climate Change 2013: The Physical Science Basis' was approved.
Note 2: Umbrella Group: a looser group of Annex I Parties, which first emerged at COP-3 in 1997, initially to oppose the EU's attempt to restrict the use of the flexibility mechanisms and whose membership currently includes Russia, Ukraine, Japan, the US, Canada, Australia, Norway, New Zealand, Iceland. (Yamin and Depledge 2004)		

It was promising for sustainable design in this decade. First of all, sustainable became policy. The Building Regulations were updated to reflect the knowledge of sustainability.

RIBA Key indicators for sustainable design were published to guide the design (RIBA 2000). Second, sustainable design started being valued as an important aspect of architectural design. Green architect Glenn Murcutt won the Pritzker Prize for design, awarded to the best designer of the year by the AIA in 2002, and he won the AIA Gold Medal Award in 2009. He practiced sustainable design in most of his work, long before sustainability became a focus. G.Z. Brown and Mark DeKay originally published the book ‘Sun, wind, and light: Architectural design strategies’ in 2001 to explore how to design buildings that heat with the sun, cool with the wind, light with the sky, and move into the future using on-site renewable resources. Third, people began to shift their attitude towards sustainable design, from a negative to positive point of view. They started to believe that sustainable design would result in better buildings which were healthier and more cost effective in a long run or even cheaper in a short term in some cases. It was the mark of success for sustainable design that people started to go green because of economic reasons. Last but not least, carbon dioxide emissions was recognized and accepted as the key issue to be addressed in the building industry.

There are three reasons for the focus on carbon. First, the well-established link between climate change and man-made greenhouse gas emissions has identified that greenhouse gas emissions are the greatest challenge facing human society. The climate change situation got worse according to the Third and Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2001, 2007). The Working Group I (WGI) contribution to the IPCC Fifth Assessment Report ‘Climate Change 2013: The Physical Science Basis’ suggested that continued greenhouse gas emissions will cause further warming and changes in all components of the climate system, and limiting climate change will require substantial and sustained reductions of greenhouse gas emissions (WGI 2013). Since carbon dioxide is one of the major greenhouse gases and almost half of carbon dioxide emissions was from energy use in buildings, low/

zero carbon buildings were designed to reduce carbon dioxide emissions in order to mitigate climate change.

Second, carbon dioxide emissions is interlocked with energy consumption and poses a problem to the whole world: the depletion fossil fuels. Nicholls (2002) summarized the four reasons to reduce the amount of energy consumed by buildings: cutting cost, protecting the environment, producing better buildings and political reason.

Third, there are many qualitative components of sustainable design which presented a challenge to Building Regulations, legislation and assessment methods. Therefore, a reduction in carbon dioxide emissions which plays an important role in sustainable design became the first task to tackle.

Figure 2-7: EMPA building by BGP (Photo by researcher)

A good example of zero energy development is the EMPA building which was designed by Bob Gusin & Partner (BGP) in Zurich, Switzerland (Figure 2-7). The strategies implemented include: high level of insulation, external shading to control the solar radiation, thermal mass integrated with night time ventilation for cooling, daylighting, ground cooling, photovoltaic system, selection of materials with resource consideration, water reservation and a green roof.

In summary, section 2.1 indicates that low/ zero carbon design concept has been put forward for decades with much research and many exemplary projects. However, low/ zero carbon design has always been kept away from the mainstream in the building industry, and raised as a special design concept with different focuses in the past several decades. There is an urge to change this situation. Next section will introduce the main drivers to push towards the low/ zero carbon develop, which reflect the need to integrate low/ zero carbon design concept into the mainstream of architectural design.

2.2 The major drivers for low/ zero carbon design in the EU and UK

Among the international communities and many countries, improving the energy efficiency of buildings and reducing carbon emissions become important in policy making. The International Energy Agency (IEA), the International Panel of Climate Change (IPCC) and the United Nations Environment Program (UNEP) have established guidelines to reduce greenhouse gas emissions and energy consumption of buildings (Noailly 2011). The European policy makers have driven a rapid movement towards sustainability and low carbon development.

2.2.1 The EU Incentives

In order to meet the commitments on climate change made under the Kyoto Protocol, the European Union has introduced legislation to support energy efficiency and ensure buildings consume less energy. A main part of this legislation was the Concerted Action Energy Performance of Buildings Directive (EPBD) in 2002, which required all EU countries to enhance their Building Regulations and to introduce energy certification schemes (Display Energy Certification and Energy Performance Certificates) for buildings. A target for all new buildings as well as existing buildings undergoing major renovation to be 'nearly zero-energy buildings' by 2020, and for public buildings by 2018 was set by the 2010 recast of the EPBD. Accordingly, Member States drew up national plans to achieve the target of nearly zero-energy buildings, including 1) to define nearly zero-energy buildings with a numerical indicator of primary energy use in kWh/m^2/year, 2) to provide intermediate targets for improving the energy performance of new buildings by 2015, and 3) to provide information on the policies and economic measures to promote nearly zero-energy buildings.

In 2005, the EU launched EU Emissions Trading System (EU ETS). It is the largest multi-country, multi-sector greenhouse gas emissions trading system for energy-intensive organizations in Europe, covering power stations, refineries and large manufacturing plants. It is a crucial step to meet the EU's 20% emissions reduction target by 2020. Two weaknesses have been recognized in the ZCB2030 report (Kemp 2010). First, the caps for countries are not strict enough since countries have an incentive to increase the cap to reduce the costs to their economy of cutting. Second, the permits have been given away based on countries' historic emissions, therefore countries with higher historic emissions are rewarded. The scheme has been expensive and ineffective in emission reductions, and lessons should be learnt by any new systems.

In 2009, the EU leaders put forward the European Renewable Energy Directive (EU2009/28/EC), and agreed to achieve a 20% of reduction in EU greenhouse gas emissions below 1990 levels, a 20% of EU energy consumption to come from renewable resources and a 20% of reduction in primary energy use compared with projected levels by 2020. This is well known as the EU '20-20-20' targets.

2.2.2 The UK Policy Statements and Acts

The UK government has been legally bound to reduce its greenhouse gas emissions from 1990 levels by ratifying the Kyoto Protocol. The Government have followed the lead of the EU toward the zero carbon transition. In the UK, Department for Environment Food & Rural Affairs (DEFRA), Department of Energy and Climate Change (DECC), the Department of Trade and Industry (DTI) and the Department for Communities and Local Government (DCLG) lead the sustainable/ low carbon development and develop policy in this area.

In 2003, 'Energy White Paper: Our Energy Future-Creating a Low Carbon Economy' was published by DTI. It aimed to cut the UK's carbon dioxide emissions by 80% by

2050 with real progress by 2020, and to maintain the reliability of energy supplies (DTI 2003). A range of the commitments have been taken forward to be implemented in Energy Act 2004.

In 2003, Climate Change Agreements Scheme (CCAs) was established by DECC to allow eligible energy-intensive businesses to receive a discount for the Climate Change Levy (CCL) which is a tax on energy delivered to non-domestic users. The discount could reach up to 90% for electricity and 65% for other fuels in return for meeting energy efficiency or carbon-saving targets from April 2013 under the management of the Environment Agency (The Environment Agency 2013).

In 2007, 'Meeting the Energy Challenge: A White Paper on Energy' was published by DTI. It outlined energy strategies and a number of practical measures to reduce carbon emissions and secure energy resource. In addition, it promoted the Carbon Reduction Commitment (CRC), introduced Energy Performance Certificates for business premises and Display Energy Certificates for public sector organisations, extended smart metering to most business premises within 5 years, and required all new homes to be zero-carbon buildings by 2016 (DTI 2007).

That the Climate Change Bill which was passed to be the Climate Change Act in 2008 committed the UK Government to reducing greenhouse gas emissions by at least 80% of 1990 levels by 2050, with an intermediate target of between 26% and 32% by 2020. It announced Carbon Reduction Commitment (CRC), introduced the Renewable Heat Incentive (RHI) and the Feed-in Tariff. The UK became the first country in the world to set significant carbon reduction target into the law (Fankhauser et al. 2009).

Carbon Reduction Commitment (CRC) Energy Efficiency Scheme was launched in 2010 with DECC developing the relevant policy. It was a mandatory carbon emissions reduction scheme to require large non-energy intensive companies to monitor and report on their annual energy use and purchase allowances to offset their emission (DECC 2013). The Scheme aimed at organizations not covered by CCAs and the EU ETS.

The Feed-in Tariffs (FITs), introduced in 2010, offered financial incentives for each unit of energy generated with eligible renewable technologies to encourage organisations, businesses, communities and individuals to invest in small-scale low carbon electricity (GOV.UK 2010). The Renewable Heat Incentive (RHI), launched in 2011, included a financial support scheme to the non-domestic sector generating heat from renewable or low-carbon sources to encourage building owners to incorporate such measures into their projects, and the scheme is planned to open to domestic sector in 2014 (GOV.UK 2011). Merton Council established the Merton Rule for the development of 10 homes or 1,000m^2 of non-residential development generating 10% of energy demand on site with renewable technologies in 2003 (Merton Council 2003). Planning and Energy Act 2008 enabled all councils in England and Wales to adopt the Merton Rule.

Low Carbon Transition Plan 2009 was the first Low Carbon Transition Plan for the UK, and required a target of 34% reduction of greenhouse gas emissions by 2020 comparing to the 1990 levels (DECC 2009a). The UK Renewable Energy Strategy was published by DECC, and was designed to comply with the European Renewable Energy Directive 2009. It set a target for the UK to achieve 15% of its energy from renewable sources by 2020 (DECC 2009b). The subsequent Carbon Plan 2011 set out the actions and milestones for achieving the Government’s carbon emissions reduction targets.

The Green Deal, launched by DECC in 2012, is a new financing framework created by the Energy Act 2011 to enable energy efficiency improvements on households and non-domestic properties. The upfront cost of the improvements which is the biggest barrier to uptake will be paid for by a loan; while these loans will be paid back over time through a regular charge placed on the property's energy bill (GOV.UK 2012). Problems for the Green Deal have been recognized. According to Dowson et al. (2012), one of the main risks is the potential that retrofit measures to be installed do not perform as expected. In addition, fuel poverty households and hard-to-treat homes are not included from the framework (Booth and Choudhary 2013). The potential energy savings of fuel poverty households will be realised as improved thermal conditions rather than savings in energy cost. The hard-to-treat homes which have solid walls, no loft space to insulate, or no connection to the gas network cannot be easily upgraded cost effectively.

In response to the recast of EPBD in 2010, 'UK National Plan: Increasing the Number of Nearly Zero Energy Buildings' was published in September 2012. It stated that the UK Government was having a more strict target for all new homes in England to be zero carbon from 2016 and an ambition for all new non-residential buildings in England to be zero carbon from 2019 and for new public sector buildings from 2018; Northern Ireland planned to achieve zero energy new homes by 2017 and zero energy new non-domestic buildings from 2020; while the Scottish Government shared the ambition for zero energy buildings (Department for Communities and Local Government 2012a). All new buildings are expected to be nearly zero energy by 2019 in Wales (The Welsh Government 2014). In May 2013, 'Cost Optimal Calculations: UK Report to European Commission' was submitted with all input data and assumptions used for the calculations of cost-optimal levels of minimum energy performance requirements (Department for Communities and Local Government 2013).

2.2.3 The UK Building Regulations and Standards

Building Regulations are statutory instruments to ensure that the policies in building industry are carried out. In the UK, the first set of national building standards were introduced in the Building Regulations1965 (GOV.UK 2013). Currently, there are 14 sections to the Building Regulations. Part L: Conservation of fuel and power is the key document addressing carbon reduction and energy efficiency in England and Wales. There are four categories: Part L1A for new dwellings, Part L2A for existing dwellings, Part L1B for new buildings other than dwellings, and Part L2B for existing buildings other than dwellings. It can be observed that the Building Regulations have significantly increased the requirement of U-values of building components from 1.7W/m^2/K for external walls in 1965 to 0.20W/m^2/K in 2010, from 1.4W/m^2/K for roofs to 0.16W/m^2/K, and from no standard for floors to 0.18W/m^2/K (HM Government 2013).

According to Hernandez (2010), Building Regulations have been updated frequently as a policy measure for the reduction in carbon emissions. The Building Regulations have been strengthened in accordance to the recommendations from the 2002 EPBD, and have been updated every four years since 2002. The influences of the EPBD on the Building Regulations include 1) adopt a methodology of calculation of the energy performance of buildings, 2) ensure that minimum energy performance requirements are set based on methodology, and 3) ensure that new buildings meet minimum energy performance requirements (Hernandez and Kenny 2010). In the 2006 Building Regulations, the methodology of calculating energy performance of buildings was introduced, and related aspects were specified including thermal characteristics of building envelope, heating installation, domestic hot water, air conditioning installation, lighting installation, position of building including outdoor climate, passive solar systems and solar protection, natural ventilation, and indoor climate conditions.

The recast of EPBD in 2010 had an impact on the Building Regulation Part L in 2013. In 2013, DCLG published the 2013 Amendments to Approved Documents which includes the force of Energy Performance Certificates, and the analysis of high efficiency alternative systems for new buildings and the major renovation of existing buildings (HM Government 2013). The Building Regulations Part L carbon reduction targets are currently driven by the stated policy to achieve zero carbon in new domestic buildings by 2016 and in non-domestic buildings by 2019, in line with the Carbon Plan 2011.

In summary, section 2.2 indicates that all the related international and national legislation and regulations have been established to promote low/ zero carbon development, and there is no sign to stop. Low/ zero carbon design targets have been fully embedded in the current EU incentives, the UK policies and Building Regulations. Therefore, low/ zero carbon design concept should be integrated into the mainstream of architectural design rather than be viewed as a branch of architectural design. The efforts from practice, research and education are required to ensure the implementation of the low/ zero carbon legislation and regulations. The next section will introduce some of the actions from architectural organizations and education in response to the main drivers to the low/ zero carbon agenda in the construction industry.

2.3 Low/ zero carbon design in practice in the UK

Buildings have a significant impact on the environment as commercial and residential buildings use more than 40% of the primary energy and are responsible for 24% of greenhouse gas emissions globally (Panagiotidou and Fuller 2013). In 2010, heating and powering buildings was responsible for 45% of carbon emissions in the UK; and by 2050, emissions would be virtually reduced to zero (Department for Communities and Local Government 2012). In order to respond to the main drivers to low/ zero carbon agenda in the construction industry, all the related sectors have put in their efforts.

2.3.1 Actions from relevant organizations

The Royal Institute of British Architects (RIBA), as the main representing body of architects in the UK, has been responding to the challenge of sustainable development via several routes. It worked with the Government to develop new policies, and drive demand for sustainable architecture. In 2000, RIBA published 'Green Guide to the Architect's Job Book' which is a process map of design and construction to aid the successful delivery of long-term sustainability in the built environment. Climate Change Toolkits was developed and updated in 2009 to introduce skills, tools and solutions to deliver low carbon built environment. Sustainability Hub Area in the RIBA website was established to share best practice and case studies. Green Overlay to the RIBA Outline Plan of Work was published in 2011 to integrate sustainability into design process (RIBA 2011a). The Green Overlay to the RIBA Outline Plan of Work revised the wording of the Outline Plan of Work (2007 version) to clarify the issues and their timing, in response to the growing imperative that sustainability should actively considered in the design and construction of buildings (RIBA 2011b). Table 2-3 shows the RIBA Plan of Work Stages with the amendments made to integrate sustainable issues. The 11 RIBA Plan of Work stages are grouped into four main phases to deliver green buildings.

Table 2-3: Sustainable issues in RIBA work stages (RIBA 2011b)

RIBA Work Stages			Low/ Zero Carbon Design Main Phases	Revised Description
Preparation	A	Appraisal	Set the goal Choose the aspiration standards	*…sustainability aspirations, …project & sustainability, …building design lifetime…*
	B	Design Brief		
Design	C	Concept	Integrate low/ zero carbon design strategies and design tools	*…environmental strategies, …site landscape and ecology, …and energy, …sustainability assessment*
	D	Design Development		
	E	Technical Design		
Pre-construction and construction	F	Production Information	Validate methods statement, carry out commissioning and feedback study	*Assist with preparation for commissioning, training, handover, future monitoring and maintenance.*
	G	Tender Documentation		
	H	Tender Action		
	J	Mobilisation		
	K	Construction to Practical Completion		
Use	L	Post Practical Completion		*NA*

The RIBA Guide to Sustainability in Practice was published in 2012, which aims to help architects build sustainability into their daily practice. It has developed 10 steps to establish a sustainable practice, including 1) commit to leadership, 2) benchmark practice impacts, 3) demonstrate practice performance, 4) build on existing resources, 5) up skill with CPD, 6) develop collaborative project methodologies, 7) consider the uses of software, 8) adopt a Knowledge Management framework, 9) follow the RIBA Outline Plan of Work, and 10) monitor sustainable projects (Sullivan 2012).

Building Research Establishment (BRE) developed the Building Research Establishment's Environmental Assessment Method (BREEAM) in 1990 and the Code for Sustainable Homes in 2006. BREEAM and its series of building assessment methodologies are the most widely used voluntary sustainability benchmarking systems in the UK. In 2005, BRE Innovation Park was established to demonstrate the emerging approaches to sustainable design and construction which can improve the built environment. It serves as a showcase of innovative construction and technologies, and a test-bed for innovative ideas and products, and a network of existing and future Parks in the UK and around the world (BRE 2005). Currently, twelve buildings (nine houses built to the Code for Sustainable Homes, one visitors' centre, one healthcare campus and a refurbished Victoria Terrace) are on the site. Among these buildings, the Kingspan Lighthouse (built in 2006) is the first net- zero carbon home that has achieved Level 6 of the Code for Sustainable Homes. And the other Code Level 6 house is the Barret Green house (built in 2007) which is the winner of the 2007 Home for the Future Design Awards designed by Guant and Francis Architects (Figure 2-6 and 2-7).

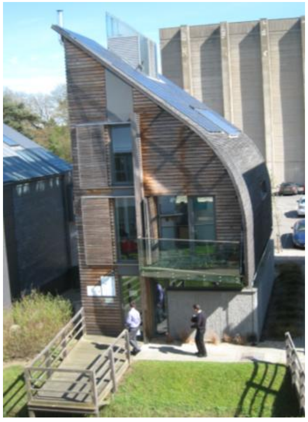


Figure 2-6: Kingspan Lighthouse

Figure 2-7: Barret Green House (Both photos by researcher)

In 2008, The BRE developed the Green Print methodology to assist design teams in delivering master plans that maximise the potential for sustainable communities. The methodology works alongside BREEAM, the Code for Sustainable Homes, and other industry recognised tools and standards. It is designed to provide a full assessment of an individual site carried out in consultation with the clients and key stakeholders who may include the master planners, the design team and developer as well as the planning authority and other statutory bodies, in order to maximise the site's sustainability potential (BRE 2008).

The Carbon Trust, founded in 2001, is a non-profit company which aims to accelerate the move to a sustainable, low carbon economy, and help organizations reduce their carbon emissions and become more energy and resource efficient.

In 2008, the Low Carbon Research Institute (LCRI) was established with the collaboration of six Welsh Universities to promote energy research for a low carbon future in Wales, including Cardiff University, University of South Wales, Swansea University, University of Wales in Bangor, Glyndwr University, and Aberystwyth University. The LCRI aims to 1) lead the way in research to cut carbon emissions, enhance employment and training, 2) support the energy sector to develop low carbon generation, storage, distribution and end use technologies and practices, and 3) provide policy analysis and advice (LCRI 2008).

In 2008, Zero Carbon Hub was launched in London to support the delivery of zero carbon homes in England by 2016. It aims to 1) develop the definition of a zero carbon home, 2) manage the unintended consequences of building more energy efficient homes, 3) provide guidance and information, 4) host events to create forums for discussion, 5) update the wider industry on changes to government policy, and 6) create profiles to highlight innovation solutions which could be incorporated in whole-house energy solutions (Zero Carbon Hub 2008).

In the US, Architecture 2030 was developed by architect Edward Mazria in 2002 as an independent organization with the mission to transform the building industry from a contributor of greenhouse gas emissions to a part of the solution to the climate and energy crises. Two objectives of Architecture 2030 are 1) to reduce global fossil fuel consumption and greenhouse gas emissions of the building industry by changing the way cities, communities, infrastructure and buildings are planned, designed and constructed, and 2) to develop an adaptive, resilient regional built environment that can manage the impacts of climate change, preserve natural resources, and access low-cost and renewable energy resources (Architecture 2030 2002).

2.3.2 Actions for professional education

To support the implementation of sustainable environmental design in academic curricula and professional training, the European Commission's Executive Agency for Competitiveness and Innovation under the Intelligent Energy Europe Programme funded a three-year Environmental Design in University Curricula and Architectural Training in Europe (EDUCATE) project in 2009 (EDUCATE Project Partners 2009). The EDUCATE project was coordinated by University of Nottingham and other six academic partners including Architectural Association of London – School of Architecture (UK), Catholic University of Louvain – Architecture et Climat, Faculté des Sciences Appliquées (Belgium), Technical University of Munich – Facultat fur Architektur (Germany), University of Rome La Sapienza – Dipartimento ITACA, Facoltà di Architettura (Italy), Seminario de Arquitectura y Medioambiente – SAMA, S.C. (Spain), and Budapest University of Technology and Economics – Faculty of Architecture (Hungary). It aims to develop and disseminate the required knowledge and skills in sustainable design in order to deliver comfortable, healthy, exciting and energy efficient buildings. There are four stages: 1) to analyze the state of the art of environmental design in higher education and in practice in order to develop a comprehensive understanding of the integration of sustainalbe design and energy efficiency in current academic pedagogies and practice, 2) to develop a knowledge base and an integrated pedagogical framework of environmental design, 3) to evaluate the integration of environmental design in architectural curricula, and 4) to formulate principles, framework and structure for sustainable architecture education and suggest criteria for professional qualification regarding environmental design (EDUCATE Project Partners 2012).

In 2011, the Welsh Energy Sector Training (WEST) Project, funded through the LCRI Convergence Energy Programme, was launched. The WEST project is led by Welsh School of Architecture in working with Cardiff School of Engineering, University of Glamorgan, Glyndwr University, Swansea Metropolitan University and Swansea University. The programme includes to review current Further Education and Higher Education provision in Low Carbon Technologies, and to determine current provision, uptake, delivery methods and successes achieved from training programmes integrating low carbon technologies (WEST 2011). In November 2013, the team travelled around Wales to promote the launch of the training courses.

In 2012, Built Environment Sustainability Training (BEST) programme was funded by the European Social Fund. The BEST programme is led by the Welsh School of Architecture with collaboration with Asset Skills, Constructing Excellence Wales, CITB-ConstructionSkills, the Energy Saving Trust, Proskills, and Summit Skills. It aims to unite the key stakeholders with responsibilities for the skills of the energy, waste, water and built environment sectors to create a 10-year strategy and training delivery roadmap which will benefit businesses, employees and training providers in Wales (BEST 2012). There are two phases: 1) to outline the type, quantity and levels of courses and qualifications to be delivered to meet the current, medium and long term future needs of the Welsh Built Environment Sector, and 2) to develop and deliver training courses (BEST 2012).

In summary, section 2.3 shows that a large amount of work has been carried out to facilitate the implementation of the low/ zero carbon legislation and regulations. It reflects the need to develop a framework of low/ zero carbon design and deliver the associated knowledge and skills to the professionals in the building industry.

2.4 Summary

This chapter first reviewed the major development towards low/ zero carbon design in the construction industry from 1970s to the present, and the fast updating carbon and energy directives from the EU and the related policies and Building Regulations in the UK. It concluded that low/ zero carbon design, driven by global and local concerns of climate change and the lack of secure energy resources, is the way forward in the construction industry in the UK. Then, the review of actions in the construction industry in response to the main drivers to reduce carbon emissions was conducted, and it indicated that it is important to establish the framework of knowledge and skills in relation to the performance based and prescriptive measures to design low/ zero carbon buildings in order to meet the tightening targets. Efforts have been made to disseminate the associated knowledge and skills to architectural students and architects in practice to enable them to conduct low/ zero carbon design. However, there have been few studies exploring the required content as well the dissemination methods with the consideration of architects' learning preference. The need for the investigation into the development of training programmes to transfer the knowledge and skills to design low/ zero carbon buildings to architects in practice can be observed.

Chapter 3. The understanding of low/ zero carbon design

In order to develop a framework of low/ zero carbon design for the building industry and disseminate the associated knowledge and skills of low/ zero carbon design to architects, it is important to develop an understanding of what the knowledge and skills are needed to deliver a low/ zero carbon project. This chapter starts with defining the low/ zero carbon design to clarify the design goals. Then a review on environmental standards and assessment methods is carried out to establish the understanding of how they define the design objectives and influence the design. These environmental standards assessment methods are design evaluation tools rather than design guidelines though they have been used to guide the design sometimes. On the other hand, low/ zero carbon design process models have been established to guide the design to achieve the low/ zero carbon target. Five models of low/ zero carbon design process are explored. Finally, an initial model of low/ zero carbon design derived from the existing models is established to reflect the initial understanding on the knowledge and skills of low/ zero carbon design required to be disseminated to the architects in practice.

3.1 The definitions of low/ zero carbon design

There is no unified statement of what low/ zero carbon design is. Some of the definitions of low/ zero carbon design were adopted by different countries in building energy policies without being clarified; therefore, a clear definition and international agreement on the measures of building performance that could inform zero energy building policies and industry application is required (Ayoub 2008). Panagiotidou (2013) summarized the development of zero energy/emission buildings concepts on the basis of the outcome of an Internal Energy Agency (IEA) Solar Heating & Cooling (SHC) Programme 'Towards Net Zero Energy Solar Buildings', starting from the first conception of 'Zero Energy House' published by Esbensen and Korsgaard in 1977 to a broad discussion around the concept in 2007.

Dunster (2013) defined zero-fossil energy development in the BedZED development as an excellent passive building envelope that reduces the demand for heat and power to the point where it becomes economically viable (sufficient to fund the cost of the renewable systems) to use energy generated on site from renewable resources.

According to the London Energy Partnership (2006), a zero carbon development achieves zero net carbon emissions from energy use on site on an annual basis; while a low carbon development achieves a reduction in net carbon emissions of 50% or more from energy use on site on an annual basis. There are three levels of zero net emissions of carbon dioxide: 1) zero net emissions of carbon dioxide from the energy use, including heating, hot water, lighting, appliances, and cooking, 2) offset the embodied energy which is the energy required to manufacture, and supply to the point of use, and 3) the zero carbon lifestyle which includes the energy use in transport, food, and products. The idea behind all three levels of zero net emission is to offset fossil fuels or other imported carbon based energy used on site by an equivalent export of energy generated on site from renewable sources. Currently, however, the focus of net zero carbon emission is to offset only the energy used for heating, hot water, lighting, electrical appliances, and cooking (first level).

Department for Communities and Local Government (2008) defined zero carbon homes as net zero carbon emissions over a course of the year, after taking account of: 1) the emission from heating, ventilation, hot water and fixed lighting, 2) the energy use from appliances, and 3) the export and import of energy from the development (and directly connected energy installations) to and from centralised energy networks.

Torcellini et al. (2006) defined a net zero energy building as a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied with renewable technologies. Also, different zero energy building definitions were proposed in the paper 'Zero Energy Buildings: A Critical Look at the Definition' since it can be influenced by the project goals, the intentions of the investor, the concerns about the climate and greenhouse gas emissions and the energy cost (Torcellini et al. 2006):

- A site zero energy building produces at least as much energy as it uses in a year, when accounted for at the site.
- A source zero energy building produces at least as much energy as it uses in a year, when accounted for at the source. The source energy refers to the primary energy used to generate and deliver the energy to the site, and is calculated by multiplying the imported and exported energy by the appropriate site-to-source conversion multipliers.
- In a cost zero energy building, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
- A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

The IEA defined zero net energy buildings as those deliver as much energy to the supply grid as they draw from the grid over a year, who do not incur any fossil fuel debt for heating, cooling, lighting or other energy used (Lausten 2008).

The concept nearly zero-energy buildings' was introduced in the 2010 recast of the EPBD, and was defined as a building that has a very high energy performance and the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby (European Commission 2010).

Hernandez and Kenny (2010) extended the definition to include the embodied energy of the building to introduce a lifecycle perspective, and defined a lifecycle zero energy building as a building whose primary energy use in operation plus the energy embedded in materials and systems over the life of the building is equal or less than the energy produced by renewable energy systems within the building.

Several issues can be noted among the different definitions of low/ zero carbon design:

First, the concept of energy efficiency is specified in some of the definitions. Energy saving measures should be applied in the first place to reduce energy demand before the installation of renewable systems. An energy efficiency threshold is essential to avoid delivering zero energy buildings with oversized and unnecessary renewable systems.

Second, the operating energy is the focus of all the definitions. Sartori (2012) suggested it is preferable to include all the operational energy uses in the balance boundary for the definition of net zero energy buildings. In addition, embodied energy is only included in the London Energy Partnership's definition, and Hernandez and Kenny's definition. Sartori and Hestnes (2007) analysed 60 cases which indicate that operating energy represents the largest part of energy demand in a building during its life cycle. Therefore, reducing the demand for operating energy should be the most important aspect for energy efficient building design. A 25kWh/m^2/year is suggested to account for the embodied energy and a potential to reduce embodied energy via recycling is suggested in the paper 'Zero Energy Building – A Review of Definitions and Calculation Methodologies' (Marszal et al. 2011).

Third, different definitions for low/ zero carbon design are necessary to reflect the different goals and concerns of different projects. One consideration for the definition of low/ zero carbon design presented by Zuo et al. (2012) was to reflect the market demand. Therefore, instead of a unified definition, a formula to define zero energy/ emission buildings under different condition with specified parameters can be beneficial. Marszal et al. (2011) indicated that the metric (energy or carbon equivalent emissions), the period and the types of energy included in the energy balance, the renewable energy supply options, the connection to the energy infrastructure, the energy efficiency, the indoor climate and the building–grid interaction requirements are the most important aspects to describe zero energy buildings.

In summary, a formula to define low/ zero carbon design in this research has been established in section 3.1, consisting of energy efficiency threshold, the metric, type of energy use, type of renewable systems, connection with the energy infrastructure, and period of the balance. It is important to define all the parameters in order to clarify the low/ zero carbon design goal for a project at the beginning of the design.

3.2 The assessment methods and standards for low/ zero carbon design

In order to make sure the targets set in the policies to mitigate climate change by reducing carbon dioxide emissions in the building industry can be achieved, many countries have established rating tools in order to improve the knowledge about sustainability in their building industry. The following table (Table 3-1) shows a range of common assessment methods and standards developed in different countries in chronological order. According to RIBA (2010a), the adoption of low/ zero carbon assessment methods is a key component of the architectural profession's response to the challenge of climate change. It is necessary for individual assessment methods for each country to reflect the individual characteristics of each country, such as the climate and type of building stock, but various rating tools for different countries with different parameters can create complications for understanding differences between each market (Reed et al. 2009).

BRE undertook a comparison of the four key environmental assessment tools in 2008, including BREEAM, LEED, Green Star, and CASBEE. These four rating tools were compared across a number of sustainability issues. The study has been concluded that there is variation in the standards and the main reason is that the schemes promote standards reflecting local sustainability issues and environmental conditions (Saunders 2008).

Table 3-1: Assessment methods or standards developed in different countries

Country	Rating system	Launch year	Organization of development	Source
UK	BREEAM (Building Research Establishment's Environmental Assessment Method)	1990	BRE (Building Research Establishment)	BRE
Germany	Passivhaus	1990	Passivhaus institute	BRE
UK	SAP (Standard Assessment Procedure)	1992	BRE (Building Research Establishment)	Department of Energy and Climate Change
Hong Kong	HK-BEAM	1996	HKGBC (Hong Kong Green Building Council)	BEAM Society
Canada and others	GB Tool	1996	Natural Resources Canada, iiSBE (International Initiative for a Sustainable Built Environment) and GBC (Green Building Council) partners.	Practical evaluation tools for urban sustainability
US	LEED (Leadership in Energy and Environment Design)	1998	USGBC (US Green Building Council)	USGBC
UK	SBEM (Simplified Building Evaluation Method)	1998	BRE (Building Research Establishment)	EPBD-NCM
Canada and US	Green Globes	2000	CSA (Canadian Standards Association), GBI (Green Building Initiative)	GREENGLOBES
Japan	CASBEE (Comprehensive Assessment Systems for Built Environment and Efficiency)	2001	JaGBC/JSBC (Japan Green Building Council)	CASBEE
Australia	Green Star	2003	GBCA (Green Building Council of Australia)	Green Building Council Australia
Singapore	Green Mark	2005	BCA (Building and Construction Authority)	Building and Construction Authority
UK	CSH (Code for Sustainable Homes)	2006	BRE Globe	Department for Communities and Local Government
Germany	German Sustainable Building Certification	2009	DGNB (German Sustainable Building Council)	German Sustainable Building Council

Since the focus of this research is the UK, a review of commonly applied low/zero carbon design standards and assessment methods in the UK is carried out to define the benchmarks of low/zero carbon design. The reviewed assessment methods include: 1) SAP/ SBEM, 2) BREEAM, 3) CSH, 4) LEED and 5) Passivhaus. SAP and SBEM are the mandatory methods to assess energy demands of domestic and non-domestic buildings for the UK Building Regulation respectively, while the other assessment methods and standards are voluntary. In the UK, BREEAM is dominant in the construction industry, while LEED attracts growing attention. Gulacsy pointed out that the driver for LEED in the UK is often the clients' global corporate policy or the needs of global tenants (Parker 2009). Passivhaus is included since it is widely accepted as a common standard for low carbon design in the UK building industry.

3.2.1 Standard Assessment Procedure (SAP)/ Simplified Building Energy Model (SBEM)

Current Building Regulations set minimum standards for energy efficiency in building design required by law and they are applied as the baseline for the other low carbon standards. The latest Building Regulation (2013) Part L requires the Design Emission Rate (DER) of new domestic buildings to achieve a 25% reduction of Target Emission Rate (TER) which is calculated for a notional dwelling that is the same size and shape, has gas-fired central heating and complies with Building Regulations Part L 2002.

The basis for the assessment of energy demands of domestic buildings for the Building Regulation is provided by Standard Assessment Procedure (SAP) energy rating. It is the Government's preferred domestic energy rating which was introduced in 1992. SAP is updated on a regular basis to incorporate the improved understanding of domestic energy use and to reflect changes in the technologies used in dwellings. The current version is SAP 2012. SAP takes into account the dwelling dimensions, climate data, ventilation rate, heat transmission, domestic hot water, internal gains, solar gains, mean internal temperature, space heating systems and cooling systems to calculate the fabric energy efficiency, total energy use and CO_2 emissions. The SAP rating of a dwelling is based on the annual fuel use for space heating, water heating and fixed internal lighting only (excluding cooking and electricity appliances), per square metre of floor space, under standard occupancy. It is expressed on a scale of 1 (very inefficient) to 100+ (very efficient). One limitation of SAP is that energy ratings are independent of location – all dwellings are assumed to be located in the East Midlands. This means that three identical dwellings built in different areas will all have the same SAP rating.

The Simplified Building Energy Model (SBEM) is a computer program developed for the Department for Communities and Local Government by the Building Research Establishment (BRE) to provide energy use calculation in non-domestic buildings for Building Regulations Compliance and for Building Energy Performance Certification purposes (EPDB-NCM 2011). SBEM is accompanied by a basic user interface, iSBEM. The latest version of iSBEM_5.2.b has been released on the 3rd April 2014 to demonstrate compliance with Part L 2013 and generate Energy Performance Certificates for England and Jersey only (NCM 2014).

3.2.2 Building Research Establishment's Environmental Assessment Method (BREEAM)

BREEAM is an environmental assessment method and rating system for buildings, which was first launched in 1990 by the BRE. The current version for new building assessment registrations and certifications is BREEAM 2011 New Construction (from 1st July 2011). It can be applied to various types of new built buildings, including offices, industrial, retail, education, healthcare, prisons, law courts, residential institutions, non-residential institutions, assembly and leisure and others in the UK. In addition, BREEAM consists of other schemes, including refurbishment, community, in use, and international schemes. Till now, more than one million buildings in the UK have been registered for assessment and 200,000 have certified BREEAM assessment ratings since 1990 (BRE 2011).

BREEAM uses a scoring and rating system, and it requires a qualified and licensed assessor to evaluate the building's performance against established environmental performance standards to collect BREEAM performance scores in order to achieve the BREEAM rating. BREEAM consists of a broad range of environmental categories with different weightings, including Management, Health & Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use & Ecology, Pollution, and Innovation. Each environmental section consists of several assessment issues, and there are 49 assessment issues in total. In order to make sure that the building's performance in fundamental environmental issues is not overlooked in the pursuit of a particular rating, BREEAM sets minimum standards for performance in key areas (BRE 2012). The basis of assessment of energy demands of non-domestic buildings for the BREEAM is provided by the SBEM energy rating.

BREEAM credits are awarded where a building demonstrates that it meets the best practice performance levels defined for each individual assessment issue. The percentage of credits multiplied by the section weighting is the section score. All section scores are added together to give the final BREEAM score, which is then compared to the BREEAM rating benchmark levels. The BREEAM rating benchmarks for new construction projects are: OUTSTANDING (>=85%), EXCELLENT (>=70%), VERY GOOD (>=55%), GOOD (>=45%), PASS (>=30%) and UNCLASSIFIED (<30%).

3.2.3 Code for Sustainable Homes (CSH)

Code for Sustainable Homes is an environmental assessment method for rating and certifying the performance of new homes developed by BRE Global based on EcoHomes in 2006. It is a Government owned national standard intended to encourage continuous improvement in sustainable home building (BRE 2010a). All new housing funded by the Homes and Communities Agency, or promoted or supported by the Welsh Assembly Government or their sponsored bodies, or self-contained social housing in Northern Ireland have been required to meet CSH level 3. Also, meeting CSH standards have been required by some local authorities as a condition of planning approval (BRE 2010b).

According to Department for Communities and Local Government (2010), there are nine categories associated with the building process which have an impact on the environment, and for which performance measures to reduce their impacts can be objectively assessed and evaluated. The nine performance categories are Energy Use and Carbon Dioxide Emissions, Water, Materials, Surface Water Run-off, Waste, Pollution, Health and Well-being, Management, and Ecology (Department for Communities and Local Government 2010). For each category, the number of credits achieved is multiplied by the environmental category weighting factor to obtain the percentage point score. The percentage point scores for all the categories are summed to get the total percentage points. The Code level is then derived from the total percentage points: Level 1>=36 points, Level 2>=48points, Level 3>=57 points, Level 4>=68 points, Level 5>=84 points and Level 6>=90 points. Results of the Code assessment are recorded on a certificate assigned to the dwelling by an equivalent number of stars from 1 to 6 (Department for Communities and Local Government 2010).

In order to achieve any level, certain mandatory points related to that level have to be collected as well as the mandatory carbon dioxide emissions standards. The basis of assessment of energy demands is provided by the SAP energy rating. Code Level 1 is a 10% reduction, Level 2 is 18%, Level 3 is 25%, Level 4 is 44%, Level 5 is 100%, and Level 6 is ‘net zero carbon’. From Level 1 to Level 5, the carbon dioxide emissions reductions are assessed by means of the Target Emission Rate (TER) as determined by the 2006 Building Regulation Standards with consideration of space heating, hot water and lighting. Code Level 6: net zero carbon covers all energy use including cooking and use of electrical appliances.

3.2.4 Leadership in Energy and Environment Design (LEED)

The U.S. Green Building Council (USGBC), founded in 1993, is committed to transform the way buildings and communities are designed, built and operated, and enable an environmentally and socially responsible, healthy and prosperous environment that improves the quality of life (Taylor 2011). The first LEED Pilot Project Program (LEED Version 1.0) was launched at the USGBC Membership Summit in August 1998 (USGBC 2009). The current version was launched in 2009, known as LEED v3. LEED provides nine assessment methods for different types of projects: 1) New Construction, 2) Existing Buildings: Operations & Maintenance, 3) Commercial Interiors, 4) Core & Shell, 5) Schools, 6) Retail, 7) Healthcare, 8) Homes and 9) Neighbourhood Development (USGBC, 2011a). Minimum Program Requirements (MPR) define the types of buildings that the LEED Green Building Assessment methods are designed to evaluate and a project must be complied with all the MPR in order to be eligible for LEED Certification (USGBC 2011b). The LEED certification process is based on a check list system with five main topics: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality (Taylor 2011). There are prerequisites and voluntary credits for each topic. The prerequisites are the mandatory requirements to ensure the minimum standards of green design to be achieved. The projects need to meet all the prerequisites and achieve enough voluntary credits to be awarded the certification. The criteria of these topics vary depending on the type of certification. There are four possible levels of certification, including Certified (40-49), Silver (50-59), Gold (60-79) and Platinum (80 and above). In terms of minimum energy performance, the LEED system requires designers to comply with ANSI/ ASHRAE/ IESNA 90.1-2007 mandatory provisions or the local code whichever is more stringent (Taylor 2011). According to USGBC (2011a), nearly 9 billion square feet of building space is participating in the suite of assessment methods and 1.6 million feet is certified per day around the world.

3.2.5 Passivhaus

The Passivhaus Standard was developed in Germany in the early 1990s, and is supported by the European Commission. Passivhaus aims to seek effective ways to reduce carbon emissions from building design while ensuring the buildings perform as predicted. It refers to a specific construction standard for buildings (including residential, commercial, industrial and public buildings) which have excellent comfort conditions in both winter and summer (BRE 2010c). The standard is performance based. Its core requirements are that annual space heating demand does not exceed 15kWh/m^2/year and that primary energy use (for all purposes) does not exceed 120kWh/m^2/yr. The standard also requires: 1) fabric U-values ≤ 0.15W/m^2K, 2) window U-values ≤ 0.8 W/m^2K, 3) air permeability ≤ 0.6 air changes per hour at 50 Pa, 4) advanced whole-house mechanical ventilation with heat recovery with at least 75% heat recovery efficiency and electricity use no greater than 0.4W/m^3 of supply air.

Performance against the Passivhaus standard is assessed using structured Excel-workbook based simulation software PHPP, which is produced by Passivhaus Institute Germany. The current version is PHPP 2007, which includes weather data for UK locations. The PHPP includes tools for: 1) calculating the U-values of components with high thermal insulation, 2) calculating energy balances, 3) designing comfort ventilation, 4) calculating the heating and cooling load, and 5) summer comfort calculations. According to BRE (2011), 30,000 buildings have been built to Passivhaus standard, the majority of those since 2000.

3.2.6 Significance and shortcomings of the standards and assessment methods for low/ zero carbon design

Building Regulations Part L sets the minimum energy efficient standard that all the projects are required to comply with. BREEAM and LEED are environmental assessment methods with higher requirement for environmental and energy performance than the Building Regulations. BREEAM is more relevant in the UK as it follows the UK policies, while LEED follows the American ASHRAE standards. Another difference between BREEAM and LEED is that BREEAM has trained assessors to assess the design, validate the assessment and issue the certificate, while the USGBC conducts the evaluation and issues the certificate of LEED. Different standards have some of the parameters in common, and they have different weighting for each parameter. Sleeuw's study (2011) indicated that BREEAM has a wider scope with more difficult standards to achieve than LEED, and also demonstrated that direct comparison of rating classifications under each method is not straightforward. According to Papadopoulos and Giama (2009), deviations in the results of the evaluation of the same project can occur by using different assessment methods. Passivhaus was designed to explore effective ways to design low energy buildings and to make sure the buildings perform as predicted, rather than to meet political aspirations of zero carbon building targets. It only assesses energy use and carbon emissions. The focus of Passivhaus is to achieve optimum internal comfort with the lowest possible energy consumption (annual space heating demand and primary energy use for all purposes).

The main contribution that these standards and assessment methods make is driving the market to improve building design and making companies care about their carbon emissions. In consequences, greenhouse gas emissions and impact on the environment can be reduced, and occupants' well-being can be improved with lower running cost. Regarding the significance of the assessment methods in understanding low/ zero carbon design, all the assessment methods promote the early engagement of environmental design at the design stage. Also, the criteria are in line with legislative developments and current best practice.

One criticism to these assessment methods and standards is that the rigid checklist system may lead the design to apply additional features to score points that may not be appropriate for that building in order to ascertain an overall rating. Another concern of these assessment methods and standards is the lack of consideration of occupants' satisfaction. The essence of low/ zero carbon building is to create a comfortable and healthy built environment for the occupants. Kim et al. (2013) pointed out that there is a lack of qualitative assessment methods for exploring occupants' experience of buildings, and research on green building assessment methods should pay attention to users' needs and satisfaction.

In summary, section 3.2 reviews the environmental standards which set a higher low/ zero carbon design goal than the Building Regulations Part L. It is of importance for projects to pursue one of the suitable, higher but voluntary low/ zero carbon standards. These environmental assessment methods are design evaluation procedures, and should not be used directly as design guidelines. Low/ zero carbon design process models have been established to guide the design to achieve the low/ zero carbon targets. Five of the existing low/ zero carbon design process models will be reviewed in next section.

3.3 The low/ zero carbon design models

A new approach is needed to deliver low/ zero carbon design in order to meet the Building Regulations and the targets of reduced carbon emissions. A series of design process models have been developed to provide guidance for the design. An overview of five design process models is carried out to prepare for the development of the initial low/ zero carbon design model for this research.

3.3.1 Model 1: The Integrated Design Process by International Energy Agency Solar Heating and Cooling Programme (IEA SHCP) Task 23 (international), 2003

Based on experience in Europe and North America, the Integrated Design Process (IDP) consists of a series of design loops for each stage of the design process, separated by transitions with decision milestones. There are three stages involved in the Integrated Design Process: 1) pre-design, 2) concept design and 3) design development. The design itself includes the following sequence (Larsson and Poel 2003):

1. The establishment of performance targets for a broad range of parameters, and development of preliminary strategies to achieve these targets
2. Minimization of heating and cooling loads and maximization of daylighting potential through orientation, building configuration, an efficient building envelope, and careful consideration of amount, type, and location of fenestration
3. Maximum use of solar, efficient HVAC systems and other renewable technologies to meet the loads
4. Iteration of the process to produce more than one concept design alternative, then using energy simulations as a test of progress to select the most promising of these for further development

Figure 3-1 indicates the layout of the IDP phases and stages.

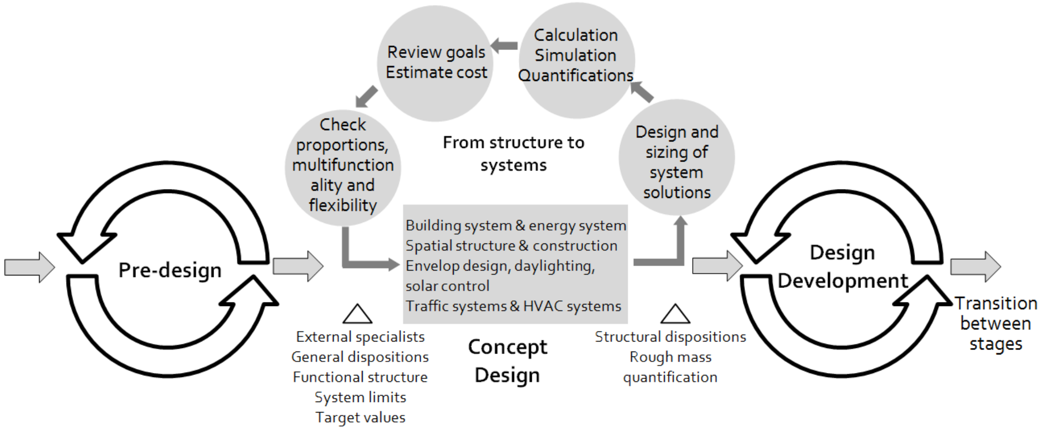


Figure 3-1: The layout of the IDP stages by IEA (Larsson and Poel 2003)

3.3.2 Model 2: The Integrated Design Process by M-A. Knudstrup, Aalborg University, Denmark, 2004

The Integrated Design Process works with the architecture, the design, functional aspects, energy consumption, indoor environment, technology, and construction. There are five stages developed in the IDP (Knudstrup 2004):

1. The description of the 'Problem or Idea' of an environmental or sustainable building is the first step of the building project.
2. The 'Analysis' stage includes an analysis of all the information that has to be understood before the designer is ready to begin the sketching process. At the end of the 'Analysis' stage, a statement of aims and a programme for the building is set up including a list of design criteria and target values.
3. The 'Sketching' stage is where the professional knowledge of architects and engineers is combined and provides mutual inspiration in the integrated design process, so that the demands for the building can be met. A designer needs to make a lot of sketches to solve various problems in order to optimise the final

and best solution, since different solutions have different strengths and weaknesses when different design criteria are evaluated.

4. The 'Synthesis' stage is where the new building finds its final form, and where the demands in the aims and programme are met. All parameters considered in the sketching phase flow together or interact and would be optimised, and the building performance is documented by detailed calculation models.

5. The 'Presentation Phase' is the final stage, which includes the presentation of the project. The project is presented in such a way that all qualities are shown and it is clearly pointed out how the aims, design criteria and target values of the project have been fulfilled for the new building owner.

Figure 3-2 indicates the layout of the IDP phases and stages.

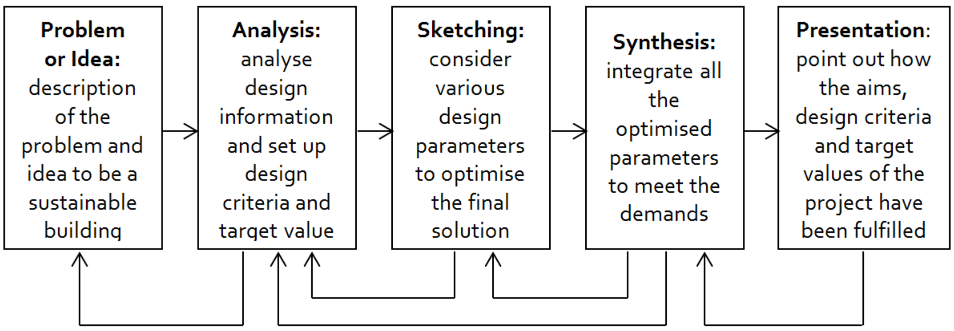


Figure 3-2: Layout of IDP stages by Knudstrup (2004)

3.3.3 Model 3: Integrated Building Design System by K. Steemers, Cambridge University, the UK, 2005

The Integrated Building Design System (IBDS) methodology provides a flexible system for assessing the interrelationships and levels of integration of design parameters for low energy design in an urban context. It is way of raising awareness of the integration implications of a range of environmental and design parameters rather than a rigid process. The IBDS contains four main stages, including 1) principles of low energy design, 2) pre-design context, 3) building design and 4) building services (IEA, 2006). Each stage can be broken down to aspects and sub categories (Figure 3-3).

