



An Evaluation of Architects' Readiness for Conducting Energy Modelling Using BIM Tools to Achieve High Energy Performance Buildings in the UK and Canada.

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i) List of Abbreviations

AEC: Architectural Engineering Construction

AI360: Autodesk Insight 360

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

BIM: Building Information Modelling

BPA: Building Performance Analysis

BREEAM: Building Research Establishment Environmental Assessment Methodology

CMM: Capability Maturity Model

DOE: Department of Environment

EPA: Energy Performance Analysis

GBS: Green Building Studio

GW: Global Warming

HEPBs: High Energy Performance Buildings

HVAC: Heating, Ventilating, and Air conditioning

IAQ: Indoor Air Quality

IDM: Information Delivery Manual

IEQ: Indoor Environment Quality

IFC: Industry Foundation Classes

IFD: International Framework for Dictionary

LEED: Leadership in Energy and Environmental Design

MEP: Mechanical, Electrical, and Plumbing

ODMP: Office of the Deputy Prime Minister

PBD:Point-Based Design

SBD: Set-Based Design

SHG:Solar Heat Gain

WWR: Window-to-Wall Ratio

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v) Abstract

Buildings, consume more than 30 % of the world's energy and is the world's largest energy consuming sector, contributing nearly a quarter of the total global greenhouse gas emissions. Global warming is the result of emission of greenhouse gases, and this represents a significant existential crisis. The effective design of buildings is one way to mitigate this issue and this starts with the design of the building. One of the architect's main responsibilities is the building's geometric design, which has a considerable impact on energy consumption. Building Performance Analysis (BPA) is generally conducted during the later design stages often in support of the mechanical and electrical design, such as heating and cooling systems. To achieve a High Energy Performance Building (HEPB), this research considers the potential impact and implementation of a process which might bring the geometric design stage and energy analysis stages closer to each other. While architects usually deal with geometrical design, much of energy performance analysis work is carried out by consultant energy specialists. However, new BIM tools have the potential to make this stage of analysis more accessible to architects, who may not have specific building physics knowledge.

The purpose of this study is to assess the acceptability of BIM based energy analysis tools to architects and assess their potential use in early stage energy analysis undertaken by non-specialist architects. The aim of this research is to evaluate the conditions of the design process for HEPB in the UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

An abductive research approach is used to test existing theories regarding the ability of BIM to design and analyse green buildings. The survey of UK and Canadian architects identifies issues such as; standards, underlying knowledge, client demand and the use of BIM tools to identify applicability of the approach. The results from the study are used to understand the processes of HEPBs architectural design, including the sources and tools which are used. The respondents' familiarity with BIM, its tools and ability for doing tasks in the design and construction industry, specifically regarding HEPBs design and the potential barriers for employing BIM are also considered.

The recognised gap in the knowledge is to develop a better understanding of the issues of the detachment of architects as first designers of buildings involved in geometrical design from the later stages (Building Performance Analysis) and the possible solutions that might be provided by BIM tools. The contribution to knowledge of the research focuses around a better understanding of the specific barriers for the implementation and use of BIM energy analysis tools by architectural practices which will be achieved through finding weaknesses in the current process of design process and discovering potential solutions.

Key Words: Architects, Energy Efficiency, Energy Modelling, High Energy Performance Buildings, Indicators, Information, Modelling, Performance Analysis.

Chapter 1.0: Introduction

Buildings consume 31% of produced energy and account for a major share of global energy consumption (Dean et al., 2016). The effective design of high performing, energy efficient buildings is important to meet increasingly stringent regulation, as well as wider energy goals, such as energy security or climate change mitigation. This has traditionally relied on specialist skills from energy consultants. This has the potential to lead to a disconnection between the architects, as principal designers, and the energy efficiency elements of design. However, with the emergence of BIM, there are new tools that may allow non-experts to quickly analyse the energy performance of buildings during the design process. This study is concerned with understanding the architects' perspective of what this might mean for the profession, the design process and the wider delivery of energy efficient buildings.

Anderson, (2014) states that in current practice, practitioners in architectural firms are detached from evaluating a building based on green building indicators. This is despite the fact that architects are initial designers of a project who deal with geometrical design which has a considerable impact on buildings' energy consumption. However, the assessment of building performance is mostly dependent on mechanical designers who are almost excluded from the process of geometrical design. Early collaboration between all designers (Mechanical, Electrical, and Plumbing (MEP) and architects) is necessary in order to study and analyse different simulations and achieve the most effective design. Recently, computational simulation tools have offered a great opportunity for architects to employ many types of beneficial simulations without the need for deep knowledge about how airflow, solar energy, HVAC, and lighting systems interact with buildings (Anderson, 2014).

1.1 Buildings and Energy Consumption

The energy consumption trends in the buildings have increased in the last 20 years. Based on Dean et al., 2016, from 1999 until 2014 the total energy consumption has increased by over 30% and in some regions the electricity consumption in buildings has increased by over 500%. By consideration of upstream power generation, buildings sector produces about 30% of global energy-related CO₂ emissions (Dean et al., 2016).

Figure 1.1 demonstrates the total energy consumption by different sectors globally and the share of different sources of energy.