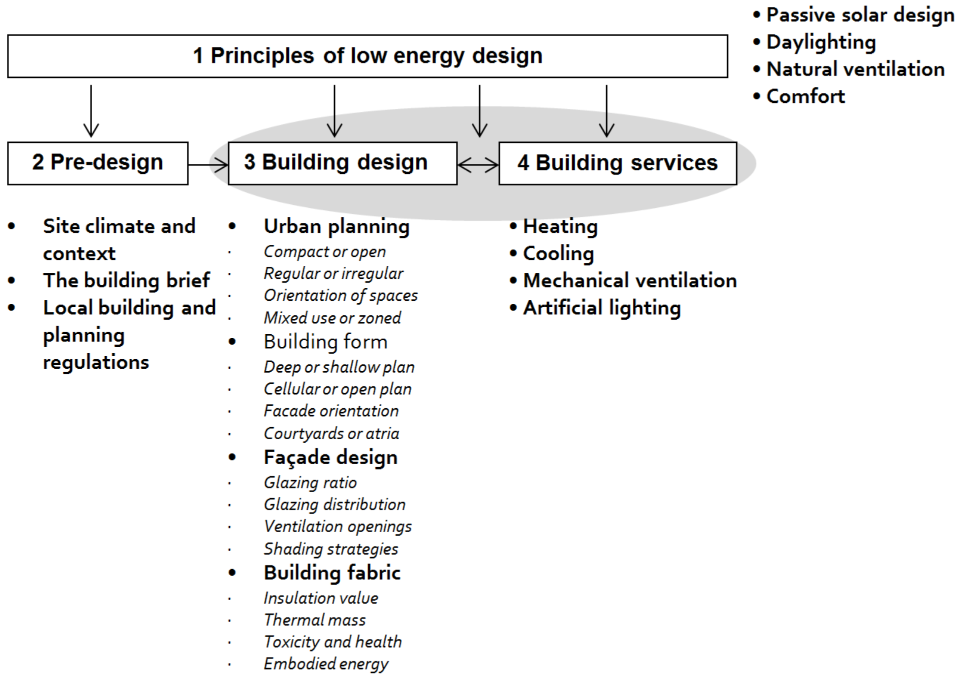


Figure 3-3: Layout of IBDS stages and relationships by Steemers (2005)

3.3.4 Model 4 and 5: Low/ Zero Carbon Design Model by Professor Jones, Cardiff University, the UK, 2007

Professor Jones from Cardiff University developed a low/ zero carbon design model (Figure 3-4) (Jones and Wang 2007). In order to achieve a required built environment with low/ zero carbon emissions, the design should start from analysing climate data to define the design objectives, i.e. possible passive design strategies can be applied to the project. Then, these passive design strategies can be integrated into each design categorise, from site planning, building form to building fabric design in order to harvest the beneficial free energy and to reduce the total energy demand. Next, energy efficient building services are installed to meet the reduced energy demand so that the desired built environment can be achieved. At last, renewable energy systems are integrated to supply energy required by the building systems. The model also considered energy associated with construction materials and products, as well as waste generated in the process (Jones et al. 2013).

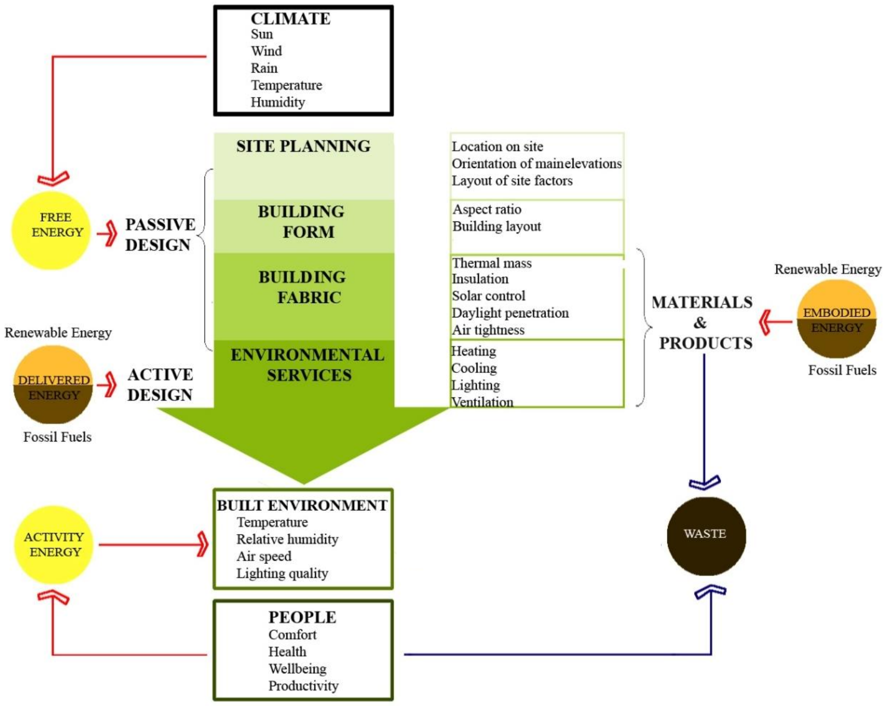


Figure 3-4: The model of low/ zero carbon design by Jones (2007)

The above model of low/ zero carbon design can be simplified to a four-stage model (Figure 3-5), presenting the design principles of low/ zero carbon design. The four stages are 1) reducing energy loads, 2) passive design, 3) mechanical systems, and 4) renewable energy supply (Jones et al. 2013). Comparing to model 4, this model added the first stage which is to reduce the energy loads, e.g. lighting and plug load.

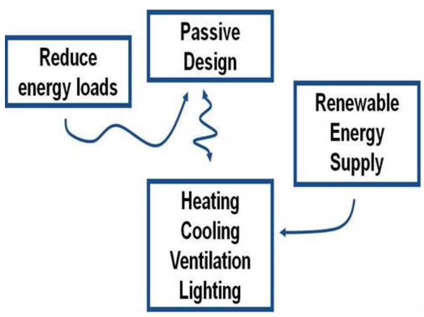


Figure 3-5: The simplified model of low/ zero carbon design by Jones. (2013)

3.3.5 Comparison of the low/ zero carbon design models

The Integrated Design Process Task 23 method presents a design process with three design stages, and there is a design loop for each design stage. The Integrated Design Process Task 23 method emphasizes the iterative design process. In the loop of the concept design stage, several design options are generated with the consideration of the whole building, and the most promising option which is evaluated by calculation and simulation is selected for further development. However, there is a lack of holistic consideration of the order of the associated design categories in the concept design stage.

The Integrated Design Process Knudstrup method describes a design process focusing the iterations in between five stages. The main design stage is the sketching phase which considers all the design parameters with design criteria and targets until the design finds its optimised solution. However, this design model does not include any associated design categories.

The Integrated Building Design System by Steemers is a design framework consisting of four design stages with the associated design categories. It emphasize the holistic approach to achieve low/ zero carbon. The principles of low energy design, which include passive solar design, daylighting, natural ventilation and comfort, determine the strategies applied in the other three design stages. However, this design model does not indicate the iterative design process.

The Low/ Zero Carbon Design Model by Jones presents a design framework from concept design to detailed design. It reflects the holistic approach to reduce carbon emissions and includes a range of associated design categories. But, it lacks the emphasis on the iterations in between the design stages. The simplified model of low/ zero carbon design summarizes the design principles which include reducing energy loads, passive design, mechanical systems, and renewable energy supply. Although there is no description of its links with the design process, the intention is that it is referred to at all stages from concept to detailed design. This model indicates the iterative design process and holistic approach to design low/ zero carbon buildings. However, the associated design categories are not proposed.

Some of the models have been successfully applied to a series of exemplary projects. For example, a Community Centre for the Municipality of Kolding in Denmark is a demonstration project successfully completed with the focus on the Integrated Design Process and the Integrated Design Process Knudstrup method has been applied at the master level of the Architecture curriculum to develop energy and climate optimised buildings. However, how to implement these models to the mainstream design remains a question. In order to achieve the benefits that these low/ zero carbon design models can provide, design tools which can facilitate the design process and integrate engineering parameters into architectural language should be developed.

The whole building design process proposed by the US Green Building Council agrees that a low/ zero carbon design requires to view all of a building's components together and think low/ zero carbon design objectives at every stage in the lifecycle (USGBC 2011a). Preparation stage is the most critical phase since the groundwork is laid for the entire project in this stage (USGBC 2011b), including to: 1) establish decision making processes and complementary design principles early in the planning, satisfying the goals of multiple stakeholders while still achieving the overall objectives of the project, 2) work to alleviate the clients' concerns to lead to a happier stakeholder group, 3) develop a clear statement of the project's vision summarizing what is trying to accomplished, 4) define the goals of the building, prioritize the low/ zero carbon goals, and determine how to reach the goals, 5) research low/ zero carbon technologies and strategies, 6) define low/ zero carbon design budget, and 7) review applicable laws and standards. Compare to the traditional design process, low/ zero carbon design is a holistic (collaboration of clients, architects, engineers and contractors at early stage) and iterative process rather than traditionally the design team working independently in a linear process. The design team is always reviewing and verifying that low/ zero carbon building goals to make sure they are met at every point in the process. The Building Regulations (from the version 2006) promotes the involvement of consultants at an early stage on all the design teams as they have to work together at a very early stage (Hazam and Greenland 2009).

In summary, section 3.3 identifies two main criteria of low/ zero carbon design from the review of these five design models and the whole building design process proposed by the USGBC:

1. The design process is an iterative process to optimise low/ zero carbon design strategies for each design categories.

2. A holistic approach to achieve low/ zero carbon design is applied.

1) Early clarification of the project goals with the clients, architects, and engineers is required to lead to achieve a low/ zero carbon design building.

2) Collaboration of the design team with all members sharing the understanding of the design process throughout the design is needed in order to accomplish the design objectives.

3) Specialists in the area of sustainability, comfort and energy are required to provide consultancy.

These criteria will be incorporated into the initial model of low/ zero carbon in next section.

3.4 The initial model of low/ zero carbon design

An iterative design process with a low carbon commitment and a holistic approach with collaboration of the members of a design team from the very beginning of the design can be identified as the main criteria from the review of design process models in the last chapter. It is important to establish a model of low/ zero carbon design for this research to represent the overall content of low/ zero carbon design training programmes. A clear yet simple framework considering all the various aspects of low carbon design should be developed (Fuller et al. 2008).

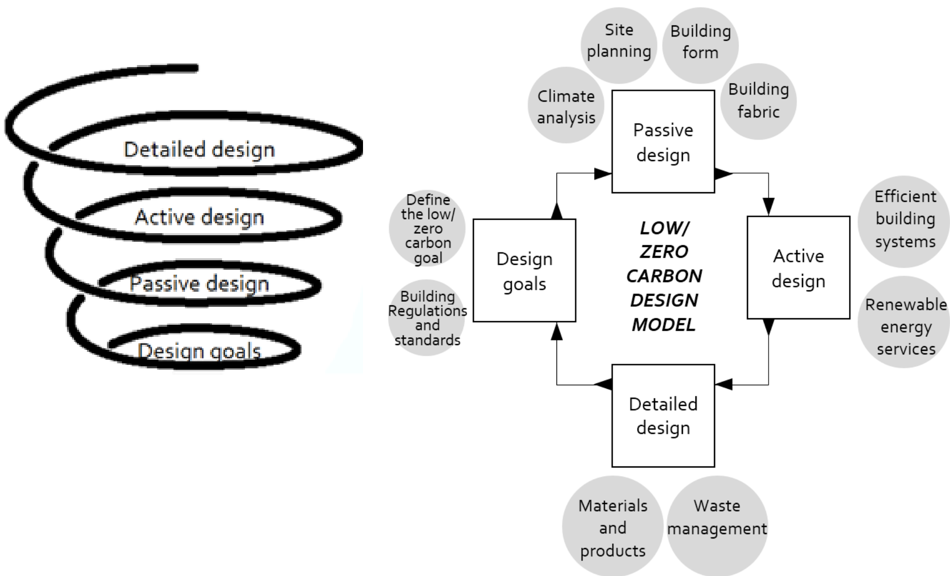


Figure 3-6: The initial model of low/ zero carbon design

The initial model of low/ zero carbon design enhances the iterative design process and the holistic approach. The initial model of low/ zero carbon design takes a loop form to organize four design stages, and reflects: 1) the iterative design process between design stages, and 2) the holistic approach which considers all the design parameters that influence energy use and carbon emissions at every design stage from planning to detailed design (Figure 3-6). So the initial model is a spiral design process with the four design stages presented at different levels of the spiral. On each level of the spiral, a loop with four design stages is presented with a focus on that particular design stage.

The four stages in the initial model of low/ zero carbon design are: 1) establish design goals, 2) develop passive design strategies from climate analysis to identify the problems and the potential solutions, through site planning, building form, and building fabric design to maximize the usage of free energy, 3) develop active design strategies to apply efficient building systems to achieve the desired built environment with lower energy requirement and use renewable energy to supply the remain energy demand, and 4) conduct detailed design with consideration of materials and products specification as well as waste management. The detailed design stage is similar to the 'developed design' and 'technical design in the RIBA stages. It is in the loop of the design process rather than a separate stage. By the end of the detailed design stage, the design can inform all the main components of the building and how they be put together. In relation to low/ zero carbon design, the detailed design should include: 1) architectural plans, sections and elevations, design of components (including glazing, blinds) and construction details; 2) system selections; 3) the use of materials and the potential for re-use, recycling and waste handling and 4) detailed cost plan showing the capital and lifecycle costs for all the components. Ten design categories are included in the initial model of low/ zero carbon design, including 1) define the low carbon design goal, 2) comply with the Building Regulations and standards, 3) climate analysis, 4) site planning, 5) building form, 6) building fabric, 7) efficient building services, 8) renewable energy systems, 9) sustainable construction materials and products, and 10) waste management.

The initial model of low/ zero carbon design provides a framework of the knowledge and skills (associated design process, approach and design categories) needed to design a low/ zero carbon project. The model starts with setting a clear goal of low/

zero carbon at the beginning of the design by the clients and the design team. The design goal of low/ carbon design should define all the parameters of low/ zero carbon building identified in section 3.1. It should include energy efficiency threshold, the metric, type of energy use, type of renewable systems, connection with the energy infrastructure, and period of the balance. A suitable environmental assessment methods can be chosen to pursue as well. It is of importance to set a measurable goal. As Fuller et al. (2008) stated, architects cannot claim a building is low carbon when there are not objective measures such as footprint or carbon emissions analysis. In addition, it should be a practical target rather than the best practice goal which can only be achieved when all the design components of the building are opted for the best specification.

Following setting the low/ zero carbon design goal, architectural concept and schematic design with passive strategies is carried out by architects with information input from engineers and building physicists to optimise the building design with reduced energy demand. During active design stage, efficient building systems should be designed with reduced capacity to meet the reduced energy demand, and renewable energy systems should be designed to supply the energy demand. In the detailed design stage, the close collaboration between the design team and contractors should be conducted to ensure the achievement of the low/ zero carbon in the construction stage.

In summary, section 3.4 proposes the initial model of low/ zero carbon design which reflects an iterative design process and a holistic approach with four stages and ten design categories, including 1) define the low carbon design goal, 2) comply with the building regulations and standards, 3) climate analysis, 4) site planning, 5) building form, 6) building fabric, 7) efficient building services, 8) renewable energy systems, 9) sustainable construction materials and products, and 10) waste management, in order to represent the overall content of low/ zero carbon design training programmes.

3.5 Summary

This chapter reviewed the definitions of low/ zero carbon design, the environmental standards and assessment methods, and the existing design process models. A formula to define low/ zero carbon design in this research has been established in order to clarify the low/ zero carbon design goals at the beginning of the design. The review of the environmental standards suggests the importance to pursue a higher but voluntary low/ zero carbon standards. Two main criteria of low/ zero carbon design have been identified from the review of the low/ zero carbon design process models and the whole building design process *by USGBC: 1) an iterative design process and 2) a holistic approach. An initial model of low/ zero carbon design is established, demonstrating the iterative design process and the holistic approach to achieve low/ zero carbon design, with four design stages and ten associated design categories where low/ zero carbon design strategies can be implemented. The intent to develop the initial model of low/ zero carbon design is to reflect the initial understanding on the knowledge and skills of low/ zero carbon design required to be disseminated to the architects in practice.*

Chapter 4. The understanding of architects' learning preference

In order to disseminate the knowledge and skills of low/ zero carbon design to architects, it is important to understand how the audience prefer to learn. The most natural instinct is to apply the approach applied in architectural schools for architectural students to the training programmes for practicing architects. However, is the training method used in architectural schools the most suitable way to disseminate knowledge and skills to architects? Bearing this question in mind, this section reviews the current architectural education and continuous professional development training for architects in order to develop an understanding of the current training process for architects. Then, a review on people's learning styles is carried out to explore the types of learning that architects may prefer. Next, adults learning is explored. Finally, an initial model of architects' learning preference is established to reflect the initial understanding on how to disseminate the required knowledge and skills of low/ zero carbon design to architects in practice.

4.1 Current architectural education system

J. Farren-Bradley (2000) pointed out that architects in the UK were the product of a predominantly office-based educational process, enhanced by an examination system and a variety of educational opportunities to support the candidates before the Oxford Conference in 1958. This conference on architectural education was held by the RIBA at Magdalen College, Oxford, on April 11th to 13th in 1958. Recorded in the report of the chairman (Martin 1958), three aspects of architectural education were discussed:

1. The needs of the profession and the community and their desirable standards
2. The means of education, the routes of entry into the profession and the standards that are being and could be achieved
3. Development of advanced training and research

At the end of the Oxford Conference, recommendations were put forward, including: office based training with the RIBA external examination was restricting to the development of architects, therefore it should be replaced by either full-time or, on an experimental basis, combined with sandwich courses in which periods of training in a school alternate with periods of training in an office (Martin 1958). In the current form of architectural education in the UK, the candidates enter the profession through a combination of five years of full-time education and a minimum two years of supervised practical training. This form of architectural education was not fully developed until the 1980s (J. Farren-Bradley 2000).

4.1.1 Design studio based approach

Webster's research (2008) indicated that architectural education remained un-theorised until Donald Schön put forward the notion that design studio learning simulated real professional action in the 1970s. Architectural education transformed the previous articled apprenticeship model into an education setting: the architectural office became the design studio, learning design from an architect based on real architectural projects turned to learning design from design tutors based on simulated projects (Webster 2008). Since then, architectural education has remained universally the same: students' major activities are centred on the design studio, they develop their own design in the form of sketches, working drawings and models, have tutorials with their tutors to solve the problems they encountered, progress in their initial design, and they present their design to their tutors and to 'impress' the jury (critics) at the crit at the end of the semester.

The current design studio nowadays stays similar to the one described by Schön (1983) three decades ago:

> *Quist examines these drawings, while Petra describes how she is stuck… After a while, Quist places a sheet of tracing paper over Petra's sketches and begins to draw over her drawing. As he draws, he talks. He says, for example, 'the kindergarten might go over here…then you might carry the gallery level through…and look down into here…*

This helps to illustrate Schön's central theory: the studio based design which simulated the complexities of real life projects and 'reflection-in-action' leads students to observe and to realign their thinking with the 'masters' thinking of their tutors.

4.1.2 Practice based (design- build) approach

Some professionals highly value doing practical work in practice which engages students on actual projects and involves them in the construction of buildings as well. Several design-build practices reintroduce the intimate connection between design and build, think and make. Famous examples include Rural Studio, Studio 804 and Ghost International Architectural Laboratory, which provide design-build architectural courses aiming at linking architectural education back to practice and the processes of physical making:

The Rural Studio, founded in 1993 by architects Samuel Mockbee and D. K. Ruth, is a design-build architecture programme for undergraduate students run by the Auburn University. It aims to enable students to create, design and build, and to allow students to put their educational values to work as citizens of a community; while also provides safe, well-constructed and inspirational homes and buildings for poor communities in rural west Alabama (Rural Studio 2010).

Studio 804 is a graduate level design-build programme at the School of Architecture and Urban Planning in the University of Kansas. Studio 804 provides students with critical knowledge to work collaboratively, not only to design a project but to actually construct it. The goal is to provide students with an experience encompassing all aspects of the design and construction process, from working with building codes, hiring third party inspectors to communicating with engineers and neighbourhood associations, signing contracts, doing estimates and driving nails (Studio 804 2010).

The Ghost Architectural Laboratory is the research facility of the MacKay-Lyons Sweetapple Architects Limited. It is an education initiative designed to promote the transfer of architectural knowledge through direct experience-project-based learning. It is taught in the master builder tradition with emphasis on issues of landscape, material culture, and community (Ghost Architectural Laboratory 2010). The Ghost Architectural Laboratory provides a two-week summer design-build internship (one week for design, one week for build) for architects, engineers, builders, professors and students.

4.1.3 Continuous Professional Development for architects

The need for the Continuous Professional Education (CPE) has been recognized by most professional workers since the 1970s; and attendance at CPE events have been made mandatory for continuing registration (Eraut 1994). CPD programmes have been set up to ensure qualified architects maintain their competence to practice within this rapidly changing industry. For example, all chartered members of the RIBA are obliged to complete certain hours of CPD every year. The latest requirement is 35 hours of CPD, along with 100 points which are given to the participants for their activities where they are using self-reflection, and at least half of the CPD activity should be structured; and at least 20 hours of CPD on core curriculum topics (at least two hours on each topic each year) from September 2011 (RIBA 2012). Comparing to the previous curriculum which requires at least 19.5 hours per year from the RIBA's prescribed core curriculum for CPD and at least 15.5 hours of professional development in other subjects relevant to CPD needs, this new curriculum increases the requirement in order to keep the architects up-to-date due to fast development of the building industry.

According to Eraut (1994), CPE takes the forms of formally organized conferences, courses or educational events. Looking through the list of training courses developed by the main CPD providers for the professionals in the building industry (RIBA, CIBSE, and BRE), most programmes are in the format of lecture and workshops.

In summary, section 4.1 indicates that theoretical lectures, design studio, and practicing in architectural firms are the main components in the current architectural education system, and the embedded teaching and learning process for architectural education is learning by doing. On the other hand, training programmes for architects tend to be in the format of lectures and workshops only, and architects acquire knowledge and skills through the study of a subject without direct experience and practice. In order to gain an understanding on whether architects have a learning preference, a systematic review on learning styles and learning process which includes learning by doing will be conducted in the next section.

4.2 Learning styles

In this section, learning styles are explored and the emphasis on education is shifted from teaching to learning. The report ‘Should we be using learning styles? What research has to say to practice’ by Learning & skills research centre summarized the appeal of learning styles, including 1) promise practitioners a simple solution to the complex problems, 2) provide an explanation for some failure of traditional methods, 3) explore all three components of the pedagogical triangle of teacher, student and subject, 4) transform the attitude toward learning difficulties, and 5) shift the responsibility for enhancing the quality of learning from management to the individual learning styles of teachers and learners (Coffield et al. 2004a). The main objections to learning styles include 1) suggest the measurements of learning preferences were derived from the subjective rather than the objective judgement, and 2) question the prominence of the variance in test scores is attributable to learning styles, and 3) suggest the rather simple conclusions derived from elaborate statistical treatment of the test scores (Coffield et al. 2004a).

4.2.1 Review about learning styles

The foundation of learning styles explored in this research is based on Riding and Rayner’s statement (1998): people differ from each other in the ways that they think and learn, and individuals have a preference for learning using particular sets of techniques, approach their study in particular ways or adopt particular strategies towards learning. Schmeck (1988) provided examples that one learner might experience learning through repetition and recitation, while another might go through an interpretative process.

Learning style is defined as a deep-rooted preference an individual has for a particular type of learning for all activities and subjects areas (Adey et al. 1999).

Cassidy (2004) pointed out that research in the area of learning styles has been active for around four decades and led to a vast body of research. The research in learning styles has generated great interest and controversy. Researchers established a range of learning styles and models with extensive literatures, wishing to gain a better understanding of how people learn and characterize different types of learners, in order to help learners learn better. Learning styles has been widely applied in academic achievement, clinical training in medical schools, career development, and management training. There was no unified model to determine a person's learning style. Coffield et al. (2004b) explained that there has been no unified focus on the research of learning styles, and the existing models of learning styles can be grouped into three categories: 1) theoretical, 2) pedagogical, and 3) commercial. The main reason for the extensive list of models was that a large number of researchers were working in isolation (Riding and Rayner 1998).

In order to provide an overview of the research in learning styles, studies were conducted to review and evaluate the existing learning styles. De Bello (1990) compared 11 learning styles models in his paper 'Comparison of Eleven Major Learning Styles Models: Variables, Appropriate Populations, Validity of Instrumentation and the Research behind Them'. Hayes and Allinson (1994) reviewed 29 learning styles and examined ways in which these styles can be classified. 71 cognitive and learning styles were reviewed in the Learning & Skill Research Centre's report 'Learning styles and pedagogy in post-16 learning: a systematic and critical review' in 2004, which was commissioned by the Learning and Skills Development Agency (Coffield et al. 2004b).

In addition, studies were carried out to characterise the learning styles. These studies included Curry's onion metaphor learning style model, Riding and Cheema's wholist-ananlytic and verbal-imagery dimensions model, Rayner and Riding's framework of cognitive-centred and learning-centred approaches, and Coffield's continuum of learning styles.

Curry categorised different learning styles, and constructed a three-level learning styles theory model resembling layers of an onion (Figure 4-1). The model shows that 1) learning behaviour is controlled by the central personality style which is the individual's approach to adapting and assimilating information, 2) then learning behaviour is translated through the middle information processing style which is the individual's intellectual approach to assimilating information, and 3) at last learning behaviour is given a final twist by interaction with instructional format preference factors which refer to the individuals' choice or environment in which to learn, including learner expectations, teacher expectations and other external features (Curry 1983).

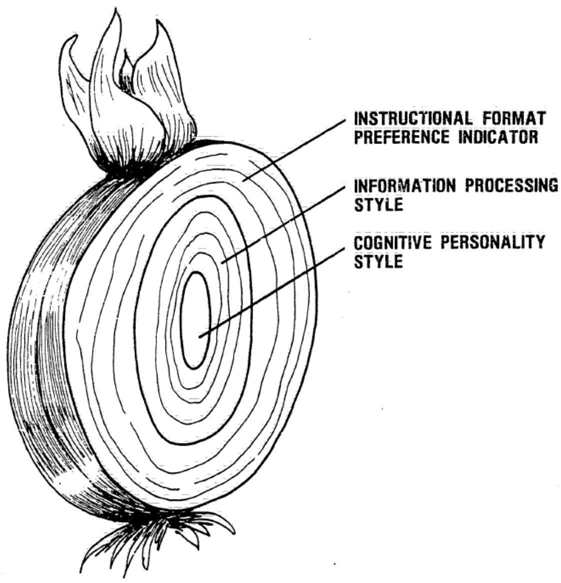


Figure 4-1: Learning styles theory (Curry 1983)

Riding and Cheema (1991) summarized the learning styles models into two families: 1) wholist-ananlytic dimension referring to styles assessing whether an individual tends to organise information into wholes or parts, and 2) the verbal-imagery dimension referring to styles whether an individual is inclined to represent information during thinking verbally or in mental pictures.

Rayner and Riding constructed a framework of cognitive-centred and learning-centred approach to categorise the learning styles. The cognitive-centred approaches focus on the identification of styles based on individual difference in cognitive and perceptual functioning. The learning-centred approaches are distinguished on the basis that there is a greater interest in the impact of style on learning in an educational setting and the development of new learning–relevant constructs and concepts, consisting of process models, preference models and cognitive skills-based approaches.

A continuum of learning styles was developed by Coffield et al. (2004b) which is based on the extent to which the developers of learning styles models and instruments appear to believe that learning styles are fixed (Figure 4-2). Theorists with strong beliefs about the influence of genetics on fixed, inherited traits and about the interaction of personality and cognition is put at the left-hand end of the continuum. Moving along the continuum, learning styles models are based on the idea of dynamic interplay between self and experience. At the right-hand end of the continuum, greater attention is paid to personal factors such as motivation, environmental factors like cooperative or individual learning, the effects of curriculum design, institutional and course culture, and assessment tasks on how students choose or avoid particular learning strategies.

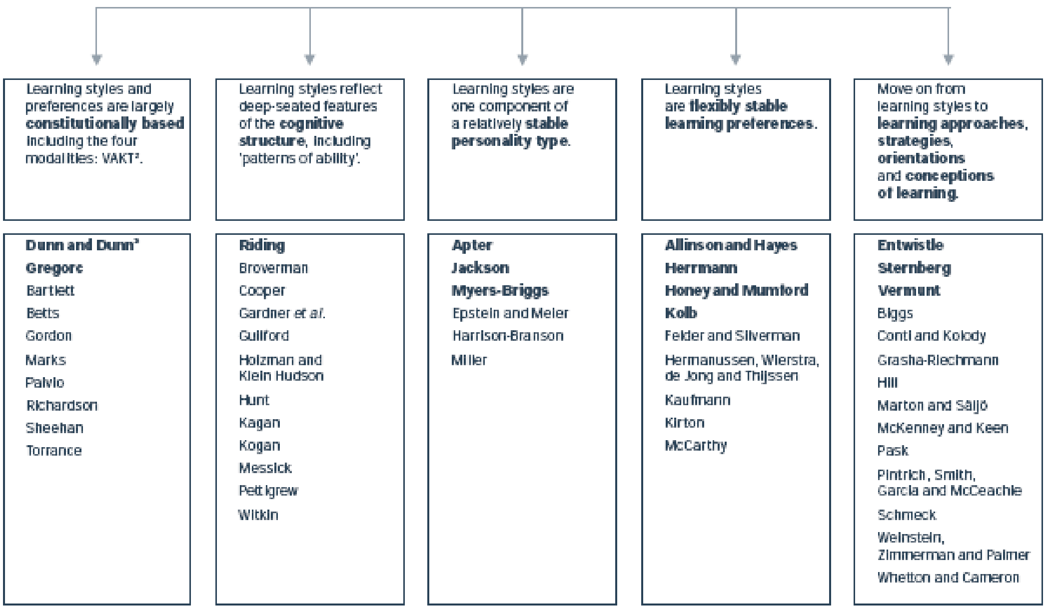


Figure 4-2: Family of learning styles (Coffield et al. 2004)

Vermunt constructed a model of the regulation of constructive learning processes to integrate the conceptualisations of students learning components (Figure 4-3). It consists of four elements: 1) the cognitive processing activities which are thinking activities students use to process learning contents and to attain their learning goals by doing so, 2) the metacognitive regulation activities they use to regulate and direct their learning processes, 3) the mental models of learning and teaching which is a coherent whole of learning conceptions: conceptions and misconceptions about learners, learning processes, learning objectives and learning tasks, and 4) the learning orientations which is the domain of personal goals, intentions, motives, expectations, attitudes, worries and doubts of students in doing courses or studies In her model, the way in which students process the subject matter is most directly determined by the regulation strategies (Vermunt 1998). Mental learning models and learning orientations have impact on the way in which students regulate their learning processes, that leads to indirectly influence on the processing strategies that students use.

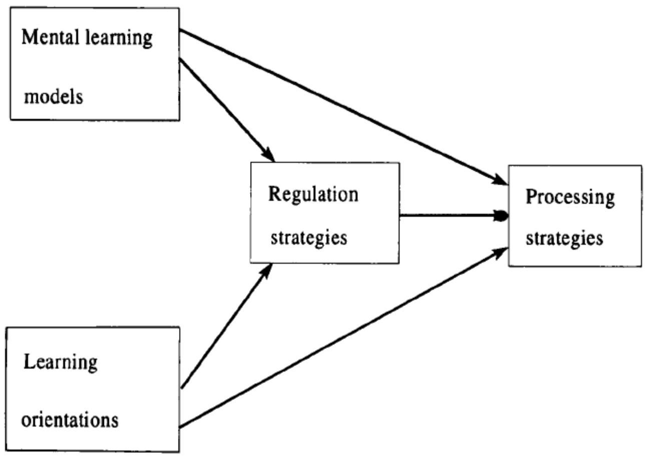


Figure 4-3: A model of the regulation of constructive learning process (Vermunt 1998)

The concept of learning styles had been criticised since it was put forward. According to Entwistles (1981), a mismatch between the nature of instruction and an individual's learning style did not hamper achievement. It was suggested that the discomfort of having to struggle with a learning style different from one's natural preference can lead to better learning (Adey et al. 1999). Moreover, critiques pointed out that few of the models were supported by sufficient evidence, and little evidence suggested the accompanying tests actually measured what their creators intended (Coffield 2004).

So what is the point of exploring the learning styles? Coffield (2004) pointed out that learning styles provided tutors and learners with a language with which to discuss their learning preferences: how people learn or fail to learn and how both parties can facilitate or hinder these processes.

4.2.2 Kolb's Experiential Learning Model and the Learning Style Inventory (LSI)

This section focuses on Kolb's Experiential Learning Model and the Learning Style Inventory. The main reason to investigate the application of Kolb's Experiential Learning Model and the Learning Style Inventory in architects' training programmes is that 1) the Experiential Learning has been developed for adults in management training which is close to the training for architects in practice and 2) it has been discussed and applied in architectural education field. In accordance to different reviewed categorisations of learning styles, it has been categorized as learning-centred process-based approach (Rayner and Riding), information processing (Curry) and flexibly stable learning style (Coffield).

The Experiential Learning circle is the process of making meaning from direct experience (Itin 1999). It is to learn by making discoveries and experiments with first-hand knowledge, rather than by being told and repeating it. In fact, the recognition of experiential learning as a learning theory is not a new idea. Aristotle stated that for the things we had to learn before we could do them, we learned by doing them (Bynum and Porter 2005). Dewey (1916) put forward a similar idea that if knowledge came from the impressions made upon us by natural objects, it was impossible to procure knowledge without the use of objects which impressed the mind. Also as Eraut pointed out, learning knowledge and using knowledge are the same process rather than separated processes, and the process of using knowledge transforms that knowledge to different knowledge (Eraut 1994).

Linking to ideas from John Dewey and other writers of the Experiential Learning paradigm, American educational theorist David Kolb and Ron Fry developed the theory of experiential learning in the early 1970s. In 1984, Kolb published his book 'Experiential Learning: Experience as the Source of Learning' in which the Learning Style Model (LSM) was established. Learning is conceived of as a four-stage cycle, including 1) concrete experiences (CE), 2) reflective observation (RO), 3) abstract conceptualization (AC) and 4) active experimentation (AE) (Kolb 1984). These four elements are recognized as the essential components of a spiral of learning that could begin with any one of the four elements, but typically begin with a concrete experience (Kolb 1984).

As illustrated below (Figure 4-4), immediate concrete experience is the basis for observation and reflection. These observations are assimilated into a theory from which new implications for action can be deduced. These implications or hypotheses then serve as guides in acting to create new experiences.

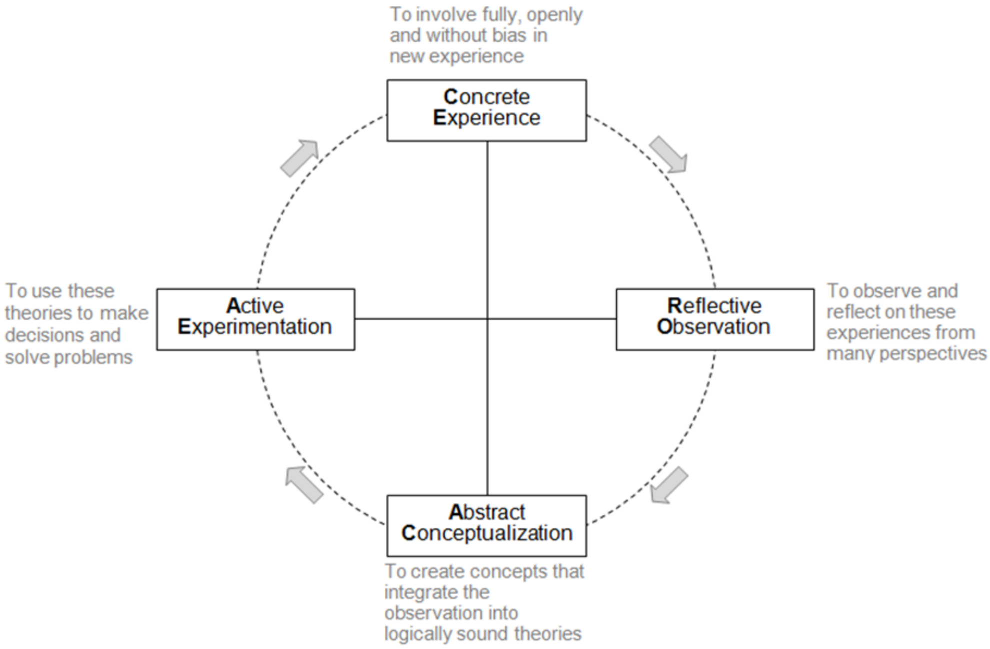


Figure 4-4: Experiential Learning Model (Kolb 1984)

Besides the four-stage learning cycle, there is another level of the Experiential Learning Model, which is a four-type definition of learning styles (Kolb 1984). Two primary dimensions to the learning process are indicated in the Experiential Learning Model: the first dimension represents the concrete experiencing of events at one end and abstract conceptualization at the other, and the other dimension has active experimentation at one extreme and reflective observation at the other (Kolb 1976). Based on this model, Kolb (1976) developed the Learning Style Inventory (LSI), in order to measure differences in learning styles along these two basic dimensions. The Learning Style Inventory is a questionnaire with 12 items where participants have to rank four words in the order that best describes their preference for particular modes of learning (Roberts 2004). Four types of learning styles are identified, including:

1. Converger: prefers learning situations where a single correct answer can be found (Hudson 1966).
2. Diverger: prefers open ended learning situations (Hudson 1966).

3. Assimilator: makes new knowledge fit within the existing knowledge (Piaget 1995).

4. Accommodator: modifies the existing knowledge in order to accommodate new knowledge (Roberts 2004).

Related to the Experiential Learning Model, each learning style represents the combination of two stages of the learning circle, like a two-by-two matrix of the four-stage cycle (Figure 4-5).

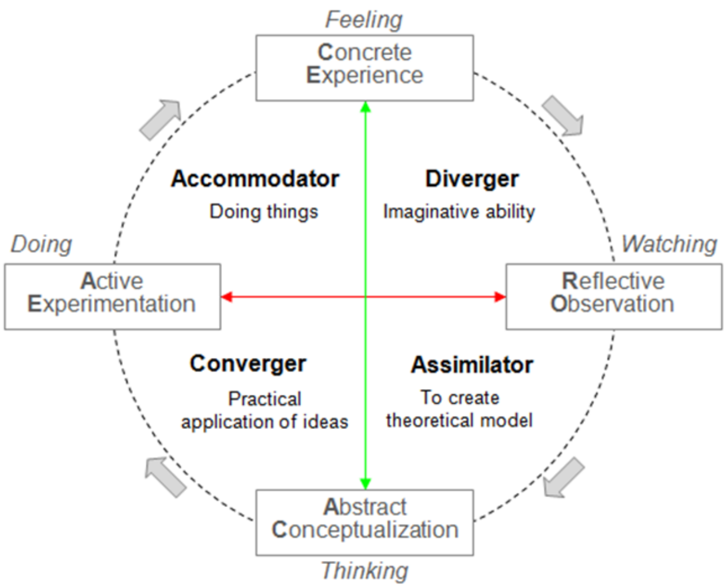


Figure 4-5: Learning Styles Inventory (Kolb 1984)

A correspondence has been noted between the Learning Style Inventory scores and initial career interests. Data analysis of the Carneige Commission Study of American Colleges and Universities showed the orientations of different academic fields along the concrete/ abstract and active/ reflective axes (Wolfe and Kolb 1991). Architecture was located in the top left quarter of the learning style grid: concrete and active. Another study carried out by Powell suggested the same result (Newland et al. 1987). This recognized that the architects' preferred learning style is accommodating, which could be interpreted as learning by doing. This matches the main method applied to the current architectural education currently which engages students' learning in the process of design (doing).

What is more, the Design Information Research Group conducted a study to investigate architects' behaviour with consideration of Kolb's learning styles and Leary's interpersonal communications. Architects are identified as four types of learners, namely common sense learners, dynamic learners, contemplative learners and zealous learners (Newland et al. 1987).

4.2.3 Honey and Mumford's Learning Style Questionnaire

Honey and Mumford (1995) suggested that learning and teaching activities should be adapted to ensure that emphasis was placed upon all stages of the learning cycle, so that learners of all types can learn effectively. Honey and Mumford developed the Learning Style Questionnaire (LSQ) to determine how individuals learn. Honey (2002) explained why he based his Learning Style Questionnaire on Kolb's Experiential Learning Model with three reasons: 1) the cycle describes the essential ingredients of the process of learning so that it can be analysed and improved, 2) the cycle helps people to identify their learning weaknesses and encourages them to move outside their 'preference zone', and 3) the cycle is a vehicle to stimulate discussion about learning. The LSQ is an 80-item self-report inventory developed specifically for the application in industry and management (Cassidy 2004). Learners are classified as activists, reflectors, theorists and pragmatists (Roberts 2004) (Table 4-1).

Table 4-1: Comparison of Honey and Mumford's learning styles and Kolb's learning styles			
Honey and Mumford's learning styles			***Kolb's learning styles***
Activists	Learn from doing things	They initiate and perform tasks, they like to experiment	*Accommodator*
Reflectors	Learn from reflection	They watch others' activities and reach decisions in their own time	*Diverger*
Theorists	Learn from a model, a framework, a concept or theory	They read, analyse and understand complex situations through intellectual engagements	*Assimilator*
Pragmatists	Learn from linking theory to actual problems	They enjoy techniques that relate directly to their own problem	*Converger*

4.2.4 McCarthy's 4MAT

McCarthy (1990) created an eight-step instructional sequence in 1972 which aims to accommodate both preferences for using the two hemispheres of the brain in learning and the four main learning styles based on Kolb's Experiential Learning Model. Each of these styles asks a different question and displays different strengths.

1. Imaginative learners demand to know 'why'. This type of learner likes to listen, speak, interact and brainstorm.
2. Analytic learners want to know 'what' to learn. These learners are most comfortable observing, analysing, classifying and theorising.
3. Common-sense learners want to know 'how' to apply the new learning. These learners are happiest when experimenting, manipulating, improving and tinkering.
4. Dynamic learners ask 'what if'. This type of learner enjoys modifying, adapting, taking risks and creating.

The 4MAT system is designed to help teachers improve their teaching by using eight strategies in a cycle of learning: alternate right and left mode techniques of brain processing at all four stages of the learning cycle. Figure 4-6 shows the four quadrants in the system (McCarthy 1990):

- In the first quadrant, the emphasis is on meaning and making connections with the new material to be learned.
- In the second, the focus is on content and curriculum.
- The third quadrant is devoted to the practical application and usefulness of the new knowledge.
- The final quadrant encourages students to find creative ways of integrating the new knowledge into their lives.

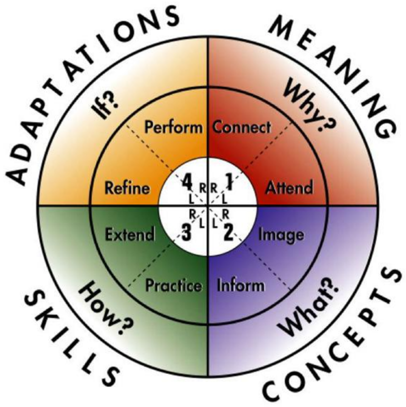


Figure 4-6: 4MAT system (McCarthy 2014)

McCarthy (1990) pointed out that the movement around this circle is a natural learning progression and all learners need all segments of the cycle. 4MAT system should be used by instructors to improve their instructional design for teaching for all learning styles.

In summary, section 4.2 indicates that people prefer different learning styles, and learning styles can provide a language to the learners to discuss their learning preferences. Kolb's Learning Styles Inventory, Honey and Mumford's Learning Style Questionnaires and McCarthy's 4MAT, which are all based on Kolb's Experiential Learning Model, are the commonly applied packages of learning styles to explore people's preferred learning styles. There are four learning styles: 1) learn from doing things, 2) learn from reflection, 3) learn from a model, a framework, a concept or theory, and 4) learn from linking theory to actual problems. The ‘learn from doing things’ is recognized as the learning style that most architectural students prefer in a series of existing studies. What is more, this section explores Kolb’s Experiential Learning Circle which provides a clear description of a four-stage learning progress: 1) concrete experience, 2) reflective observation, 3) abstract conceptualization, and 4) active experimentation (learning by doing). The teaching and learning process in architectural education for architectural students follows the Experiential Learning Circle to combine learning the knowledge and using the knowledge; while the training programmes for architects miss the fourth stage: active experimentation. The next section will explore architects’ learning preference from another perspective: adult learning.

4.3 Adult learning

4.3.1 Introduction about adult learning

The central point of this section is that adults and children learn differently (Suires 1993). The aim of adult learning is limited to problem solving at work rather than lifelong body and mind development.

According to Knowles et al. (2005), a growing body of ideas about the unique characteristics of adult learners began emerging in the US and in Europe in the 1920s. As early as 1926, Lindeman (1926) published his book ‘The Meaning of Adult Education’ and stated that the authoritative teaching and examinations which precludes original thinking and rigid pedagogical formula are not suitable in adult education. Knowles et al. (2005) stated that the notions that adults learn differently evolved into an integrated framework of adult learning in the past few decades. Also, Knowles et al. (2005) pointed out that the concept of the learning/ teaching process for adults was a process of mental inquiry rather than passive reception of transmitted content. His argument was influenced by those great teachers in ancient times, such as Confucius of China, Jesus in Biblical times, and Aristotle, Socrates and Plato in ancient Greece whose students were adults.

The main outcome of these ideas is that adults and children have different motivations to learn. Children do not take the initiative to acquire new knowledge. The motivation to learn they possessed is usually from outside sources, such as passing marks and rewards. However, adult learners are self-motivated. They first investigate why they must undertake the learning task, assess the possible positive or negative outcomes, and then they will focus their energy and time on the task of obtaining this knowledge (Hill 2001). Two terms have been created to describe the study of education oriented toward children learning and the study of adult learning, which are pedagogy and andragogy respectively.

In this section, the concept of andragogy is explored due to it being the most popular single concept in adult learning. According to Smith (1996), andragogy (Greek: andr-meaning ‘man’, agogos- meaning ‘leading’) was coined in 1833 by a German educator Alexander Kapp, to be contrasted with pedagogy (Greek: paid-meaning ‘child’), and Rosenstock reused the term in his report in 1921 to refer to the special requirements of adult education regarding teachers, methods and philosophy. In 1927, Anderson and Lindeman referred to Andragogy in a volume titled ‘Education through Experience’ and in the journal ‘Worker’s Education’ (Davenport 1993). By the 1970s, andragogy has been developed into a theory of adult education by an American educator, Malcolm Knowles, which suggested that adult learning should be distinguished from children learning and promoted many subsequent studies (Knowles 2005). Knowles' theory has been developed and refined since 1975, and currently six assumptions of andragogy are put forward in Knowles' theory. Figure 4-7 shows the latest model of andragogical theory.

In the central ring of the graph, the six core principles of adult learning are presented, including:

1. Adult learners need to know why, what and how to learn
2. Adult learners needs to be responsible for their decisions on education, including involvement in the planning and evaluation of their instruction
3. The experience of the learners (including error) provides the basis for learning activities
4. Adult learners are most interested in learning subjects that have immediate relevance to their work and/or personal lives
5. Adult learning is problem-centred rather than content-oriented
6. Adult learners respond better to internal versus external motivators

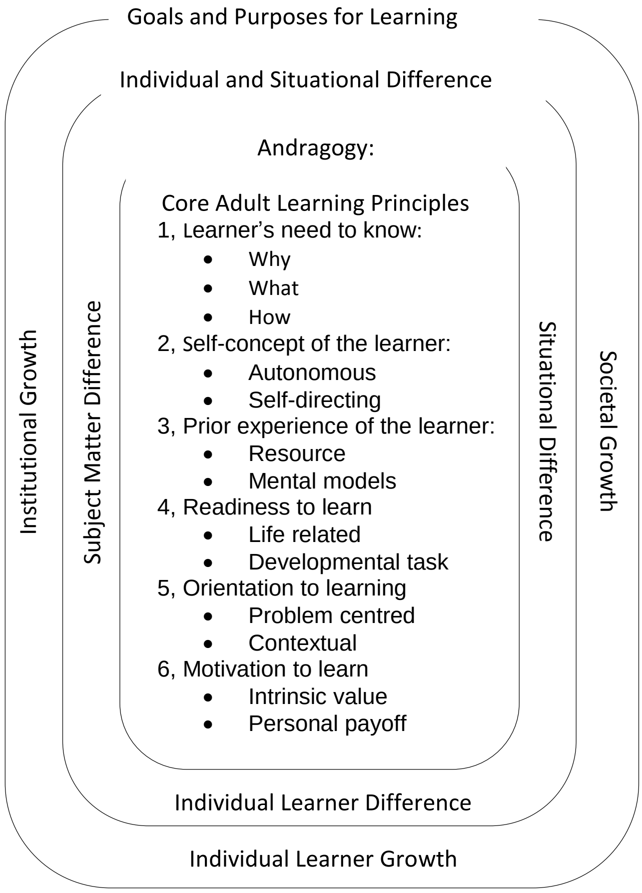


Figure 4-7: Andragogy in practice (Knowles 2005)

There are several ways to interpret the concept of Andragogy, such as an empirical descriptor or a conceptual anchor from which a set of appropriate adult teaching behaviours can be derived (Brookfield 1986). In this research, the concept of andragogy is taken as simply a model of assumptions about adult learners as Knowles (2005) described. Seven components of andragogical practice have been identified by Knowles and Associates (1984):

1. Facilitators establish a physical and psychological climate conducive to learning.
2. Facilitators involve learners in mutual planning of methods and curricular directions.
3. Facilitators involve participants in diagnosing their own learning needs.

4. Facilitators encourage learners to formulate their own learning objectives.
5. Facilitators encourage learners to identify resources and to devise strategies for using such resources to accomplish their objectives.
6. Facilitators help learners to carry out their learning plans.
7. Facilitators involve learners in evaluating their learning, principally through the use of qualitative evaluative modes.

4.3.2 Different opinions on adult learning

According to Davenport (1993), critics challenged everything from andragogy's assumption to its effectiveness. The main criticisms included:

1. It was a different approach from pedagogy to educate children or adults, rather than a distinct art and science of teaching adult (Elias 1979).
2. It was an educational ideology rooted in an inquiry-based learning and teaching paradigm rather than a theory of adult learning (Day and Baskett 1982).
3. The assumptions underlying andragogical theory were shaky; and it was not clear whether it was prescriptive or descriptive (Hartree 1984).
4. There was inconsistency in defining pedagogy and andragogy (Davenport 1993). Pedagogy is literally interpreted as 'the art and science of teaching children'; while andragogy is interpreted as 'the art and science of helping adults learn'.

On the other hand, many educators and trainers of adults believed that the andragogy concept represented a professionally accurate summary of the unique characteristics of adult education practice (Brookfield 1986). Several attempts to use the concept as a guide to constructing a model of effective educational practice have been proved to be successful.

According to Cross (1981), andragogy is much more successful than most theories in the adult learning field in gaining the attention of practitioners; and it have promoted much subsequent research and debate. Brookfield (1986) put forward several principles of effective practice in facilitating adult learning which shares certain points of view with andragogy: 1) participation in learning is voluntary, 2) effective practice is characterized by a respect among participants for each other's self-worth, 3) facilitation is the collaboration between facilitators and learners, 4) learners and facilitators are involved in a continual process of action and reflection, 5) facilitation aims to foster in adults a spirit of critical reflection, and 6) the aim of facilitation is the nurturing of self-directed and empowered adults.

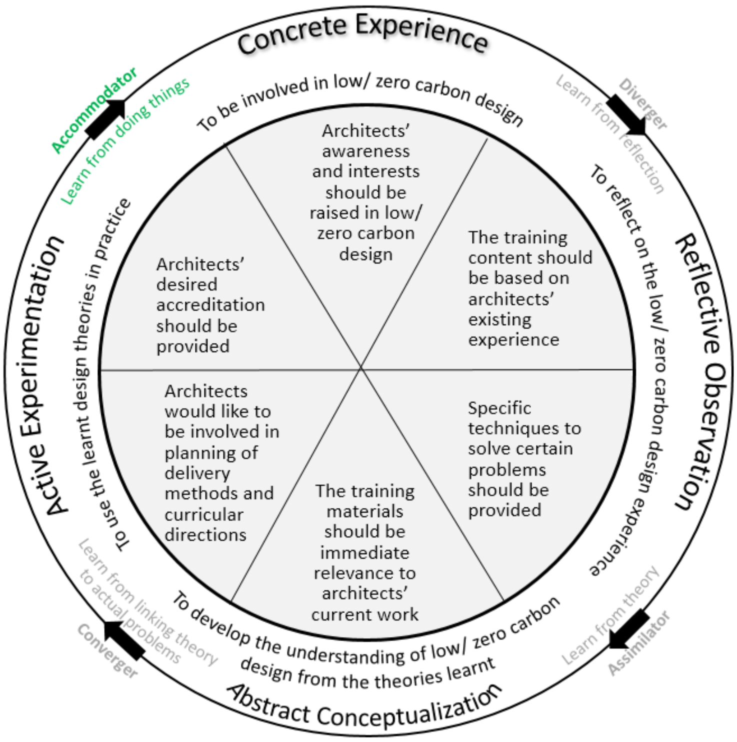
In summary, section 4.3 identifies a set of characteristics of adult learning which are assumed to be helpful to facilitate adult learning. These characteristics include:

1. Adult learners need to know why, what and how to learn
2. Adult learners need to be responsible for their decisions on education, including involvement in the planning and evaluation of their instruction
3. The experience of the learners (including error) provides the basis for learning activities
4. Adult learners are most interested in learning subjects that have immediate relevance to their work and/or personal lives
5. Adult learning is problem-centred rather than content-oriented
6. Adult learners respond better to internal versus external motivators

4.4 The initial model of architects' learning preference

The understanding of architects' learning preference is established from three perspectives, including: the architectural education, the Experiential Learning Circle and learning styles, and the characteristics of adult learning. It can be recognized that the teaching and learning process in architectural education follows the Experiential Learning Circle where learning the knowledge and using the knowledge are united. However, the training programmes for architects tend to be in the format of lectures and workshops only, and architects acquire knowledge and skills through the study of a subject without direct experience and practice. Then, the architects are expected to apply the theories and concepts learnt in the training programmes to their projects. However, the application of the knowledge and skills learnt in the training programmes to practice does not happen in most of the cases. As Eraut (1994) explained, the introducing new knowledge in contexts of normal professional practice, where work is likely to involve behavioural routines which are difficult to deconstruct and reassemble, can cause disorientation and the threat of a temporary inability to cope. Therefore, the whole Experiential Learning Circle should be applied to the low/ zero carbon design training programmes. Moreover, adult learning reflects learning preference from a different perspective and has been applied to constructing several successful model of educational practice. Therefore, the characteristics of adult learning are considered to be incorporated into the development of low/ zero carbon design training programmes.

The initial model of architects' learning preference is developed, combining the Experiential Learning Circle and learning styles, and the characteristics of adult learning (Figure 4-8).



Note: the green highlight indicates the learning style preferred by architects.

Figure 4-8: The initial model of architects' learning preference

There are two layers in the initial model of architects' learning preference. The outer layer is essentially Kolb's Experiential Learning Circle and learning styles in low/ zero carbon design training context, and the inner layer consists of the six characteristics of adult learning in the context of the low/ zero carbon design training programmes. The initial model of architects' learning preference can provide a framework for the dissemination methods of the low/ zero carbon design knowledge and skills.

Regarding the Experiential Learning Circle and learning styles (the outer layer), it presents the four stages of the learning process, including 1) participants are involved in low/ zero carbon design, 2) participants reflect on the low/ zero carbon design experience, 3) participants develop the understanding of low/ zero carbon design from the theories learnt, and 4) participants use the learnt design theories in practice. The experiential learning is an iterative process, and further reflection and experience are required for the establishment of knowledge and skills. What is more, it also indicates that most architects prefer to learn by doing things, thus a low/ zero carbon training programme should focus on the stage where the participants use the learnt design theories in practice to enable the participating architects to apply the learnt knowledge and skills to practice.

Regarding the characteristics of adult learning (the inner layer), the identified characteristics of adult learning are applied to architects in low/ zero carbon design training programmes. It indicates architects’ preference for low/ zero carbon design training programmes in relation to Knowles’ assumption of adult learning:

1. Architects need their awareness and interests in low/ zero carbon design to be raised.
2. Architects prefer to be involved in planning of methods and curricular directions.
3. Architects prefer the starting point of the training materials of the low/ zero carbon design training programmes is based on their experience.
4. Architects prefer the training materials have immediate relevance to their current work.
5. Architects prefer the training materials can provide specific techniques to solve certain problems rather than structured lectures of theoretical knowledge.
6. Architects prefer the training can provide desired accreditation.

4.5 Summary

This chapter explored the current architectural education and continuous professional development training for architects, the Experiential Learning Circle and learning styles, and the characteristics of adult learning. Learning by doing is identified as the main teaching and learning process for architectural education, while the training programmes studied for architects is identified as separating learning from doing. Also, learning by doing is recognized as the preferred learning style by most architectural students. Moreover, Kolb's Experiential Learning Circle is acknowledged to reflect the essential learning process which unites learning the knowledge and using the knowledge. What is more, six characteristics of adult learning, derived from Knowles' andragogy theory, are considered to be helpful to facilitate architects' learning in low/ zero carbon design training programmes. At last, the initial model of architects' learning preference is established, consisting of the Experiential Learning Circle and learning styles, and the characteristics of adult learning. The intent to develop the initial model of architects' learning preference is to reflect the initial understanding on how to disseminate the required knowledge and skills of low/ zero carbon design to architects in practice.

Chapter 5. Survey Research Methodology

In order to disseminate the required knowledge and skills of low/ zero carbon design to architects in architectural practices with concerns for their learning preference, a questionnaire survey is considered to be the suitable, feasible and ethical research approach in order to achieve the research aim. Issues related to carrying out questionnaire surveys are reviewed in detail.

A series of questionnaire surveys have been conducted accordingly. First, questionnaire surveys are conducted during the three case studies to gain understanding of low/ zero carbon design training programmes and to collect experience for the nationwide questionnaire survey. Then, with the lesson learnt from the questionnaire surveys carried out for the case studies, a nationwide questionnaire survey is conducted to establish the understanding of architects' requirements of low/ zero carbon design training programmes in terms of knowledge and skills as well as their learning preference.

5.1 Survey research

5.1.1 Definition of survey research

Survey research is an established research technique which can be traced back to the time of ancient Egypt, and it is a frequently applied mode of observation in social science (Babbie 2007). It is one of many different strategies used by social scientists. Other strategies include experiments, qualitative field research, unobtrusive research and evaluation research. Compared to other strategies, the characteristics of survey research include (Gomm et al. 2000):

1. Investigate a relatively large number of cases

2. Gather and analyse information about a small number of features of each case

3. Study the selected sample to maximize its representativeness in relation to some larger population

4. Quantification of data is a priority

The advantages of survey research are summarized as: being economical, the chance to sample a large population, the amount of data that can be collected and standardization of the data collected. Babbie (2007) pointed out that survey research is probably the best method available to the social researcher who is interested in collecting original data for describing a population too large to observe directly.

There are three main methods of surveys research, including 1) self-administered questionnaires, 2) personal interviews surveys, and 3 telephone surveys. A self-administered questionnaire survey is to ask respondents to read questionnaires and enter their own answers. A mail survey is the typical method used in self-administered questionnaire surveys, along with sending questionnaires to a group of respondents gathered at the same place at the same time. With the development of Internet technology, it is becoming more common to send out questionnaires to respondents and receive answers via the Internet (Babbie 2007). A personal interview survey is when interviewers are face to face with the respondents, ask the questions orally and record respondents' answers. Telephone surveys are the alternative way to conduct personal interviews since telephones have become common.

Each method has its own advantages and disadvantages in certain survey conditions. There are several factors determining which survey method is more suitable for a study, including time, cost, accessibility, convenience for the respondent, assurance of anonymity, interview bias, wording standard, securing information, flexibility, control of question order, control of environment, response date, response rate, response quality (completeness), spontaneity, and complexity of questionnaire (Babbie 2007).

5.1.2 Quality of survey research

According to Groves (1987), three factors affect the quality of a survey, namely:

1. Coverage factor: the differences between sample survey results and the results of a full enumeration of the population under study, which arises because some members of the population are not covered by the sampling frame[1].
2. Sampling factor: the differences between population characteristics and those estimated from a sample survey, which arise because some members of the population were deliberately excluded from the survey measurement through selection of a subset.

[1] A sampling frame is the list from which a sample is to be drawn in order to represent the survey population

3. Non-response factor: the differences between population characteristics and those estimated from a survey sample, which arise because some members of the sample were not measured in the survey.

Besides the above three factors, Dillman (2000) suggested the fourth cornerstone of survey precision or accuracy is the measurement error, caused by wrong answers due to the questions being misunderstood. Dillman (2000) continued that perhaps the most difficult challenge of surveying is to minimize all four types of potential survey errors. However, certain measures can be carried out to reduce the effect of these four sources of errors to an acceptable level on overall accuracy.

5.1.3 Ethical issues of survey research

Ethical issues are to be considered at the beginning of the survey design. Ethical practice is a moral stance that involves conducting research to achieve high professional standards of technical procedures based on respect and protection of the people actively consenting to be studied (Payne and Payne 2004). Payne and Payne (2004) continued that ethical issues lie in the very heart of social research rather than at the periphery. Babbie (2007) emphasized that anyone involved in social scientific research should be aware of the general agreements shared by researchers about what is proper and improper in the undertaking of scientific inquiry. A comprehensive and credible code of ethics has been issued by the American Psychological Association, while the British Psychological Society has developed its own code of ethics as well (Burns 2000). The most important ethical issues that prevail in social research are reviewed below as a guideline for this research (Babbie 2007):

1. Voluntary participation: acknowledge that participation in the research often disrupts the subject’s regular activities, thus the participation should be voluntary.

2. No harm to the participants: never injure the people being studied, regardless of whether they volunteer for the study. No information that would embarrass subjects or endanger their home lives, friendships, jobs and so forth should be revealed.

3. Anonymity and confidentiality: protect the subjects' identity. Anonymity and confidentiality can assist researchers in this regard. Anonymity is guaranteed in a research project when neither the researchers nor the readers of the findings can identify a given response with a given respondent. Confidentiality is guaranteed in a research project when the researcher can identify a given person's responses but promises not to do so publicly. In all the surveys carried out for this research, the collected data remains anonymous to protect the candidates' identity.

5.2 Self-administered questionnaire survey

The question raised is that which of available instruments of survey research this research should use. According to Fink (1995b), the most important consideration in adapting a survey instrument is whether it has the characteristics important to the study. The self-administered questionnaire survey is chosen for this research since the method meets the needs of the survey and balances cost, time and sample size. The advantages of a self-administered questionnaire survey includes cheaper and quicker administration, convenience for respondents, and absence of interviewer effects (Bryman 2004). A questionnaire can be most fruitfully used for respondents with a strong interest in the subject matter, greater education and higher social status (Goode and Hatt 1952). At the same time, weaknesses of a self-administered questionnaire survey are acknowledged. Compared to the other survey research methods, it has a higher risk of low completion rate, is less effective for complicated questions, and lacks further observation aside from the responses to the questions. What is more, self-administered questionnaires provide no second chance for errors such as ambiguous questions or missing responses to questions due to inappropriate questionnaire formats. These shortcomings can be avoided or reduced by careful survey design.

According to Babbie (2007) along with other reviewed researchers, self-administered questionnaire survey research involves three steps: 1) questionnaire construction, 2) sample selection and 3) data collection. Guidelines for conducting questionnaire surveys has been established with the three steps in order to minimize survey errors; as Burns (2000) pointed out the purpose of the research design is to minimize error and increase the likelihood that it will produce reliable results (Figure 5-1). In each step, issues required to be addressed in order to achieve the validity and reliability of a survey are identified and summarised to inform the questionnaire surveys conducted in this research.

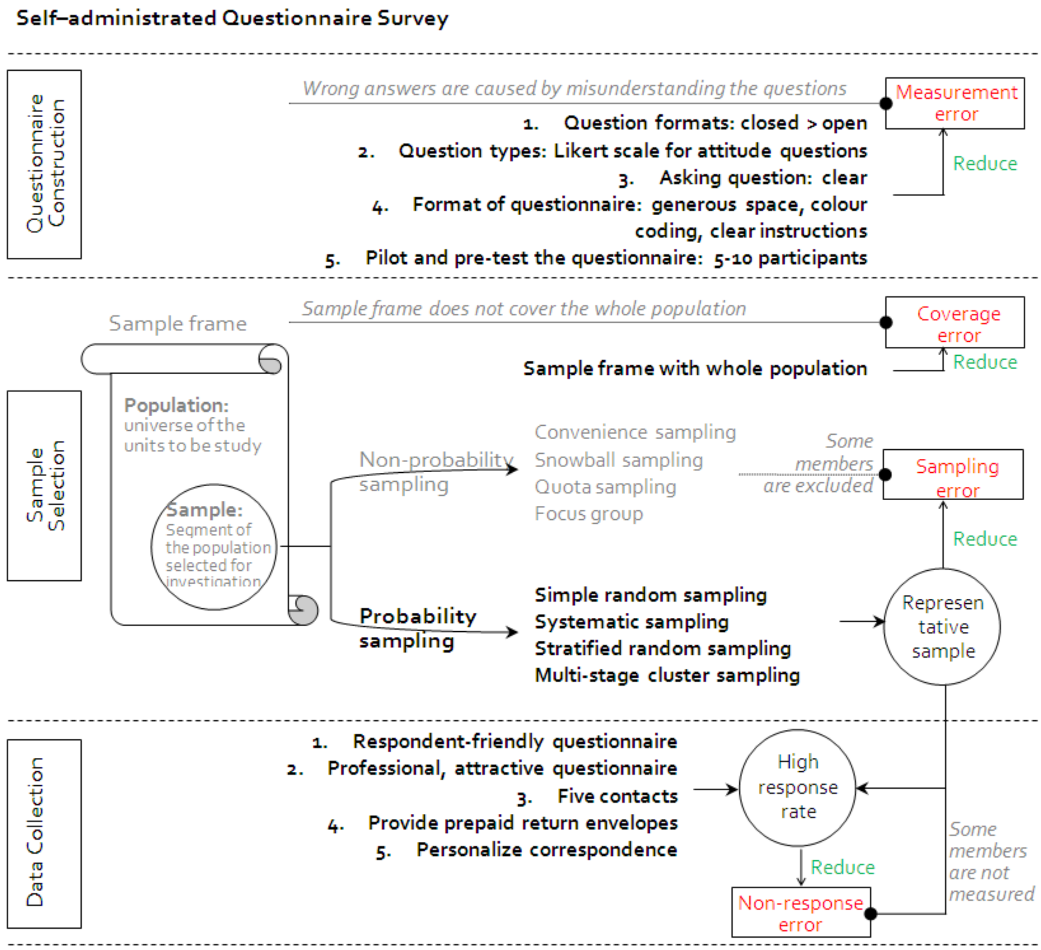


Figure 5-1: Guidelines for questionnaire survey research (Developed by the researcher)

5.2.1 Questionnaire construction

A: Question formats: open or closed questions

Open questions are questions to which the respondent can provide their own answers; while closed questions come with a set of fixed alternatives from which the respondent have to choose the answer(s) (Bryman 2004). Although both formats have advantages and disadvantages, closed questions are generally preferred in the self-administered questionnaire survey. May (2011) pointed out two advantages of closed questions, including 1) they are easier to use and be analysed relative to open questions, and 2) they permit comparability between people's answers. Bryman (2004) added that coding is a particular problem when dealing with answers to open questions. Considering the respondents, the response tasks for closed questions is easy to complete, such as check a box, circle a number or some other equally simple task rather than write answers (Fowler 2002).

B: Question types

Generally, more than one, often several types of questions are involved in a single questionnaire, including classification questions, factual questions, knowledge questions, belief questions and attitude questions. Understanding these question types helps to ask questions in an appropriate format. For example, use an appropriate attitude scale for attitude questions is essential. Bryman (2004) stated that the Likert scale is one of the most frequently used formats for measuring attitude. A Likert scale is to place peoples' answers on an attitude continuum. Statements are devised to measure a particular aspect in which the researcher is interested; the respondent is normally invited to agree strongly, agree, neither agree nor disagree, disagree or disagree strongly with these statement (May 2011). Two specific issues are pointed out to be considered by May (2011): 1) the 'error of central tendency' which is the avoidance of using the extreme ends of the scales, and 2) the ‘halo effect’ which is one attitude response impacting on the following responses.

C: Asking questions

It is important to avoid pitfalls that can result in useless or even misleading information. Issues that need extra considerations include: questions that are relevant, proper question forms, items that are clear and short, provision of a ’do not know’ answer and avoidance of double-barrelled questions which could lead to negative and biased items.

D: Format of questionnaire

The importance of the format of a questionnaire cannot be ignored as respondents can miss questions, get confused about the nature of desired data or even skip questions because of improper format. An extensive exploration of general rules and guidelines for formatting a questionnaire was carried out to provide the guidance for questionnaire surveys carried out in this research:

1. The questionnaires are spread out on pages comfortably without squeezing them into a small space.
2. There are no abbreviated questions and generous space is provided for the open ended questions.
3. Survey questions intended for only some respondents, determined by their responses to another question, are colour coded to facilitate the respondents’ task in completing the questionnaire.
4. In all the questionnaires, clear instruction to each question is provided.

E: Piloting and pre-testing the questionnaire

A pre-test of the questionnaire is essential to avoid or reduce measurement error. A pilot investigation is a small-scale trial before the main investigation intended to assess the adequacy of the survey design and the instruments to be used for data collection (Sapsford and Jupp 1996). It is desirable to carry out a pilot study before carrying out the self-administered questionnaire survey (Bryman 2004). Babbie suggested that questionnaires should be piloted with at least five candidates, while Fink (1995b) advised 10 or more people should be involved in the pilot.

What is more, the pilot should be carried out on a small set of respondents who are comparable to members of the population from which the sample of the full study is taken, rather than on the members of the study.

The questionnaire surveys conducted in this research follow these guidelines for questionnaire construction in order to effectively reduce the measurement error.

5.2.2 Sample selection

A: Select a sample

Two of the four factors which affect the quality of a survey are related to sample selection, namely: the coverage factor and the sampling factor. In order to reduce the effects of these factors and to improve the precision and accuracy of the questionnaire surveys, selection of a sample for the surveys requires extra care. The key of selecting a sample is to achieve a random sample, so the survey findings can be generalized from this representative sample to the population. Sampling methods are divided into two types: probability sampling and non-probability sampling (Fink 1995a). Table 5-1 summarizes the different strategies of sampling.

Table 5-1: Summary of sampling strategies (Fink 1995a)		
Methods	**Definitions**	**Strategies**
Probability sampling	Every member of the target population has a known, nonzero probability of being included in the sample.	***Simple random sampling***: every unit has an equal chance of selection
		Systematic sampling: every X^{th} unit on a list of eligible units is selected
		Stratified sampling: the population is grouped according to meaningful characteristics or strata, and a random sample is then selected from each subgroup
		Cluster: natural groups or clusters are sampled, with members of each selected group sub-sampled afterwards
Non-probability sampling	Samples are chosen based on judgment regarding the characteristics of the target population and the needs of the survey. By chance, the survey's findings may not be applicable to the target group at all.	***Convenience sampling***: use of a group of individuals or unit that is readily available
		Snowball sampling: previously identified members identify other members of the population
		Quota sampling: a sample is selected based on the proportions of subgroups needed to represent the proportions in the population

Probability sample stands a better chance than non-probability sample of keeping sampling error in check. But probability sample cannot eliminate sampling error.

B: Determine the sample size

The sample size mentioned in this research is the number that the researcher eventually has available to use for data analysis. The number of samples that are initially contacted in the survey is called the relative sample size.

In general, the bigger the sample the more representative it is likely to be, regardless of the size of the population from which it is drawn (Bryman 2004). However, what is a sufficient sample size in order to be able to measure differences or variability in the sample and to use these findings as estimates of the population? Researchers tend to have no direct answer. May (2011) stated that there is no simple or straightforward answer. Bryman (2004) mentioned there is no definite answer and the size depended on several considerations, including time, cost, the required precision and the heterogeneity of the population. He continued that when the sample is very heterogeneous, the larger a sample would need to be. Bouma and Atkinson (1995) replied that it is a very difficult question to answer. For practical purposes, two basic rules are provided for the sample size of student projects: 1) 30 is the minimum sample size, and 2) the sample size must be five times the number of cells in the table when tabular analysis is intended. Denscombe (2011) talked about the statistical approach to decide the sample size, which depends on four elements: 1) the size of the research population, 2) the accuracy of the estimates, 3) confidence that the sample would produce representative results, and 4) variation in the population. Sample Size Calculator is available to determine the sample size in order to obtain results reflecting the population.

C: Calculate the relative sample size

The researcher needs to predict the response rate that is likely to be achieved, and build into the relative sample size an allowance for non-responses (Denscombe 2011). Non-usable responses, which are the responses returned but cannot be used in the final dataset, should be taken into account as well.

The questionnaire surveys conducted in this research carefully follow these guidelines for sample selection in order to effectively reduce the coverage and sampling error.

5.2.3 Data collection and response rate

Response rate is the number of people participating in a survey divided by the number selected in the sample, in the form of a percentage. Response bias becomes a concern when the initial sample turns out to be of a smaller size than expected. According to Bolstein's research (1991), a smaller sample is not always a random sample of the initial sample, for example those who do not respond to a pre-election political poll are less likely to vote that those who do participate. Generally, a high response rate represents a lesser chance of significant response bias than a low rate.

So, what response rate can be regarded as sufficient to diminish the response bias for the questionnaire surveys conducted in this research? A wide range of response rates can be found in the survey literature. Babbie (2007) mentioned that a response rate of 50% is adequate, 60% is good and 70% is very good. Mangione (1995) provided the bands of response rate to postal questionnaires: over 85% is excellent, 70-85% is very good, 60-70% is acceptable, 50-60% is barely acceptable and below 50% is not acceptable. However, a lot of published research achieved much lower response rates. As Bryman (2004) suggested, it is important to recognize the implications of the possible limitations of a low response rate.

In order to obtain a high response rate, Dillman's (2000) five elements for achieving high response rate are reviewed and considered for application wherever possible:

1. Respondent-friendly questionnaire
2. Four contacts by first class mail with an additional special contact
    - A brief pre-notice letter that is sent to the respondent a few days prior to the questionnaires.
    - A questionnaire mailing that includes a detailed cover letter explaining why a response is important
    - A thank you postcard that is sent a few days to a week after the questionnaire.
    - A replacement questionnaire that is sent to non-respondents 2-4 weeks after the previous questionnaire mailing.
    - Final contact that may be made by telephone a week or so after the fourth contact.
    - Return envelopes with real first-class stamps

- Personalization of correspondence
- Token prepaid financial incentives

A general rule is concluded by Fowler (2002) which is anything that makes a mail questionnaire look more professional, more personalized or more attractive would have some positive effect on response rates.

The questionnaire surveys carried out in this research follow these guidelines to boost the response rate in order to effectively reduce the non-response error.

5.2.4 Data analysis and result

In order to conduct the data analysis, several steps need to be carried out in preparation: 1) prepare code book, 2) enter survey data, 3) deal with missing data and 4) review data set. Table 5-2 summarizes the commonly used methods of statistical analysis for surveys.

Table 5-2: Summary of methods of statistical analysis

Group	Data type	Methods		Note
Descriptive statistics	Numerical and ordinal data	Measures of central tendency	Mean	NA
			Median	NA
			Mode	NA
		Measures of spread	Range	NA
			Standard deviation	NA
			Percentile	NA
			Interquartile range	NA
	Nominal data	Proportion and percentage		NA
		Ratio and rate		NA
Correlation	Numerical data	Correlation coefficient		-1,+1
	Ordinal data (or one ordinal, one numerical)	Spearman's rho		NA
	Nominal data	Chi-square Fisher's exact test		A=0.01, crucial value is 6.635
Comparison	Nominal independent with numerical dependant	T-test		Statistical significance P value <=0.05

5.3 Summary

In summary, this chapter identified self-administered questionnaire survey to be the suitable approach to carry out the research and achieve the research aim. Guidelines for developing questionnaire surveys to reduce errors and increase reliability of the research were established. Also, commonly applied statistical analysis methods were explored to provide a foundation for handling the data.

Chapter 6. Three Case Studies

This section explores three low/ zero carbon design training programmes. For each training programme, the background information and programme design is studied first. Then, one or two questionnaire surveys are conducted for each training programme in order to understand the participants' evaluation of the programme. Also, discussions with the participants are arranged during each training programme. The focuses of the discussions are 1) how to conduct low/ zero carbon design, and 2) how to improve the training programmes. With the feedback from the discussions and the survey results, the initial model of low/ zero carbon design and the initial model of architects' learning preference are revised. The reason to validate the initial models is to make sure the initial models derived from the existing literature can reflect architects' current perspectives on low/ zero carbon design and their learning preference. What is more, the lessons learnt regarding questionnaire survey are summarized.

6.1 Introduction of the three case studies

There are three criteria to choose these case studies: 1) the case studies should reflect experiential learning process (i.e. having a practical session), 2) the case studies should disseminate the overall knowledge and skills to sustainable design instead of certain specific aspects of sustainable design, and 3) each case study should represent a different type of training programmes, such as company training, higher education, and continuous professional development. There are reasons for setting up these three criteria. First, learning by doing has been recognized architects' preferred learning style. It is importance to observe whether a practical session have an impact on the dissemination of the knowledge and skills. Second, if the training programme aims to deliver the all-around knowledge and skills of sustainable design, the responses from questionnaire surveys should reflect the overall consideration of sustainable design. Third, different types of the three training programmes can provide a broader view of the situation of sustainable design training programmes.

Table 6-1 shows the three case studies chosen for this study.

Table 6-1: Background information of the three case studies

Cases	Organizations	Audience background	Categories
'Enable Sustainability—Raising Awareness' programme (ESRA)	Atkins, Cardiff University, and the British University in Dubai	Members in design team	Company internal staff training
Sustainable Design Masters Programmes (SCM)	The Welsh School of Architecture (WSA)	Various backgrounds, mainly architects and engineers	Higher education
Pilot of Environmental Professional Development (EPD)	The Royal Society of Architects in Wales (RSAW)	Architects	Continuous Professional Development

The ‘Enable Sustainability—Raising Awareness’ programme (ESRA) was selected since it covered the overall knowledge and approaches to sustainable design, and it had planned a competition of a sustainable design with knowledge and skills learnt from the lectures at the end of the programme. It had been realized that the ESRA was developed for the participants in the UK as well as the participants from other countries. This can provide an indication on how different locations can have an impact on the requirements for low/ zero carbon design training programmes. This research aimed to provide some understanding on the architects’ requirements for low/ zero carbon design training programmes in England and Wales. However, reduction of carbon emissions in the building industry is a global issue, and to what extent the understanding can be generalized to architects from different countries should be acknowledged.

The Sustainable Design Masters Programme (SDM) was chosen because it was delivery the overall knowledge and skills, and using the design studio based approach. Learning by doing was the essence of the course development: students learning design theories and concepts in core modules, and applying them in project modules.

The Pilot of Environmental Professional Development (EPD) was selected because it aimed to develop an overall package of sustainable design for architects in Wales, which was the same as the training programmes to be explored in this research. And participating architects were expected to take an exam in relation to the knowledge and skills they learnt from the course.

One of the limitations of the case studies was that only one case ‘the Pilot of Environmental Professional Development (EPD)’ being developed for architects’ training in the UK, which is the same as the training programmes aimed to be explored in this research. However, due to the time limitation (to find more training programmes delivering overall knowledge and skills of sustainable design with a practical session), it was decided to carry out more detailed case study rather than study more cases. And the Pilot of Environmental Professional Development was an exemplary case to study since the reason for the programmes was to investigate how to develop a CPD programmes specializing in sustainability for architects. The participating architects made more time and efforts to provide feedback as well.

The other limitation of the case studies was that the small size of sample population (23, 43 and 12 for the three case studies respectively) for the questionnaire surveys conducted for the case studies. This might reduce the generality of the survey results.

6.2 Case study 1: ‘Enable Sustainability—Raising Awareness’ programme for Atkins by Cardiff University and the British University in Dubai

6.2.1 Background information

Atkins has expertise to respond to technically challenging and time-critical infrastructure projects and the urgent transition to a low-carbon economy, such as the concept for a new skyscraper, the upgrade of a rail network, and the modelling of a flood defence system (Atkins, 2007). With increasing attention on sustainability, the CEO of Atkins believes sustainable design in the construction industry is the way forward and sustainability is an invaluable tool for exploring ways to reduce costs, manage risks and drive fundamental internal changes in culture, structure and quality of life.

In order to make the designers in Atkins conscious of sustainable issues and capable to achieve sustainability in their projects, Atkins invited Cardiff University in association with the British University in Dubai (BUiD) to deliver a programme to raise awareness of sustainable design, named ‘Enable Sustainability— Raising Awareness’ (ESRA), for the key designers from Akins in the Middle East, UK, Republic of Ireland and China in 2007.

6.2.2 Programme design

The main aim of the ESRA programme was to raise the designers’ awareness of sustainable design and deliver the required knowledge and techniques of sustainable design to the designers.

Three modules at different levels with different focuses were designed for ESRA (Figure 6-1). Module one aimed to raise designers’ general awareness and try to convince designers and help designers to convince their clients about the necessity of sustainable design. Module two was developed to introduce the specific strategies and technologies of sustainable design to the designers. Module three was intended to be a practical session to actually help the participants to apply theories of sustainable design to practice. It took the form of a competition. The task for participants was to apply sustainable design strategies that they learnt from ESRA programme to a chosen on-going project. Each module was developed to be a one day course. Considering designers' busy schedule, it was decided that three modules would be delivered separately rather than over three continuous days.

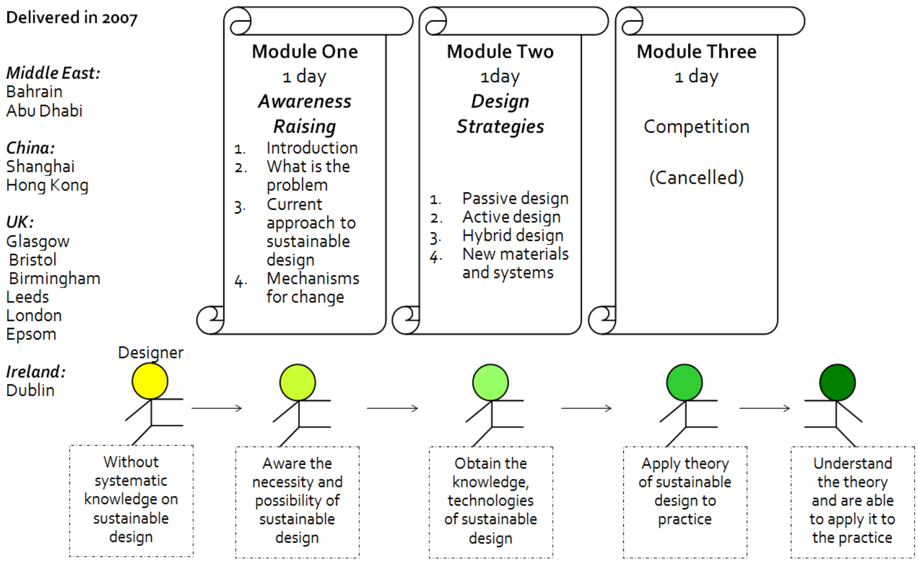


Figure 6-1: ESRA programme design (Developed by the researcher)

Interactive lectures were considered to be the appropriate method to disseminate the knowledge. The programme was designed to encourage the designers' involvement. Discussion questions were carefully designed and raised during the lectures to challenge participants' critical thinking. Each group had a maximum of 20 staff to make sure the functionality of the group. A handout was prepared as a reference book and a notebook for the participants. It contained all the information presented in lectures in more detail. Hard copies were distributed to the participants during the event; and a digital copy was available to all the Atkins staff on the online database. Figure 6-2 captured the delivery of the ESRA programme.

Figure 6-2: Delivery of ESRA programme (Photos taken by the researcher)

6.2.3 Questionnaire survey and feedback

A. Questionnaire survey to evaluate the ESRA programme:

A questionnaire survey was developed as an integrated part of the ESRA programme. The purpose of this questionnaire survey was to collect feedback from the participating designers to evaluate the modules developed for Atkins.

Step 1: Questionnaire construction

The questionnaire comprised three main parts:

1. Information about the delegates: delegate's own experience in design and sustainable design
2. Delegates' evaluation of the ESRA programme: 20 single-choice questions asking the delegates to assess the organization, content, materials of the programme and whether the programme was enjoyable and helpful for their work

3. General comments: two open-ended questions to collect participants' relevant comments, 1) information that was missed by the programme, and 2) any other suggestions

In order to avoid tiring out the participants with paper work, the questionnaire was piloted with PhD students to make sure that no more than 15 minutes was required to complete the questionnaire.

Step 2: Sample selection

The population of the survey was all the participants in the ESRA programme. All the units in the population were selected as samples.

Step 3: Data collection

Questionnaires were distributed to the participants by Atkins after the delivery of both modules. There were two reasons to ask Atkins to send out the questionnaires after two modules:

1. Some of the participants could not manage to attend both of the modules, which was noticed during the delivery of module two. In order to make sure the questionnaires reach every participant, the distribution plan was changed to send out the questionnaires after the event by email rather than send out the questionnaires in hard copies after module two.
2. Atkins had the authority and convenience to contact all the participants and collect the questionnaires.

Just the branches in Shanghai (China) and Dubai (Middle East) managed to collect the questionnaires from their participants. There were 15 questionnaires out of 23 participants collected from Shanghai, and 12 questionnaires out of 20 participants collected from Dubai. One questionnaire from Shanghai and three questionnaires from Dubai were not completed. Therefore, the return rate was 53.5% [(14+9) ÷ 43] if the participants from other areas were not taken into account. It has been noted that indirect distribution and collection might influence the response rate. Also, that the participants were from Shanghai and Dubai rather than England and Wales were acknowledged.

A completed questionnaire can be found in Appendix II. Figure 6-3 shows the distribution of the participants' field of work

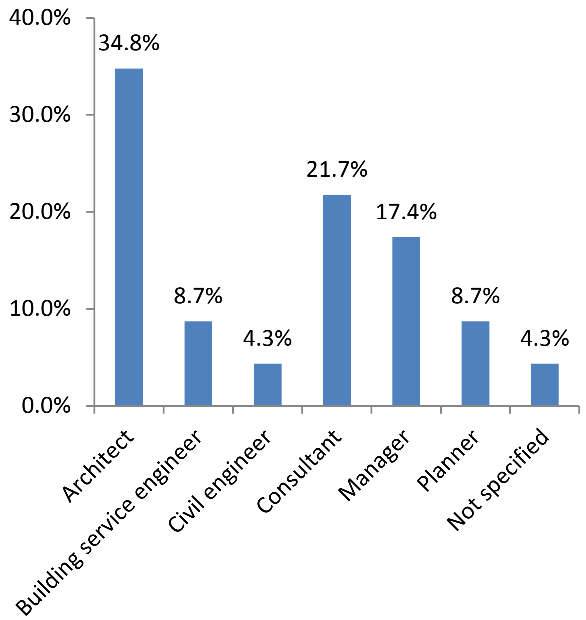
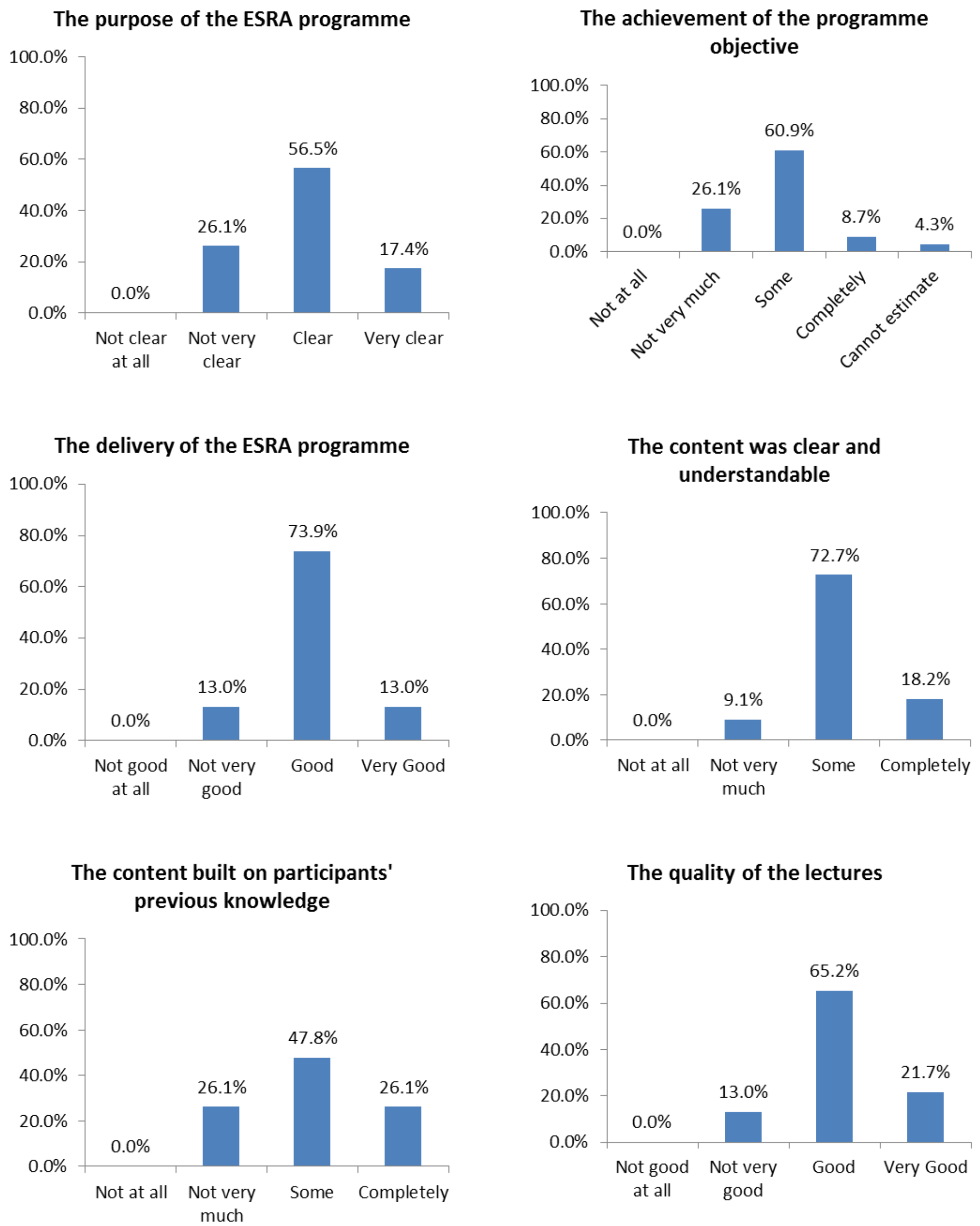


Figure 6-3: The distribution of the participants' field of work

Step 4: Analysis and result

Statistical analysis was conducted on the 23 questionnaires collected from Shanghai and Dubai by Atkins. The analysis results are summarized below:

1. Most of the results from evaluating specific aspects of the ESRA programme indicated participants were positive about the programme (Figure 6-4). For example, the majority of the participants agreed that the purpose of the ESRA programme was clear and achieved well, the programme was delivered well, the content was clear, understandable and built on their existing knowledge, the lectures and the handouts were clear and informative, and the programme improved understanding of sustainable design, provided information resource and stimulated further interest.



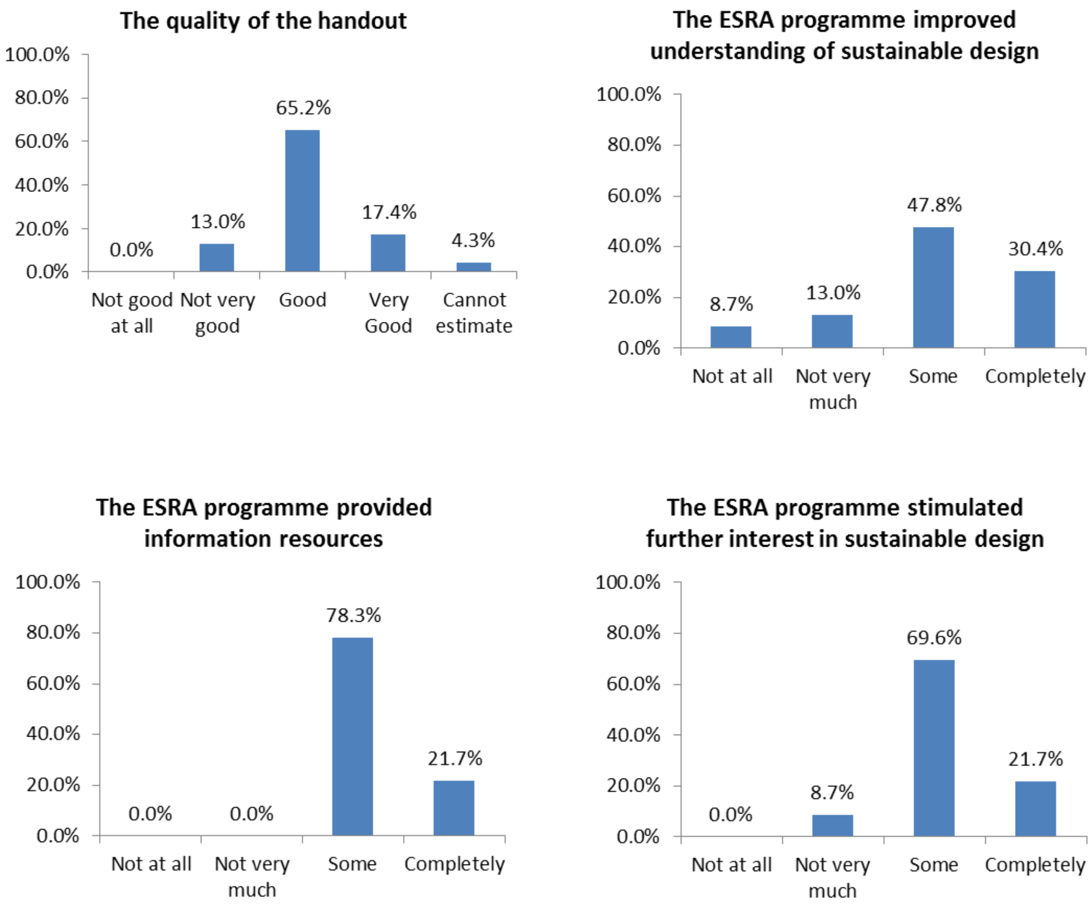


Figure 6-4: Graphs of analysis point 1

2. However, some aspects were evaluated less positive (Figure 6-5): only 47.8% (= 43.5% + 4.3%) of participants agreed that the areas covered in this programme matched their expectation, 54.6% (= 45.5% + 9.1%) of participants agreed that the ESRA programme facilitated the decision-making process, and 45.4% (= 31.8% + 13.6%) of participants answered that the ESRA programme improved their practical skills in sustainable design. 34.7% (= 4.3% + 30.4%) of the participants thought the time allocated to each module was not reasonable.

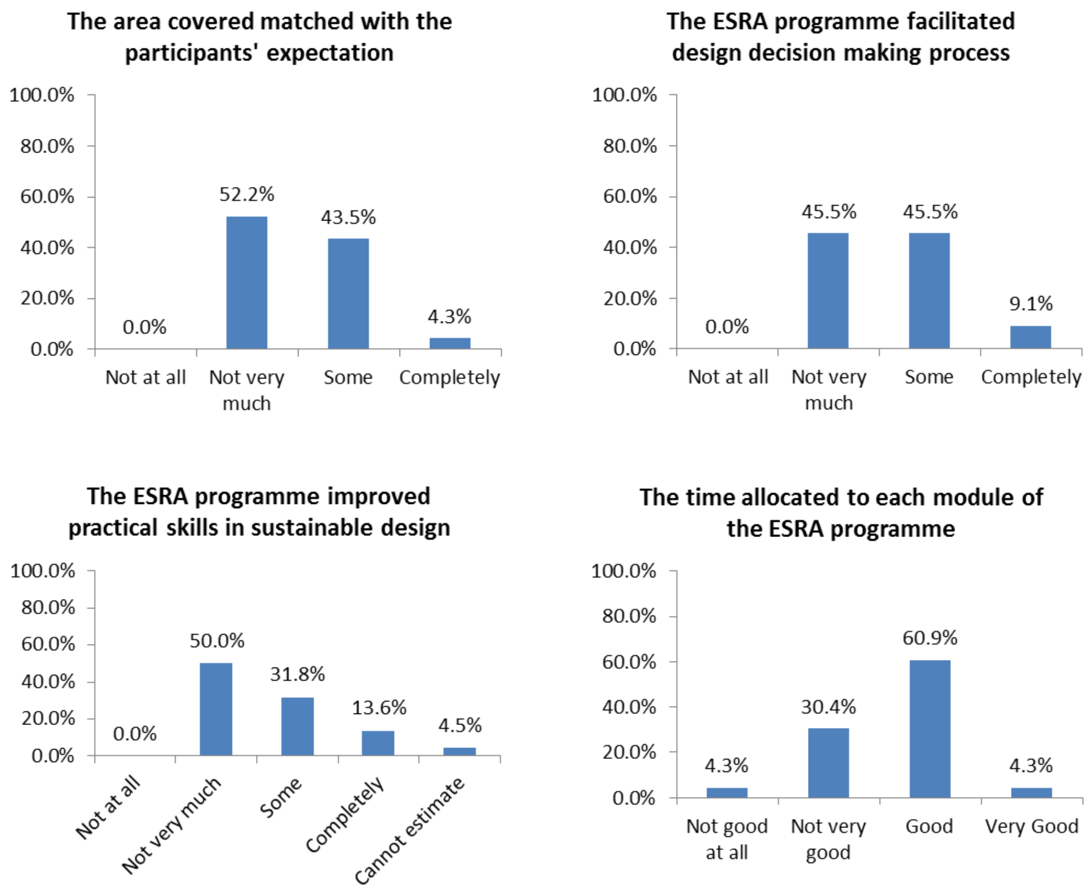


Figure 6-5: Graphs of analysis point 2

3. The participants were considered to be satisfied with ESRA programme (Figure 6-6): All the participants thought the programme was necessary and 82.6% (= 73.9% + 8.7%) of them enjoyed the programme.

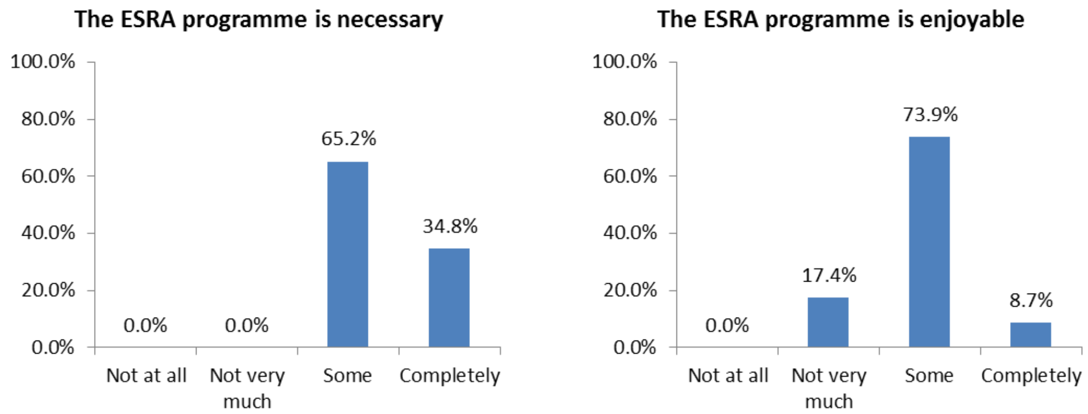


Figure 6-6: Graphs of analysis point 3

4. The majority of the participants indicated they did not consider sustainable design in their work before taking the ESRA programme (Figure 6-7). 39.1% (= 34.8% + 4.3%) of the participants took sustainable design into account in their projects to a certain degree.

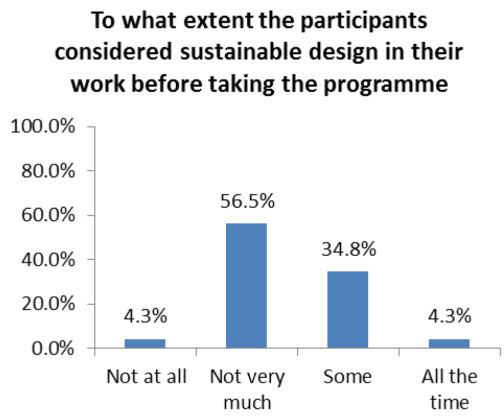


Figure 6-7: Graphs of analysis point 4

5. The participants considered 'lack of knowledge', 'lack of skills and techniques', and 'a tight budget' as the main barriers for sustainable design (Figure 6-8). And 'time limitation' was also a problem.

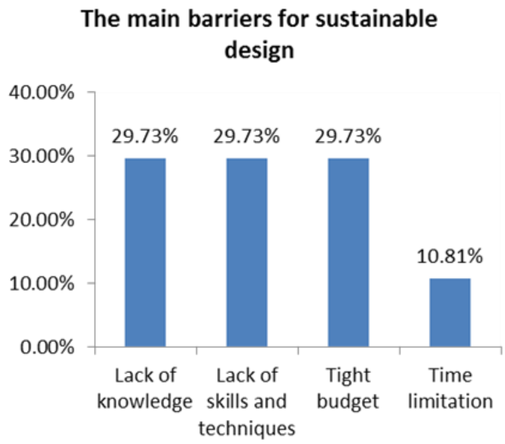


Figure 6-8: Graphs of analysis point 5

6. ESRA programme was developed without consideration of the potential differences among the audience from different branches of ATKINS in different location. However, the teaching experiences were quite different in these two areas due to different cultural backgrounds, different working experiences and environments. The Participants' responses from Dubai were more positive than responses from Shanghai. What is more, the different focuses on sustainable design were quite obvious, e.g. water conservation attracted more attention in Dubai than in Shanghai. More detailed data can be found in Appendix III. Therefore, it is of importance to consider differences in audience when developing training programmes, including the meaning of low/ zero carbon design, the main concerns regarding the low/ zero carbon agenda, as well as the differences of culture and working experience.

B. Observation:

During the delivery of the first two modules, the participants actively involved themselves in the courses. Several issues were realized:

- The participants acknowledged the issues related to sustainable design included environmental, social and economic aspects.
- The designers agreed built environment affected the global issues regarding depletion of resources, generation of pollution and health and lifestyle degradation.
- They understood sustainable design was to balance the input and output consequences.
- They felt excited and thought sustainable design was an opportunity to gain a competitive advantage.
- The participants suggested in their future work they should identify government existing policies/ approaches to sustainable design, increase awareness by intercompany communication, highlight the benefits of sustainable design to clients, and carry out further research based on the implementations learnt from the ESRA programme.
- The designers believed that the design team should set out firmer and harder targets (maybe develop an Atkins green standard or a sustainability assessment tool), develop more tangible procurement guidelines, and team-up with environmental engineers, and consultants to achieve sustainability in their projects.

6.3 Case study 2: MSc Course in Sustainable Design in the Welsh School of Architecture

6.3.1 Background information

The Welsh School of Architecture offers master's taught programmes in advanced practice to candidates with architectural backgrounds or non-architectural backgrounds. Four MSc programmes provide practitioners a range of perspectives to choose from: 1) Theory and Practice of Sustainable Design, which provides an array of practical tools for implementation and guides students in applying their knowledge to a live project, 2) Environmental Design of Buildings, which provides the skills and knowledge required by building design teams to create comfortable physical environments in and around buildings that are healthy, sustainable and energy-conscious, 3) Building Energy and Environmental Performance Modelling, which focuses on the use of computer software for studying diverse aspects of building and urban design, including lighting, thermal simulation, air flow, carbon-dioxide emission and life-cycle analysis, and 4) Sustainable Mega-Buildings, which focuses on principles of sustainable planning and design of mega-buildings (WSA 2014).

6.3.2 Programme Design

The programme is a full year taught course for full time students or two years for part time students. The programme is designed to support students' reflection on their learning, provide opportunities for students to articulate their values and their personal standpoint on sustainability, and encourage the students' understanding of both the principles and the application of its subject (WSA 2014).

The taught content is delivered in a set of separately-assessed core modules using a variety of media, including lectures, seminars, workshops and course work, to disseminate the related knowledge and help students to develop their understanding of the concepts and theories. The core modules include Low Carbon Footprint, Earth and

Society, Site and Environment, Outside Inside, Building Fabric, Passive Design and Efficient Services.

Project work is pursued in specialist modules that run parallel to the core models, and the project work gives students opportunities to apply what they have learned in a live situation or excises which are similar to real problems. Project work is an important component of the programme, which is intended to focus on practicalities and establish the necessary working skills for the students (WSA 2014).

The final module is a research dissertation, and the students carry out an investigation of a research question that interests them under supervision (WSA 2014). The dissertation will help the students to develop their capacity for independent study and their ability to make contributions to the existing body of knowledge.

6.3.3 Questionnaire survey

This survey research was designed to identify why the candidates chose to take the master's course in sustainable design and what they expected from the course. This survey research was approved by the Research Ethics Committee of the Welsh School of Architecture on the 26th November 2010 (EC1011.051). The questionnaire can be found in IV.

Step 1: Questionnaire construction

This questionnaire comprised 27 questions, covering three main topics:

1. About the candidates' background: (11 questions)

   The aim of this section was to identify who the candidates were. There were two levels: 1) about general issues, including their gender, age group, previous education level and subject, and work experience, and 2) about academic issues, including their preferred learning style, the components of sustainable design that they were interested in, and their expected career in the future.

2. About the master's course: (six questions)

This section was designed to investigate why the candidates took the course and what they were expecting. Specific questions were designed to collect distance learners' opinion on the advantages and disadvantages of e-learning.

3. About sustainable design: (nine questions)

The aim of this section was to explore the candidates' opinion, understanding and their previous experience regarding sustainable design. Two questions were designed to investigate candidates' understanding of sustainable design. Question 20 presented five definitions to ask the candidates to pick the one most close to their understanding of sustainable design in the building industry. Except the definition for sustainable design, the other definitions presented included passive design, environmental design, zero carbon design and design with renewable energy. Question 21 presented a matrix to ask the candidates to suggest which professions (including architects, planners, engineers, building physicists, contractors and others) should be responsible for each component of sustainable design (including site layout and ecology, passive design, building fabric and insulation, efficient heating, lighting and ventilation strategies, use of water efficiently, use of sustainable and recycled materials, energy management, use of renewable energy, and waste minimization and management on site).

4. One open ended question was provided to ask the candidates to give any comments, suggestions or requirements about their master's course in sustainable design.

5. The questionnaire was piloted with five PhD students to make sure all the questions were clear and easy to understand without ambiguity.

Step 2: Sample selection

The study population of this survey research was all the students in the master's course in the Welsh School of Architecture in 2010/2011. In total, there were 83 master's students, including 60 local full-time students and 23 distance learners.

Step 3: Data collection

The questionnaire survey was carried out on the 14th December 2010. For the local master's students, the questionnaires were distributed to the students by the researcher following a briefing about the aim of the research before their lecture, and the questionnaires were collected at the end of the lecture. 46 questionnaires were sent out, while 40 were returned. For distance learners, group emails with the questionnaire attached were sent out with the help of the tutor of master's course. Three questionnaires were completed and returned. At a satisfactory response rate of 62.23% [(40+3) ÷ (46+23)], the analysis was conducted.

Step 4: Analysis and result

Frequency analysis was conducted for all the questions (Figure 6-9). Out of the 43 research subjects, there were 46.5% females and 53.5% males. 81.4% of the participants were in the age group of 'from 20 to 29'. 60.5% of them had a bachelor's degree, while 39.5% had a master's degree. 90.7% of the candidates had experience in built environment, while 9.3% did not. Among the candidates, 53.5% of them had an architectural background, 20.9% had an engineering background, while the others were planners, architectural technicians, and physicists.

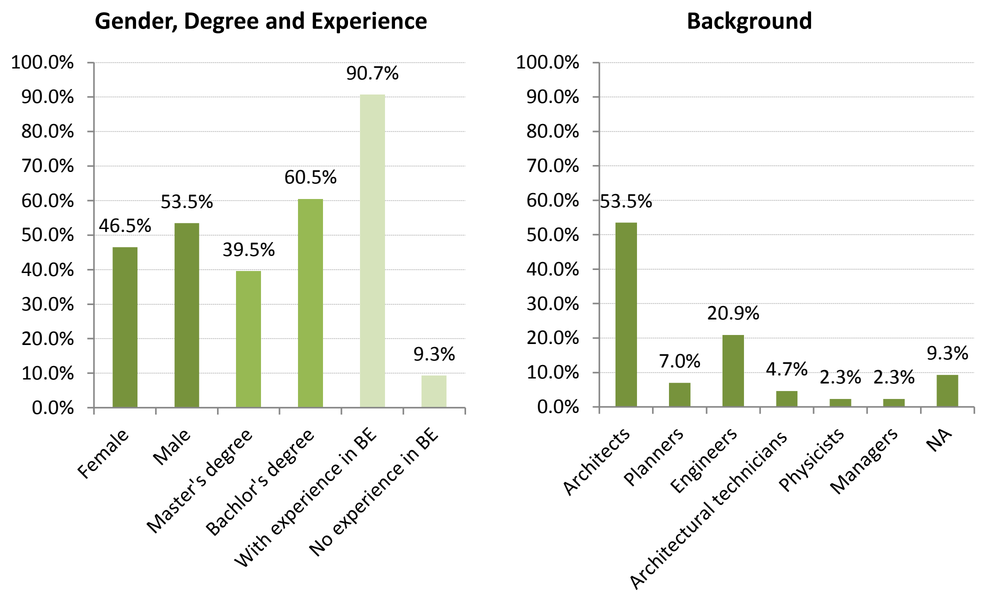


Figure 6-9: Sample condition

The summary of the analysis results suggested:

1. The overall response to the importance of sustainable design was positive (Figure 6-10). Since the candidates chose to carry out study in this field, it was an obvious answer.

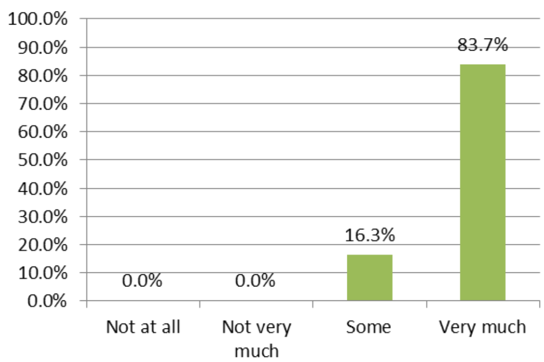


Figure 6-10: The candidates' evaluation of the importance of sustainable design in the building industry nowadays

2. 79% (= 67.4% + 11.6%) of the candidates suggested they were familiar with the theory and strategies of sustainable design (Figure 6-11).

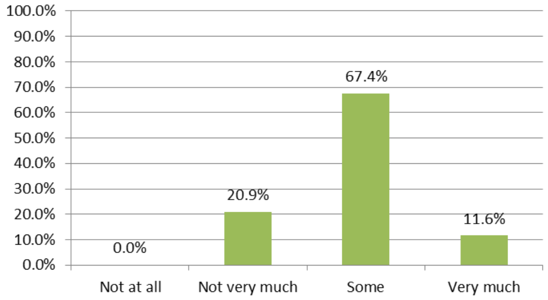


Figure 6-11: To what extent were the candidates familiar with sustainable theories and strategies

3. 67.5% (= 51.2% + 16.3%) of the candidates indicated that they learnt sustainable design in relation to the building industry previously (Figure 6-12). And the main source to learn about it was from previous education (55.3%) (Figure 6-13).

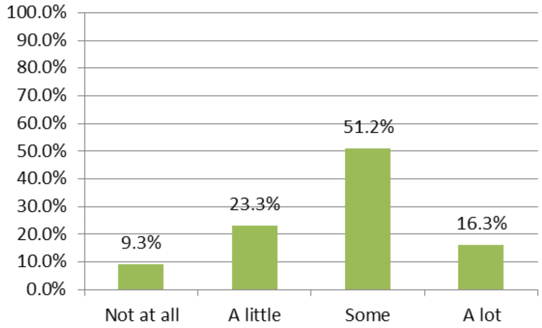


Figure 6-12: Did the candidates ever learn about sustainable design previously

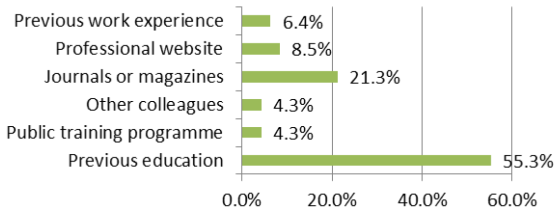


Figure 6-13: The source for the candidates to learn about sustainable design previously

4. 54.8% (= 28.6% + 26.2%) of the candidates indicated that they had not applied sustainable design or had applied it a little to their previous work (Figure 6-14).

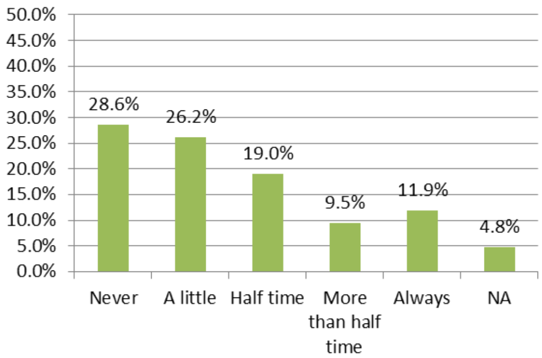


Figure 6-14: Had the candidates ever applied sustainable design to practice

5. Within the candidates who had applied sustainable design in their work, less than half (40% = 36.7% + 3.3%) of them thought that they were confident (Figure 6-15). In general, the candidates suggested that their ability to deliver sustainable design needed to be improved.

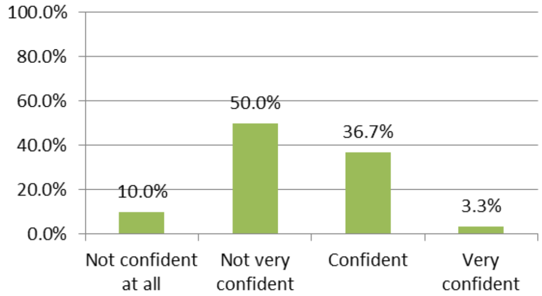


Figure 6-15: How confident did the candidates feel to implement sustainable design in their projects previously

6. The opinions on architects' responsibilities to sustainable design were not unified. Passive design, use of sustainable and recycled materials, efficient building services, building fabric and insulations, and site layout and ecology were recognized as architects' responsibilities (Figure 6-16).

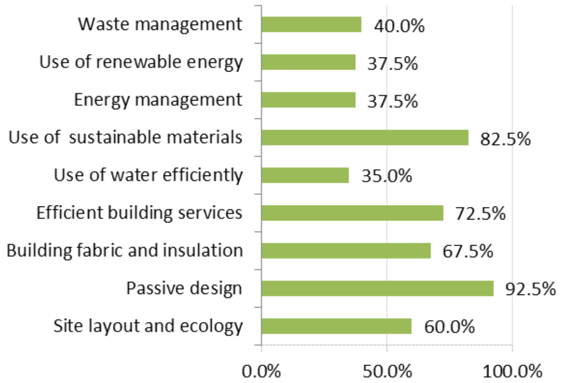


Figure 6-16: Recognized architects' responsibility for the components of sustainable design by the candidates

7. For most of the candidates, taking the master's course in sustainable design was an active choice to the development of sustainable design in the construction industry (Figure 6-17).

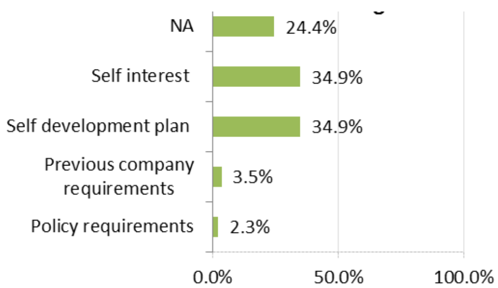


Figure 6-17: The reason why the candidates chose to learn about sustainable design

8. When asked why the candidates chose to enrol a master's course rather than to take other forms of training, the candidates indicated the advantages of master's courses included 1) it helps to change the career direction to sustainable design, 2) it provides the opportunity to learn the knowledge, to apply new knowledge and reflect upon it, and 3) it provides more detailed knowledge in a specific area of sustainable design (Figure 6-18).

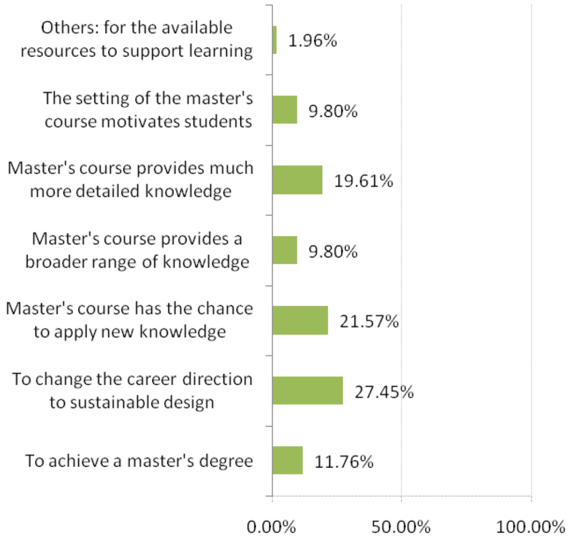


Figure 6-18: Why did candidates choose to take a master's course rather than to take continuing professional development training programmes

9. In terms of learning styles, learn from relating techniques directly to solving problems (47.7%) or learn from experience(43.2%) were preferred (Figure 6-19).

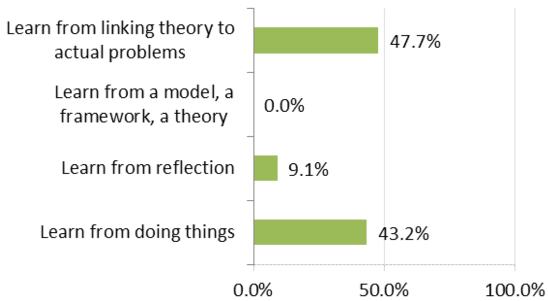


Figure 6-19: Candidates' preferred learning styles

6.4 Case study 3: Environmental Professional Development (EPD) Pilot for Architects in Wales by the Royal Society of Architects in Wales

6.4.1 Background information

As part of the drive to place architects at the heart of the sustainability agenda, the Royal Society of Architects in Wales (RSAW) created a new scheme called Environmental Professional Development (EPD). It provided a framework to encourage architects to acquire expertise in sustainable design principles and maintain a high level of environmental understanding. To enter the EPD scheme, individual architects were required to have their understanding of sustainability assessed: RSAW teamed up with the University of Wales Institute, Cardiff (UWIC) to create an externally audited assessment. The assessment was intended to cover the principles of sustainable development as set out in the published syllabus. Passing this external assessment would be a requirement for entry into the EPD scheme. It provided a demonstrable level of competence for all those participating, as well as a robust justification of their member's skills and commitment to the low carbon agenda.

From the 15th of April to the 6th of May 2010, a four-session pilot was launched. 12 architects volunteered to take part in the development of the EPD programme.

6.4.2 Programme design

The scheme was an enhanced form of Continued Professional Development based around a core curriculum of sustainable issues. The RSAW collaborated with the Building Research Establishment (Wales) to create a comprehensive series of training modules. These training courses would be available across Wales either in a comprehensive sequence or as a 'pick and mix' selection.

The EPD pilot was delivered in 4 consecutive Thursdays (starting 15/04/2010) from 8:30 to 16:30 in Swansea. LLYS GLAS was chosen as the venue which was five minute walk from the train station in order to encourage the participants to use public transportation to reduce their carbon footprint. The programme was held in the form of lecture: a presenter standing in the front while the audience sitting in rows. PowerPoint presentations with compact information were delivered.

The 20 modules produced for the EPD pilot included (Table 6-2):

Table 6-2: The EPD pilot modules

Modules	Topics
1. Background Information	· What is sustainability · Climate change · Sustainable architects · What is the RIBA view · The role of architects
2. Production of Energy	· UK energy source · Energy use trends · Impacts of energy use
3. Renewable Energy	· Source · Applicability · Security of supply · Problem
4. Life Cycle Assessment	· What is LCA · External costs · Embodied impacts · Operational impacts
5. Collaborative Working	· Sustainable design schemes · Working methods
6. Basic Sustainable Design Elements	· Thermal comfort · Elementary measures · Insulation · Air tightness
7. Advanced Sustainable Design Elements	· Heat flows · Thermal bridges · Windows · Thermal mass
8. Zero Carbon	· What is zero carbon · How does it fit in with sustainability generally · Allowable solutions · Renewable energy zero carbon solutions
9. Carbon Offsetting	· The carbon cycle · Carbon cycle rebalancing · Carbon capture & sequestration
10. Very Low Impact Design	· Traditional materials · Low impact materials · Future trends
11. Passive houses and Passivhaus	· What is Passivhaus · What is passive solar · Differences & similarities · Design issues and perspective

12. Water and Sewage	· Why water use is important · Virtual water · Water and CSH · Grey water and rainwater · SUDS
13. On Site and Waste Issues	· Architects and waste · Waste hierarchy · Dematerialisation · Zero waste · SWMP
14. Post Occupancy	· Handover · Factors in POE · Why it is useful · How to carry out POE
15. Code for Sustainable Homes	· What is the Code for Sustainable Homes · What are the credits · How to achieve the rating
16. Refurbishment	· New build or refurbish · Refurbishment techniques · Tools available · Case study
17. Green Guide	· What is the green guide · How does it work · Some examples · Strengths & weakness
18. BREEAM	· What is BREEAM · What are the credits · How to achieve BREEAM
19. SAP and Building Modelling	· What is SAP · How do you use it · Types of model · Examples
20. Planning Issues	· TAN22 · MIPPS · Local issues

6.4.3 Questionnaire survey and feedback

The aim of the questionnaire survey was to explore five topics: 1) participants' understanding of sustainable design, 2) participants' current application of sustainable design, 3) participants' opinion on existing sustainable design training programmes, 4) the participants' requirements for new sustainable design training programmes, and 5) their evaluation of the EPD pilot.

Two sets of questionnaires were designed, one was sent out before the pilot event, and the other was sent out after the pilot. The reason for the two sets of questionnaire was twofold:

1. Distribution of the five topics on two questionnaires could reduce the number of questions on each questionnaire
2. The questions about participants' requirements for new sustainable design training programmes were included in both sets of the questionnaires. With the fresh real-time experience of the sustainable design training programme, the participants may change their reply to certain aspects of their requirements. Also certain answers could be double checked.

This first questionnaire and the second questionnaire were approved by the Research Ethics Committee of the Welsh School of Architecture, and the reference numbers are EC1004.031 and EC1005.033 respectively. Two sets of questionnaires can be found in Appendix Va and Vb.

Step 1: Questionnaire construction

Table 6-3 demonstrates the structure of both sets of the questionnaire.

Table 6-3: Structure of questionnaires

	Topics	**Questions**
Questionnaire 1 (36 questions)	The participants' understanding of sustainable design in architecture	• Definition of sustainable design • How confident to implement sustainable design in projects • Available information of sustainable design, and their quality • The main sources to obtain the information and knowledge of sustainable design, and the preferred ones
Questionnaire 1 (36 questions)	The participants' current application of sustainable design	• Applied sustainable design strategies before • How often have they applied sustainable design strategies • The main reasons to apply • The main barriers to apply • The importance of applying sustainable design strategies
Questionnaire 1 (36 questions)	The participants' opinion on existing sustainable design training programmes	• Frequency they have attended architectural design training programmes and sustainable design training programmes • The most important reasons to attend sustainable design training programmes • The expectation from the programmes • The satisfaction with previous programmes • Frequency they have applied the knowledge delivered from previous programmes • The most liked and disliked factors of previous sustainable design training programmes • Any improvement
Questionnaire 1 (36 questions) / Questionnaire 2 (18 questions)	The participants' requirements for new sustainable design training programmes	Including: information, type, presenter, fee, venue, length , time and material
Questionnaire 2 (18 questions)	The participants' attitudes towards specific aspects of the EPD pilot?	Including: organization, aim, expectation, content, delivery method, presenter, course material, time, venue etc.

Step 2: Sample selection

All the 12 participating architects were the survey population. The limitation of generality of the result was considered. The main objective of this case study was not to draw a conclusion from a statistical result, but to collect experience in survey research as well as to verify two initial models.

Step 3: Data collection

Both sets of the questionnaires were distributed by the researcher during the EPD pilot.

1. Following a briefing, the first set of questionnaires was sent out during the first session of EPD Pilot on 15/04/2010 and 12 completed questionnaires were collected at the end of the session.
2. The second questionnaires were sent out during the final session on 06/05/2010. 11 questionnaires were collected after the programme and one questionnaire was received by post on 20/05/2010.

Step 4: Analysis and result

The summary of the analysis result in each of the five topics is presented:

- Participants' understanding of sustainable design in architecture
  1) All of the participants agreed that sustainable design was important.
  2) Most of the participants (58.4% = 41.7% + 16.7%) indicated that there was sufficient information on sustainable design available, and 58.3% (= 50% + 8.3%) of the participants agreed that the quality was good. (Figure 6-20, 6-21).

3) The main sources for the participants to obtain information and knowledge were internet browsing, books/ journals and training programmes. Compared to other sources, training programmes was preferred (Figure 6-22).

4) 66.7% (= 50% + 16.7%) of the participants felt confident to implement sustainable design to their projects (Figure 6-23).

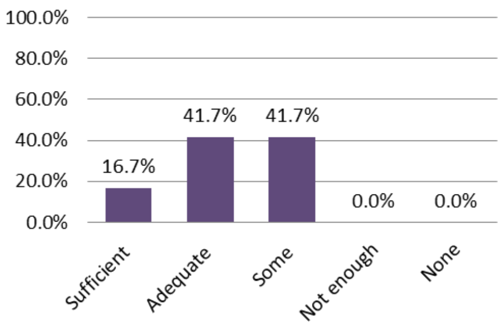


Figure 6-20: How much information on sustainable design did the participants feel was available to them?

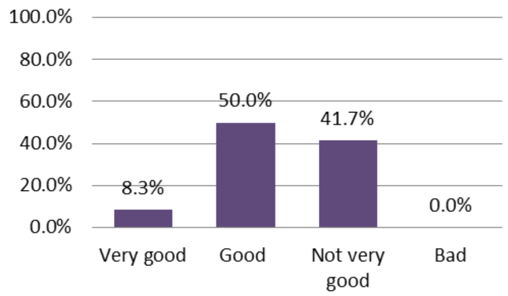


Figure 6-21: The quality of the available information on sustainable design

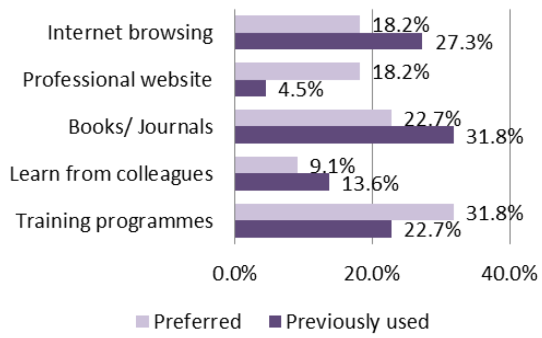


Figure 6-22: The main sources for participants to obtain information and knowledge of sustainable design

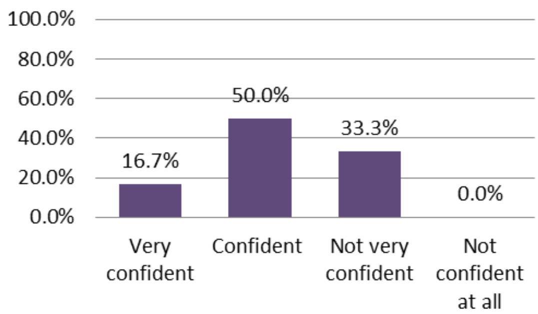


Figure 6-23: How confident did the participants feel to implement sustainable design in their projects?

- The participants' current application of sustainable design (Figures 6-24to 6-27)

1) 75% of the participants applied sustainable design to projects. But the frequency varied, 44.4% of the participants only applied to less than half of their projects.

2) The main driver for sustainable design was either clients' requirements or regulation requirements.

3) The main barriers to apply sustainable design were lack of clients' support and tight budget.

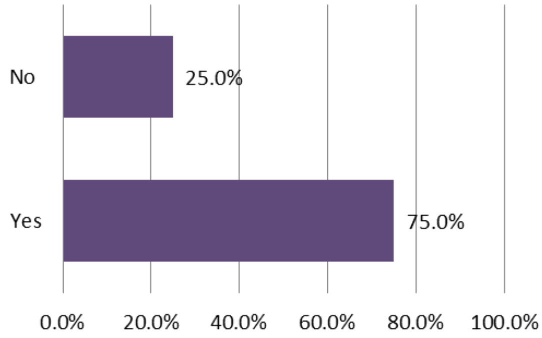


Figure 6-24: Did the participant apply sustainable design strategies to his/her project before?

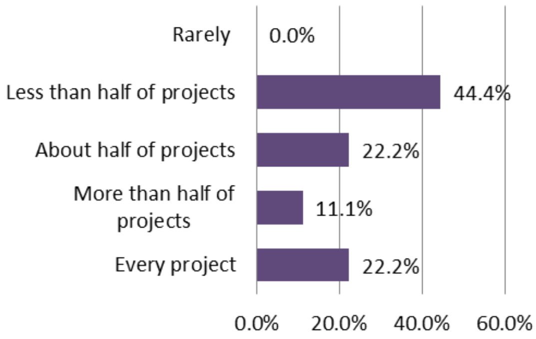


Figure 6-25: How often had the participants applied sustainable design strategies to his/her project over the past five years?

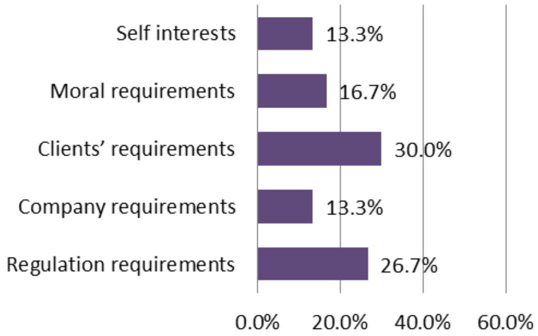


Figure 6-26: The drivers for the participants to apply sustainable design to their projects

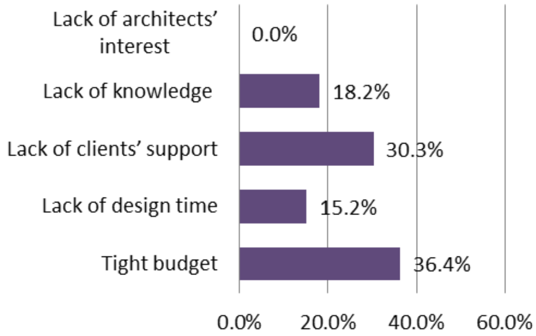


Figure 6-27: The barriers to stop participants applying sustainable design strategies to their projects

- Participants' attitude to existing sustainable design training programmes:

1) The majority of the participants (83.3%= 41.7% + 33.3% + 8.3%) attended less than nine hours of sustainable design training programmes per year (Figure 6-28). And the main reason they chose to go was self-development plan (Figure 6-29).

2) For most of the participants, the existing training programmes were satisfying (Figure 6-30).

3) The expectation from the sustainable design training programme was updating knowledge and raising awareness (Figure 6-31).

4) The most frustrating aspect of existing sustainable training programmes was that knowledge was easily forgotten due to the lack of a connection with their projects (Figure 6-32).

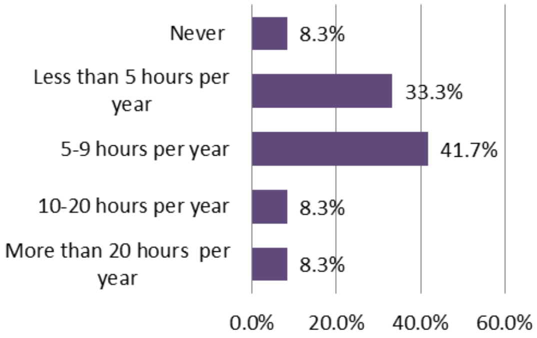


Figure 6-28: How often did the participants attend sustainable design training programmes over the last year?

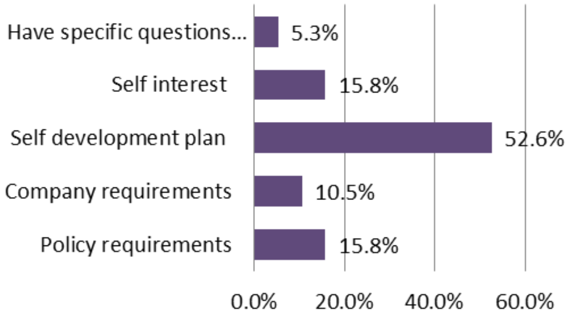


Figure 6-29: Reasons that the participants chose to attend sustainable design training programmes

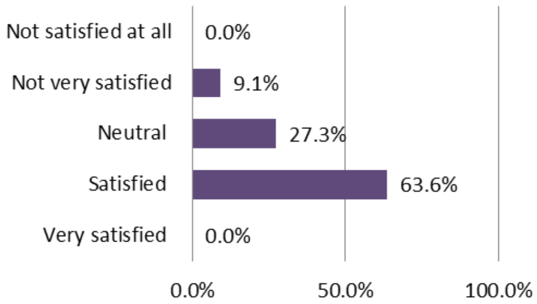


Figure 6-30: To what extent were the participants satisfied with previous sustainable design training programmes they attended over the last year?

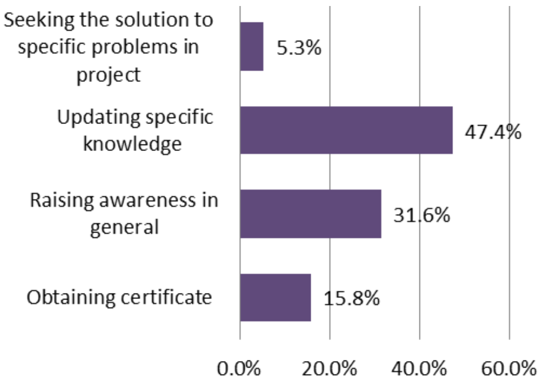


Figure 6-31: What did the participants expect from the sustainable design training programmes?

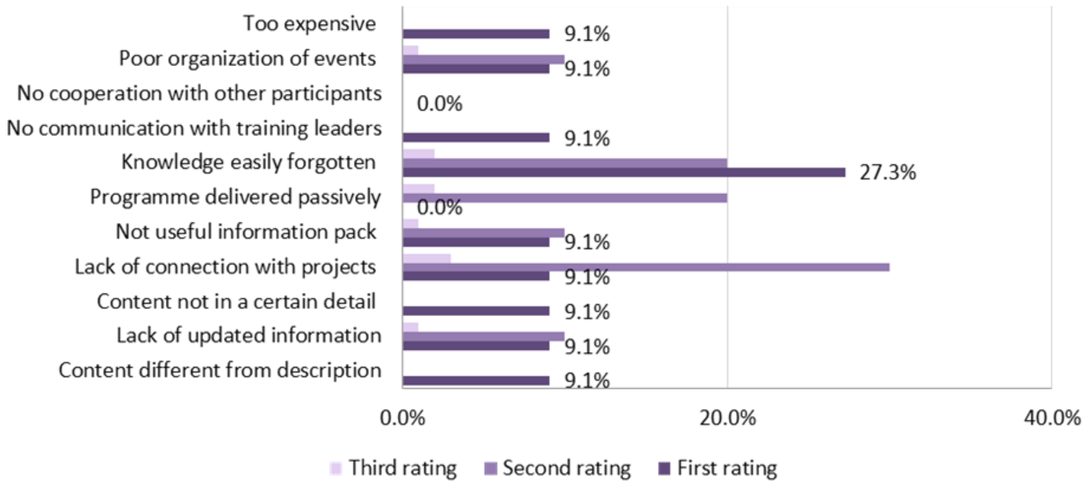


Figure 6-32: What did the participants like the least about previous sustainable design training programmes?

- The participants' requirements for new sustainable design training programmes (Figure 6-33 to 6-38): There was only one obvious change in the responses to both sets of the questionnaire, which is shown in Figure 6-39.

1) Workshop and seminar was the most preferred training programme type (Figure 6-33).

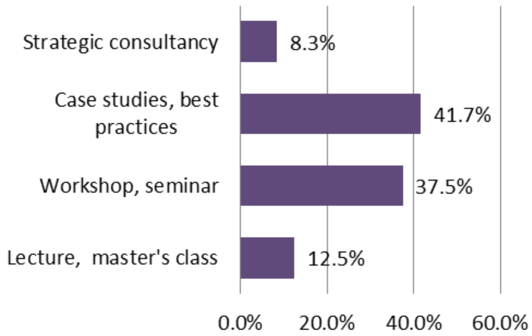


Figure 6-33: Preferred type of sustainable design training programmes

2) Experts or researchers in the sustainable design field and architects practicing sustainable design were preferred to be the presenter (Figure 6-34).

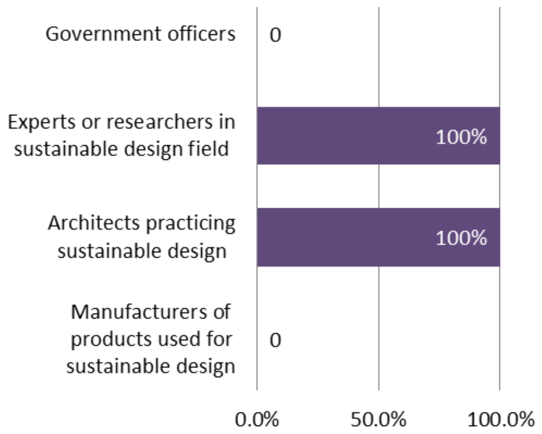


Figure 6-34: Preferred presenters of sustainable design training programmes

3) The majority of the participants would be prepared to pay £50-100 for a one day programme which they were interested in, while only 16.7% of participants would like to pay £150-200 (Figure 6-35).

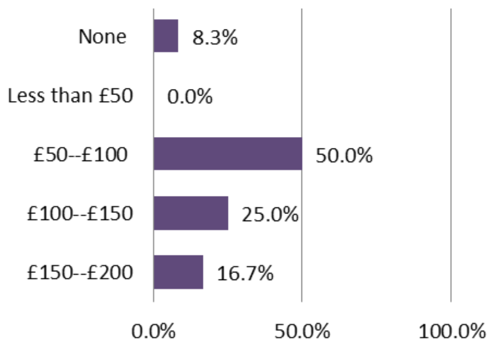


Figure 6-35: The fee that participants prepared to pay for a one day sustainable design training programme

4) Most (75% = 66.7% + 8.3%) of the participants agreed that holding the training programme in a sustainable building would help improve the quality of the programme (Figure 6-36).

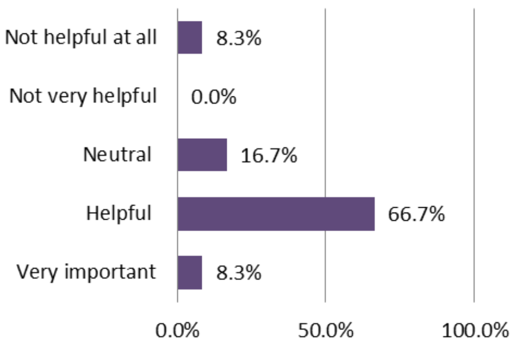


Figure 6-36: The importance of holding the training programme in a sustainable building

5) The majority of the architects would like to attend the training programme during normal work hours or early in the morning (Figure 6-37).

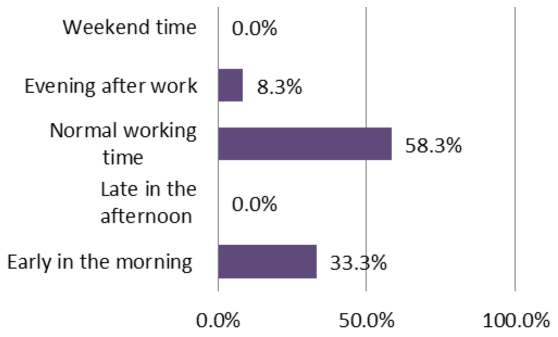


Figure 6-37: Prefer time to attend training programmes

6) A website with updated follow up information was preferred as the handout format (Figure 6-38).

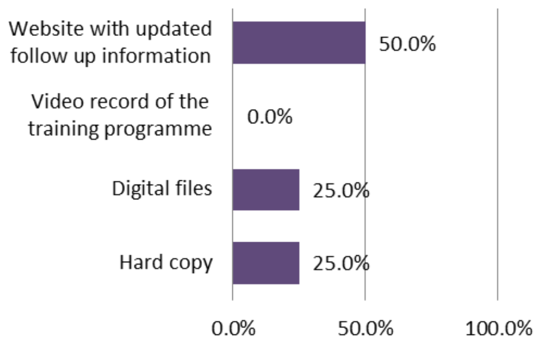


Figure 6-38: Preferred format for course materials

7) Most of the participants indicated that one (36.4%) and 1 to 3 days (45.5%) were a suitable length for one training programme. But there was an increase by 45.4% from 9.1% to 54.5% for more than 3 days in the responses to the second survey (Figure 6-39). An explanation for this was after the EPD pilot, participants realized a lot of information that they were interested in or required to learn about. There is a significant learning

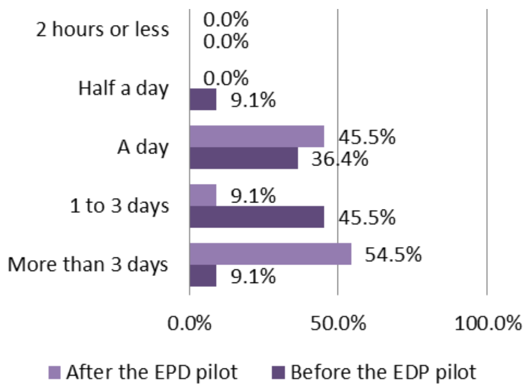


Figure 6-39: Preferred length for a single training programme

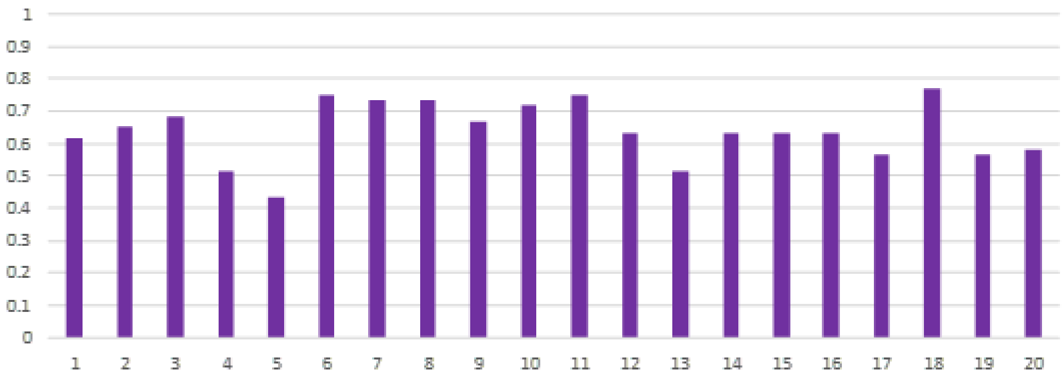
process involved.

- Participants' evaluation of the EPD pilot

1) The overall assessment of the EPD pilot was positive.

2) The helpful modules included 1) Basic sustainable design elements, 2) Advanced sustainable design elements, 3) Zero carbon, 4) Very low impact design, 5) Passive house and Passivhaus and 6) BREEAM (Figure 6-40).

3) Not helpful modules included 1) Collaboration working, 2) Life Cycle Assessment, and 3) On site and waste issues (Figure 6-40).



1 Background Information	2 Production of Energy	3 Renewable Energy	4 Life Cycle Assessment	5 Collaborative Working
6 Basic Sustainable Design Elements	7 Advanced Sustainable Design Elements	8 Zero Carbon	9 Carbon Offsetting	10 Very Low Impact Design
11 Passive houses and Passivhaus	12 Water and Sewage	13 On Site and Waste Issues	14 Post Occupancy	15 Code for Sustainable Homes
16 Refurbishment	17 Green Guide	18 BREEAM	19 SAP and Building Modelling	20 Planning Issues

Figure 6-40: Evaluation of the topics of the EPD pilot

6.5 Lessons learnt from the three case studies

6.5.1 The revised model of low/ zero carbon design

During all the three training programmes, discussions with the participants regarding low/ zero carbon design and their learning preference were carried out.

During the discussion in the Environmental Professional Development pilot, one suggestion to the initial model of low/ zero carbon design was put forward, which was to establish the model in relation to the RIBA Plan of Work stages. The RIBA Plan of Work stages was introduced as an innovative management tool for architects in 1963 and remained to be the essential. The RIBA has updated the 2007 version to the Plan of Work 2013, changing stages A to L to eight new stages numbered 0 to 7. One of the main changes is that it focuses on the stages before and after the design, which can be identified as a necessary step into a holistic process. The Plan of Work 2013 also has the ‘Sustainability Checkpoints’ Taskbar, but it can be switched off. This has raised concerns from some architects that this sends out the wrong message that sustainable design and the reduction of carbon emissions is optional (Myers 2013)

Architects are familiar with the RIBA Plan of Work stages, and the associated professionals in the construction industry in the UK also recognise it as a model with set of procedures for building project administration (Baba 2013). It was considered by the participating architects as a systematic way to present the content of low carbon design training programmes. More importantly, in order to help architects to integrate the model of low/ zero carbon design to their own projects, it is necessary to map the design process on the RIBA Plan of Work. Baba et al. (2012) carried out survey research which confirmed that architects found information difficult to comprehend which was not represented in the recognised RIBA Plan of Work stages, or graphically and pictorially.

The RIBA Plan of Work 2013[2] has been established for the construction industry in the 21st century to help deliver capital and operational efficiencies, carbon reductions, better briefing and outcomes (RIBA 2013). According to Shingler (2014), the new Plan of Work intends to prompt the designer to test key sustainability considerations with the design team at the right time, and to encourage a collaborative, coordinated approach to making buildings more sustainable.

The design process in the revised model of low/ zero carbon design has been mapped against the RIBA Plan of Work 2013. Consequently, the design process has been extended to the Handover and Close Out stage (Stage L Post Practical Completion in RIBA Plan of Work 2007), adding the topics of commissioning and feedback study to the model of low/ zero carbon design. The revised model could guide the design team to consider low/ zero carbon design aspect at the related time in the RIBA Plan of Work. The revised model of low/ zero carbon design is illustrated below (Figure 6-41).

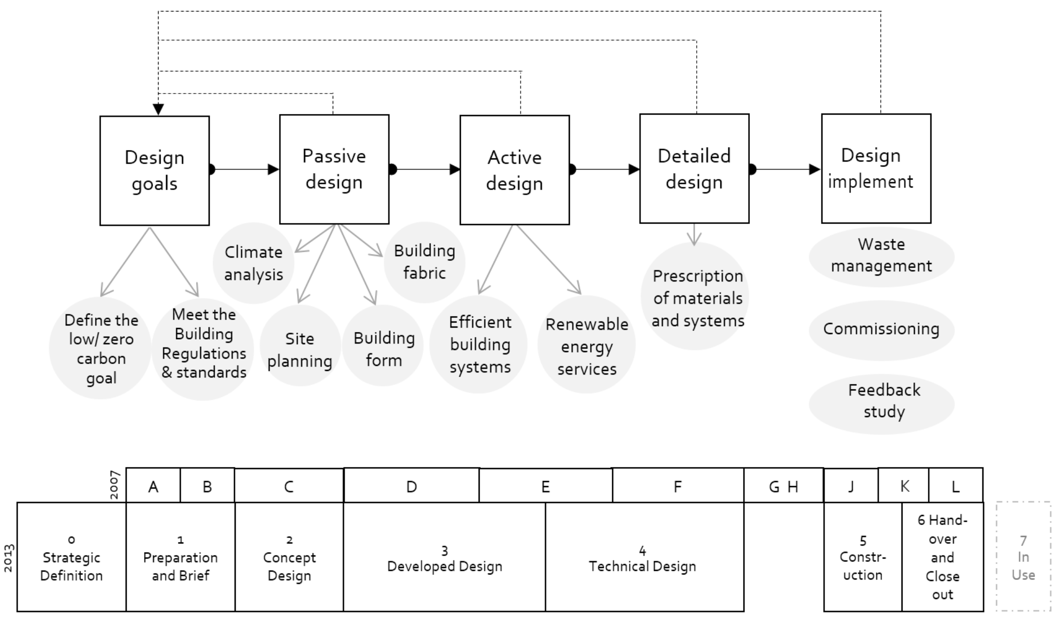


Figure 6-40: The revised model of low/ zero carbon design

[2] The revised model of low/ zero carbon design has been mapped against the RIBA Plan of Work 2007 during the conduction of the research. The RIBA Plan of Work 2013 was put forward during the correction of the thesis. Efforts have been made to update the model with the latest RIBA Plan of Work 2013.

A project is strategically appraised and defined in Strategic Definition stage before a detailed brief is created. This is important in the context of low/ zero carbon design to identify the low/ zero carbon design goals of the project and consider the team members and their responsibilities to the associated low/ zero carbon design goals. The Preparation and Brief stage requires architects to define the project’s parameters and set the low/ zero carbon design goals that require continued commitment to the achievement of the design performance. During the Concept Design stage, the initial design concept regarding passive design in low/ zero carbon design model should be developed with consideration of detailed design and technical design to fulfil the requirements of the initial project brief. During the Developed Design stage, the concept design is developed further with the development of the architectural, building services and structural engineering designs. Architects and engineers work together with an iterative process to optimise the design in order to achieve the design goals. During the Technical Design stage, the architectural, building services and structural engineering designs are further refined to provide technical definition of the project, and make sure the design goals can be achieved. In the Construction stage, the building is constructed on site, and the design team should ensure the implementation of the low/ zero carbon design strategies as well as waste management. During the Handover and Close Out stage, commissioning which ensures operation and management of the building to achieve the designed low/ zero carbon performance, and feedback study to learn lessons which may be applied to future projects should be carried out.

The low carbon design process has been integrated with the RIBA Plan of Work. The integration with the RIBA Plan of Work enhances the reflection of the holistic approach to achieve low/ zero carbon design with collaboration of the design team from the beginning of a project to the construction and handover stages. Early preparation has been promoted at the beginning when the groundwork is laid for the entire project, while sufficient attention has been paid through the design stages and to the construction, handover and close out stages in order to make sure the implementation of the low carbon design strategies and further improvement.

Also, the revised model still emphasizes the iteration of the design process, and the iterative process can be reflected on the RIBA Plan of Work. For each stage, the design needs to be checked against the design objectives which have been set during the stages of Strategic Definition, and Preparation and Brief. Building Regulations and environmental assessment methods in relation to low/ zero carbon design are major force and reference for the design objectives and should be clarified at the start of the design. During the stages of Concept Design, Developed Design, Technical Design, Construction, and Handover and Close Out, a continuous circle of analysing, proposing design options, predicting/ calculating performance of design options, checking the low/ zero carbon design objectives and optimising should be conducted. This is different from the traditional design practice described by Hetherington et al. (2010), that client signs off the design, architect conducts design, then technical solutions are used to correct the problems caused by the lack of consideration at the design stage.

6.5.2 The revised model of architects' learning preference

Feedback from the discussions in the three training programmes confirmed that the training programmes should be tailored to architects' practical needs. The requirements for low/ zero carbon design training programmes suggested the training programmes need:

- Practical techniques and clear methods to achieve sustainable design
- A hands-on design approach, such as application tool box
- A front runner to be introduced to demonstrate a path for the future
- A data base
- Case studies, exemplary buildings, best practice, worst practice, and live projects

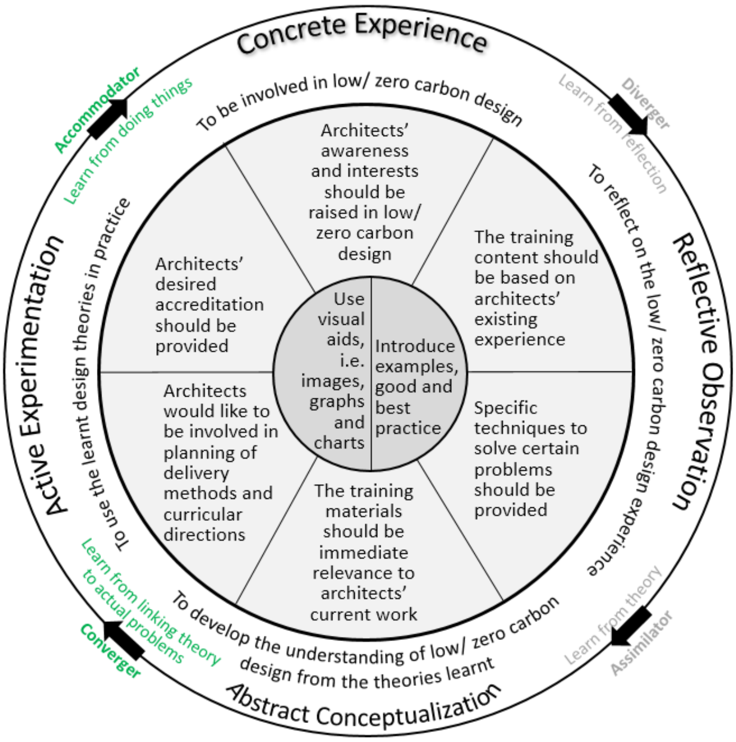
- Presentations with architects' language, i.e. images, graphs and charts
- Modules for different levels
- Specialised knowledge of a single design strategy
- Participating architects sharing their experience in sustainable design
- Application of the knowledge and skills in practice on specific projects in the office after the training

These requirements are in accord with the concepts of the Experiential Learning Circle and the characteristics of adult learning in the initial model of architects' learning preference.

The results of questionnaire survey for the MSc Course in Sustainable Design in the Welsh School of Architecture suggest that the candidates prefer both learn from doing things and learn from linking theory to actual problems. Therefore, converger has been added to the revised model to indicate architects' preferred learning styles.

Two additional points were made by the participants during the discussions in the Enable Sustainability—Raising Awareness programme and the Environmental Professional Development Pilot in relation to the delivery format of knowledge and skills, including 1) using images, graphs and charts, and 2) including examples, good and best practices. Goody and Matthew (1971) conducted a study which indicated that presentational style is the key factor in the transfer processes. Mackinder and Marvin (1989) confirmed that diagrammatic presentation fits designers' preference of information format best. Therefore, these two points regarding delivery format of the content were added to the revised model of architects' learning preference.

The revised model of architects' learning preference is shown below (Figure 6-42):



Note: the green highlight indicates the learning styles preferred by architects.

Figure 6-41: The revised model of architects' learning preference

The revised model of architects' learning presence consists of three layers. The outer layer represents the Experiential Learning Circle and architects' preferred learning styles. The middle layer represents the characteristics of adult learning. The inner layer represents the delivery format of knowledge and skills. Each layer indicates the assumptions made in one of the three aspects of architects' learning preference, which were derived from literature and case studies. These assumptions will be tested in the final nationwide questionnaire surveys.

What is more, eight general delivery factors of training programmes were raised and discussed during the case studies. Generally, the training providers of low/ zero carbon design training programmes need to make sure the price of programmes is acceptable by most potential participants, and certain accreditation is provided. Experienced researchers and practitioners usually take on the role to disseminate the knowledge in the form of lecture, workshops, and field studies. Hard copies, USB drives with digital files, video tapes, and websites with follow up information are the frequent types of handout. These eight factors included 1) the fee, 2) the location, 3) travel distance, 4) the handout, 5) other participants, 6) the presenters, 7) delivery methods and 8) types of training programmes. These factors are administrative aspects which are not related to the concept of learning preference, thus they were not added to the revised model of architects' learning preference.

6.5.3 Lessons learnt regarding the questionnaire survey

From the 'Enabling Sustainability—Raising Awareness' programme for Atkins:

1) It was important to add instructions under all the questions to remind the participants how to answer the questions.
2) It was important to have multi-choice questions, and clarify how many answers the participants should provide. This type of question can further stimulate participants' thoughts during the process of comparing and choosing; therefore, more reliable answer could be obtained. This standardized answer would also make analysis easier. Alternatively, a question can ask the participants to 'rank all the options' or 'choose the top three options and rank them'.
3) A more organized system for questionnaire distribution and data collection was required to increase the response rate.

From the master's taught programmes in sustainable design in the Welsh School of Architecture:

1) The rating type of question was introduced in this questionnaire, and the response was that it was difficult to answer.

2) In order to avoid a long questionnaire, only one question regarding participants' understanding of sustainable design was included. This question of how participants understand sustainable design was decided to be taken out since the general definition did not provide further interpretation. Participants tended to choose the most extensive definition while the answer had no indication of their intention to deliver the design.

3) The survey results of the opinion of the candidates from the master's course regarding architects' responsibilities to low/ zero carbon design indicated that design categories it the design stage were well accepted as architects' responsibility, such as passive design, use of sustainable and recycled materials and efficient building services. This finding lead to the question design in the final nationwide questionnaire survey to investigate architects' understanding of the importance and their capability of each design aspect in the revised model of low/ zero carbon design.

From the Environmental Professional Development Pilot by the Royal Society of Architects in Wales:

1) One questionnaire was sent out before the participants taking the training programme and the other one was sent out after them taking the programme. It would be useful to identify the difference between the answers to the first questionnaire and the second questionnaire, and analyse how the participants changed their opinions with the impact of training. Since the survey was anonymous, certain techniques should be applied to match up the two questionnaires from one participant. For example, the two sets of the questionnaires can be numbered, and two questionnaires with the same number should be given to one participant before the training programme; then

ask the participants to complete the first one before the training and the other one after the training.

2) Enough space should be provided for the participants to write their answers.

6.6 Summary

This chapter investigated three case studies of existing training programmes to pilot the questionnaire survey method, and verify the initial models of low/ zero carbon design and architects' learning preference with the feedback from the discussions and surveys conducted in the training programmes in order to reflect architects' current perspectives on low/ zero carbon design and their learning preference. A revision for the initial model of low/ zero carbon design is mapping the design process against the RIBA Plan of Work 2013. The main revisions for the initial model of architects' learning preference are adding a third layer which represents the delivery format of knowledge and skills, and identifying learning from linking theory to actual problems as one of architects' preferred learning styles. This chapter prepared the foundation for the development of the nationwide questionnaire survey. Each element of the two revised models will be taken to form questions in the nationwide questionnaire survey in Chapter seven.

Chapter 7. Questionnaire Survey: Architects' Requirement for Low/ Zero Carbon Design Training Programmes

The aim of this nationwide survey research is to investigate what knowledge and skills architects in practice in England and Wales need from low/ zero carbon design training programmes and how to disseminate the knowledge and skills.

This chapter introduces the procedures of developing the self-administered questionnaire survey. Three stages are included:

1) Questionnaire construction
2) Sample selection
3) Data collection

7.1 Questionnaire construction

According to the objectives of this survey research, the questionnaire was organized into three main sections:

1) Architects' attitude and experience regarding low/ zero carbon design and the associated training programmes
2) Architects' required content of low/ zero carbon design training programmes
3) Dissemination methods of low/ zero carbon design training programmes

For section two, the revised model of low/ zero carbon design was applied as the framework to develop specific questions. For section three, the revised model of architects' learning preference was used as the framework to raise the questions. Each element of the models was converted to a question.

Two supporting sections were added, namely:

1) General information of the participants and their practices for potential correlation analysis (at the beginning)
2) An open-ended question about participants' general comments on low/ zero carbon design training programmes for extra opinion collection (at the end)

7.1.1 Question design related to architects' attitude and experience regarding low/ zero carbon design and the associated training programmes

Eight topics were established to explore architects' attitude and experience regarding low/ zero carbon design and the associated training programmes (Table 7-1):

Table 7-1: Topics on architects' attitude and experience regarding low/ zero carbon design and the associated training programmes	
Categories	**Topics**
Low/ zero carbon design concept	1. Whether architects think the low/ zero carbon design concept is important 2. Whether architects have learnt about low/ zero carbon design concept before 3. What were the main sources from which architects learned about low/ zero carbon design concept 4. Whether architects have applied low carbon design strategies to their projects previously and to what extent 5. What were the barriers to apply low/ zero carbon design to projects
Previous low/ zero carbon design training programmes	1. How often did architects attend low/ zero carbon design training programmes 2. Whether the participants thought the previous low/ zero carbon design training programmes were helpful 3. How did the architects evaluate the previous low/ zero carbon design training programmes that they attended

7.1.2 Question design regarding the content of low/ zero carbon design training programmes

Each element of the revised low/ zero carbon design model from the brief stage to the completion stage was converted to a question, in order to investigate the participants' requirement for learning each individual design task of low/ zero carbon design. The questionnaire asked the participants to provide answers to each design task from different angles, for example 1) to evaluate the importance of this design task, 2) to assess their confidence (ability) to conduct the task, and 3) to allocate the responsibility of the design task to members in a design team. These multi-perspective questions would help revealing the participants' current understanding and involvement in low/ zero carbon design, which could lead to identify their real requirements from the training programmes. For example, if architects thought certain design task was not important, and they were not confident to deliver it in their projects; the training programmes would be developed to raise their awareness first, and then disseminate the related knowledge and skills. The design tasks with multi-perspective questions regarding the content of low/ zero carbon design training programmes are shown in Table 7-2:

Table 7-2: Aspects related to the content of low/ zero carbon design training programmes with multi-perspective questions		
Stages	**Design tasks**	**Question perspectives**
Brief stage	1. Set the goal to achieve low/ zero carbon design at the beginning of design process 2. Understand current Building Regulations and standards	Perspective 1): whether carrying out the design task is important Perspective 2): whether the participants are confident to carry out the design task
Design stage	Seven components of low/ zero carbon design: 1. Climate Analysis 2. Site Planning 3. Building Form 4. Building Fabric 5. Efficient Building Services 6. Renewable Energy Systems 7. Construction Materials and Products	Perspective 1): whether carrying out the design task is important Perspective 2): whether the participants are confident to apply it to practice Perspective 3): who do the participants think should be responsible for the design task
Build stage	Implement the low/ zero carbon design during construction	Perspective 1): whether carrying out the design task is important Perspective 2): whether the participants are confident to carry out the design task
Completion stage	Commissioning and feedback study to make sure that the low/ zero carbon design is realized during operation	Perspective 1): whether carrying out the design task is important Perspective 2): whether the participants are confident to carry out the design task

7.1.3 Question design regarding dissemination methods

Three categories of dissemination methods were established in the revised model of architects' learning preference. The first category was related to architects' preferred learning styles. The second category was related to the characteristics of adult learning. And the third category was related to the format of the content. What is more, eight general delivery factors of training programmes, which were developed through discussion in the three case studies, were an additional categories for the questionnaire.

The aspects related to delivery methods to disseminate the knowledge and skills are listed in Table 7-3.

Table 7-3: Aspects related to the dissemination methods

Categories	Aspects
Architects' preferred learning styles (outer layer of the final model of architects learning preference)	1) Learn from doing things: initiate and perform tasks, like to experiment 2) Learn from reflection: watch others' activities and reach decisions in the own time 3) Learn from a model, a framework, a concept or theory: read, analyse and understand complex situations through intellectual engagements 4) Learn from linking theory to actual problems: enjoy techniques that relate directly to their own problem
Characteristics of adult learning (middle layer of the final model of architects learning preference)	1) Raise the architects' awareness and interests in low/ zero carbon design 2) Involve participating architects in mutual planning of methods and curricular directions 3) The starting point of the training material of the low/ zero carbon design training programme should be based on the architects' experience 4) Arrange the training material so that it has immediate relevance to the architects' current work 5) Organize the training material to provide specific techniques to solve certain problems rather than structured lectures of theoretical knowledge 6) Provide desired accreditation
Format of the content (inner layer of the final model of architects learning preference)	1) Using images, graphs and charts 2) Including examples, good and best practices
General delivery factors of the training programmes (additional)	1) Types of training programmes 2) Delivery methods 3) Presenters 4) Other participants 5) Handouts type 6) Fee 7) Travel distance 8) Venue location

7.1.4 Design of questions

As presented in Chapter Six, lessons about questionnaire design were learnt from the three case studies. These rules were taken into account and applied to the design of questions for the nationwide questionnaire survey, including:

1) All of the questions were simple single or multiple choice questions in order to reduce the confusion raised by various types of questions.
2) For each question, an indication on how to answer this question was clearly stated at the end of the question.
3) For single or multiple choice questions with options provided by the researcher, there was always an option provided as 'Others please specify' to keep an open mind.
4) Rating questions were eliminated due to participants' negative responds to this type of question. Matrix type was provided to replace it.

7.1.5 Questionnaire improvement

Whether and how the answer to each question in the draft questionnaire can contribute to the research questions had been checked to make sure that the right questions were included in the questionnaire to provide the answers to the research questions. Based on the draft questionnaire, three meetings were set up with experts in the field of organizing training programmes, and a pilot study was carried out. The aim of the meetings and the pilot study is to obtain feedback for the questionnaire design, in order to collect missing points related to the research questions, as well as to make sure the questionnaire was clear and easy to fill out (Table 7-4). The returned pilot questionnaires were analysed, and the analysis results were checked with the research questions to identify any gaps in-between the answers to the questionnaire and the research questions. All the feedback regarding the questionnaire design was taken into account. At last, a covering letter for the questionnaire was carefully prepared. The information about the research and the researcher was included. The final questionnaire and its covering letter can be found in Appendix VI.

Table 7-4: Events to improve the questionnaire

Events (Date)	Experts	Feedback
Meeting with Clare Sinclair 27th/07 /2011	Ms Sinclair is the business development manager from the Professional Development Team Support for Cardiff University Schools. She is an expert in planning and organizing CPD programmes and developing market research.	1. Suggestion: a clear covering letter should be included 2. Suggestion: to explore more about the accreditation that the participants preferred, e.g. CPD credit
Meeting with Huw Jenkins 2nd/08/2011	Mr Jenkins is the Commercial Manager in the Centre for Research in the Built Environment. He is very experienced in providing a business-focused approach to research and consultancy services with the aim of providing solutions for its clients.	1. Discussion: scales for the questions were discussed, and five -level Likert scale which is a scaling method, measuring positive or negative response to a statement was suggested 2. Suggestion: to clarify the content section, and distinguish the instruction to answer the questions and the actual questions
Meeting with Milicia Kiston 17th/08/2011	Ms Kiston is the Chief Executive in Constructing Excellence in Wales. She introduced Constructing Excellence as a best-practice organisation, and shares certain experience about training programmes Constructing Excellence hold.	Shared the experience of holding training programmes by Constructing Excellence: • Charging over £100 made it hard to get people to attend • Breakfast meetings at 7.30am which enable attendees to be back at work by 10am, or half day events were more popular • Charging for non-attendance as an incentive to attend was recommended to make sure high attendance rate
Questionnaire pilot 3rd/08/2011	A pilot was carried out in Design Research Unite Wales (DRUw). Six questionnaires were sent out to the architects by the researcher, and six were collected back.	The architects' main feedback was the content section was difficult to complete. One of them mentioned that she could not finish this section when she tried to complete it at the first time. As she would like to help this research, she decided to have a second try to fill it out.

This survey research used agreed departmental procedures and was approved by the Research Ethics Committee of the Welsh School of Architecture on the 05th October 2011 (EC1110.089).

7.2 Sample selection

Two main questions were required to be answered at this stage of the research:

1) How to select the sample?
2) How to decide on the sample size?

How to select the sample? The population for this research was all the registered architects (who are legally allowed to practice under the title Architect) in England and Wales. According to the Architects Register Board (ARB)[3] (2011), there were 30,000 architects on the Register in the UK. A PDF copy of the register was available to purchase, which could provide the list of the whole population. One the other hand, the latest copy of the directory of RIBA Charted Practices ‘RIBA Education 10: Royal Institute of British Architects Directory of Chartered Practices’ (published July 2010) was available, which can provide the full list of architectural practices. Two approaches to select samples for this research were considered (Figure 7-1):

[3] The Architects Registration Board (ARB) is the UK's statutory regulator of architects, set up by an Act of Parliament. ARB is responsible for keeping the Register of Architects, which is the only statutory register of architects in the UK.

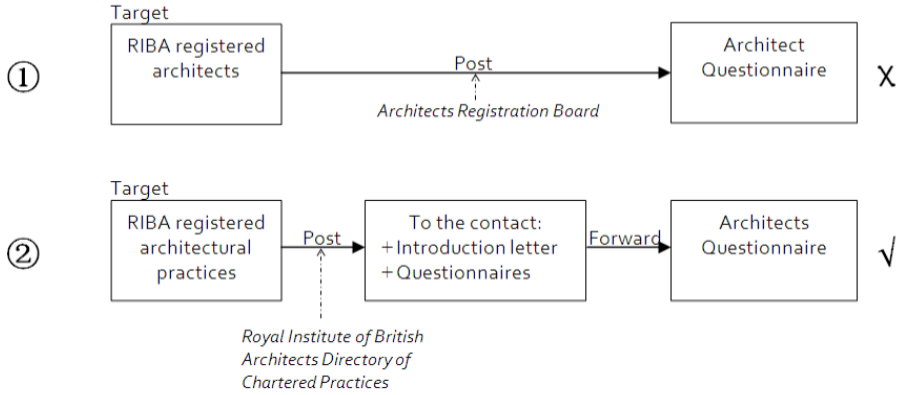


Figure 7-1: Two approaches to select samples

Approach 1: The sample could be obtained by randomly selecting from the list of registered architects, whose office address could be obtained through the Architects Registration Board website by entering his/ her ARB Registration Number or Name. A hard copy of the questionnaire with the covering letter could be sent to each sample architect, with a prepaid return envelope. This approach was straightforward. On the downside, there might be a low response rate since people tend not to respond to random questionnaire that they receive in the post.

Approach 2: The sample could be architects from randomly selected RIBA Chartered Practices. A certain percentage of the practices could be chosen to be the sample practices, and the architects in these practices were the sample units. A package with a research information letter explaining this survey research and several questionnaires could be sent to the contact of each sample practice which was available in the Royal Institute of British Architects Directory of Chartered Practices. In the research information letter, the objective of the questionnaire survey could be clearly presented, and the contact could be politely asked to distribute the questionnaires to their architect colleagues in the practice. In this way, it might encourage more responses. Therefore, the second approach was adopted in this research.

The second question was how to decide on the sample size. According to De Vaus (1990), one of the main factors that influences the required sample size is the degree of accuracy. A review was carried out to find out how many responses other questionnaire surveys in this field had. 10 papers with survey research carried out in the UK, Sweden, China, India and Taiwan in peer reviewed journals were collected (Table 7-5). The result showed that the number of participants varied from 41 to 681, with the response rate ranging from 5% to 84%. The sample size for this nationwide questionnaire survey was defined to be 200 architects with the consideration of the confidence level of 95% (how often the true percentage of the population who would pick an answer lies within the confidence interval), the confidence interval of 7 (margin of error), as well as the population of 30000.

Table 7-5: Exploration of the sample size in the sustainable architecture field

Paper title	**Participants number and response rate**	**Country**	**Reference**
Feasibility of zero carbon homes in England by 2016: A house builder's perspective	41 (41%)	UK	(Osmani & O'Reilly 2009)
Architects' perspectives on construction waste reduction by design	46 (40%)	UK	(Osmani, Glass & Price 2008)
Low carbon housing refurbishment challenges and incentives: Architects' perspectives	45 (45%)	UK	(Davies & Osmani 2011)
Specifying recycled: understanding UK architects' and designers' practices and experience	681 (5%)	UK	(Chick & Micklethwaite 2004)
The lonesome architect: to develop more effective support for architectural knowledge sharing	142 (52.4%)	UK	(Hoorn et al. 2011)
Perceptions, attitudes and interest of Swedish architects towards the use of wood frames in multi-storey buildings	412 (11.4%)	Sweden	(Hemstroma, Mahapatraa & Gustavssona 2011)
Evaluation of domestic Energy Performance	347 (17%)	UK	(Watts, Jentsch & James 2011)
Can consumers save energy? Results from surveys of consumer adoption and use of low and zero carbon technologies	390 (NA)	UK	(Caird, Herring & Roy 2007)
Indoor air quality assessment in and around urban slums of Delhi city, India	90 (NA)	India	(Kulshreshtha, Khare & Seetharaman 2008)
The Effectiveness of the Green Building Evaluation and Labelling System	74 (36%)	Taiwan	(Vivian 2007)

How many RIBA registered practices in England and Wales should be selected? The number of RIBA registered practices in each region was counted. The total number was 1415 based on data from 2010. Figure 7-2 summarized the regional distribution of RIBA registered architectural practices in England and Wales. It was noticed that the practices were not evenly distributed.

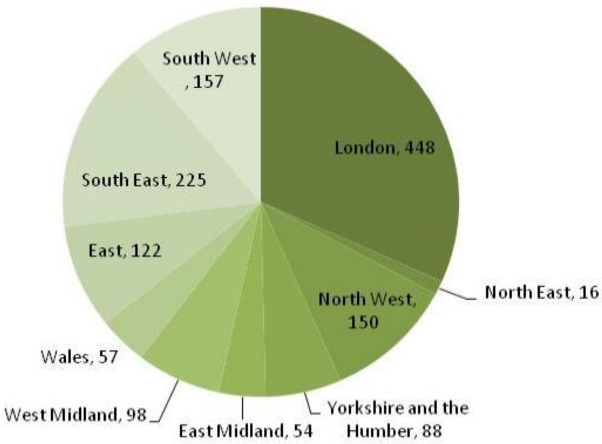


Figure 7-2: The distribution of RIBA registered architectural practices in England and Wales

Difference between regions was one aspect to be explored. A stratified sampling strategy was applied to get an equal number of sample practices. Due to the small number of practices in the North East region and little difference among certain regions, ten regions were combined into six regions: 1) London, 2) South West, 3) South East and East, 4) Wales, 5) West Midland and East Midland and Yorkshire and the Humber, and 6) North West and North East.

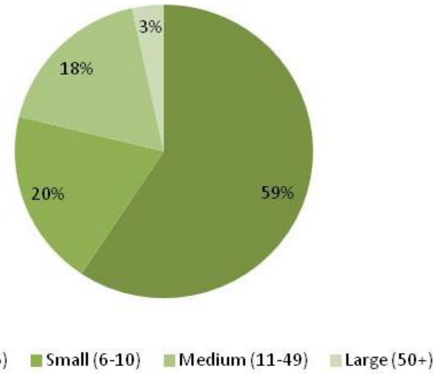


Figure 7-3: Size of RIBA registered architectural practices

For each of the six regions, how many practices should be collected? According to Just Practicing (2010b), the breakdown of practice sizes recorded by the RIBA in 2009 showed that 79% of chartered practices had fewer than 10 staff, and 18% of practices were medium sized (11-49 staff) and large practice (50+ staff) occupied 3% of chartered practices (Figure 7-3). The average number of architects in RIBA charted practices was around 6 = [(1+5)/2*59% + (6+10)/2*20% + (11+49)/2*18% + (50+100)/2*3%]. According to experience, the response rate was often around 10%. Therefore, in order to obtain 200 survey samples, 2000 questionnaires should be sent out. If six is used as the average number of architects in architectural practice, 333 architectural practices were required. Thus, for each region 57 architectural practices should be randomly selected. Table 7-6 shows the proportion of the sampled practices in each region.

Table 7-6: Selection of sampled practices in each region

Regions	**Number of practices**	**Selection of sampled practices**
London	448	57 (12.7%): one in seven
North East	16	57 (34.3%): one in three
North West	150	
Yorkshire and the Humber	88	57 (23.8%): one in four
East Midland	54	
West Midland	98	
Wales	57	57 (100%): all
East	122	57 (16.4%): one in six
South East	225	
South West	157	57 (36.3%): one in two

7.3 Questionnaire distribution and data collection

The questionnaires were distributed to 342 RIBA registered practices. Due to the limitation of the available information on exact numbers per practice, one copy was sent to one-person practices, three copies to micro companies, six copies to small companies, nine copies to medium companies and 20 copies to large companies. If the information of company size was not available, six copies were sent.

A prepaid return envelope was provided with each questionnaire in order to make it convenient for the participants to send the completed questionnaires back. A response service (instead of prepaying all the return envelopes of which probably only 10% would actually return) was set up with Royal Mail to collect the responses in a more cost effective way.

In order to increase the response rate, emails or phone calls were made to the contacts and to politely ask his/her participation in the research. Eight weeks after the questionnaires were sent out, 84 questionnaires were returned. This was less than the expected sample size of 200. It was realized that there were no more than two completed questionnaires coming back from the same company, and some companies requested to complete one questionnaire representing the whole company. It seemed that the applied procedure of forwarding the questionnaires to each individual architect in one practice did not work. On the other side, if the architectural practices were viewed as the survey units, the response rate reached 25%.

The second round of questionnaires survey was required to be sent out (Table 7-7). Three changes were made: 1) an email was sent before the questionnaires were posted to inform the sampled architects the coming of the survey, 2) the first reminder phone call was made earlier, and a second reminder phone call was included, and 3) each of the single covering letters were signed. 80 questionnaires were returned this time.

Table 7-7: Summary of the second round questionnaire survey		
Questionnaire construction	1. Same questionnaire 2. A package including: • Research introduction • Just 2 copies of the questionnaires with a covering letter and prepaid self-addressed envelopes	
Sample selection	1. 342 architectural practices (*The sample size was kept the same in order to provide comparison. It had been assumed this would provide a similar response rate.)* 2. Systematic selection	
Data collection	*Date of distribution*	20/02/2012
	Date of the first reminder	27/02/2012
	Date of the second reminder	05/03/2012

7.4 Lessons learnt regarding the questionnaire survey

During the whole process from the questionnaire design, through the sample selection and the questionnaire distribution to the result analysis, valuable lessons have been learnt.

Regarding questionnaire design, a complicatedly designed questionnaire stops the participants completing the questionnaire. And it is of importance to make sure the questions in the questionnaire provide answers to the research questions. Double check whether the answer to each research question is covered by one or more questions in questionnaire is essential.

Regarding questionnaire distribution and data collection, if the questionnaires are sent to contacts to be distributed to the contacts' companies, the returned ones tend to be completed by the contacts. Setting up of a Response Service is a cost effective way to send out a large amount of postal questionnaires (related payment: a licence fee and the returned mail at a lower rate). If printing artwork on the envelope is required, a lighter envelope (80g) is easier to be handled by printers. Also, printing the return envelope can be time consuming, so if the budget permits, a higher license fee could be paid to get a free design. In addition, it is necessary to call the people after the questionnaires are sent out to check whether they have received them since some posts did get lost. Finally, a personally signed covering letter does not have an impact on response rate.

7.5 Summary

This chapter described the procedure of establishing the questionnaire survey based on the revised models of low/ zero carbon design and architects' learning preference, the guidance for questionnaire survey and lessons learnt from the case studies. It prepared the research tool to investigate the answers to the two research questions in order to develop low/ zero carbon design training programmes for architects in practice.

Chapter 8. Results of the Questionnaire Survey: Architects' Requirement for Low/ Zero Carbon Design Training Programmes

This chapter introduces the statistical analysis results of the nationwide questionnaire survey in relation to architects' opinion on low/ zero carbon design training programmes, including architects' attitude and experience regarding low/ zero carbon design and low/ zero carbon design training programmes, the required content of low/ zero carbon design training programmes, as well as the preferred dissemination methods.

8.1 Sample description

164 questionnaires were returned, and 161 were completed. The overall response rate reached 25% when architectural practices are viewed as the sample units. Table 8-1 summarizes the general information of the sampled architects. Descriptive statistics/ frequencies procedure was carried out to present the relevant characteristics of the sample. What is more, information of each characteristic was stratified in accordance with the location of the practices to provide an insight to potential differences between regions.

Table 8-1: General information of the sampled architects

			London	North East & North West	Yorkshire and the Humber, East Midland & West Midland	Wales	East & Southeast	South West
			15.2%	12.1%	19.7%	17.7%	16.5%	19.0%
Gender	Female	22.9%	50.0%	5.3%	16.7%	32.1%	19.2%	13.3%
	Male	77.1%	50.0%	94.7%	83.3%	67.9%	80.8%	86.7%
Position	Principal	45.6%	37.5%	42.1%	48.4%	53.6%	34.6%	53.3%
	Associate	17.1%	20.8%	15.8%	16.1%	17.9%	30.8%	3.3%
	Architects	32.9%	37.5%	26.3%	25.8%	28.6%	34.6%	43.3%
	Others	4.4%	4.2%	15.8%	9.7%	0.0%	0.0%	0.0%
Practicing years	>=21 yrs.	44.9%	37.5%	47.4%	51.6%	46.4%	42.3%	43.3%
	16-20 yrs.	7.0%	0.0%	5.3%	6.55	14.3%	3.8%	10.0%
	11-15 yrs.	14.6%	16.7%	26.3%	12.9%	10.7%	11.5%	13.3%
	6-10 yrs.	21.5%	29.2%	5.3%	16.1%	17.9%	34.6%	23.3%
	<= 5 yrs.	12.0%	16.7%	15.8%	12.9%	10.7%	7.7%	10.0%
Practice size	Micro	28.5%	25.0%	15.8%	19.4%	35.7%	38.5%	33.3%
	Small	19.6%	8.3%	26.3%	25.8%	10.7%	26.9%	20.0%
	Medium	36.7%	25.0%	36.8%	45.2%	39.3%	23.1%	46.7%
	Large	15.2%	47.1%	21.1%	9.7%	14.3%	11.5%	0.0%
Practices' ability to deliver low/ zero carbon design	Very much	25.9%	29.2%	21.1%	29.0%	25.0%	19.2%	30.0%
	Much	43.1%	41.7%	36.8%	45.2%	46.4%	46.2%	40.0%
	Some	27.2%	25.0%	36.8%	25.8%	25.0%	34.6%	20.0%
	A little	3.8%	4.2%	5.3%	0.0%	3.6%	0.0%	10.0%
	Not at all	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Among the 161 participants, 77.1% were males while 22.9% were females.

45.6% of the participants were principals, 17.1% were associates, 32.9% were architects and assistant architects and 4.4% were others (including architectural technicians and planners). According to a crosstab analysis, the position of the participants was compatible with the number of their practicing years.

Architectural practices were spread evenly in terms of the size of the practices. 28.5% of the participants were from micro practices (1-5 staff), 19.6% were from small practices (6-10 staff), 36.7% were from medium practices (11-49 staff), while 15.2% were from large companies (50 or more staff).

The geographical distribution of the participating architects was quite even. 15.2% of the participants were from the practices in London, 12.1% were from North East and North West, 19.6% were from Yorkshire and the Humber, East Midland and West Midland, 17.7% were from Wales, 16.4% were from East and South East, while 19.0% were from South West.

96.2% of participants indicated their practices could deliver projects with integrated low/ zero carbon design strategies, while 69% of the participating architects thought their practice could deliver low/ zero carbon design well. Whether this result reflected the real condition will be discussed in Chapter Nine.

8.2 Architects' attitude and experience regarding low/ zero carbon design and low/ zero carbon design training programmes

8.2.1 About low/ zero carbon design

In terms of the importance of low/ zero carbon design, the majority of the participating architects (91.8% = 49.4% + 42.4%) agreed that the low/ zero carbon design concept was important in current construction industry (Figure 8-1).

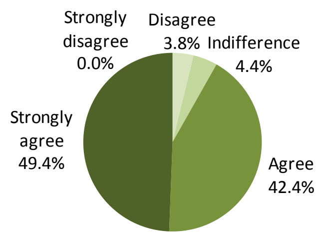


Figure 8-1: Participating architects' opinion on the importance of low/ zero carbon design

It was perceived that less than half of these architects (45.4% = 8.7% + 19.9% + 16.8%) indicated that they had learnt low/ zero carbon design at college (Figure 8-2). A higher percentage of architects with less years in practice tended to have learnt about low/ zero carbon design at college, while architects with more than 20 years practicing experience (attended college earlier than the 1990s) had a lower response to have learnt about the subject, as sustainability did not widely attract attention at that time.

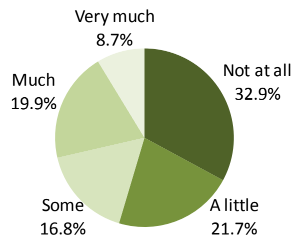


Figure 8-2: To what extent did the participating architects learn about low/ zero carbon design when they were at college

The architects were learning low/ zero carbon design through many routes, particularly journals and magazines (32.7%), online information (23.1%), work experience (23.1%) and training programmes (21.2%) (Figure 8-3).

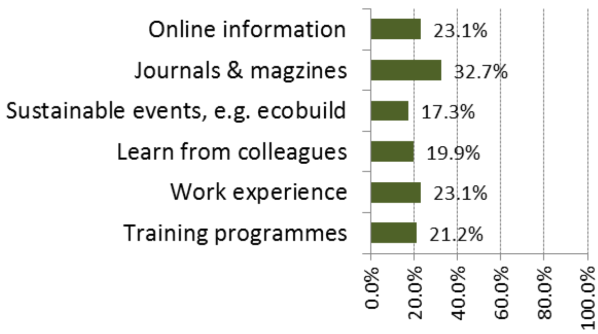


Figure 8-3: The main sources for the participating architects to learn about low/ zero carbon design

Most of the architects (91.8% = 22.6% + 48.4% + 20.8%) suggested that they were capable of low/ zero carbon design to a certain extent, and 22.6% of them were very confident to integrate low/ zero carbon design to their projects (Figure 8-4).

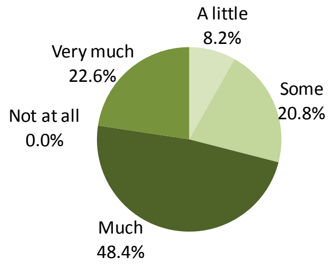


Figure 8-4: To what extent are the participating architects are confident to deliver low/ zero carbon design

More than half of the participants (57.6% = 29.1% + 28.5%) indicated that they applied low/ zero carbon design to more than half of their projects, while 29.1% of the participating architects applied it to all of their projects (Figure 8-5).

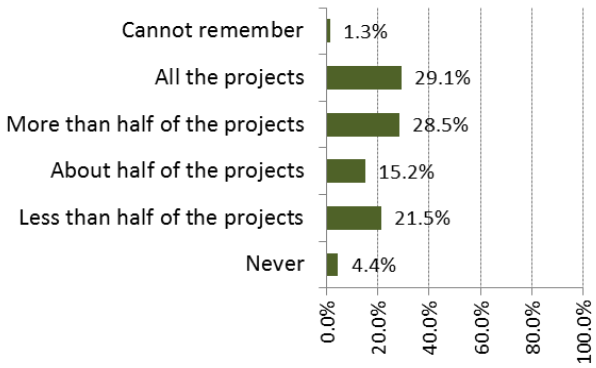


Figure 8-5: How often the participating architects apply low/ zero carbon design

The design categories where low/ zero carbon design strategies applied the most included building fabric (85.2%), efficient building services (76.6%), site planning (76.3%) and building form (75.0%). Climate analysis and waste management were the least applied strategies. One participant stated that they knew the local weather data so well that it was not necessary to conduct climate analysis (Figure 8-6).

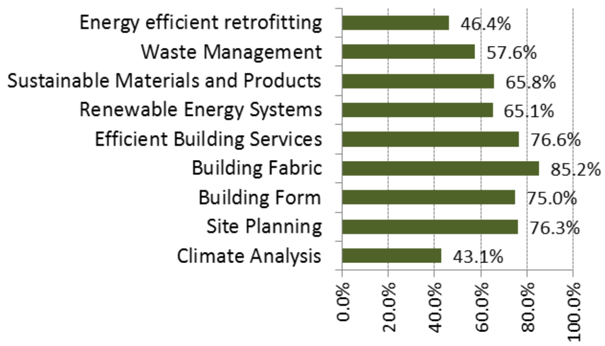


Figure 8-6: The design categories where low/ zero carbon design strategies applied the most

Regarding the barriers that stopped the architects applying low/ zero carbon design, two major factors were recognized: 1) lack of client's support and 2) a tight project budget (Figure 8-7).

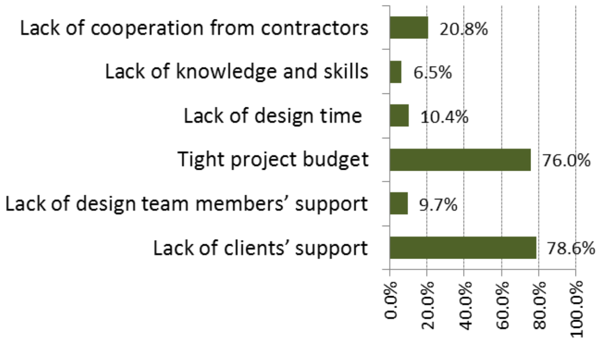


Figure 8-7: The main barriers of low/ zero carbon design application

8.2.2 About low/ zero carbon design training programmes

In terms of the importance of low carbon design training programmes, the majority of the participating architects (91.2% = 28.3% + 62.9%) recognized the necessity of low/ zero carbon design training programmes in their work (Figure 8-8).

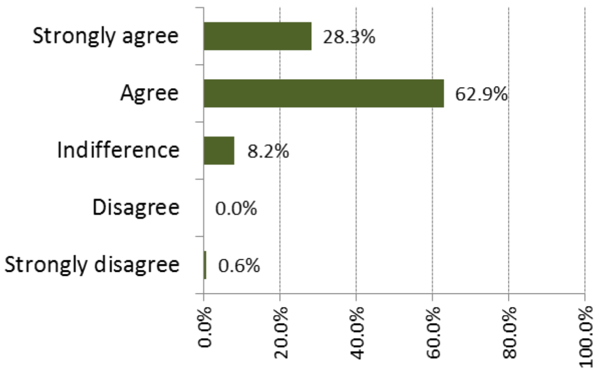


Figure 8-8: Participating architects' opinion on the importance of low/ zero carbon design training programmes

However, less than half of the participating architects (45.1% = 10.3% + 7.1% + 27.7%) attended more than seven hours of low/ zero carbon design training programmes last year, while 13.5% of them did not attend any low/ zero carbon design training in last year (Figure 8-9).

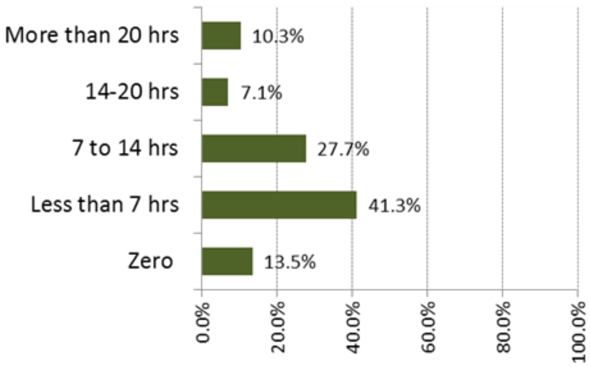


Figure 8-9: Participating architects' participation in low/ zero carbon design training programmes in last year

80.3% (= 2.9% + 27.7% + 49.6%) of the architects who attended low/ zero carbon design training programmes last year indicated that the low/ zero carbon design training programmes they attended met their requirements to some degree, but only 2.9% answered total satisfaction (Figure 8-10).

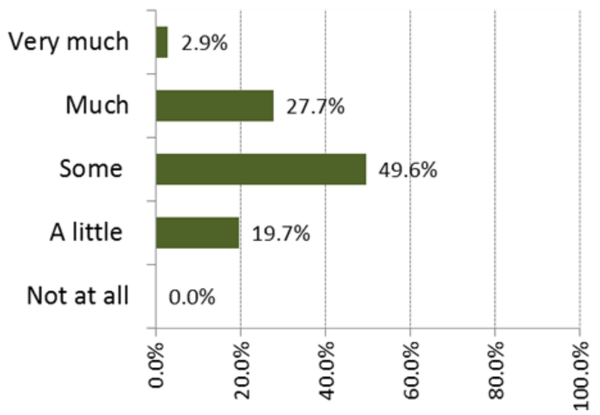


Figure 8-10: Participating architects' satisfaction with the low/ zero carbon design training programmes

Fee, travel distance and type of handouts were the main factors that the participants disliked. While, content, accreditation, presenters and delivery method were the aspects that the participants liked the most. More importantly, the result indicated how the participating architects ranked the relevant issues of training programmes. From the most important to the least important the list was: content, fee, accreditation, presenter, delivery method, travel distance, handouts type, venue location, length of the programme, and delivery time. They were most indifferent to other participants' profession and the number of other participants (Figure 8-11).

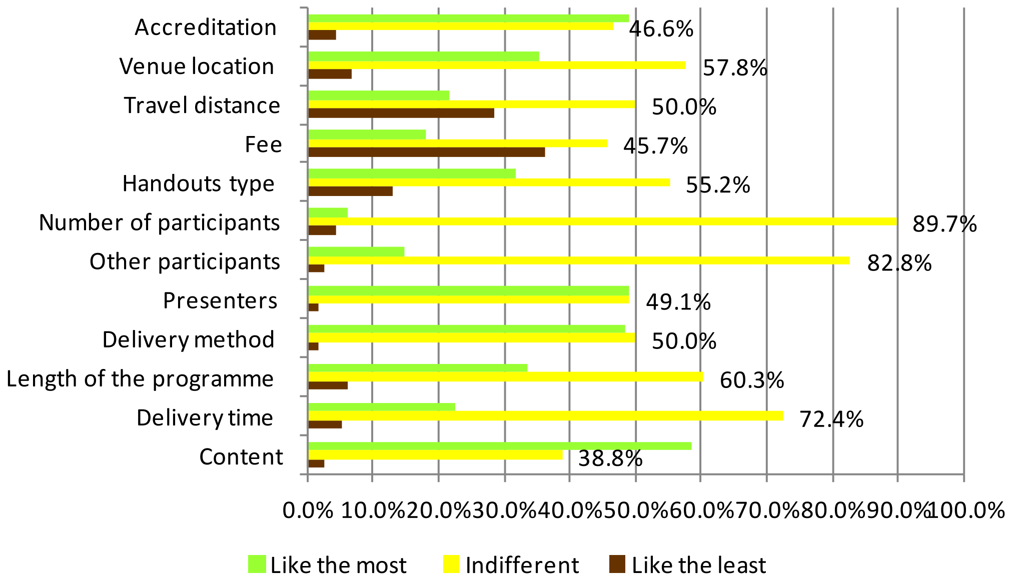


Figure 8-11: Participating architects' evaluation of existing low/ zero carbon design training programmes

8.3 Content of low/ zero carbon design training programmes

8.3.1 RIBA work stages A and B

The majority of participating architects (91.6% = 49.0% + 42.6%) agreed that setting low carbon design as one of the design goals at the beginning stage was important, while 81.3% (= 16.1% + 65.2%) of the architects evaluated that they were confident to do so (Figure 8-12).

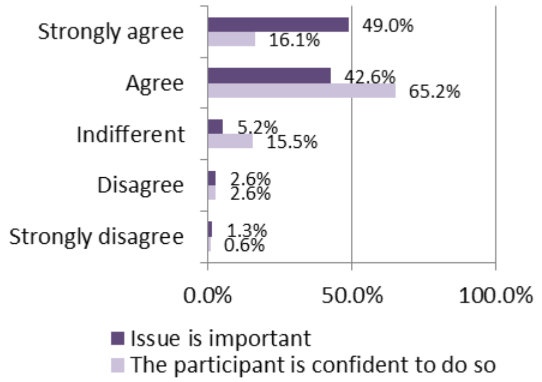


Figure 8-12: Setting low carbon as one of design goal at the beginning stage

Most of the participants (95.5% = 48.4% + 47.1%) agreed understanding Building Regulations and design guidelines about energy efficiency was important, while 87.1% (= 31.6% + 55.5%) thought they were confident to do so (Figure 8-13).

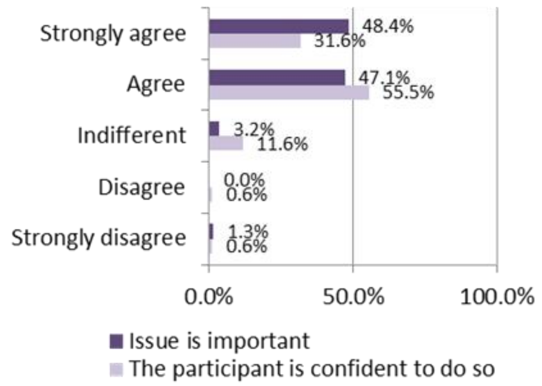


Figure 8-13: Understanding Building Regulations and design guidelines

Regarding the low/ zero carbon design standards and guidelines, SAP/SBEM, Code for Sustainable Homes, and BREEAM were more commonly applied than PASSIVHAUS and LEED. However, 71.7% of architects expressed that they would like to learn about PASSIVHAUS (Figure 8-14).

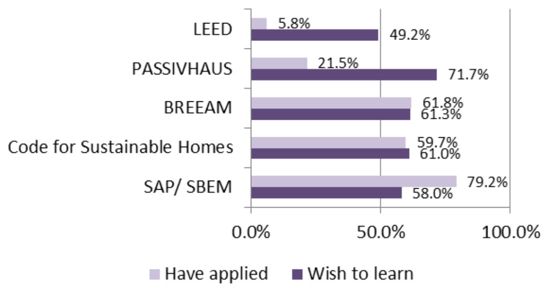


Figure 8-14: Participating architects' experience and attitude towards low/ zero carbon design standards and guidelines

8.3.2 RIBA work stages C, D, E and F

Three interlinked questions were asked to define to what degree praticing architects need to learn about low carbon design. For all seven components derived from the low/ zero carbon design model, architects expressed their views on the importance of these components and their capability of applying the design strategies. Building fabric, site planning, efficient building services and building form were the four most important components recognized by participating architects. They thought they were confident in applying low/ zero carbon design strategies related to building fabric, building form and site planning.

By comparing the architects' opinion on the importance of each component, and their evaluation of their ability to apply these components, efficient builing services, construction materials and products and renewable energy systems were the components that architects would like to learn about (Figure 8-15).

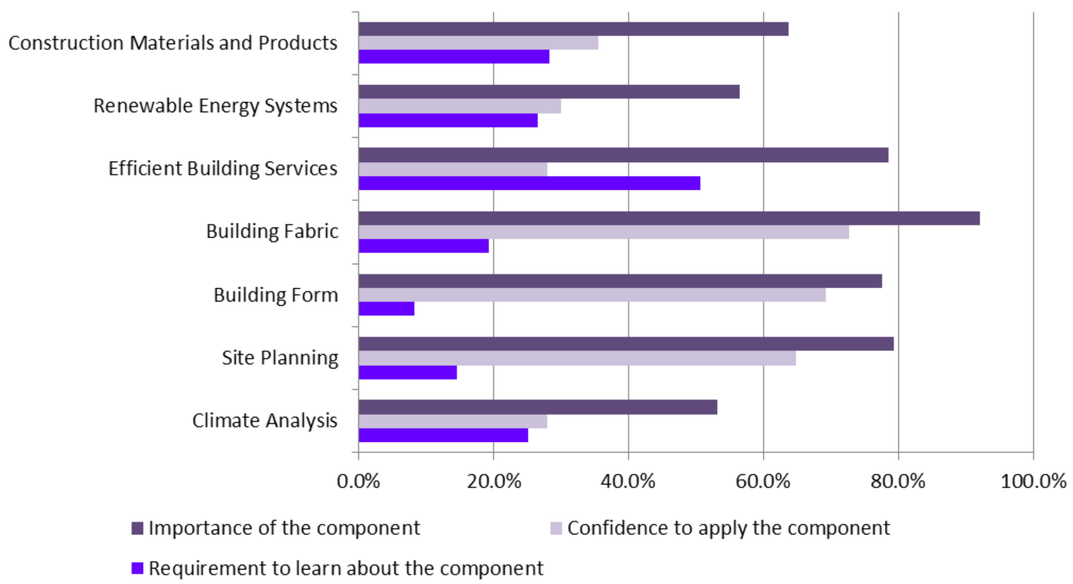


Figure 8-15: Participating architects' opinion on each component of low/ zero carbon design

In terms of using computer assisted building simulation to help make design decision for low/ zero carbon design, 76.2% (= 60.5% + 15.7%) of the participating architects agreed on its importance, and only 25.6% (= 23.0% + 2.6%) of them were confident to apply simulation (Figure 8-16). Some participating architects mentioned that it should be M+E engineers' responsibility to use these tools.

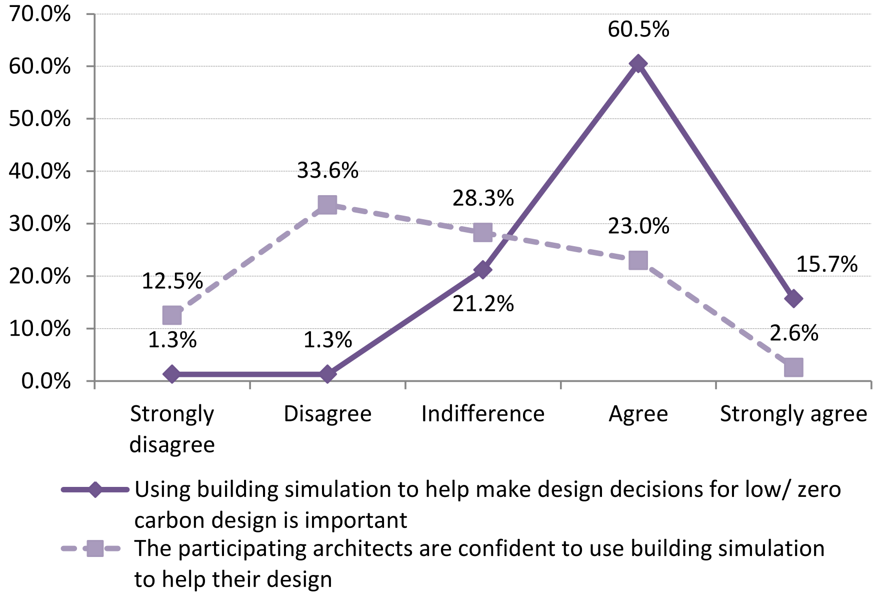


Figure 8-16: Participating architects' opinion on building simulation

Regarding different computer assisted simulation tools, Ecotect and IES can be recognized as more popular tools as more architects used these software packages than the others: 21.0% of architects used Ecotect, 22.4% used IES, 7.7% used Energy Plus, 2.1% used ESP-r and 4.2% used HTB2. More than 70% of the architects expressed that they would like to learn more about these tools to a certain degree (Figure 8-17). No obvious preference of particular software was recognized.

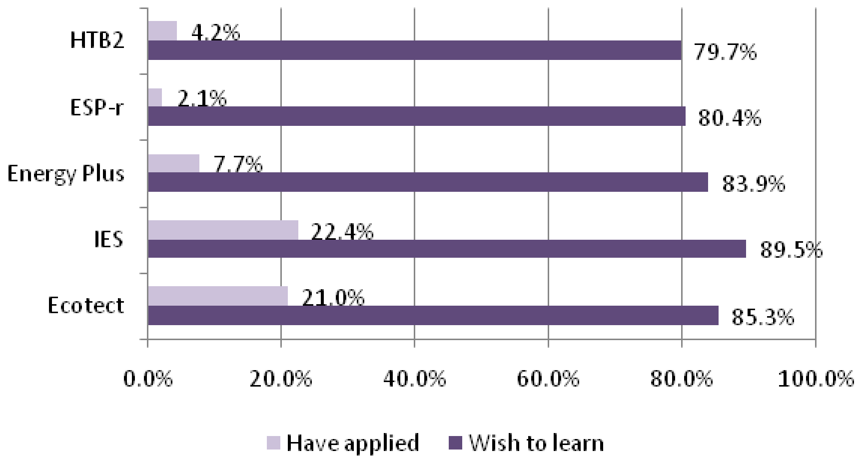


Figure 8-17: Participating architects' opinion on different simulation software

8.3.3 RIBA work stages G, H, J, K, L and M

Regarding the three issues in construction and handover stages, 1) validating the method statements for waste and resource management with the main contractors, 2) carrying out proper commissioning and briefing the occupants and the building managers and 3) carrying out feedback studies to analyse the real performance of the building in order to benefit future projects; the participating architects gave a high evaluation of the importance of these issues. 69.9% (= 51.4% + 18.5%), 93.2% (= 46.6% + 46.6%) and 89.9% (= 48.6% + 41.2%) of the sampled architects agreed that these issues were important respectively. Even though the importance of these issues was recognized, there was a clear drop in percentage regarding the confidence to carry them out. The expressed confidences to deliver these issues were 24.7% (= 19.6% + 4.1%), 46.6% (= 36.5% + 10.1%), and 27.7% (= 20.9% + 6.8%) respectively. Significant rises in the category of 'indifference' can be observed which indicated that some of the architects did not think these issues were their responsibility. Figure 8-18 summarizes these trends.

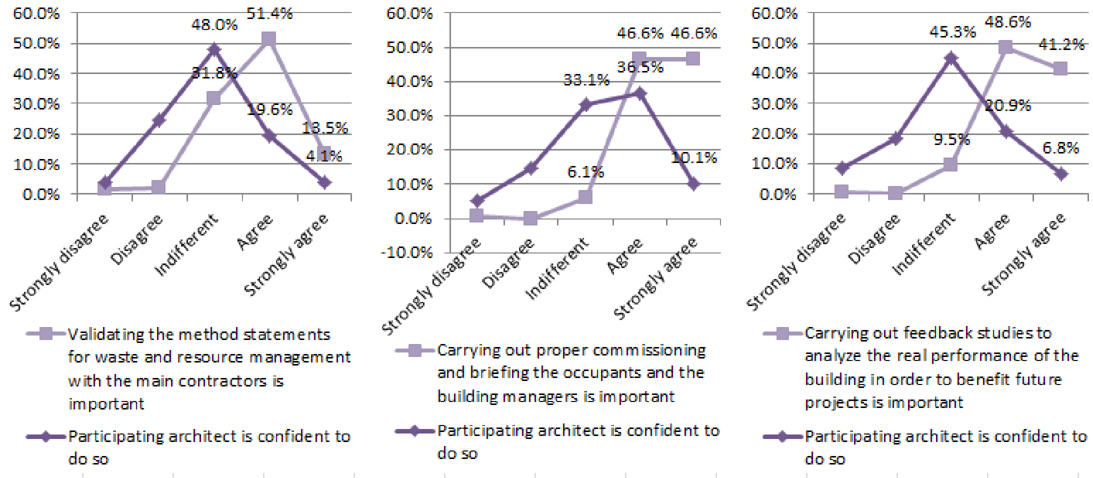


Figure 8-18: Participating architects' opinion on waste management, commissioning and feedback studies

8.3.4 Contents of low/ zero carbon design training programmes

Participating architects indicated that efficient building systems, materials and products for low carbon design, specific passive design strategies, low carbon design regulations and standards and renewable energy systems were the most required topics (Figure 8-19). However, validating waste and resource management, global issues, and drivers and policies of low carbon design were the least favourable topics among the participating architects.

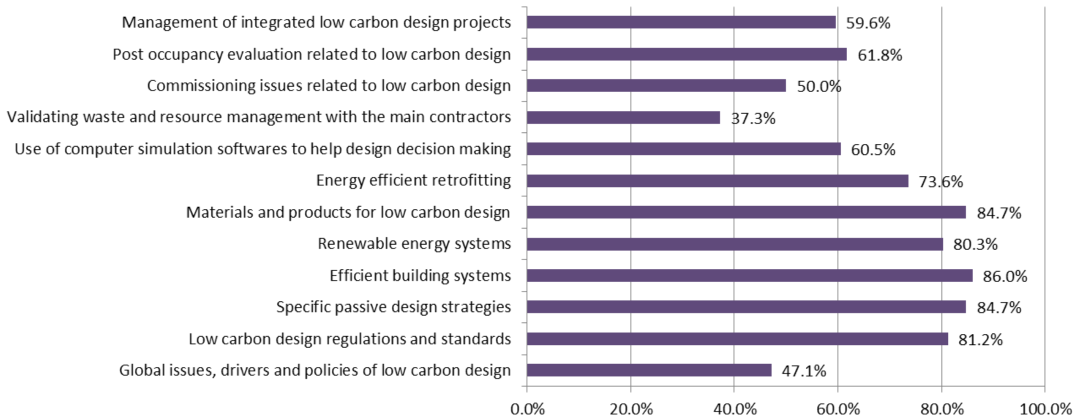


Figure 8-19: Issues in low/ zero carbon design that participating architects were interested in learning about

8.4 Dissemination approach of low/ zero carbon design training programmes

8.4.1 General delivery factors

In terms of **the type of training programmes**, more than half of the participating architects indicated that a short daytime school was most preferable (59.0%), followed by a shorter version of an evening school (41.7%), a longer version of an evening school (33.0%) and a shorter version of a weekend school (33.0%) (Figure 8-20). Summer school and longer version of weekend school were the least favourable types with 79.8% of the participating architects indicating they do not want it at all.

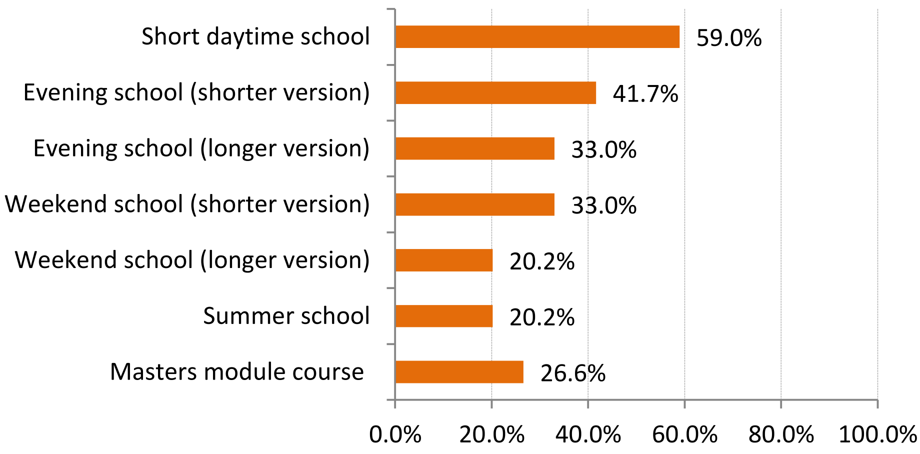


Figure 8-20: Participating architects' preferred types of low carbon design training programmes

As for the short daytime school, a one day course (49.0%), a full morning course (46.2%), a two hour after work course (45.2%) and a full afternoon course (44.2%) were preferred (Figure 8-21). Participating architects also mentioned that they would like to have short programmes during lunch time due to their busy work schedule.

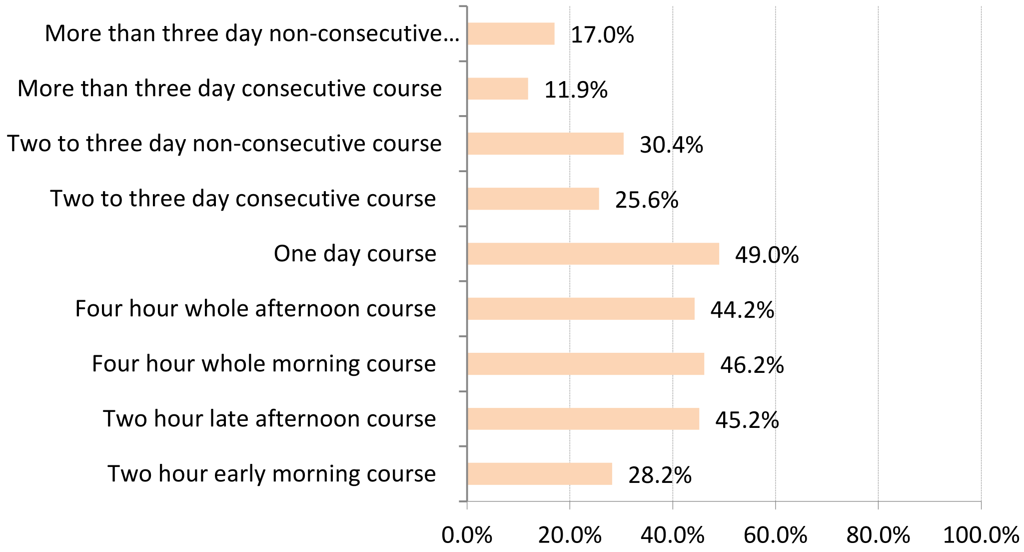


Figure 8-21: Participating architects' preferred types of short daytime low carbon design training programmes

In terms of **delivery methods**, 58.6% of the participating architects preferred lectures and workshops (Figure 8-22). However, strategic consultancy (5.1%) and conference (9.6%) were the least favourable types.

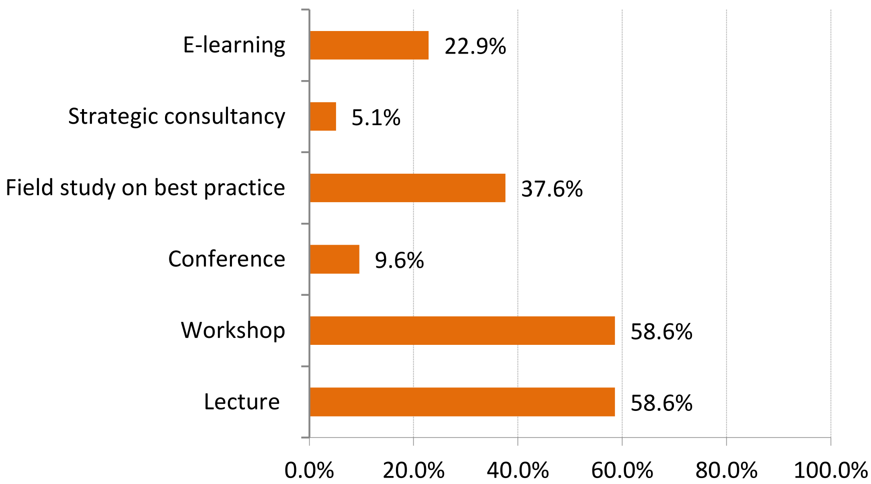


Figure 8-22: Participating architects' preferred delivery methods for low/ zero carbon design training programmes

Regarding the **preferable presenters**, architects and other professionals in the design team practicing low carbon design were more preferable, and achieved support from

72.9% and 67.7% of participating architects respectively (Figure 8-23). Some of the participants mentioned that practicing experience was what they were looking for.

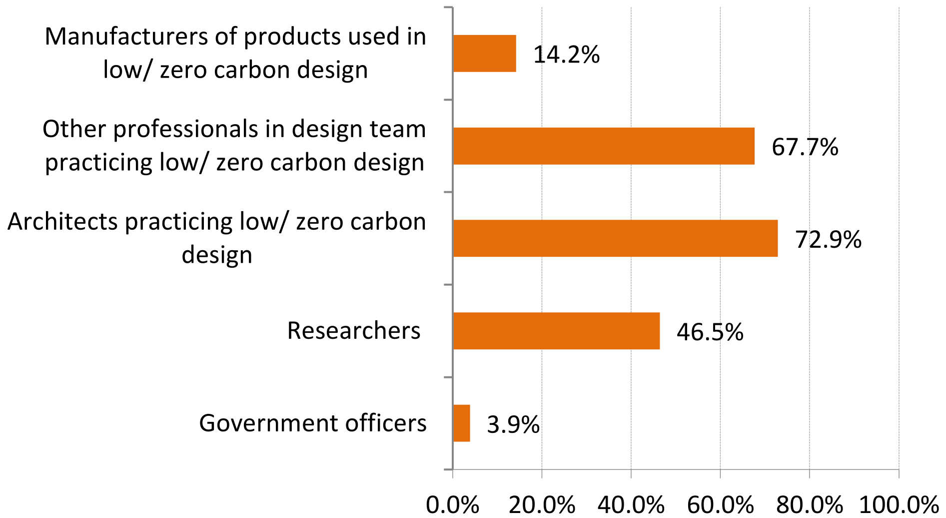


Figure 8-23: Participating architects' preferred presenter for low/ zero carbon design training programmes

In terms of **attendees** that participating architects preferred to go to low carbon design training programmes together with, mixed professionals in the design team sharing similar experience on low carbon design were favourable (Figure 8-24). 78.7% of participating architects preferred 6 to 20 attendees in a low carbon design training programme, while only one participant would like to take the programme with more than 51 attendees (Figure 8-25).

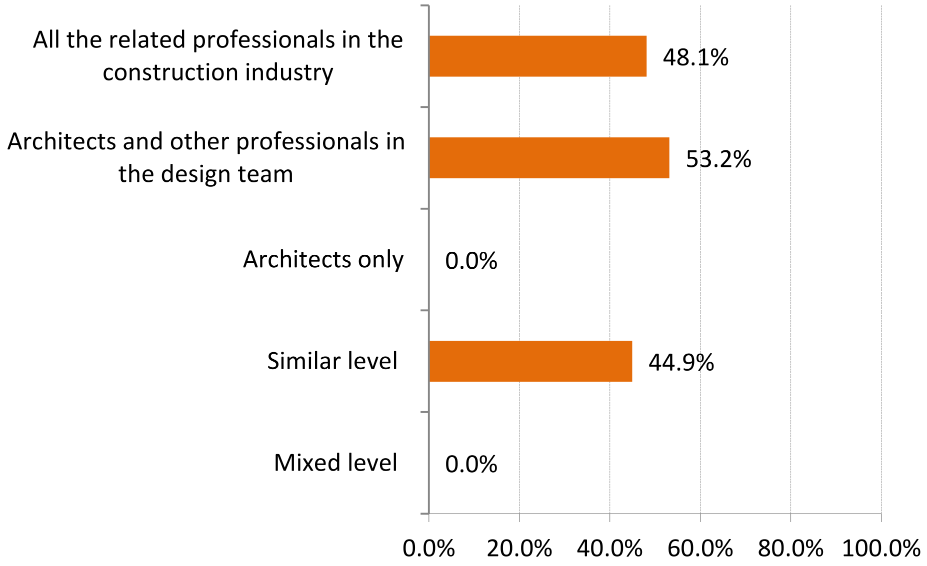


Figure 8-24: Other attendees that participating architects preferred to attend low/ zero carbon design training programmes with

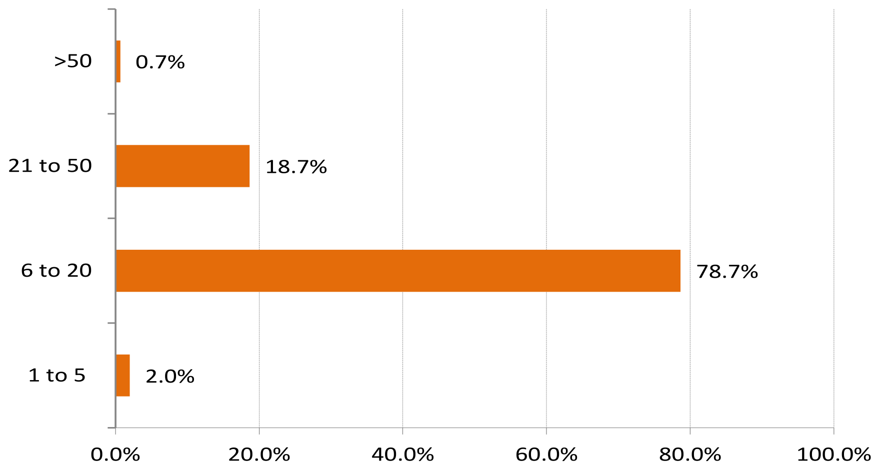


Figure 8-25: Participating architects preferred size of low/ zero carbon design training programmes

In terms of **training materials**, the most preferred type was a website which could be revisited with updated follow up information (40.8%), and the second favourite type was digital files (33.8%) (Figure 8-26). 22.6% of participating architects liked hard copies, while some other architects mentioned they never had time to go through the documents.

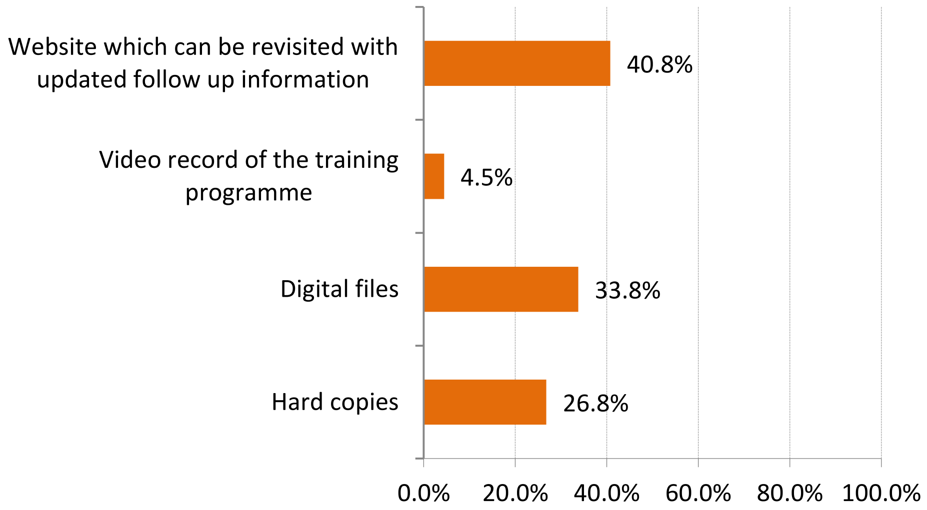


Figure 8-26: Participating architects preferred types of handouts for low/ zero carbon design training programmes

Regarding the **fee** for a one day low/ zero carbon design training programme, 35.9% of the participating architects were prepared to pay 50 to 100 pounds, with another 28.1% could pay up to 150 pounds (Figure 8-27). However, only 6.5% (= 2.6% + 3.9%) of them would pay more than 150 pounds. Some architects mentioned that it was expensive to pay their architects to attend a training programme because the cost was not just the fee, but the costs for travel and the working task assigned to the day.

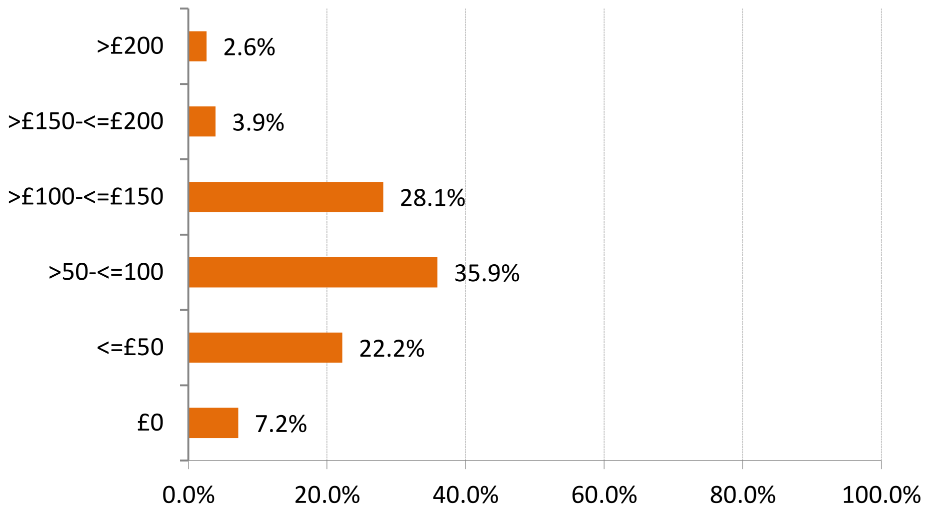


Figure 8-27: The fee that participating architects were prepared to pay for a one day low/ zero carbon design training programme

In terms of **travel distance** (one way), the accepted travel time increased as the length of the training programme increased (Figure 8-28):

- For a two hour training programme, 28.1% of participating architects indicated that less than half an hour travel was acceptable; while another 56.9% of participants were prepared to add another half an hour travel time; however, no one would travel more than one and half hours for a two hour course.
- For a half a day course, 42.5% of participants were prepared to travel for half an hour to one hour; while another 38.6% of architects accepted another half an hour travel time; and only 7.8% (=6.5% + 1.3%) would travel more than one and a half hours to attend a half day training programme.
- For a one day course, the travel time limit could be pushed to two hours. Only 10.5% of participating architects would like to travel more than two hours to attend a one day training programme. 29.4% of participating architects agreed to travel for up to one hour; while another 34.2% accepted another half an hour more travel; and another 22.2% could accept to travel for up to two hours.

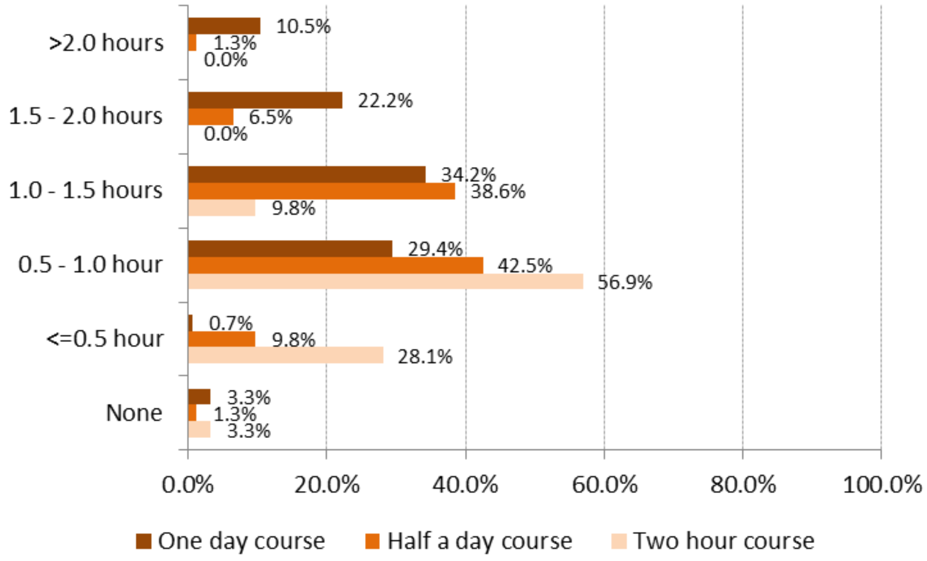


Figure 8-28: The travel time that participating architects were prepared to accept to attend a low/ zero carbon design training programme

Regarding the **location**, 75.8% (= 33.1% + 42.7%) of participating architects would like a location holding low/ zero carbon design training programmes where public transportation was available (Figure 8-29).

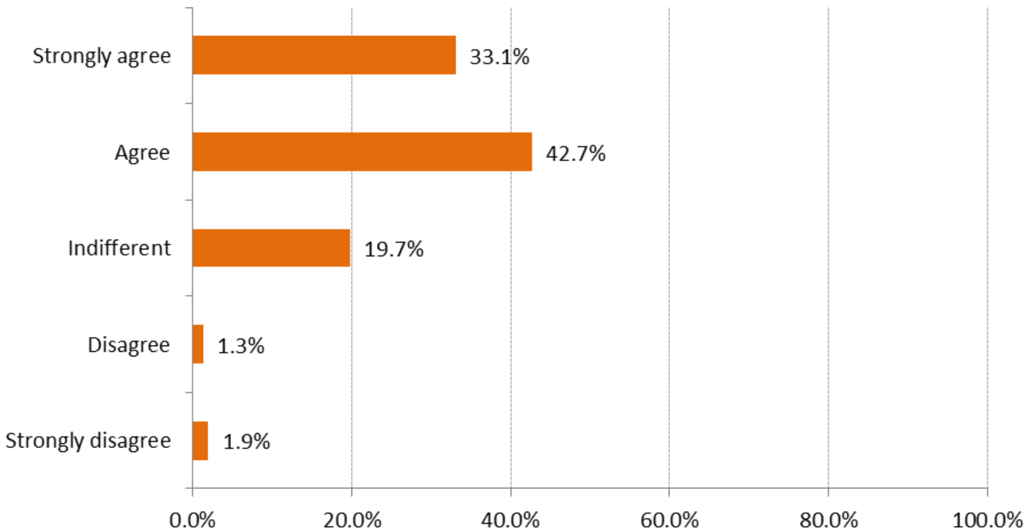


Figure 8-29: Architects' preference on location where public transportation is available

8.4.2 Architects' preferred learning styles and characteristics of adult learning

In terms of learning style, 52.6% of participating architects indicated that they were pragmatists, who learnt best when there was an obvious link between the subject matter and a real life problem and there was an immediate chance to try out and practice techniques learnt. 5.8% of participating architects indicated they had more than one preferred learning style (Figure 8-30). However, the rest of the architects preferred different learning styles.

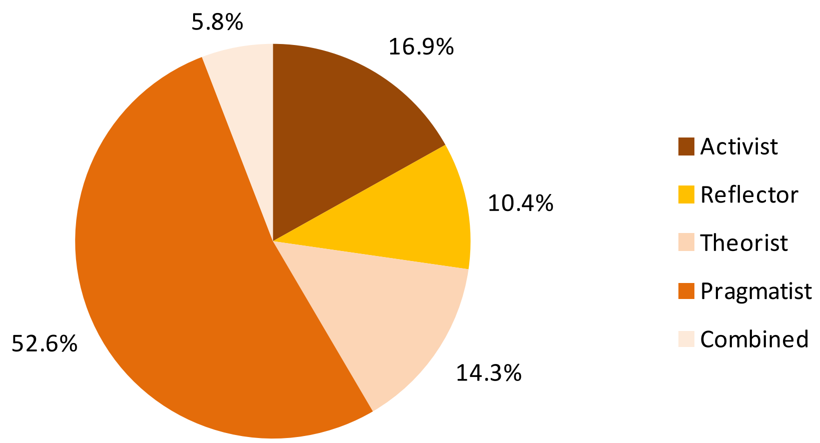


Figure 8-30: Participating architects preferred learning styles

Regarding the hypotheses of adult learning, the participating architects' overall attitude was positive (Figure 8-31). The hypotheses in the model that the majority of architects agreed upon include: raising interests and awareness is important for training programmes, starting point of the training should be based on architects' experience, specific techniques (knowledge) are desired from training programmes, and the content should be relevant to their work. On the other hand, most of the architects (62.1%) did not consider 'being involved in the planning of the methods and curricular directions for the future training programmes' to be important.

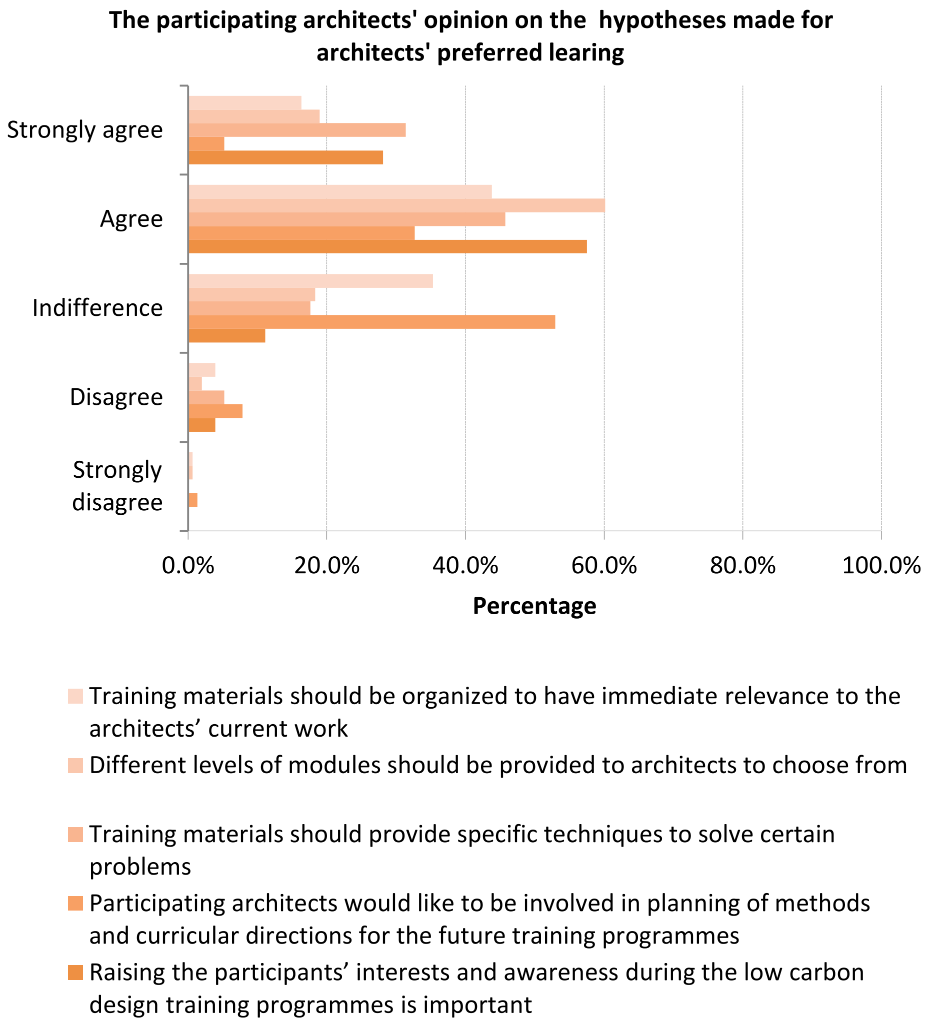


Figure 8-31: Participating architects’ opinion on the model of architects’ preferred learning system

The majority of participating architects indicated that the main drivers for them to attend low carbon design training programmes were to update knowledge required during practice (85.4%) and personal interest (67.1%), compared to 24.7% to obtain CPD credit, 9.5% to obtain a specific certificate and only 4.4% to obtain a higher level of qualification (Figure 8-32).

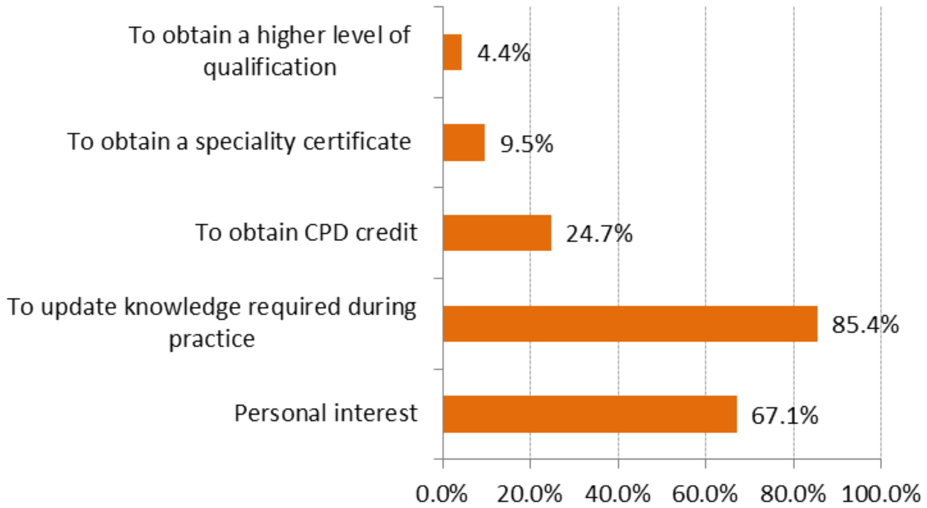


Figure 8-32: Main drivers for participating architects to take low/ zero carbon design training programmes

If accreditation was available, 76.9% of participating architects indicated they would like to receive CPD credit as the accreditation, while 12.8% of the architects did not expect any accreditation (Figure 8-33).

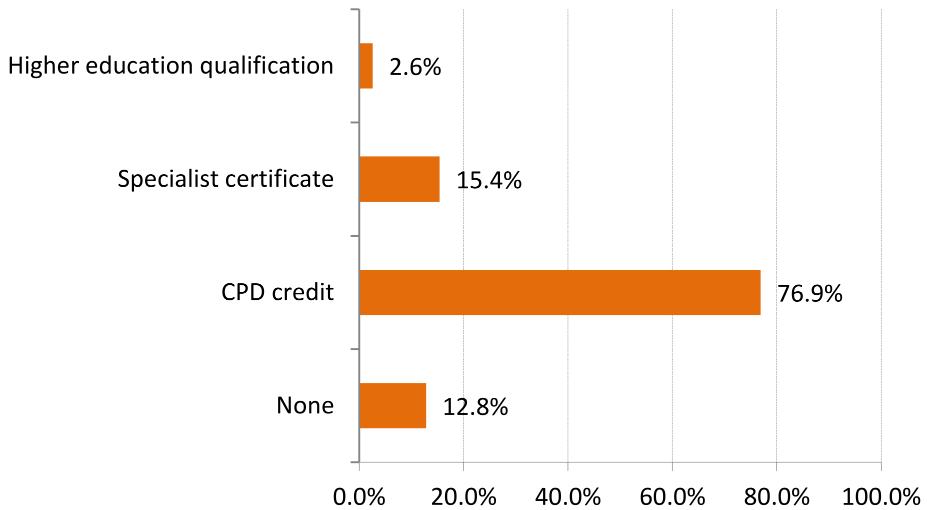


Figure 8-33: Participating architects preferred accreditation for attending low/ zero carbon design training programmes

8.5 Limitations of the questionnaire survey

The main limitation of the nationwide questionnaire survey is the lack of methods to test architects' real knowledge and skills of low/ zero carbon design. The questionnaire survey aimed to understand architects' current knowledge and skills of low/ zero carbon design, then the knowledge and skills gap can be identified. And the training programmes can be developed to disseminate these knowledge and skills. However, it was not a straight forward task to identify the gap. There was a difficulty to differentiate between the participants' subjective perception of their knowledge and skills, and their actual knowledge and skills. The reason was that architects were unaware of their lack of the overall understanding of low/ zero carbon design. It had been considered to include questions to test architects' real understanding of low/ zero carbon design, but this would end up with a long questionnaire, which might make the architects reluctant to participate the survey. What is more, including only one question regarding the definition of sustainable design was tested in the surveys for the case studies. However, it was realized that the general definition could not provide further interpretation. Participants tended to choose the most extensive definition, while the answer had no indication of their intention or ability to deliver the design. Finally, questions that asked the participants to provide opinions from different angles to the same topic had been developed to help understanding participants' real situation, including whether the low/ zero carbon design strategies in each design category are important, whether they are capable of applying these design strategies to their projects, and whose responsibilities it is to take care of the implementation of these design strategies. But architects could only judge their ability to apply low/ zero carbon design strategies in accordance to their own understanding. The lack of support to justify architects' awareness of low/ zero carbon design was recognized.

If without the restrictions of cost and time, follow-up face to face interviews would be carried out with some of the participants after the questionnaire survey.

8.6 Summary

This chapter analyzed the data collected by the nationwide questionnaire survey and presented the origin results, including the sample, architects' attitude and experience regarding low/ zero carbon design and the associated training programmes, architects' required content of low/ zero carbon design training programmes and their learning preference. It prepared to answer the two research questions regarding developing low/ zero carbon design training programmes for architects in practice.

Chapter 9. The research results and discussion

This chapter summarizes the results of the nationwide survey. It discusses the main findings in a broader context in three aspects:

1. Architects' current position in relation to low/ zero carbon design
2. The required content of low/ zero carbon design training programmes
3. Architects' learning preference

In addition, the survey results are added to the revised models, and the final model of low/ zero carbon design and the final model of architects' learning preference are established. The implications of the two models are discussed.

9.1 Architects' current position in relation to low/ zero carbon design

The nationwide survey results (Figure 8-1) suggested that the majority of the participating architects agreed that the low/ zero carbon design concept was important in current construction industry. Most of the architects suggested that they were capable of conducting low/ zero carbon design to a certain extent, but less than a quarter of the architects were very confident to integrate low/ zero carbon design into their projects (Figure 8-4). More than half of the participants indicated that they applied low/ zero carbon design to more than half of their projects, while less than one third of the participating architects applied it to all of their projects (Figure 8-5). Building fabric, efficient building services, site planning and building form were the main design categories where architects were confident to conduct low/ zero carbon design strategies (Figure 8-6). Regarding the barriers that stopped the architects delivering low/ zero carbon design, two major factors were identified: 1) the lack of client's support and 2) a tight project budget (Figure 8-7).

The nationwide survey identified that less than half of these architects had learnt low/ zero carbon design at college (Figure 8-2); and journals and magazines, online information, work experience and training programmes were the current sources to learn about low/ zero carbon design (Figure 8-3). The majority of the participating architects recognized the value of low/ zero carbon design training programmes for their work (Figure 8-8). However, less than half of the participating architects attended more than seven hours of low/ zero carbon design training programmes in the last year, while more than one tenth of them did not attend any low/ zero carbon design training at all (Figure 8-9). The majority of the architects who attended low/ zero carbon design training programmes indicated that these low/ zero carbon design training programmes met their requirements to a certain degree (Figure 8-10).

Three interesting points regarding architects' current position in relation to low/ zero carbon design were revealed in the survey results. They will be discussed in the following sections.

9.1.1 Architects' acknowledgement of the importance of low/ zero carbon design and their lack of commitment

The nationwide survey results suggested that the majority of architects in practice agreed on the importance of low carbon design in current construction industry. They also indicated that they were confident in their ability to deliver low/ zero carbon design to a certain degree. However, most of the participating architects stated that they did not have the experience to apply low carbon design strategies to many of their projects.

Similar results were noted in a global survey regarding the awareness, knowledge and requirements of sustainable environmental design among architectural firms conducted by the EDUCATE programme (EDUCATE Project Partners 2010). Among the 33 participants in the UK, the majority of the participants indicated that they were conscious about sustainable environmental design, and sustainable environmental design was key to their design approach, and it provided a creative input and inspiration to their design. Most participants agreed that sustainable environmental design should be included in the curriculum of architecture education, and competence in sustainable environmental design should be required for professional registration.

A report to explore the vision for the construction industry from 2020-2050 was published by the Low Carbon Construction Innovation & Growth Team in 2010. It described a situation where British architects, engineers and other consultants were working at home and abroad, earning the UK a reputation as leaders in sustainable design; while construction companies and specialist contractors were putting sustainability at the very core of their own businesses to deliver the buildings and infrastructure to support greener ways of living (HM Government 2010).

The results of this survey were optimistic, but whether this optimistic data regarding architects' current position in relation to the low/ zero carbon design reflected the reality of the construction industry needs further investigation. A similar survey was conducted among 650 Australian architects with a response rate of 62%. The results suggested that architects shared a common agreement on the benefits of energy efficient design, but they had low levels of commitment towards incorporating the energy efficient design features in their projects (Wittmann 1998). Wittmann (1998) reported one possible reason which was that most architects did not perceive energy efficient design as important enough to place it high on the list of factors to define good architecture. Seidel et al. (2006) reported the results from a study of a survey conducted in the UK in 2005 with a sample size of 1200 and a response rate of 51%. The results confirmed that client satisfaction, visual aesthetics and function were the most important aspects for architects, while sustainability was at a lower level on the list.

As mentioned in the sample description, the majority of the participants were principals of architectural practices. Wittmann's research (1998) suggested that the respondents' position in an architectural firm did not influence their level of commitment.

In summary, this research showed that architects lacked commitment to low/ zero carbon design even though they agreed on the importance of low/ zero carbon design. The main reason was that traditional factors were still dominant, such as cost, aesthetic and functional factors. So it is important to investigate how to integrate low/ zero carbon design into projects within the traditional considerations of cost, aesthetic aspects and function. Low/ zero carbon design training programmes should be a channel to demonstrate the integration of low/ zero carbon design with clients' satisfaction, and disseminate the related knowledge and skills to architects.

9.1.2 Main barriers to low/ zero carbon design: the lack of clients' support and a tight budget

The survey results indicated that the lack of clients' support and a tight project budget are the main barriers for architects to deliver low carbon buildings. These two barriers were closely related.

The EDUCATE project reported that the priority for clients in the design brief and requirement was the reduction of investment and capital cost, out of factors including energy efficiency, reduction of carbon emissions, aesthetical appearance, occupant comfort and well-being, financial incentives and ecological/ ethical issues (EDUCATE Project Partners 2010). An industry-wide survey of 200 leaders in contractor and consultant organizations in the UK construction industry was conducted by Opoku and Ahmed (2014), and the results revealed that the increased capital cost was the most significant challenge facing construction organizations in attempt to adopt sustainability practices. With the potential of larger investment, longer payback time and risky non-traditional strategies, some clients tended to choose the conventional approach. The Energy Efficiency in Built Environment (EEBE) established six categories of barriers to energy efficiency in the building industry, namely technological, organisational, information, cultural, economic and political issues. The lack of affordable energy efficient technologies suitable for local use and the emphasis on reducing capital rather than life-cycle cost explained why a tight budget was perceived as a barrier (EEBE 2011).

As for the lack of clients' support, Fuller et al. (2008) provided five options for architects who were facing a client who wanted a normal building without considering any sustainable features: 1) reject the client, 2) confront the client and seek design changes or compromises, 3) confront the client and ask for an offset, 4) do not confront client and seek design changes or compromises, and 5) practice self-selection. In reality, both having enough projects for practice survival and being responsible for the future of our planet should be important for most of practices. None of the above provides an ideal practical solution: the first case can cause practice failure, the second and third cases present the opportunities to educate the clients, the fourth case may end up with the client going elsewhere with worse design, and the fifth case can establish a reputation for sustainable design but with a smaller client base, less earning and limited opportunities to educate. Under current circumstances, architects should choose the feasible options with the awareness of the impact of their choice of design on the planet. Janda (2011) suggested that building professionals, particularly architects, should accept greater responsibility to improve the understanding of the majority of population who use the buildings in relation to the built environment and building performance. Whether there were differences between clients in terms of their commitments to low/ zero carbon design had been explored by other studies. The levels of environmental awareness and opportunity expressed by private and public clients to consider design solutions that can go beyond simply fulfilling regulatory requirement were recognized as being similar in the UK (EDUCATE Project Partners 2010). Hazam and Greenwood (2009) carried out survey research and the results suggested that only a minority of clients require higher building performance than required by basic compliance either as a marketing opportunity or in fear that energy requirements are tightening before the project is being realized; and these clients tends to be for large scale projects or government funded projects.

Financial incentives have been established to encourage the clients' pursuit of low/ zero carbon design, e.g. the Climate Change Agreements Scheme, the Green Deal, Feed-in Tariffs and the Renewable Heat Incentive in the UK. Also, the mandatory

Climate Change Levy and the Carbon Reduction Commitment Energy Efficiency Scheme have been put into action to push the market towards low/ zero carbon design.

Regarding the project budget, it is a common perception that the application of low/ zero carbon design would lead to additional cost. A costing analysis for four different types of buildings was carried out by the BRE, using real cost data for a broad range of sustainability technologies and design solutions. It demonstrated significant improvements in environmental performance with very little additional cost and major cost savings when in use (BRE 2005). The whole-building budget restrictions were applied for these four buildings, rather than separate budgets for individual building systems. This allowed extra costs for one system with reduced costs for other systems. For example, investment for a shading system can be balanced by the savings made from a cooling system with a smaller cooling capacity, since the cooling load is reduced by the reduction of solar gain. This takes the discussion back to the iterative and holistic design process with collaboration of the design team. Also, changes and improvements in the design process were relatively easy to make at the beginning of the process, but became increasingly difficult and disruptive as the process carried on and were likely to results in only modest gains in performance (Larsson and Poel 2003). This observation can support that the early integration of low/ zero carbon design is essential.

In addition, if more low/ zero carbon projects were developed, it would encourage the innovation of new products and technologies. Noailly (2011) suggested that strengthening regulatory standards would have a greater impact on innovation than energy prices or research support in the building sector. Consequently, more investment would be brought into the development of new products, and the cost of the new products would be reduced due to mass production. More detailed data on the products regarding value, application and monitored performance would be available, which would promote demand as well. Currently, the products on the market tend to be pieces that can be bolted on the building. If these products could be merged to be parts of building materials or construction components, they would be more financially and aesthetically attractive. Examples include roof panels with integrated PV and wall systems with integrated solar thermal collectors.

In summary, the barriers to low/ zero carbon design were associated with the project budget and clients' support, and there were no simple solutions for architects. It is important to tackle these barriers with the consideration of every member in the building industry as well as the population who use the buildings. Financial models can be developed to look into how to attract investment and deliver low/ zero carbon value to the clients with their investment paid back.

9.1.3 Architects' sources of knowledge for low/ zero carbon design

The nationwide survey results revealed that most of the participating architects agreed on the importance of training programmes and attended some low carbon design training programmes. The survey results confirmed that a lot of architects attended the training programmes to update their knowledge or fulfil their personal interests. The majority of the participants who attended low/ zero carbon design training programmes suggested that they were satisfied with the existing training programmes to a certain degree, but spaces for improvement existed. On the other hand, more than one tenth of participating architects did not attend any training in relation to low/ zero carbon design. RIBA (2011b) requires that all the registered architects must carry out at least two hours of study in each of the 10 mandatory topics every year since 2011. 'Climate: Sustainable Architecture' is one of these topics. One of the reasons for the low attendance to the training programmes is that training programmes require more dedicated time and cost comparing to self-directed learning.

The survey results also indicated that low/ zero carbon design was gradually integrated to architectural education in colleges with increasing attention to the environmental issues, climate change and the depletion of energy sources. The survey results identified that journals and magazines, online information, work experience and training programmes were the main sources for architects to learn about the low/ zero carbon knowledge and skills. This was confirmed by the survey carried out by the EDUCATE project that concluded that literature and publication, website and media coverage were the major sources of information for architects (EDUCATE Project Partners 2010). Mackinder and Marvin (1982) reported a similar conclusion that technical and professional journals have a major impact on designers in general planning and design of buildings as well as for continuing technical education.

The survey results of the EDUCATE project also suggested that the general public could be better informed by website and media coverage (EDUCATE Project Partners 2010). Osmani and O'Reilly (2009) indicated that the education of the general public to appreciate the benefits of a low/ zero carbon building was crucial for tackling the cultural barriers to the low/ zero carbon agenda.

In summary, journals and magazines, and online information which could be easily obtained were the main sources that architects used to learn about low/ zero carbon design. Architects also liked to attend a training programme to update their knowledge related to low/ zero carbon design, and dedicated time and higher cost were the drawbacks. Therefore, how to combine the platforms of journals, magazines and websites with training programmes to disseminate systematic knowledge and skills of low/ zero carbon design to architects is a topic worth investigating. Also, low/ zero carbon design training programmes have a social and cultural function and can provide the opportunities for people to network outside their own unit. The value of such networks should be explored.

9.2 The required content of low/ zero carbon design training programmes

The nationwide survey results suggested that the content of low/ zero carbon design training programmes was the most important aspect of a training programme (Figure 8-11). Combining architects' opinion on the knowledge and skills needed with the identification of their current understanding of low/ zero carbon design (via answers to multi-perspective questions), the results indicated that:

Regarding setting a low/ zero carbon design goal:

Architects were generally aware of the importance of setting low/ zero carbon design as one of the design goals at the beginning of the design stage and they were capable of doing so (Figure 8-12). Also, architects understood the Building Regulations and assessment methods (Figure 8-13), and most of them had the experience to apply SAP/ SBEM to their projects, followed by BREEAM and Code for Sustainable Homes (Figure 8-14). They also expressed their wish to learn more about the relevant low/ zero carbon design standards, especially PASSIVHAUS (Figure 8-14).

Regarding the design stages:

Architects were generally aware of the importance of the passive and active design strategies (Figure 8-15). They were familiar with low/ zero carbon design strategies in the following design categories: climate analysis, site planning, building form and building fabric. They expressed their need to learn about materials and products, efficient building systems and renewable energy systems. Most architects acknowledged the importance of using computer simulation tools to assist in design decision making to achieve low/ zero carbon design (Figure 8-16). No particular simulation tool was identified as the one they preferred to learn about (Figure 8-17).

Some of them expressed their criteria to choose simulation tools, including straight forward, easy to use from the earliest stage and universally accepted; while others thought that simulation should be mechanical engineers' responsibility.

Regarding the design implementation stage:

There was a need to raise the awareness of the importance of waste and resource management in relation to low/ zero carbon design, and architects needed to learn how to do it (Figure 8-18). Also, architects were aware of the importance of carrying out proper commissioning and briefing occupants and building managers, as well as feedback studies to analyse the real performance of the building in order to benefit future projects. They also wished to learn about these two topics.

Three interesting points in relation to the content of low/ zero carbon design training programmes were revealed in the survey results. They will be discussed in the following sections.

9.2.1 The holistic approach of low/ zero carbon design

The nationwide survey results suggested that most participating architects agreed on the importance of low/ zero carbon design strategies in most design categories, except waste and resource management. But their confidence to apply the design strategies to their projects fell behind (Figure 9-1).

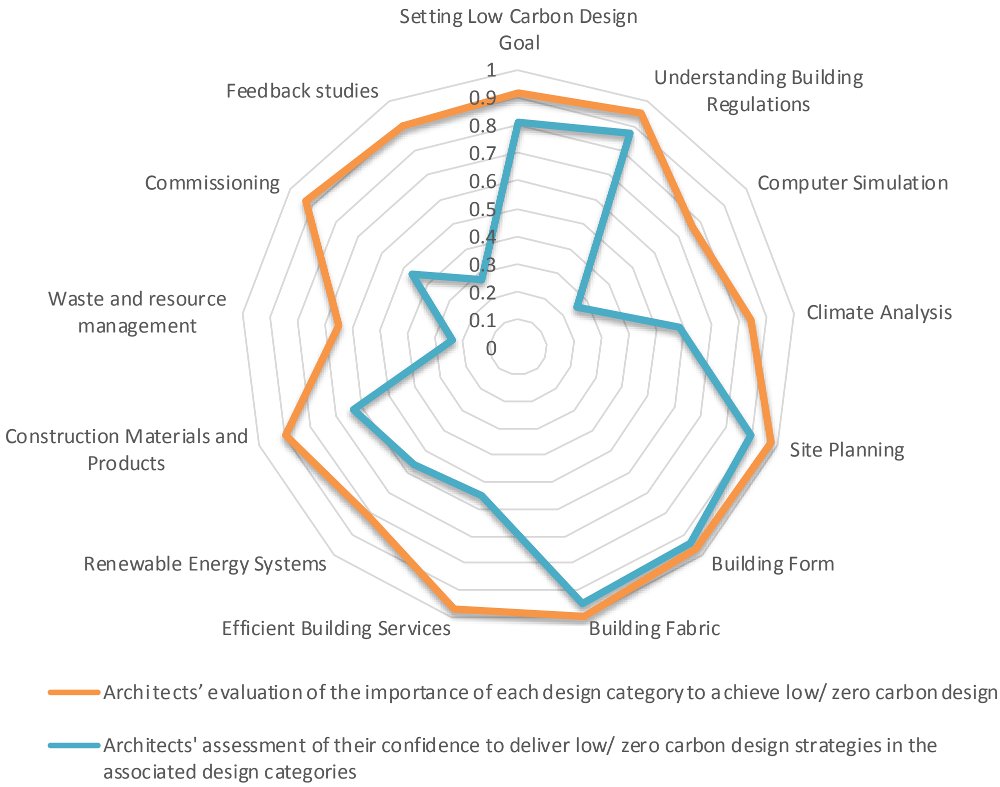


Figure 9-1: The comparison between the architects' evaluation of the importance of each design category to achieve low/ zero carbon design and their assessment of their confidence to deliver low/ zero carbon design strategies in the associated design categories

The majority of the participants realized the importance of setting low carbon as one of design goals at the beginning of a design and they showed sufficient confidence to do so. However, as the design process progressed, the participants' confidence to carry out low/ zero carbon design in certain design categories which are related to the newly developed technologies and techniques dropped, including 'computer simulation to inform design decision making', 'construction materials and products', 'efficient building services' and 'renewable energy systems'. At the same time, architects showed confidence in the delivery of low/ zero carbon design strategies in other design categories which had been a part of architectural design for a long time and regularly applied. These design categories include 'understanding the Building Regulations', 'climate analysis', 'site planning', 'building form', and 'building fabric'. Since the Building Regulations have been updated frequently, trainings to disseminate the updated information are required. In the design implementation stage, architects' confidence to apply low/ zero carbon design strategies decreased in the design categories of ‘waste and resource management’, ‘commissioning’ and ‘post occupancy study’.

It is a good start that architects could set a low/ zero carbon design goal at the very beginning. Kanters et al. (2012) mentioned that early consideration of energy efficiency and collaboration of the design team at the beginning of design phase were recognized as the key to achieve energy efficient projects. The reason was that the groundwork was laid for the entire project during the preparation stage. Clients were in a position to promote the successful collaboration, but Sorrell (2003) suggested that the reduction of design fees would militate against such integrated approach.

A survey conducted among architectural firms by the EDUCATE project suggested that most participants agreed their practice gave a main priority to sustainable environmental design at all the stages of design, including outline proposal and planning design, scheme design and planning, detailed design, and products and materials specification; especially, all of them agreed on the application in the stage of planning and schematic design (EDUCATE Project Partners 2011).

However, the implementation of the design in the construction and handover stages seemed to be overlooked. Zuo et al. (2012) also suggested that it was crucial to follow through an integrated design into actual construction activities. ‘Waste and resource management’, ‘commissioning’ and ‘post occupancy study’ were equally crucial stages for the delivery of a low/ zero carbon project. To achieve low carbon buildings was not only about how buildings were designed, but how they were built, commissioned and used (Janda 2011). Commissioning is an important step towards realizing a low carbon project, especially with the increasing complexity of the building systems. There are cases where the clients fails to manage the building services due to inadequate commissioning. Sorrel (2003) suggested that time constraints could impact on building commissioning which could be imposed by a client or caused by contractor overrunning on the construction process and squeezing the time available for commissioning. The key points of the UK Government's Low Carbon Construction Action Plan 2011 reflected similar consideration: 1) aligning design and construction with operation and asset management, 2) advocating the use of the 'Soft Landings' project methodology to encourage user and building management input during the briefing and design development process, and 3) extending post-contract monitoring and feedback through to occupation (HM Government 2011). More recently, both BREEAM and Code for Sustainable Homes introduced a post-construction assessment as an option to achieve higher sustainability levels as well as some criteria relating to building management.

In summary, a holistic approach was essential to achieve low carbon design, from setting the goal of low carbon design at the very beginning of the design to waste and resources management, commissioning and post occupancy study. However, the current effort to achieve low/ zero carbon design tended to be made at the beginning of the design without being carried out to the end of the projects in the construction and handover stages. Therefore, it is necessary to raise architects' awareness of the importance of stages for low/ zero carbon design implementation in the training programmes, and disseminate the associated knowledge and skills. In addition, it is important to explore the factors that would impact on carrying out these tasks, such as time and cost.

9.2.2 Compliance with low/ zero carbon design standards and assessment methods: reactive VS proactive

The nationwide survey results showed that 79.2% of architects had experience in applying SAP/ SBEM to their projects, 61.8% and 59.1% of the participants had the experience in applying BREEAM and Code for Sustainable Homes respectively, and 21.5% and 5.8% of participants had applied PASSIVHAUS and LEED respectively.

The results indicated that most projects were only complied with the mandatory standards rather than seeking to achieve higher but voluntary standards. The most frequently mentioned documents have an impact on design decisions was the Building Regulations (Mackinder and Marvin 1982). A survey conducted by Adeyeye et al. (2007) with a sampling frame of 100 architects and a response rate of 32% to study the current position of UK architects confirmed the same finding that most architects were requested by their clients to only meet the minimum requirements needed to comply with the Building Regulations. Inducements such as energy efficiency awards and innovation in buildings did not produce decisive responses (Adeyeye et al. 2007). Pitt et al. (2009) suggested that financial incentives and the Building Regulations, clients' awareness and clients' demand were the main areas that could force changes towards low/ zero carbon targets. The construction industry is facing pressure to adopt higher standards for low/ zero carbon design. The regularly tightened Building Regulations could cause a project to fail to meet the updated Building Regulations upon completion. DTZ (2012) suggested that around 40% of commercial buildings in the UK could start rapidly losing value as these future energy standards approach unless improvement works were undertaken.

In addition, these assessment methods and compliance tools are not design tools. In order to use the assessment methods to guide a design, a simplified evaluation method for energy efficiency is required. It should allow the designers to estimate the performance based on fewer parameters which are available at the beginning of a project, and to make design decisions in the right direction (Praznik et al. 2013). Due to the possible difference between the results of the simplified method and the actual values calculated, the application of this simplified evaluation method should only applied to identify the energy efficiency strategies at the early design phase.

To summarize, architects tended to be reactive to meet the mandatory low/ zero carbon targets of the Building Regulations, rather than proactive to take responsibility to achieve more carbon emissions reduction and apply higher but voluntary standards. Therefore, it is important to raise the architects' and clients' awareness of the benefits of achieving the higher standards as well as the balance of initial cost and the overall value achieved in higher environmental design standards. On the other hand, the enforcement on low/ zero carbon standards might be needed to reduce the clients' influence on the application of low/ zero carbon design strategies in their projects.

9.2.3 Building simulation to help design decision making

The nationwide survey results suggested that the majority of the architects agreed that building simulation would help design decision making. Only one quarter of the architects suggested they felt confident to carry out simulation, and some participants would like to learn about building simulation with no specific software being recognized.

Building simulation is not a new concept. According to Hong et al. (2000), building simulation began in the 1960s and became a hot topic within the energy research community in the 1970s. While simulation tools have been developed for decades, the barriers to routine use of simulation to support design still exist. The reasons why these simulation tools are not being used to their greatest impact in the construction industry include the need for specialist computing equipment, a steep learning curve, the fear of unrecognised data input errors and a lack of credibility of predictions (Howrie 1995). There also remains a perception that simulation is costly and slow, users lack trust in the outputs and in their ability to interpret results. Crawley et al. (2001) pointed out that compared to simulations, real buildings use more energy, produce less power, have worse controls and have more occupant complaints. There are clear indications that simulation will have a more central role in the design of energy efficient buildings, notably with the adoption of the European Energy Performance of Buildings Directive

(Strachan et al. 2008). Crawley et al. (2000) summarised the main function of building simulation: 1) to inform energy decisions from the earliest stages of design through construction and into operation, 2) to help the design team and owner focus energy-use reduction efforts where they will be most effective, 3) to permit assessment of predicted performance with established benchmarks or project goals, 4) to size renewable energy systems and determine their likely contribution, and 5) to evaluate alternatives through programming, design, construction, operation and retrofit. Also, simulation is much cheaper than constructing a wrong building.

Kanters et al. (2012) claimed when designing low/ zero carbon architecture, architects preferred using a rule of thumb and doubted whether it was the architects' responsibility to perform advanced computer simulation since engineers are considered to have the technical knowledge for data input. Hensen (1994) suggested that building simulation should be employed to make design decisions as it takes into account the complex dynamic thermal interactions between the external environment, building fabric, internal heat gains and the building service systems, and predicts the building energy consumption and the indoor built environment. Building simulation provides the most direct help to the designers, compared to design guide lines or rules of thumb, traditional physical calculation methods and correlation based methods. One of the key points of the UK Government's Low Carbon Construction Action Plan 2011 suggests the need to close the gap between modelled and actual performance of buildings (HM Government 2011).

What is more, there are so many simulation tools available, so which one to choose? Studies have been conducted to compare different simulation tools. However, there is no straightforward way to compare these tools, therefore, it is impossible to conclude that a certain tool is superior to other tools. The overall conclusion of one study comparing EnergyPlus and ESP-r was that it was possible to use different building simulation tools to predict the temperature with reasonable agreement between the tools and reality (Souza et al. 2006). In another study, Lomas (1995) explained that different results in temperatures and energy demand from different simulation tools were caused by the different algorithms for representing the heat transfer from internal surfaces to the room air and different glazing algorithms. In the same study, the Simulation Resolution (SR) was proposed, which is a measure of the uncertainty which may be attributed to the prediction. Knowing the appropriate SR value can lead to more informed design decisions that are made on the basis of program predictions (Lomas 1995). Overall, the main criterion is to match the software capabilities to the objectives of the simulation. Hong et al. (2000) put forward three issues that need to be considered: 1) the purpose of the analysis, 2) the budget, and 3) the availability of facilities. In addition, architects have started writing plugins for common architects' software to improve the design fluidity of low carbon design. As Hetherington et al. (2010) suggested, there is need to develop software which supports and facilitates optimisation of the building design as the design.

To summarize, architects realized the importance of computer simulation to inform the design decision making toward more energy efficient options. It is important to explore how to integrate computer simulation into the design process at different stages without influencing the design streamline. However, the complexity of simulation may lead to a steep learning curve for architects. So it is necessary to investigate whether existing members of the design team should be responsible for the task or a new member (e.g. building physicists) should be introduced to the design team.

9.3 Architects' learning preference

The nationwide questionnaire survey collected architects' opinion on three aspects of the delivery of low/ zero carbon design training programmes, namely the Experiential Learning Circle and learning styles, the characteristics of adult learning and the delivery format of the content. In terms of Experiential Learning Circle and learning styles, the survey results indicated that architects had different learning styles rather than had one preference (Figure 8-30). Regarding the characteristics of adult learning, architects agreed that they shared most characteristics of adult learning. The characteristics of adult learning agreed upon by the architects in descending order of support were: 1) raise architects' awareness and interests in low/ zero carbon design, 2) begin the training content based on architects' existing experience, 3) provide specific techniques to solve certain problems, 4) design the training materials to be immediately relevant to the architects' current work, and 5) provide CPD credit (Figure 8-31, 33). The characteristic of adult learning not well supported was that architects would like to be involved in planning of methods and curriculum for future training programmes. Regarding the delivery format of knowledge and skills, architects support both hypotheses: 1) using images, graphs and charts, and 2) including examples, good and best practices.

In addition, the survey results suggested that the importance of each factors of general delivery was valued different by architects. These factors were summarised in descending order of architects' evaluation of importance (Table 9-1):

Table 9-1: architects' preference on general delivery elements		
Rank	Elements	Details
1	Fee (Figure 8-27)	• Between 50 to 100 pounds for a one day training programme • No more than 150 pounds
2	Presenters (Figure 8-23)	• Architects or other professionals in the design team practicing low/ zero carbon design
3	Delivery methods (Figure 8-22)	• Lectures and workshops
4	Travel distance (Figure 8-28)	• A two-hour course: less than one hour (each way) • A half a day course: less than one and half hours (each way) • A whole day course: no more than two hours travel (each way)
5	Handout type (Figure 8-26)	• Website which can be revisited with updated follow up information • Digital files
6	Venue location (Figure 8-29)	• Public transportation being available
7	Programme types (length of the programme and delivery time) (Figure 8-20, 21)	• Short daytime school (one day course, full morning course, full afternoon course and two hour after work course) • Shorter version of evening school • Longer version of evening school • Shorter version of weekend school
8	Other participants (Figure 8-24, 25)	• Mixed professions at similar level • Small group programmes (6-20 participants, and no more than 50)

Three interesting points in relation to architects' learning preference were revealed in the survey results. They will be discussed in the following sections.

9.3.1 Architects' preferred learning styles

The nationwide survey results suggested that architects had different learning styles with 52.6% of them preferred learning from linking theory to actual problems. 16.9% of the participants would like learning by doing, while 14.3% and 10.4% chose learning from theory and by reflection respectively. 5.8% of the participating architects suggested that their learning styles combined two or more types. The results were different from the findings from the literature review where the majority of architectural students preferred learning by doing. However, Tucker (2007) found a shift of learning styles to the abstract conceptualisation model of the learning process as students near the completion of their studies based on an investigation of learning styles of 152 undergraduates.

Should the teaching styles match the learning styles, or should a variety of teaching approaches be applied? Regarding the ‘matching hypothesis’, a lot of studies failed to find substantial evidence to support that matching the styles of learners and tutors improved the attainment of learning quality with both positive and negative results claimed (Coffield et al. 2004a). Regarding the ‘mismatching theory’, more empirical verification is required to support this argument (Coffield et al. 2004a). Felder (1993) suggested that identifying students’ learning styles was to understand the students, so teaching should be arranged around the learning cycle, and teaching to learning styles exclusively should be avoided.

Therefore, learning styles could be linked to low carbon design training programmes in three ways: 1) to increase architects’ self-awareness of their strengths and weaknesses as learners to increase their learning ability, 2) to provide a language with which presenters and participants of low carbon design training programmes can communicate how they learn, and 3) to arrange training with four learning stages rather than to focus on a certain stage which is suitable for a certain learning style.

In summary, participating architects had different learning styles. So, it is worth exploring how to deliver low/ zero carbon design training programmes to accommodate all four learning styles. An example is the 4MAT system reviewed in the literature review. In addition, the training programmes should raise participants’ awareness of learning processes and styles in order to develop a platform for the participants to discuss how to improve their learning and achieve the desired learning outcomes.

9.3.2 Types of low/ zero carbon design training programmes

The nationwide survey results suggested that lectures and workshops were the most preferred low/ zero carbon training programme types. Eraut (2007) confirmed that training courses and workshops were still used by most employers in technical training and training to meet statutory or regulatory requirements and in generic skill areas. However, as Shannon and Radford (2010) pointed out that the design process was a cyclical reflective practice where the design situation and potential could only be understood through the process of reflecting on the design proposal; therefore students found it difficult to develop strategies and technologies for their own designs after they learnt how environment, building performance, construction and building services interacted and worked in case buildings. This explained why many participants did not apply the low/ zero carbon design strategies they were taught in training programmes to practice. Some of the existing training programmes included a session on application of the knowledge and skills learnt. They were in different forms, such as a design competition, exams or project modules, as in the case studies of the three training programmes.

Eraut et al. (2001) explained that a complete learning package that delivered the desired outcomes needed a considerable amount of on-the-job learning. This could only happen when the learning was treated as a high priority by the participants' work group and the training was delivered in time. He repeatedly reported that it was important to keep the training relevant and well-timed, and more importantly, further workplace learning was needed (Eraut 2007). Therefore, if low/ zero carbon design was new to an architectural practice, a follow-up session should be delivered after the low/ zero carbon design course to make sure the training could be used to the best effect. If the practice had the experience in low/ zero carbon design, new practitioners would need to have access to further practice and work with experienced team members. Otherwise, the training would not be effective.

In summary, low/ zero carbon design training was the way to disseminate the critical knowledge and skills; but if it was not followed up in the work context, the training could be not effective. Therefore, it is important to investigate how to develop feasible low/ zero carbon design training programmes with workplace follow-up sessions. The proportion of time spent on the courses and the follow-up sessions should be explored, as well as how to organize the follow-up sessions within the participants' work frame. Also, how to deliver the follow-up sessions in a cost effective way should be investigated. In addition, it is worth exploring how to enhance workplace learning.

9.3.3 A delivery method of low/ zero carbon design training programmes: e-learning

The nationwide survey results showed only one fourth of the participants preferred e-learning as the delivery method of low/ zero carbon design training programmes. However, digital learning element has been widespread in all level of education due to its efficiency and effectiveness. According to Sloman (2001), e-learning caused great excitement in the 1990s in the UK, especially in IT skills; while currently it took its place alongside other methods rather than replacing them. A case study conducted in the School of Architecture, Landscape Architecture and Urban Design in the University of Adelaide from 2006 to 2011 identified that the value of e-learning included independent learning, re-visitation and reiteration (Shannon et al. 2012). Meredith and Newton (2003) reviewed how different key authors were viewing the acceptance of e-learning into main stream education at a global level, and suggested that e-learning had the capacity to change educational delivery systems as well as the markets which the institutions chose to enter. In addition, the use of electronic media can provide access to a collection of learning information, as well as to facilitate the development of learning communities.

In summary, e-learning has a potential to be developed as one of the main delivery methods for low/ zero carbon design training programmes. Therefore, it is important to investigate into the right technology, and the cost of implementation and maintenance for the development of e-learning low/ zero carbon design training programmes in the near future. Also, it is worth considering e-learning as one feasible solution for the follow-up sessions of training programmes.

9.4 The final model of low/ zero carbon design

The final model of low/ zero carbon design has been developed via adding the findings of the nationwide questionnaire survey to the revised model of low/ zero carbon design. The information related to the survey findings that is incorporated in the revised model includes: 1) architects' requirement to learning about low/ zero carbon design strategies in each design category, 2) the need to use computer simulation to inform design decision making, and 3) the need to promote architects' commitment to low/ zero carbon design.

First, regarding architects' requirement to learning about low/ zero carbon design strategies in each design category, the survey results of whether architects need to be informed the importance of low/ zero carbon design in each design category and whether they need to learn about the design strategies have been added to the final model. With the survey results, the final model of low/ zero carbon design categorizes the design categories in which design strategies can be applied to achieve low/ zero carbon targets into three groups:

i. The design categories that architects think important and feel confident to conduct (green boundary): These topics include 'set the goal of low/ zero carbon', 'climate change', 'site planning', 'building form' and 'building fabric'. So, the associated knowledge and skills are not necessary to be disseminated.

ii. The design categories that architects recognize the importance but lack confidence to apply the associated design strategies (orange boundary): These topics include 'meet the Building Regulations and standards', 'efficient building systems', 'renewable energy services', 'materials and products', 'commissioning' and 'feedback study'. So, it is important to disseminate the associated knowledge and skills to architects.

iii. The design categories that architects overlook the importance and lack confidence to apply the associated strategies (red boundary): The topic is ‘waste management’. So, it is necessary to raise architects’ awareness of the importance of ‘waste management’, and disseminate the associated knowledge and skills to them.

Second, the use of computer assisted simulation tools is added to the final model to indicate the importance of the simulation to inform design decision making in order to achieve the low/ zero carbon goal.

Third, two elements, which are a) low carbon legislations and policies, and b) the information of the cost, benefits and values, are added to the final model in response to architects’ lack of commitment and the main barriers to low/ zero carbon design.

The final model reveals the knowledge and skills needed by architects to deliver low/ zero carbon projects (Figure 9-2).

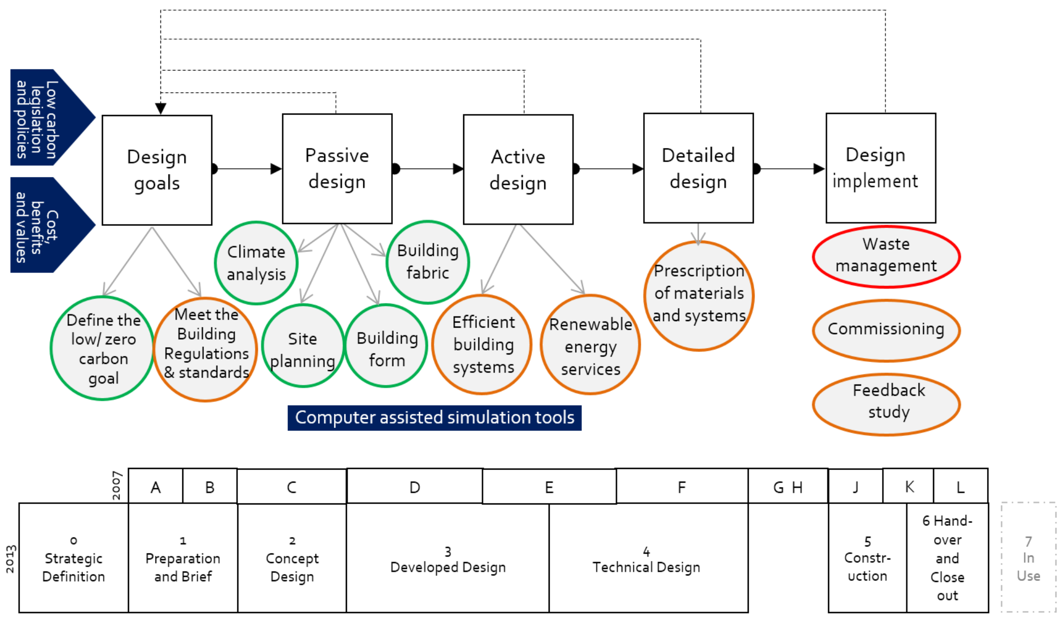


Figure 9-2: The final model of low/ zero carbon design

The final model of low/ zero carbon design reveals that most architects are not quite capable of conducting low/ zero carbon design, and they do not have an overview of low/ zero carbon design, and they are not fully aware of what knowledge and skills they need in order to enable them to deliver low/ zero carbon design. Therefore, it is important to raise architects' awareness of the overall design process and tasks involved in low/ zero carbon design. Five specific areas are identified:

First, the current focus to achieve low/ zero carbon design is to set the goal to achieve low/ zero carbon design and to integrate low/ zero carbon design strategies in the early stage of the design. Architects are aware the importance of this procedure, but the goal of low/ zero carbon design needs to be clarified and quantified in terms of the energy efficiency threshold, the metric, type of energy use, type of renewable system, connection with the energy infrastructure and period of the balance.

Second, architects are quite familiar with certain low/ zero carbon design strategies during the design stages, so there is no need for training programmes to emphasize the related topics. These topics include climate analysis, site planning, building form, and building fabric. On the other hand, the topics related to the newly developed technologies and techniques are needed. Currently, these topics include low/ zero carbon construction materials and products, efficient building services and renewable energy systems.

Third, less attention is paid to the implementation of low/ zero carbon design strategies during the construction and handover stages. So it is important to raise architects' awareness of the importance of the implementation of low/ zero carbon design in the training programmes, and to disseminate the associated knowledge and skills. In addition, the factors that would influence on carrying out these tasks, such as time and cost, should be explored, and solutions to the problems should be disseminated to architects.

Fourth, architects acknowledge that computer simulation to inform the design and assist in making the design decision is important for low/ zero carbon design. Due to the complexity of simulation, a new team member, building physicists, can be introduced to the design team to conduct the simulation. But, the knowledge regarding what type simulation should be conducted and how to interpret the simulation results to optimize the design is necessary to be disseminated to architects. More importantly, design with simulation results as well as the conventional considerations (such as function, aesthetic and cost factor) can be complex, and the design fluidity can be interrupted. Therefore, the associated problems in terms of working with the simulation results is worth of exploration, and possible solutions should be passed to the architects in the training programmes.

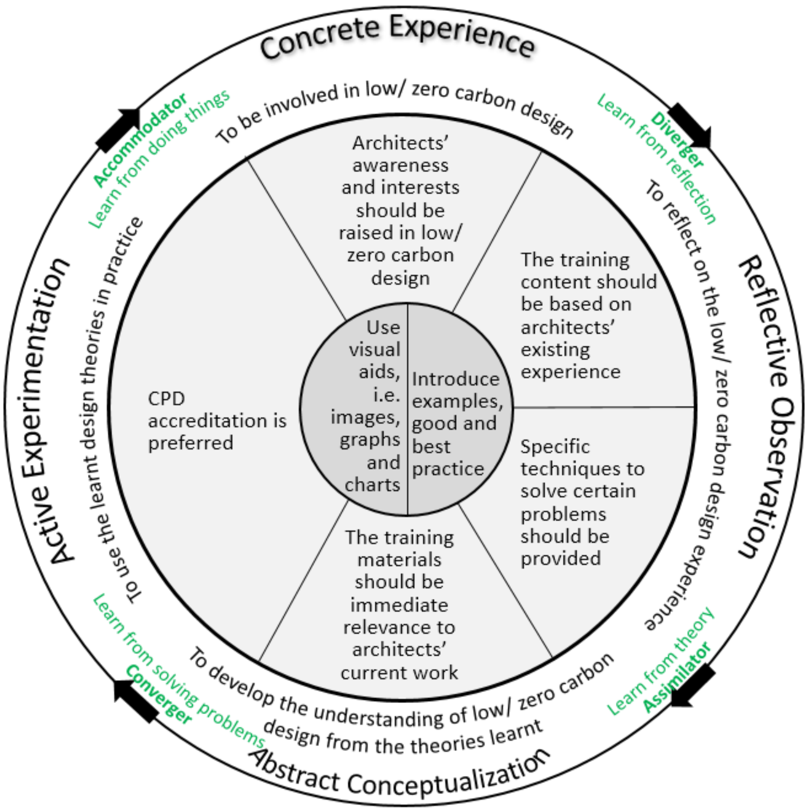
Fifth, not all of the architects are familiar with the existing legislation and policies in relation to energy efficiency, such as the Energy White Paper, the Climate Change Act, the Low Carbon Transition Plan 2009 and the UK Renewable Energy Strategy. It is important to introduce how the building energy conservation legislation and policies influence the Building Regulations to motivate architects to develop their ability to deliver low/ zero carbon projects, as well as to translate the building energy conservation legislation and policies into more practical guides and ensure the implementation.

Six, in order to tackle the main barriers of delivering low/ zero carbon projects, it is important to identify the value of low/ zero carbon projects in a broader context without costing much more. Low/ zero carbon design training programmes should demonstrate that low/ zero carbon design with little additional cost and major cost savings can be achieved with the iterative design process and the holistic approach. What is more, information related to the benefits of achieving the higher environmental design standards and the balance of initial cost and the overall value should be disseminated, in order to convince architects and help architects convincing their clients.

9.5 The final model of architects' learning preference

The final model of architects' learning preference has been established by amending the revised model in relation to the results of the nationwide questionnaire survey regarding architects' evaluation of each element to the revised model. The final model has been amended to 1) suggest that architects have different preferences for all four learning styles rather than only learning from doing and linking theory to actual problems, and 2) indicate that architects do not want to be involved in the planning of the methods and curriculum for the future training programmes and they prefer CPD credits.

The final model reveals the architects' preference of the dissemination methods of low/ zero carbon design training programmes (Figure 9-3).



Note: the green highlight indicates the learning styles preferred by architects.
Figure 9-3: The final model of architects' learning preference

The final model of architects' learning preference has three layers which represent three aspects of architects' learning preference identified in this study:

1) The outer layer: the Experiential Learning Circle and learning styles

The outer layer of architects' learning preference model suggests that architects have different preferences for the learning styles. Therefore, the dissemination approach of low/ zero carbon design training programmes should follow the four stages of Experiential Learning Circle and accommodate all learning styles. Each learning stage represents the learning preference of one learning style, so the training programme can make all participants with different learning styles 'comfortable' and 'challenged' at the different stages by following the whole Experiential Learning Circle. Moreover, the Experiential Learning Circle completes the learning process which consists of learning knowledge and using knowledge in accordance to Eraut's research. The fourth stage in the Experiential Learning Circle can be the workplace follow-up sessions when the training supports the architects applying the new knowledge and skills to their own projects. E-learning has the potential to be one of the feasible solutions for the follow-up sessions.

2) The middle layer: the characteristics of adult learning

The middle layer of architects' learning preference model suggests that architects share five out of six of the characteristics of adult learning. The exception is that architects do not want to be involved in the planning of the methods and curriculum for the future training programmes. The reason may be that the planning of the methods and curriculum for the future training programmes can be a time consuming process. According to architects' evaluation of the importance of each characteristic, the most important element is that architects need the programmes to raise their interests and awareness. It is crucial for participants to know why they need to learn. This characteristic of adult learning corresponds to the first stage of the learning circle which links the low/ zero carbon design content to the architects' work. Then, architects' previous experience should provide the basis for learning activities. The starting point of the content should be based on architects' existing experience rather than a constant point without considering whether the participants know about it. So, different levels of a topic should be provided in accordance to participants' levels of knowledge. Next, architects prefer specific techniques to solve certain problems. In order to achieve this, the training materials should be relevant to architects' work, and the implication of how the knowledge and skills learnt can be implemented to architects' current work is needed. Although the main reason for architects taking training programmes is to update their knowledge or fulfil personal interests, they would like to receive CPD credits if accreditation is provided.

3) The inner layer: the format of the content of training programmes

The inner layer of the architects' learning preference model suggests that architects prefer the delivery format of knowledge and skills 1) using images, graphs and charts, and 2) including examples, good and best practices.

9.6 Summary

This chapter discussed the main findings of the nationwide survey, regarding architects' current position in relation to low/ zero carbon design, the required content of low/ zero carbon design training programmes and architects' learning preference. The results indicate that architects acknowledge the importance of low/ zero carbon design but they lack commitment to the low/ zero carbon design targets due to the lack of clients' support and a tight budget; which explains why most projects only comply with the Building Regulations without aiming to achieve higher but voluntary standards. Also, the results identify the gap in between the required knowledge and skills to achieve low/ zero carbon design and architects' evaluation of their competence, and suggest that more efforts should be made to the implementation of the low/ zero carbon design strategies in the construction and handover stages. What is more, the results promotes the importance of computer assisted building simulation, the information related to how the building energy conservation legislation and policies influence the Building Regulations, and the information regarding the benefits of low/ zero carbon projects and the balance of initial cost and the overall value.

In terms of architects' learning preference, the results propose that architects prefer different learning styles, and workplace follow-up sessions are important to the transfer of the knowledge and skills. E-learning has the potential to be one of the main delivery methods for low/ zero carbon design training programmes and a feasible solution for the follow-up sessions. What is more, journals, magazines and website can be the platform to disseminate systematic knowledge and skills to architects.

Adding the survey results to the revised models, the final models of low/ zero carbon design and architects' learning preference were established to inform the development of low/ zero carbon design training programmes for architects in practice in England and Wales.

Chapter 10. Research Conclusion

The aim of this research was to investigate the development of low/ zero carbon design training programmes for the purpose of disseminating the knowledge and skills of low/ zero carbon design to architects in practice in England and Wales. Two research questions were raised to assist in achieving the research aim, 1) what knowledge and skills of low/ zero carbon design are needed and 2) how to disseminate them in low/ zero carbon design training programmes.

This chapter presents the conclusion of the research. Then, the research limitations are acknowledged. At the end of this chapter, future work to extend this research is outlined.

10.1 Research conclusion

The main contribution of the research is the establishment of a mixed-method approach which combined literature review, case studies and questionnaire survey to explore the required content and dissemination methods of low/ zero carbon design training programmes for architects. In this investigation, two models have been developed to inform the required content and dissemination methods: one is a model of low/ zero carbon design and the other one is a model of architects' learning preference. Both the research methodology and the two models can be adopted by professional bodies and academic institutions to develop comprehensive professional training to enable architects to deliver low/ zero carbon design.

10.1.1 The model of low/ zero carbon design

The model of low/ zero carbon design aimed to identify the required knowledge and skills of low/ zero carbon design. There were three stages for the establishment of the low/ zero carbon design model.

Stage 1: An initial model of low/ zero carbon design was set up through the review of five existing design process models. It took a loop form to organize four design stages (setting design goals, passive design, active design and detailed design) to emphasize the iterative design process which had been applied by the existing design process models. What is more, the model intended to reflect a holistic approach to achieve low/ zero carbon design. At the same time, it comprised ten design categories related to the four design stages (Figure 10-1).

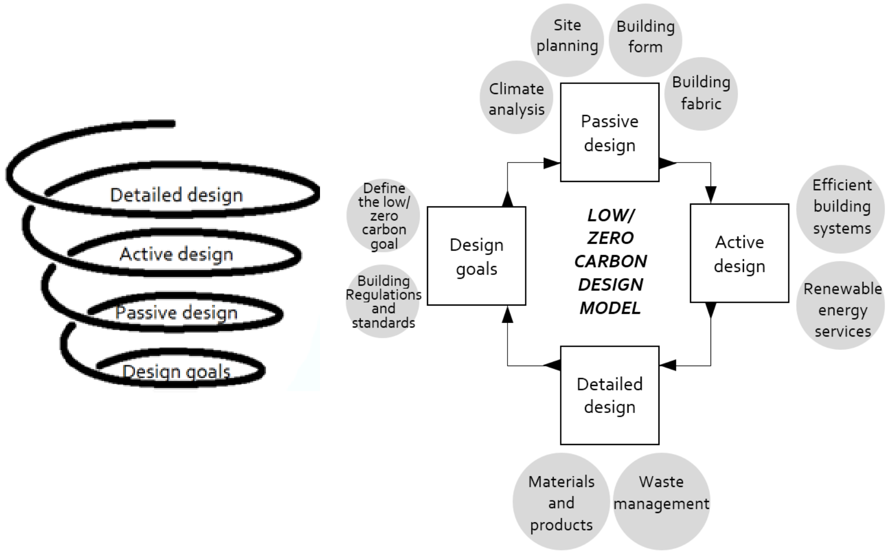


Figure 10-1: The initial model of low/ zero carbon design

Stage 2: A revised model of low/ zero carbon design was developed by relating the initial model to the RIBA Plan of Work stages in accordance to the feedback from the case studies of three training programmes (Figure 10-2). The revised model still had the emphasis on the iterative and holistic design process. Then, the design topics included in the revised model were taken as the framework to design questions for a nationwide questionnaire survey in order to find out which low/ zero carbon design topics are needed to be learnt about by architects.

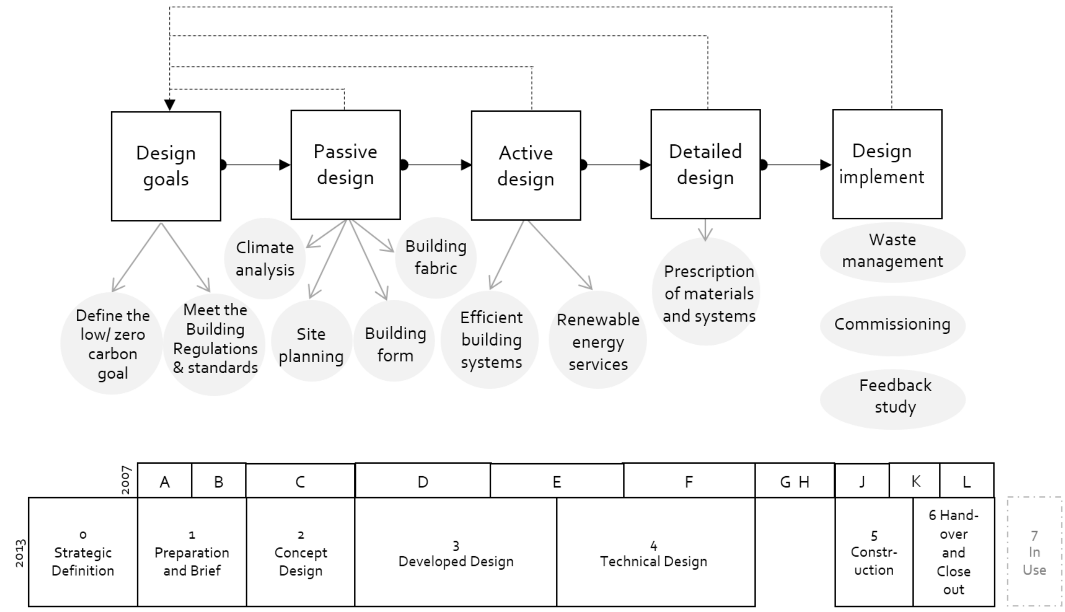


Figure 10-2: The revised model of low/ zero carbon design

Stage 3: The final model of low/ zero carbon design was established by adding the results of the nationwide questionnaire survey to the revised model to indicate which low/ zero carbon design topics are required by architects (Figure 10-3). The information that was added to the revised model includes: 1) architects' requirement to learn about low/ zero carbon design strategies in each design category, 2) the need to use computer simulation to inform design decision making, and 3) the need to promote architects' commitment to low/ zero carbon design.

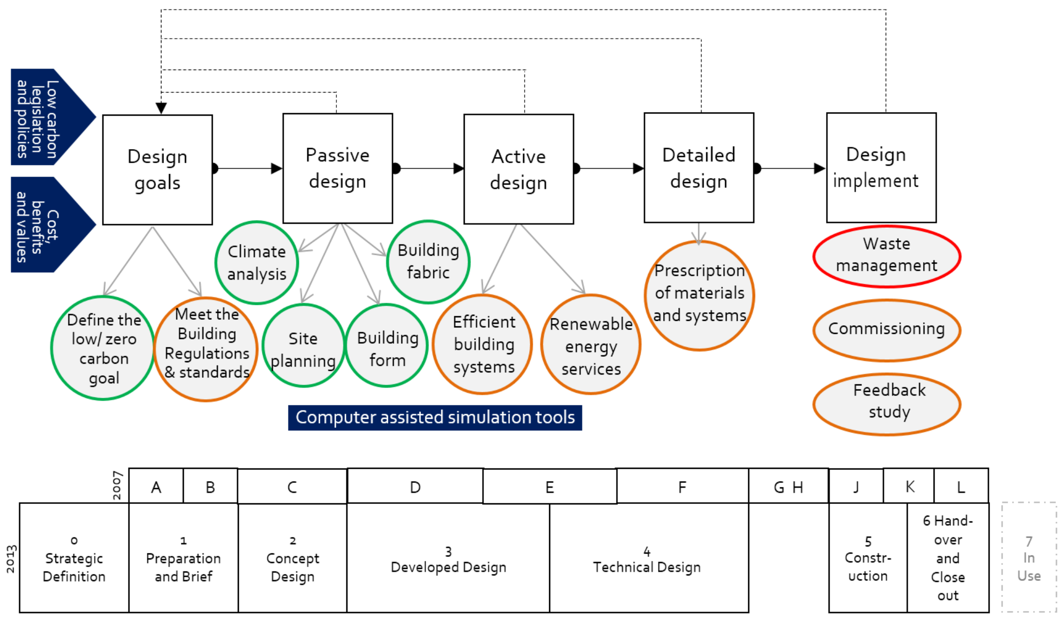


Figure 10-3: The final model of low/ zero carbon design

The final model of low/ zero carbon design reflects the design topics in relation to the RIBA Plan of Work. From the Strategic Definition stage, a project is strategically appraised and defined, and the team members and their responsibilities to the associated low/ zero carbon design goal are considered. During the Preparation and Brief stage, architects need to set the low/ zero carbon design goal for the project, decide which standards to be complied with, and define all the associated parameters. During the Concept Design stage, the initial design concept regarding passive design in low/ zero carbon design model should be developed with consideration of detailed design and technical design to fulfil the requirements of the initial project brief. During the Developed Design stage, the concept design is developed further with the development of the architectural, building services and structural engineering designs. Architects and engineers work together with an iterative process to optimise the design in order to achieve the low/ zero carbon design goals. During the Technical Design stage, the architectural, building services and structural engineering designs are further refined to provide technical definition of the project, and make sure the low/ zero carbon design goal can be achieved. In the Construction stage, the building is constructed on site, and the design team should ensure the implementation of the low/ zero carbon design strategies with waste management. During the Handover and Close Out stage, commissioning which ensures operation and management of the building to achieve the designed low/ zero carbon performance, and feedback study to learn lessons which may be applied to future projects should be carried out.

The design topics in the overall design process are categorized into three groups:

1) The topics that architects need to learn about (orange boundary):

   These topics are mainly related to the new active technologies, updated legislation and regulations, and tasks in construction and handover stages, including ‘meet the Building Regulations and standards’, ‘efficient building systems’, ‘renewable energy services’, ‘materials and products’, ‘commissioning’ and ‘feedback study’.

2) The topics that architects need to realize the importance and learn about (red boundary):

   The topic is ‘waste management’.

3) The topics that architects do not necessarily need to learn about (green boundary):

These topics are mainly related to the conventional passive design strategies which architects are quite familiar and have practiced in their projects. These topics include ‘set the goal of low/ zero carbon’, ‘climate change’, ‘site planning’, ‘building form’ and ‘building fabric’.

There are three main outcomes from the development of the final model of low/ zero carbon design. They are listed as follows:

First, the final model of low/ zero carbon design reflects the iterative design process to deliver a low/ zero carbon project. The iterative approach balances the consequences of each design decision in order to reduce carbon emissions effectively. The essence of this approach is to reduce the energy demand by a combination of passive design strategies and active design with efficient building services, then decarbonise the remaining energy requirements using renewable energy supply (for example through integrating renewable energy systems into the buildings). Comparing to this new approach, the traditional linear design process, from architects designing the building first, then engineers facilitating the systems, to the last step where contractors and builders delivering the construction is less effective to achieve a low/ zero carbon target. If applied, it can end up with bolting some low/ zero carbon design techniques on a completed design, and the upfront cost will be increased.

Second, the final model of low/ zero carbon design demonstrates a holistic approach to achieve low/ zero carbon design. The holistic approach has two layers of meanings: 1) the collaboration of the design team from the very beginning to the end of the design, and 2) the application of building simulation.

1) Regarding the collaboration of the design team from the very beginning to the end of the design, the design starts with setting and defining the low/ zero carbon goal

of a project. A unified framework with six parameters has been established to help the design team and the client to clarify and quantify the carbon emissions reduction target. These parameters consist of energy efficiency threshold, the metric, type of energy use, type of renewable system, connection with the energy infrastructure, and period of the balance. Then, the design is carried out through the stages of passive design, active design and detailed design; and the design decisions made in each stage are checked against the design goal at each design stage. Finally, the low/ zero carbon design strategies should be implemented during the construction and post occupancy stages. The final model of low/ zero carbon design also reflects that architects are aware of the importance of the integration of low/ zero carbon design from the start of a project, but they pay less attention and lack of confidence towards the implementation in the construction and post occupancy stages.

2) Regarding the application of computer assisted building simulation, computer simulation to optimize the design is an important part of the design process since the parameters related to low/ zero carbon design, such as building energy consumption and the indoor built environment, are determined by complex dynamic thermal interactions between the external environment, building fabrics, internal heat gains and the building systems. The final model of low/ zero carbon design suggests to disseminate the knowledge regarding what type simulation should be conducted, how to interpret the simulation results to inform design decision making and how to work with simulation results in the design process.

Third, the final model of low/ zero carbon design reveals the gaps in between the required knowledge and skills to achieve low/ zero carbon design and architects' understanding and their evaluation of their capability of delivering a low/ zero carbon design project. Low/ zero carbon design knowledge and skills in relation to ‘efficient building systems’, ‘renewable energy services’, ‘sustainable materials and products’, ‘commissioning’ and ‘feedback study’ are needed to be disseminated; while architects are able to conduct ‘climate analysis’, ‘site planning’, ‘building form’, and ‘building fabric’. In addition, the training programmes should point out the importance of ‘waste management’ in relation to achieving low/ zero carbon design; and introduce how to conduct ‘waste management’ to ensure the implementation of the low/ zero carbon design strategies. Moreover, the information related to how the legislation and policies impact on the Building Regulations, as well as the benefits of low/ zero carbon design and the balance of initial cost and the overall value can motivate architects and help them convince their clients.

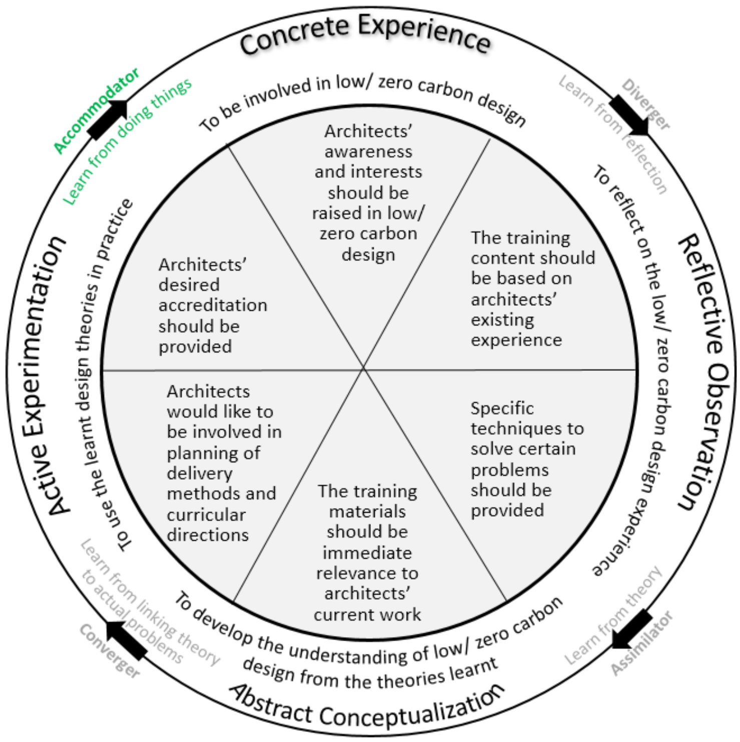
In the development of the final model of low/ zero carbon design, it is identified that architects lack commitment to apply low/ zero carbon design strategies to their projects. The research finds out that the majority of the projects only follow the Building Regulations currently, even though low/ zero carbon buildings are proved technically and theoretically feasible. And the main barriers are the tight project budgets and clients’ reluctance to support. It is a problem to be tackled with the involvement of all parties in the construction industry, including the clients, design teams, contractors, manufacturers and the government, rather than architects only. On the one hand, financial models can be developed to look into how to attract the investment and deliver low/ zero carbon value to the clients with the investment paid back. On the other hand, it is important to investigate how to integrate low/ zero carbon design strategies into projects within the traditional consideration of clients’ satisfaction, cost, aesthetic factor and function. The training programmes should demonstrate how low/ zero carbon design can fulfil the current expectations from buildings with benefits of carbon emissions reduction; and disseminate the related knowledge and skills to architects. In addition, the enforcement to low/ zero carbon standards is needed to drive innovation.

In conclusion, the final model of low/ zero carbon design reflects the iterative design process, the holistic approach and specific knowledge and skills needed to enable architects to deliver low/ zero carbon projects in relation to the current low/ zero carbon design situation in the UK building industry. The final model has been set up in the context of the international and national legislation and regulations of carbon emissions reduction: from the Kyoto Protocol, the EU Energy Performance of Building Directive, to the UK Building Regulations; as well as the current main actions of professional organizations (such as RIBA and BRE) to promote low/ zero carbon and research programmes (such as EDUCATE, WEST and BEST) to support the implementation of low/ zero carbon design in academic curricula and professional training. Regarding the design process of low/ zero carbon design, this research supports the existing notion of the iterative design process and the importance of early design collaboration from existing design process models, and links it to the RIBA Plan of Work stages to promote the application. In terms of the holistic approach, the findings of this research support. What is more, the design topics related to each design stage are identified in relation to architects need to learn. Due to the lack of methods to test architects' real knowledge and skills of low/ zero carbon design, there is a lack of support to justify the findings. In addition, this research identifies the lack of attention and competence to the implementation of low/ zero carbon design in the construction and post occupancy stages in the holistic approach to deliver low/ zero carbon design.

10.1.2 The model of architects' learning preference

The model of architects' learning preference was developed to promote the application of the knowledge and skills architects learnt in low/ zero carbon design training programmes in their projects. There were three stages for the establishment of the architects' learning preference model.

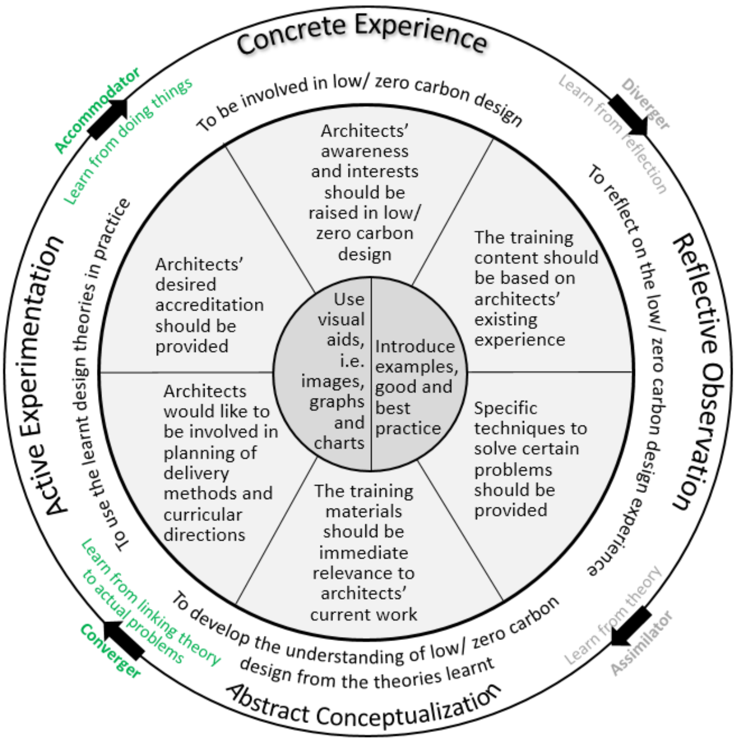
Stage 1: An initial model was set up through the review of architectural education, theories of Experiential Learning Circle and learning styles and the characteristics of adult learning. It had two layers: 1) a centre that consisted of six characteristics of adult learning in the context of low/ zero carbon design training programmes, and 2) an outer layer which was the Experiential Learning Circle in low/ zero carbon design training context and indicated learn from doing things as architects' preferred learning style (Figure 10-4).



Note: the green highlight indicates the learning style preferred by architects.

Figure 10-4: The initial model of architects' learning preference

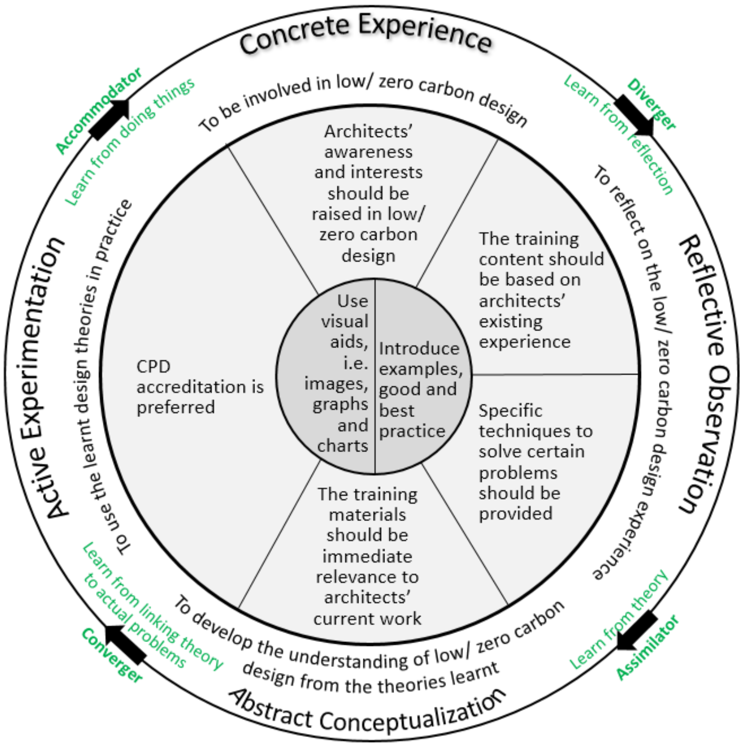
Stage 2: A revised model of architects' learning preference was developed by incorporating two points in the feedback from the three training programmes in the case studies: 1) using images, graphs and charts, and 2) including examples, good and best practices. Both of these two points were considered to be related to the delivery format of the content of training programmes, and added as a third layer. What is more, learn from linking theory to actual problems was identified as another architects' preferred learning style from the survey for the MSc Course in Sustainable Design in the Welsh School of Architecture in the case studies, and it was added to the revised model. Then, the elements in the revised model were taken as the framework to design questions for a nationwide questionnaire survey in order to find out architects preference of the dissemination methods of low/ zero carbon design training programmes (Figure 10-5).



Note: the green highlight indicates the learning styles preferred by architects.

Figure 10-5: The revised model of architects' learning preference

Stage 3: The final model of architects' learning preference was established by amending the revised model in relation to architects' evaluation of each element in the nationwide questionnaire survey (Figure 10-6). Comparing to the revised model, the final model was amended to 1) indicate that architects have different preferences for all the learning styles rather than only learning from doing and linking theory to actual problems, and 2) present that architects do not want to be involved in the planning of the methods and curriculum for the future training programmes and they prefer CPD credits.



Note: the green highlight indicates the learning styles preferred by architects.

Figure 10-6: The final model of of architects' learning preference

There are two main outcomes from the development of the final model of architects' learning preference. They are listed as follows:

First, the final model of architects' learning preference reflects three learning themes to address the preferred dissemination methods of low/ zero carbon design training programmes, namely the theory of Experiential Learning Circle and learning styles, the characteristics of adult learning, as well as the delivery format of the content. The model enhances the links between the theory of Experiential Learning Circle and learning styles, and the characteristics of adult learning; and forms the foundation to organize and disseminate the training materials for low/ zero carbon design training programmes.

Second, the final model of architects' learning preference reveals how to disseminate low/ zero carbon design knowledge and skills to accommodate architects with different learning styles. The delivery of a low/ zero carbon design training programme has four steps:

1) The training programme should link the low/ zero carbon design concept with architects' daily work to raise their awareness and interests in low/ zero carbon design.

2) The holistic approach to achieve low/ zero carbon design should be introduced, then thoeries of specific parts of low/ zero carbon design can be disseminated and related back to the holistic approach. The content should be based on architects' existing experience. Exemplary buildings, good and best practice should be included. And images, graphs and charts should be applied in the presentations.

3) The training programme should help the participants to develop their basic skills to identify, articulate and use the knowledge and skills learned. Specific techniques to solve certain design problems are provided. Also, the training materials should have immediate relevance to architects' current work to support the follow-up session.

4) A workplace follow-up session should be included to support the participants to apply the new knowledge and skills to their own projects. To support the usage of the knowledge and skills learnt from low/ zero carbon design training programmes in architects' work is vital to promote the application of the knowledge and skills in practice. Comparing to most existing low/ zero carbon design training programmes for architects, the workplace follow-up session is the missing step. E-learning has the potential to be one of the feasible solutions for the follow-up sessions.

In the development of the final model of architects' learning preference, eight general delivery factors of training programmes that can influence the participants' decision on whether or not to attend a training programme have been identified. These factors include the fee, the presenters, delivery methods, travel distance, handout types, the location, types of training programmes and other participants.

In conclusion, the final model of architects' learning preference provides suggestions on how to disseminate low/ zero carbon design knowledge and skills to architects with consideration of the theory of Experiential Learning Circle and learning styles, the characteristics of adult learning, as well as the delivery format of the content. Regarding the Experiential Learning Circle and learning styles, this research finds out that the sampled architects prefer different learning styles other than the one particular style (learning by doing) as suggested in a series of previous studies. In addition, this research points out the importance of workplace follow-up sessions in low/ zero carbon design training programmes. This finding supports that learning by doing or using the knowledge learnt is a vital part of learning process. Regarding the characteristics of adult learning, this research connects the adult learning hypotheses in a general context to a specific professional group, i.e. the architects. The findings of this research support that architects share most of the characteristics of adult learning with one exception of 'wanting to be involved in the planning of the methods and curriculum for the future training programmes'. Regarding the format of the content, this research supports the previous research which indicated that presentational style is a key factor in the knowledge transfer processes for architects. This research finds out that using visual aids (i.e. images, graphs and charts) and introducing examples, good and best practice when disseminate the required knowledge and skills are preferred by architects in practice.

One issue to be mentioned is that the study focused only on the architects in England and Wales and the questionnaire survey was carried out in 2011/ 2012. It has been acknowledged that the results would not represent the view of other constructional professionals or the view of architects during other time period.

10.2 Research limitations

The main research limitations were recognized and discussed in the related section previously:

One of the limitations related to the case studies was that only one case 'the Pilot of Environmental Professional Development (EPD)' in the three case studies was developed for architects' training in the UK, which was the same as the training programmes focused in this research. However, due to the time limitation (to find more training programmes delivering overall knowledge and approaches to sustainable design and having a practical session), it was decided to carry out more detailed case study rather than to study more similar cases.

The other limitation of the case studies was that the small size of sample population for the questionnaire surveys conducted for the case studies. This might reduce the generality of the survey results.

The limitation related to the nationwide questionnaire survey was the lack of methods to test architects' real knowledge and skills of low/ zero carbon design. The questionnaire survey aimed to understand architects' current knowledge and skills of low/ zero carbon design, then the knowledge and skills gap can be identified. And the training programmes can be developed to disseminate these knowledge and skills. However, it was not a straight forward task to identify the gap. There was a difficulty to differentiate between the participants' subjective perception of their knowledge and skills, and their actual knowledge and skills. The reason was that architects were unaware of their lack of the overall understanding of low/ zero carbon design. Questions that asked the participants to provide opinions from different angles to the same topic had been developed to help understanding participants' real situation, including whether low/ zero carbon design in each design category are important, whether they (architects) are capable of applying low carbon design strategies in each design category to their projects, and whose responsibilities to take care of the application of low carbon design in each design category. But architects could only judge their ability to apply low/ zero carbon design strategies in accordance to their own understanding. The lack of support to justify architects' awareness of low/ zero carbon design was recognized.

10.3 Future work

This research can be extended in several directions:

1. A low/ zero carbon design training programme should be developed in according to the model of low/ zero carbon design and the model of architects' learning preference. The programme should be delivered, and feedback from the participants can be collected for further verification and improvement of the models. A set of criteria to assess the effectiveness of the training programme should be developed.

2. The main aim of the training programmes of low/ zero carbon design is that the participants implement the knowledge and skills learnt to their projects. Therefore, it would be necessary to develop a system to review the impact of low/ zero carbon design training programmes on the participants' on-going projects and investigate how to ensure the participants to apply their new knowledge and skills.

3. Workplace follow-up should be an integrated session of low/ zero carbon design training programmes in order to complete the learning circle. Further exploration should determine how to organize a follow-up session within the participants' work frame in a cost effective way, as well as the proportion of time spent on courses and follow-up sessions. In addition, it is worth exploring how to enhance workplace learning with the training programmes.

4. E-learning has the potential to reduce the cost, travel and time limitation of the traditional face to face training programmes. Also, the use of electronic media can provide access to a collection of learning information, as well as facilitate the development of learning communities. Therefore, explorations should be

carried out on the opportunities to integrate e-learning to low/ zero carbon design training programmes with the consideration of suitable technologies, and the cost of implementation and maintenance.

References

Adeyeye, K., Osmani, M. and Brown, C. 2007. Energy conservation and building design: the environmental legislation push and pull factors. *Structural Survey* 25, pp.375 - 390.

Ahmad, J. 1994. *Energy efficiency: the best practice programme*. London: ETSU for the Energy Efficiency Office.

Allard, F. 1998. *Natural ventilation in buildings: a design handbook*. London: James and James Ltd.

Allen, D. 2012. *Building Regulations 2013 Consultation summary document* [Online]. Available at: http://www.butlerandyoung.co.uk/assets/Butler-Young-Consultation-Summary.pdf [Accessed: 05 April 2014].

Architecture 2030. 2002. *Architecture 2030* [Online]. Available at: http://www.architecture2030.org [Accessed: 04 January 2014].

Arup Associates. 1983. *Gateway house 2.* [Online]. Available at: http://www.arupassociates.com/en/projects/GatewayHouse2/ [Accessed: 07 November 2013].

ATKINS. 2007. *Introduction* [Online]. Available at: http://www.atkinsglobal.co.uk/en/about-us [Accessed: 05 April 2007].

Ayoub, J. 2008. *IEA Solar Heating and Cooling Programme: Net Zero Energy Solar Buildings* [Online]. Available at: http://www.iea-shc.org [Accessed: 10 December 2013].

Baba, A., Mahdjoubi, L., Olomolaiye, P. and Booth, C. 2012. Insights of architects' knowledge of the Code for Sustainable Homes (CSH) in relation to low carbon housing design and delivery in the UK. *Structural Survey* 30, pp. 443-459.

Baba, A. 2013. *Developing a decision support framework for low carbon housing design and delivery in the UK*. PhD Thesis, University of the West of England.

Babbie, E. 2007. *The practice of social research*. Belmont: Thomson Wadsworth.

Bailey, K. D. 1994. *Methods of social research*. New York: The Free Press

Banham, R. 1984. *The architecture of the well-tempered environment*. London: The Architectural Press Ltd.

BEST. 2012. *About built environment sustainability training* [Online]. Available at: http://www.best.cf.ac.uk [Accessed: 06 January 2014].

Bolstein, R. 1991. Comparison of the likelihood to vote among pre-election: poll respondents and non-respondents. *Public Opinion Quarterly*, pp. 648-650.

Booth, A.T. and Choudhary, R. 2013. Decision making under uncertainty in the retrofit analysis of the UK housing stock: Implications for the Green Deal, *Energy and Buildings* 64, pp. 292

Bouma, G. D. and Atkinson, G. B. J. 1995. *Social Science Research: A Comprehensive and Practical Guide for Students*. Oxford: Oxford University Press.

BRE. 2005. BRE Innovation Park [Online]. Available at: http://www.bre.co.uk/innovationpark [Accessed: 06 January 2014].

BRE. 2008. *Green print - enabling sustainable communities* [Online]. Available at: http://www.bre.co.uk [Accessed: 04 January 2014].

BRE. 2010a. *Code for Sustainable Homes* [Online]. Available at: http://www.breeam.org/page.jsp?id=86 [Accessed: 05 September 2012].

BRE 2010b. *Guidance for local planning authorities incorporating BREEAM and the Code for Sustainable Homes within planning policy* [Online]. Available at: http://www.breeam.org/filelibrary/BREEAM%20and%20Planning/PDF_-_Having_a_sound_evidence_base_v5__2.pdf [Accessed: 08 November 2013].

BRE. 2010c. *PassivHaus* [Online]. Available at: http://www.passivhaus.org.uk [Accessed: 05 September 2012].

BRE. 2011. *BREEAM celebrates 21 years with awards for ten top assessors* [Online]. Available at: http://www.bre.co.uk/news/BREEAM-celebrates-21-years-with-awards-for-ten-top-Assessors-741.html [Accessed 05 March 2012].

BRE CENTRE FOR SUSTAINABLE CONSTRUCTION, BRE TRUST and SWEETT, C. 2005. *Putting a price on sustainability*. Watford: BRE.

BRECSU. 2002. *General information report 89: BedZED - Beddington Zero Energy Development, Sutton*. Garston: BRE.

BREEAM. 2012. *Good practice guidance: sustainable design and construction*. London: Cross Sector Group on Sustainable Design and Construction.

British Gas. 1980. *Studies in energy efficiency in buildings: energy demand and system sizing*. British Gas Corporation.

Brookfield, S. 1986. *Understanding and facilitating adult learning: a comprehensive analysis of principles and effective practices*. Buckingham: Open University Press.

Brown, G. Z. and Ddkay, M. 2001. *Sun, wind, and light: architectural design strategies*. New York, John Wiley and Sons.

Bryman, A. 2004. *Social research methods*. Oxford: Oxford University Press.

Burns, R. B. 2000. *Introduction to research methods*. London: SAGE Publication Ltd.

Bynum, W. F. and Porter, R. (eds.) 2005. *Oxford dictionary of scientific quotations*, Oxford: Oxford University Press.

Cassidy, S. 2004. Learning styles: an overview of theories, models, and measures. *Educational Psychology* 24, pp. 419-444.

Caird, S., Horace, H., Robin, R. 2007. Can consumers save energy? Results from surveys of consumer adoption and use of low and zero carbon technologies. In: *European Council for an Energy Efficient Economy Summer Study 2007*, 4-5 June.

Chapman, F. P. 1990. The Milton Keynes Energy Cost Index. *Energy and Buildings* 14, pp. 83-101.

Chapman, J., Lowe, R. and Everett, R. 1985. *The Pennyland project*. Milton Keynes: Energy Research Group.

Chick, A. and Micklethwaite, P. 2004. Specifying recycled: understanding UK architects' and designers' practices and experience. *Design Studies* 25, 251-273.

Coffield, F. 2004. *Revealing figures behind the styles* [Online]. Available at: http://www.timeshighereducation.co.uk/news/revealing-figures-behind-the-styles/182018.article [Accessed: 01 February 2004].

Coffield, F., Moseley, D., Hall, E. and Ecclestone, K. 2004. *Should we be using learning styles: what research has to say to practice*? London: Learning and Skills Research Centre.

Coffield, F., Moseley, D., Hall, E. and Ecclestone, K. 2004*. Learning styles and pedagogy in post-16 learning: a systematic and critical review*. London: Learning and Skills Research Centre.

Conti, G. J. 1985. Assessing teaching style in adult education: how and why. *Life-long Learning: an Omnibus of Practice and Research* 9, pp. 7-11.

Crawley, D. B., Lawrie, L. K., Pedersen, C. O. and Winkelmann, F. C. 2000. EnergyPlus: Energy Simulation Program. *ASHRAE* 42, 12.

Crawley, D. B., Lawrie, L. K., Pedersen, C. O., Winkelmann, F. C., Buhl, W.F., Huang, Y. J., Strand, R. K., Liesen, R. J., Fisher, D. E., Witte, M. J. and Glazer, J. 2001. EnergyPlus: creating a new-generation building energy simulation program. *Energy and Buildings* 33, p.12.

Cross, K. P. 1981. *Adults as learners: Increasing participation and facilitating learning*. San Francisco: Jossey-Bass.

Curry, L. 1983. An organisation of learning styles theory and constructs. *American Educational Research Association Annual Meeting*. Montreal: Canada.

Davenport, J. 1993. *Is there any way out of the andragogy morass*? London: The Open University.

Davies, P. and Osmani, M. 2011. Low carbon housing refurbishment challenges and incentives: Architects' perspectives. *Building and Environment* 46, 1691-1698.

De Bello, T. C. 1990. Comparison of eleven major learning styles models: variables, appropriate populations, validity of instrumentation, and the research behind them. *Reading, Writing, and Learning Disabilities* 6, pp. 203-222.

DECC. 2009a. *The UK low carbon transition plan: national strategy for climate and energy*. Norwich: The Stationery Office.

DECC. 2009b. *The UK Renewable Energy Strategy*. Norwich: The Stationery Office.

DECC. 2013. *CRC Energy Efficiency Scheme* [Online]. Available at: https://www.gov.uk/crc-energy-efficiency-scheme [Accessed: 04 January 2014].

Denscombe, M. 2011. *The good research guide: for small-scale social research projects*. Maidenhead: Open University Press.

Department for Communities and Local Government. 2006. *Building a greener future: towards zero carbon development - consultation.* Wetherby: Communities and Local Government Publications

Department for Communities and Local Government. 2008. *Consultation definition of zero carbon homes and non-domestic buildings*. Wetherby: Communities and Local Government Publications

Department for Communities and Local Government. 2010. *Code for Sustainable Homes, technical guide*. Wetherby: Communities and Local Government Publications

Department for Communities and Local Government. 2012a. *UK National Plan: increasing the number of nearly zero energy buildings*. Wetherby: Communities and Local Government Publications

Department for Communities and Local Government. 2012b. *National Planning Policy Framework*. Wetherby: Communities and Local Government Publications

Department for Communities and Local Government. 2013. *Cost optimal calculations: UK report to European Commission*. Wetherby: Communities and Local Government Publications

Der Ryn, S. V. and Stuart, C. 2007. *Ecological design*. Washington, DC: Island Press.

Dewey, J. 1916. *Democracy and education: an introduction to the philosophy of education*. New York: WLC Books.

Dillman, D. A. 2000. *Mail and internet surveys: the tailored design method*. New York: John Wiley and Sons, Inc.

Dowson, M., Poole, A., Harrison, D., Susman, G. 2012. Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal. *Energy Policy* 50, pp. 294

DRESNER, S. 2002. *The principles of sustainability*. London: Earthscan Publications Ltd.

DRESNER, S. 2008. *The Principles of Sustainability*. London: Earthscan Publications Ltd.

Drummond, W. J. 2010. Statehouse versus Greenhouse. *Journal of the American Planning Association* 76, pp. 413-433.

DTI. 2003. *Energy White Paper: Our Energy Future-Creating a Low Carbon Economy*. Norwich: The Stationery Office.

DTI. 2007. *Meeting the Energy Challenge: A White Paper on Energy*. Norwich: The Stationery Office.

DTZ. 2012. *Tougher Government energy standards could significantly impact commercial property values* [Online]. Available at: http://www.dtz.com/UK/Tougher+Government+energy+standards+could+significantly+impact+commercial+property+values [Accessed: 06 December 2013].

EDUCATE Project Partners. 2009. *Environmental Design in University Curricula and Architectural Training in Europe* [Online]. Available at: http://www.educate-sustainability.eu [Accessed: 01 December 2013].

EDUCATE Project Partners. 2010. *EDUCATE State of the Art of Environmental Sustainability in Professional Practice*. Nottingham: EDUCATE press

EDUCATE Project Partners. 2011. *EDUCATE Benchmarking Professional Needs: European and Extra-European Countries*. Nottingham: EDUCATE press

EDUCATE Project Partners. 2012. *Education for Sustainable Environmental Design: The EDUCATE Project Summary of Results*. Nottingham: EDUCATE press

EEA. 2010. *Tracking progress towards Kyoto and 2020 targets in Europe*. Luxembourg: Office for Official Publications of the European Union

EEBE. 2011. *How can barriers to energy efficiency be overcome?* [Online]. Available at: http://www-csd.eng.cam.ac.uk/themes0/energy-demand/energy [Accessed: 04 January 2014].

Entwistle, N. J. 1981. *Styles of learning and teaching: an integrated outline of educational psychology for students, teachers, and lecturers*. Chichester: Wiley.

Eraut, M. 1994. *Developing Professional Knowledge and Competence*. London: The Falmer Press.

Eraut, M, Alderton, J, Cole, G, Senker, P. 2001. Development of knowledge and skills at work. In Coffield, F. ed. *Differing Visions of a Learning Society* Vol 1. Bristol: Policy Press, pp. 231-262.

Eraut, M. 2007. *Learning from other people in the workplace*. Oxford Review of Education 33, pp. 403-422.

Eraut, M. and Hirsh, W. 2007. *The significance of workplace learning for individuals, groups and organisations*. Oxford and Cardiff: SKOPE.

European Commission. 2010. *Energy Performance of Buildings Directive* [Online]. Available at: http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm [Accessed: 08 November 2013].

Fadey, P., Fairbrother, R., William, D., Johnson, B. and Jones, C. 1999. *Learning style and strategies: a review of research*. London: King's College London School of Education.

Fanger, P. O. 1970. *Thermal comfort: analysis and applications in environmental engineering*. New York: McGraw-Hill.

Fankhauser, S., Kennedy, D. and Skea, J. 2009. *The UK's carbon targets for 2020 and the role of the committee on Climate Change* [Online]. Available at: http://www.lse.ac.uk/Granthaminstitute/publications/research-articles/Docs/uk-carbon-targets-2020.pdf [Accessed: 04 January 2014].

Farman, J. C., Gardiner, B. G. and Shanklin, J. D. 1985. Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction. *Nature* 315, pp. 207-210.

Fathy, H. 1986. *Natural energy and vernacular architecture: principles and examples, with reference to hot arid climates*. Chicago: London University of Chicago Press for UNU.

Felder, R. M. 1993. Reaching the second tier. *Journal of College Science Teaching* 23, pp. 286-290.

Fink, A. 1995. *How to analyse survey data*. Thousand Oaks: SAGA Publications.

Fink, A. 1995. *How to sample in surveys*. Thousand Oaks: SAGA Publications.

Fink, A. 1995. *The survey handbook*. Thousand Oaks: SAGA Publications.

Fowler, F. J. 2002. *Survey research methods*. Thousand Oaks: SAGE Publications Inc.

Fuller, R., De Jong, U. and Mellersh-Lucas, S. 2008. The ethics of sustainable housing design: the dilemma for practising architects. *Architectural Science Review* 51, pp. 231-238.

Ghost Architectural Laboratory. 2010. *Ghost Architectural Laboratory* [Online]. Available at: http://www.mlsarchitects.ca/mobile/ghost.htm [Accessed: 24 January 2010].

Gomm, R., Hammersley, M. and Foster, P. 2000. *Case study method, key issue, key texts*. London: SAGE Publication Ltd.

Goode, W. J. and Hatt, P. K. 1952. *Methods in social research*. Tokyo: McGraw-HILL BOOK COMPANY, INC.

Goody, J. and Matthew, K. 1971. *Architects and information Research Paper I*. UK: Institute of Advanced Architectural Studies, University of York.

GOV.UK. 2010. *Feed-in Tariffs Scheme* [Online]. Available at: https://www.gov.uk/feed-in-tariffs/overview [Accessed: 04 January 2014].

GOV.UK. 2011. *Renewable Heat Incentive* (RHI) [Online]. Available at: https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi [Accessed: 04 January 2014].

GOV.UK. 2012. *Green Deal: energy saving for your home or business* [Online]. Available at: https://www.gov.uk/green-deal-energy-saving-measures [Accessed: 04 January 2014].

GOV.UK. 2013. *Providing effective building regulations so that new and altered buildings are safe, accessible and efficient* [Online]. Available at: https://www.gov.uk/government/policies/providing-effective-building-regulations-so-that-new-and-altered-buildings-are-safe-accessible-and-efficient [Accessed: 06 January 2014].

Greatbuildings. 2011. *Gregory Bateson Building* [Online]. Available at: http://www.greatbuildings.com/buildings/bateson_building.html [Accessed: 16 June 2010].

Groves, R. M. 1987. Research on survey data quality. *The Public Opinion Quarterly* 51, p. 169.

Häkkinen, T. and Belloni, K. 2011. Barriers and drivers for sustainable building, Build, 39 (3), pp.239–255.

Hamilton-Maclaren, F., Loveday, D. L., Mourshed, M. 2013. Public opinions on alternative lower carbon wall construction techniques for UK housing. *Habitat International* 37, pp. 163-169.

Hamza, N. and Greenwood, D. 2009. Energy conservation regulations: impacts on design and procurement of low energy buildings. *Build. Environ* 44 (5), pp.929–936.

Hawkes, D. 1995. *The environmental tradition: studies in the architecture of environment*. London: E and FN Spon.

Hayes, J. and Allinson, C. W. 1994. Cognitive style and its relevance for management practice. *British Journal of Management* 5, pp. 53-71.

Hemstrom, K., Mahapatra, K. and Gustavsson, L. 2011. Perceptions, attitudes and interest of Swedish architects towards the use of wood frames in multi-storey buildings. *Resources, Conservation and Recycling* 55, 1013-1021.

Hensen, J. L. M. 1994. Energy related design decisions deserve simulation approach. In *International Conference on Design and Decision Support Systems in Architecture and Urban Planning*. Vaals, 15-19 August, 1994.

Hernandez, P., Kenny, P. 2010. From net energy to zero energy buildings: defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings* 42, pp. 815-821.

Herzog + Partner 2013. *Projects* [Online]. Available at: http://www.herzog-und-partner.de/english/projects [Accessed: 16 December 2013].

Hetherington, R., Laney, R. and Peake, S. 2010. *Software engineering challenges: achieving zero carbon buildings by 2019*. ACM-BCS Visions of Computer Science, 13th -16th April. Edinburgh University.

Hill, L. F. 2001. *Pedagogical and andragogical learning* [Online]. Available at: http://www.authorsden.com/visit/viewArticle.asp?id=1416 [Accessed: 16 June 2010].

HM Government. 2010. Low Carbon Construction Innovation and Growth Team Final Report. London: Department for Business, Innovation and Skills

HM Government. 2010. *The Building Regulations 2000, Part L1A Conservation of Fuel and Power in New Dwellings*. London: NBS

HM Government. 2011. *Low Carbon Construction Action Plan 2011: Government response to the Low Carbon Construction Innovation and Growth Team Report*. London.

HM Government. 2013. *Amendments to the Approved Documents: The Building Regulations 2010*. London: NBS

Hoffman, L. 2000. Introduction. In: *Earth Pledge ed. Future Fashion White Papers*. New York: Earth Pledge Foundation.

Honey, P. 2002. *Why I am besotted with the learning circle*. Maidenhead: Peter Honey Publications Ltd.

Honey, P. and Mumford, A. 1995. *Using your learning styles*. Maidenhead: Peter Honey.

Hong, T., Chou, S. K. and Bong, T. Y. 2000. Building simulation: an overview of developments and information sources. *Building and Environment* 35, p. 15.

Hoorn, J. F., Farenhorst, R., Lago, P. and Vliet, H. V. 2011. The lonesome architect. In: *Software Architecture, 2009 & European Conference on Software Architecture*. Cambridge, 14-17 September 2009.

Hopkins Architects. 1994. *Inland Revenue Centre* [Online]. Available at: http://www.hopkins.co.uk/projects/5/88/ [Accessed: 02 February 2014].

Horton, A. 1987. Energy initiatives in Milton Keynes. *Property Management* 5, pp.122-130.

Howrie, J. 1995. Building modelling: an architect's view. *Bepac Newsletter* 12.

Hudson, L. 1966. *Contrary Imagination*. London: Methuen.

IEA. 2006. *Integrated building concepts state-of-the-art review report* [Online]. Available at: http://www.ecbcs.org/docs/Annex_44_SotAr_Vol_1.pdf [Accessed: 18 May 2011].

IPCC. 1990. *IPCC First Assessment Report (FAR)*. Cambridge: IPCC.

IPCC 1995. *IPCC Second Assessment Report: Climate Change 1995 (SAR)*. Cambridge: IPCC.

IPCC, 2013: Summary for policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Itin, C. M. 1999. Reasserting the philosophy of experiential education as a vehicle for change in the 21st century. *The Journal of Experiential Education* 22, p. 8.

Janda, K. B. 2011. Buildings don't use energy: people do. *Architectural Science Review* 54, pp. 15-22.

Jones, P. and Wang, Y. 2007. A strategy for sustainable housing development in Xi'an. Cardiff: Welsh School of Architecture.

Jones, P. J. 2005. Energy efficient housing – developments over the last three decades.

Jones, P., Hou, S. and Li, X. 2013. Towards zero carbon design in offices: integrating smart facades, ventilation, and surface heating and cooling. In *International Conference of SuDBE 2013,* Chongqing, October 2013.

J. Farren-Bradley 2000. *Learning in practice: a retreat, an opportunity or an imperative*? In D. Nicol and S. Pilling eds. Changing Architectural Education: Towards a New Professionalism. London: Spon Press.

Kanters, J., Dubois, M. C., Wall, M. 2012. Architects' design process in solar-integrated architecture in Sweden*. Architectural Science Review* 56, pp. 141-151.

Kemp M. 2010. *Zero Carbon Britain 2030 - a new energy strategy: the second report of the Zero Carbon Britain project*. Powys: Centre for Alternative Technology.

Kim, M. J., Oh, M. W., Kim, J. T. 2013. A method for evaluating the performance of green buildings with a focus on user experience. *Energy and Buildings* 66, pp. 203-210.

Knowles, M. S. and Associates. 1984. *Andragogy in action: applying modern principles of adult learning.* San Francisco: Jossey-Bass.

Knowles, M. S. 2005. *The adult learner: The definitive classic in adult education and human resource development*. London: Elservier.

Knudstrup, M. A. 2004. Integrated Design Process in PBL. In. *The Aalborg PBL Model, red. Annette Kolmoes, Flemming K. Fink, and Lone Krogh*, Denmark: Aalborg University Press

Kolb, D. 1976. *The Learning Style Inventory: technical manual*. Boston: McBer and Co.

Kolb, D. 1984. *Experiential learning: experience as the source of learning*. Englewood Cliffs: Prentice Hall.

Kulshreshtha, P., Khare, M. and Seetharaman, P. 2008. Indoor air quality assessment in and around urban slums of Delhi city, India. *Indoor Air* 18, 488-98.

Larsson, N. and Poel, B. 2003. *Solar low energy buildings and the integrated design process: an introduction*. Rotterdam: Task 23-Optimization of Solar Energy Use in Large Buildings.

Lausten, J. 2008. *Energy efficiency requirements in building codes - policies for new buildings*. Paris: International Energy Agency.

LCRI. 2008. *Low Carbon Research Institute* (LCRI) [Online]. Available at: http://www.lcri.org.uk [Accessed: 06 January 2014].

Lindman, E. C. 1926. *The meaning of adult education*. New York: New Republic, Inc.

Lomas, K. J. 1995. The U.K. applicability study: an evaluation of thermal simulation programs for passive solar house design. *Building and Environment* 31, p. 10.

Long, N., Long, A. 1992. *Battlefields for knowledge: the interlocking of theory, and practice in social research and development*. London: Routledge.

Macdonald, W. L. 1977. *Roman architects*. New York: Oxford University Press.

Mackinder, M. and Marvin, H. 1982. Design decision making in architectural practice: the roles of information, experience and other influences during the design process. *Institute of Advanced Architectural Studies 19*, University of York: York.

Mangione, T. W. 1995. *Mail survey: improving the quality*. Thousand Oaks: SAGE Publications Ltd.

Marsh, A. 2008. *Generative and performative Design: A challenging new role for modern architects* [Online]. Available at: http://companyshed.com/1023649200/documents/2008_OxfConf.pdf [Accessed: 20 May 2012].

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I. and Napolitano, A. 2011. Zero energy building – a review of definitions and calculation methodologies. *Energy and Buildings* 43, pp. 971-979.

Martin, L. 1958. *Report of RIBA conference on architectural education by the chairman* [Online]. Available at: http://www.oxfordconference2008.co.uk/1958conference.pdf [Accessed: 20 May 2012].

May, T. 2011. *Social research: issues, methods and process*. Maidenhead: Open University Press.

McCarthy, B. 1990. Using the 4MAT system to bring learning styles to schools. *Educational Leadership* 48.

McCarthy, B. 2014. *About learning* [Online]. Available at: http://www.aboutlearninsg.com/ [Accessed: 04 January 2014].

Mclennan, J. F. 2006. *The philosophy of sustainable design: the future of architecture*. Missouri: Ecotone.

Meredith, S., Newton, B. 2003. Models of eLearning: technology promise vs learner needs literature review. *The International Journal of Management Education* 03/03, pp. 43-56.

Merton Council. 2003. *What is the Merton Rule*? [Online]. Available at: http://www.merton.gov.uk [Accessed: 04 January 2014].

Monbiot, G. 2007. This crisis demands a reappraisal of who we are and what progress means. *The Guardian Newspaper*, 4 December 2007.

Morbitzer, C. A. 2003. *Towards the integration of simulation into building design process*. Degree of Doctor of Philosophy, University of Strathclyde.

Myers, J. 2013. *Consulting discusses the new RIBA Plan of Work* [Online]. Available at: http://www.fticonsulting.co.uk/global2/case-law/james-myers-of-fti-consulting-discusses-the-new-riba-plan-of-work.aspx [Accessed: 31 August 2013].

Nicholls, R. 2002. *Low energy design*. Greenfield: Interfacing Publishing.

Noailly, J. 2011. Improving the energy efficiency of buildings: The impact of environmental policy on technological innovation. *Energy Economics* 34, pp. 795-806.

Olgyay, V. 1963. *Design with climate: bioclimatic approach to architectural regionalism*. New Jersey: Princeton University Press.

Olgyay, V. and Olgyay, A. 1963. *Design with climate: bioclimatic approach to architectural regionalism*. Princeton: N.J, Princeton University Press.

Opoku, A. and Ahmed, V. 2014. Embracing sustainability practices in UK construction organizations: challenges facing intra-organizational leadership. *Built Environment Project and Asset Management* 4, pp. 90-107.

Osmani, M., Glass, J. and Price, A. D. F. 2008. Architects’ perspectives on construction waste reduction by design. *Waste Management* 28, 1147-1158.

Osmani, M. and O'Reilly, A. 2009. Feasibility of zero carbon homes in England by 2016: A house builder's perspective. *Building and Environment* 44, pp. 1917-1924.

Palladio Andrea. 1570. Quattro Libri dell'Architettura (The Four Books on Architecture). Venice.

Panagiotidou, M., Fuller, R. J. 2013. Progress in ZEBs: a review of definitions, policies and construction activity. *Energy Policy* 62, pp. 196-206.

Papadopoulos, A. M. and Giama, E. 2009. Rating systems for counting buildings' environmental performance. *International Journal of Sustainable Energy*, pp. 29-43.

Parker, J. 2009. *BREEAM or LEED - strengths and weaknesses of the two main environmental assessment methods* [Online]. Available at: https://www.bsria.co.uk/news/article/breeam-or-leed// [Accessed: 08 January 2014].

London Energy Partnership. 2006. *Towards zero carbon developments: supportive information for borough*s [Online]. Available at: http://www.cse.org.uk/pdf/pub1074.pdf [Accessed: 11 May 2012].

Payne, G. and Payne, J. 2004. *Key concepts in social research*. London: SAGE Publications Ltd.

Piaget, J. 1995. *The child's conception of reality*. Northvale: Jason Aronson.

Pitt, M., Tucker, M., Riley, M. and Longden, J. 2009. Towards sustainable construction: promotion and best practices. *Construction Innovation* 9, pp. 201-224.

Praznik, M., Butala, V. and Zbasnik, S. M. 2013. Simplified evaluation method for energy efficiency in single-family houses using key quality parameters*. Energy and Buildings* 67, pp. 489-499.

Rapoport, A. 1969. *House, form and culture*. Englewood Cliffs: Prentice Hall.

Reed, R., Bilos, A., Wilkinson, S. and Schulte, K. W. 2009. International comparison of sustainable rating tools. *The Journal of Sustainable Real Estate* 1, pp. 1-22.

International Union for Conservation of Nature and Natural Resources (IUCN). 1980. *World conservation strategy: living resources conservation for sustainable development*. Gland: IUCN.

RIBA. 2000. *RIBA Environmental Manifesto* [Online]. Available at: http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/Environment/EnvironmentManifesto.pdf [Accessed: 28 May 2013].

RIBA. 2010a. *Climate Change Toolkit: Low Carbon Standards and Assessment Methods*. London: RIBA

RIBA 2010b*. Climate Change Toolkit: Carbon Literacy Briefing*. London: RIBA

RIBA. 2011a. *CPD at the RIBA* [Online]. Available at: http://www.architecture.com/RIBA/CPD/CPD.aspx [Accessed: 21 December 2013].

RIBA. 2011b. *Green Overlay to the RIBA Outline Plan of Work*. London: RIBA.

RIBA. 2012. *New CPD Core Curriculum* [Online]. Available at: http://www.architecture.com/EducationAndCareers/CPD/NewCPDCoreCurriculum.aspx [Accessed: 10 April 2012].

RIBA. 2013. *RIBA Plan of Work 2013* [Online]. Available at: http://www.ribaplanofwork.com/ [Accessed: 21 June 2014].

RIBA. 2014. *Queens Building, De Montfort University* [Online]. Available at: http://www.walkingarchitecture.co.uk/eastmidlands/building.php?id=39 [Accessed: 02 February 2014].

Riding, R. and Cheema, I. 1991. Cognitive styles: an overview and integration. *Educational Psychology* 11, pp. 193-215.

Riding, R. J. and Rayner, S. 1998. *Cognitive styles and learning strategies*. London: David Fulton.

Ridley, D. 2012. *The literature review: a step-by-step guide for students*. London: SAGE Publications Ltd.

Ritchie, A. and Thomas, R. 2009. *Sustainable urban design: an environmental approach*. Oxon: Taylor and Francis.

Ritter, J. 1981. *Building design: information and aids*. Percy Thompson Partnership.

Roberts, A. 2004. *The relationship between cognitive style and a student's performance in architectural design education*. PhD Thesis, Cardiff University.

Rural Studio 2010. *Rural studio education* [Online]. Available at: http://www.ruralstudio.org/ [Accessed: 24 January 2010].

Sapsford, R. and Jupp, V. 1996. *Data collection and analysis*. London: SAGE Publications Ltd.

Sartori, I. and Hestnes, A. G. 2007. Energy use in the life cycle of conventional and low-energy buildings: a review article. *Energy and Buildings* 39, pp. 249-257.

Sartori, I., Napolitano, A. and Voss, K. 2012. Net zero energy buildings: a consistent definition framework. *Energy and Buildings* 48, pp. 220-232.

Sassi, P. 2006. *Strategies for sustainable architecture*. Oxon: Taylor and Francis.

Saunders, T. 2008. *A discussion document comparing international environmental assessment methods for buildings*. BRE, March.

Schmeck, R. R. 1988*. An introduction to strategies and styles of learning*. New York: Plenum press.

Schon, D. 1983. *The reflective practitioner: how professionals think in action*. New York: Basic Books.

Seidel, A. D., Holden, G. and Ozdil, T. R. 2006. What principals of firms say an architect needs to know: international comparisons? *Architectural Science Review* 49, pp. 196-203.

Shannon, S. and Radford, A. 2010. Iteration as a strategy for teaching architectural technologies in an architecture studio. *Architectural Science Review* 53, pp. 238-250.

Shadnnon, S. J., Francis, R. L., Chooi, Y. L. and Ng, S. L. 2012. Approaches to the use of blended learning in teaching tectonics of design to architecture/design and architectural engineering students. *Architectural Science Review* 56, pp. 131-140.

Shingler, A. 2014. *Intelligence: Plan of work 2013*. [Online]. Available at: http://www.ribajournal.com/pages/jan_2014__intelligence_plan_of_work_2013 [Accessed: 21 June 2014].

Sloman, M. 2001, *The E-learning Revolution*. CIPD: London.

Sleeuw, M. 2011. *A comparison of BREEAM and LEED environmental assessment methods*. Norwich: University of East Anglia.

Smith, M. K. 1996. *Andragogy, the encyclopaedia of informal education* [Online]. Available at: http://infed.org/mobi/andragogy-what-is-it-and-does-it-help-thinking-about-adult-learning [Accessed: 24 January 2012].

Smith, P. F. 2005. *Architecture in a climate of change: a guide to sustainable design*. Oxford: Architectural Press.

Sorrell, S. 2003. Making the link: climate policy and the reform of the UK construction industry. *Energy Policy* 31, pp. 865-878.

Souza, C. B. D., Knight, I., Dunn, G. and Marsh, A. 2006. Modelling buildings for energy use: a study of the effects of using multiple simulation tools and varying levels of input detail. In: *International Conference on Electricity Efficiency in Commercial Buildings* 2006. Frankfurt, Germany.

Steele, J. 2005. *The critical review of ecological architecture*. London: Thames and Hudson.

Strachan, P. A., Kokogiannakis, G. and Macdonald, I. A. 2008. History and development of validation with the ESP-r simulation program. *Building and Environment* 43, p. 9.

Studio 804. 2010. *Studio 804* [Online]. Available at: http://studio804.com/ [Accessed: 24 January 2010].

Suires, G. 1993. *Education for adults*. London: The Open University.

Sullivan, L. 2012. *RIBA guide to sustainability in practice*. London: RIBA.

Summerfield, A. J., Lowe, R. J., Bruhns, H. R., Caeiro, J. A., Steadman, J. P. and Oreszczyn, T. 2007. Milton Keynes Energy Park revisited: changes in internal temperatures and energy usage. *Energy and Buildings* 39, pp. 783-791.

Tam, V. W. Y. 2007. The effectiveness of the green building evaluation and labelling system. *Architectural Science Review* 50, pp. 323-330.

Tang, Z., Brody, S. D., Quinn, C., Chang, L. and Wei, T. 2010. Moving from agenda to action: evaluating local climate change action plans. *Journal of Environmental Planning and Management* 53, pp. 41-62.

Taylor, T. A. 2011. *Guide to LEED 2009*. New Jersey: John Wiley and Sons, Inc.

The Environment Agency. 2013. *Climate Change Agreements Scheme* [Online]. Available at: http://www.environment-agency.gov.uk/ [Accessed: 04 January 2014].

The Low Carbon Construction Innovation and Growth Team. 2010. *Low Carbon Construction Innovation and Growth Team: Final Report*. London.

The Welsh Government. 2014. *Amendments to the Approved Documents L1A, L1B, L2A and L2B Conservation of Fuel and Power 2013 – for use in Wales* [Online]. Available at: http://wales.gov.uk/docs/desh/publications/140116building-regs-part-l-amendment-slip-en.pdf [Accessed: 18 April 2014].

Thomas, R. 2006. *Environmental design: an introduction for architects and engineers*. London: Taylor and Francis.

Torcellini, P., Pless, S., Deru, M. and Crawley, D. 2006. Zero energy buildings: a critical look at the definition. In: *ACEEE Summer Study*. Pacific Grove.

Tucher, R. 2007. Southern Drift: The learning styles of first-and third-year students of the built environment. *Architectural Science Review* 50, pp. 246-255.

UKERC-EDC. 1990. *Milton Keynes Energy Park Dwellings*. Energy Research Centre.

UK-GBC. 2014. UK Green Building Council [Online]. Available at: http://www.ukgbc.org/site/home [Accessed 04 February 2009].

UNFCCC. 2014a. The United Nations Framework Convention on Climate Change [Online]. Available at: http://unfccc.int/2860.php [Accessed: 04 January 2014].

UNFCCC. 2014b. The United Nations Framework Convention on Climate Change [Online]. Available at: http://unfccc.int/meetings/items/6240.php [Accessed: 06 October 2014].

UN. 2014. *UNFCCC and the Kyoto Protocol* [Online]. Available at: http://www.un.org/wcm/content/site/climatechange/pages/gateway/the-negotiations/the-un-climate-change-convention-and-the-kyoto-protocol [Accessed: 04 January 2014].

USGBC. 2009. *LEED reference guide for green building design and construction*. Washington, DC: USGBC.

USGBC. 2011. *An Introduction to LEED* [Online]. Available at: http://www.usgbc.org/leed [Accessed: 04 January 2014].

USGBC 2011. *LEED 2009 Minimum Program Requirements*. Washington, DC: USGBC.

Vermunt, J. D. 1998. The regulation of constructive learning processes. *British Journal of Educational Psychology* 68, pp. 149-171.

Watts, C., Jentsch, M. F. and James, P. A. B. 2011. Evaluation of domestic Energy Performance Certificates in use. *Building Services Engineering Research and Technology* 32, 361-376.

Watson, D. 1998. Who was the first solar architect? In: *Environmentally Friendly Cities, Proceedings of PLEA'98*. Lisbon, June, 1998. James and James Science Publishers Ltd, pp. 213-216.

Webster, H. 2008. Architectural education after Schon: cracks, blurs, boundaries and beyond. *Journal for Education in the Built Environment* 3.

WEST. 2011. *Welsh Energy Sector Training* [Online]. Available at: http://www.westproject.org.uk [Accessed: 06 January 2014].

WGI. 2013. *Climate Change 2013: the physical science basis*. Switzerland: IPCC.

WIKIPEDIA. 2007. *BedZED* [Online]. Available at: http://upload.wikimedia.org/wikipedia/commons/0/05/BedZED_2007.jpg [Accessed: 02 February 2014].

WIKIPEDIA. 2009. *Contact Theatre* [Online]. Available at: http://en.wikipedia.org/wiki/File:Contact_Theatre_2009.jpg [Accessed: 02 February 2014].

WIKIPEDIA. 2011. *Menara Mesiniaga aerial view* [Online]. Available at: http://en.wikipedia.org/wiki/File:Menara_Mesiniaga_aerial_view.jpg [Accessed: 02 February 2014].

WIKIPEIDIA. 2012. *Coventry University Lanchester Library* [Online]. Available at: http://commons.wikimedia.org/wiki/File:Coventry_University_Lanchester_Library_6933825422.jpg [Accessed: 02 February 2014].

Wittmann, S. 1998. Architects' commitment regarding energy efficient/ ecological architecture. *Architectural Science Review* 41, pp. 89-92.

Wolfe, D. M. and Kolb, D. I. E. E. 1991. *Career development, personal growth, and experiential learning*. Englewood Cliffs: Prentice Hall.

World Commission on Environment and Development. 1987. *Our common future*. Oxford: World Commission on Environment and Development.

World Council of Churches. 1974. *Report of ecumenical study conference on science and technology for human development*. Geneva: World Council of Churches

World Green Building Council. 2010. *Tackling global climate change - meeting local priorities* [Online]. Available at: http://www.ukgbc.org/resources/publication/world-gbc-special-report-tackling-global-climate-change-meeting-local-priorities [Accessed: 08 November 2013].

WSA. 2014. [Online]. *Masters courses at the Welsh School of Architecture*. Available at: http://www.cardiff.ac.uk/archi/programme-structure [Accessed: 21 June 2014].

Yamin, F. and Depledge, J. 2004. *The international climate change regime: a guide to rules, institutions and procedures*. Cambridge: Cambridge University Press.

Yeang, K. 1995. *Design with nature: the ecological basis for architectural design*. New York: McGraw-Hill, Inc.

Yeang, K. 1996. *The skyscraper bioclimatically considered: a design primer*. London: Academy Group, Ltd.

Zapata-Poveda, G. and Tweed, C., 2014. Official and informal tools to embed performance in the design of low carbon buildings: an ethnographic study in England and Wales. *Automation in Construction*, 37(0), pp.38–47.

Zero Carbon Hub. 2008. *Zero Carbon Hub* [Online]. Available at: http://www.zerocarbonhub.org [Accessed: 04 January 2014].

Zuo, J., Read, B., Pullen, S. and Shi, Q. 2012. Achieving carbon neutrality in commercial building developments – perceptions of the construction industry. *Habitat International* 36, pp. 278-286.