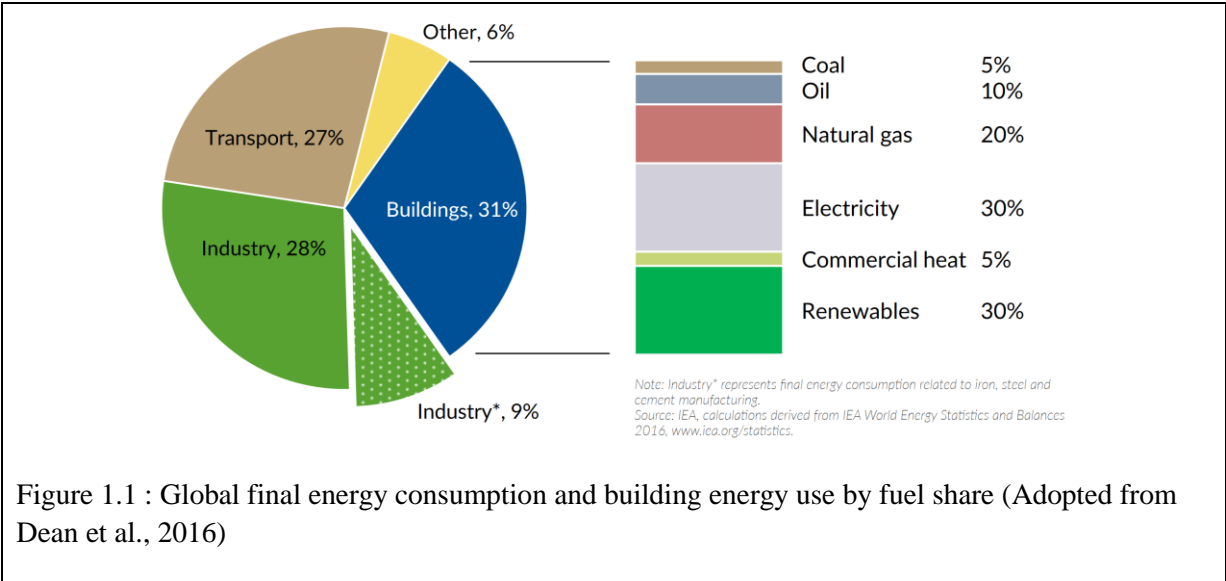


Figure 1.1 : Global final energy consumption and building energy use by fuel share (Adopted from Dean et al., 2016)

Residential and Commercial buildings are the two major building categories. The Department of Energy (U.S) identifies the different categories of energy consumption in buildings (Figure 1.2), indicating that space heating and cooling make up a large proportion of energy use, particularly in residential buildings. Another study of residential energy use conducted by International Institute for Applied System Analysis (IIASA) and the results are reported in Global Energy Assessment in year 2012 (Figure 1.3). As the graphs show, in both residential and commercial buildings, most energy is consumed for space heating. Water heating is the second energy consumer in some countries while in other countries appliances stay in second place. Lighting and space cooling are the other users which consume the most energy.

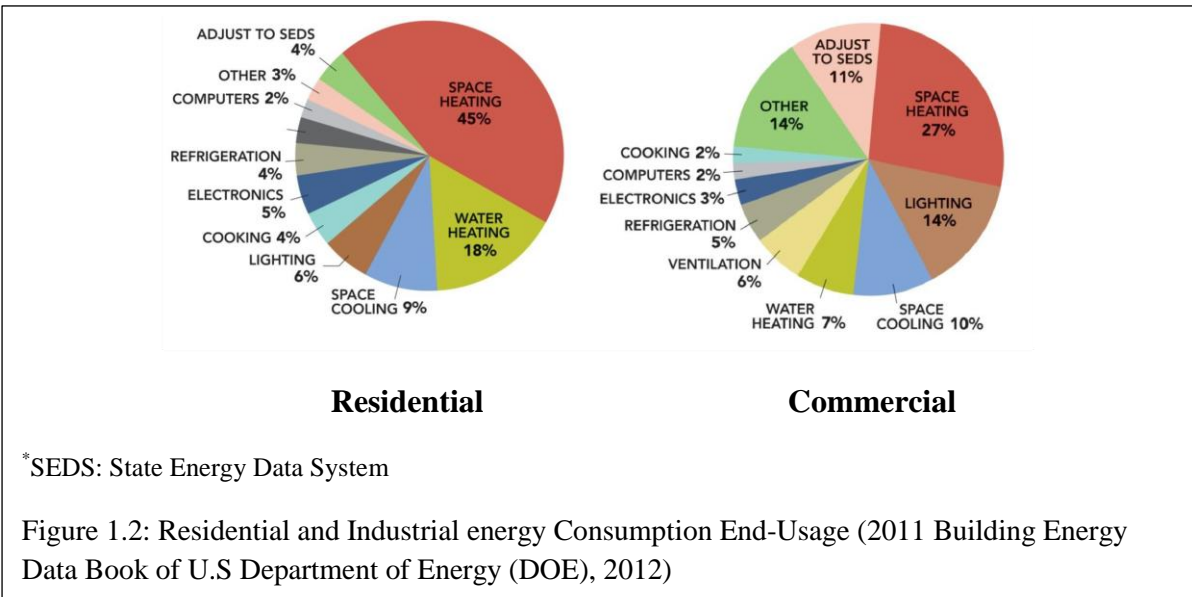
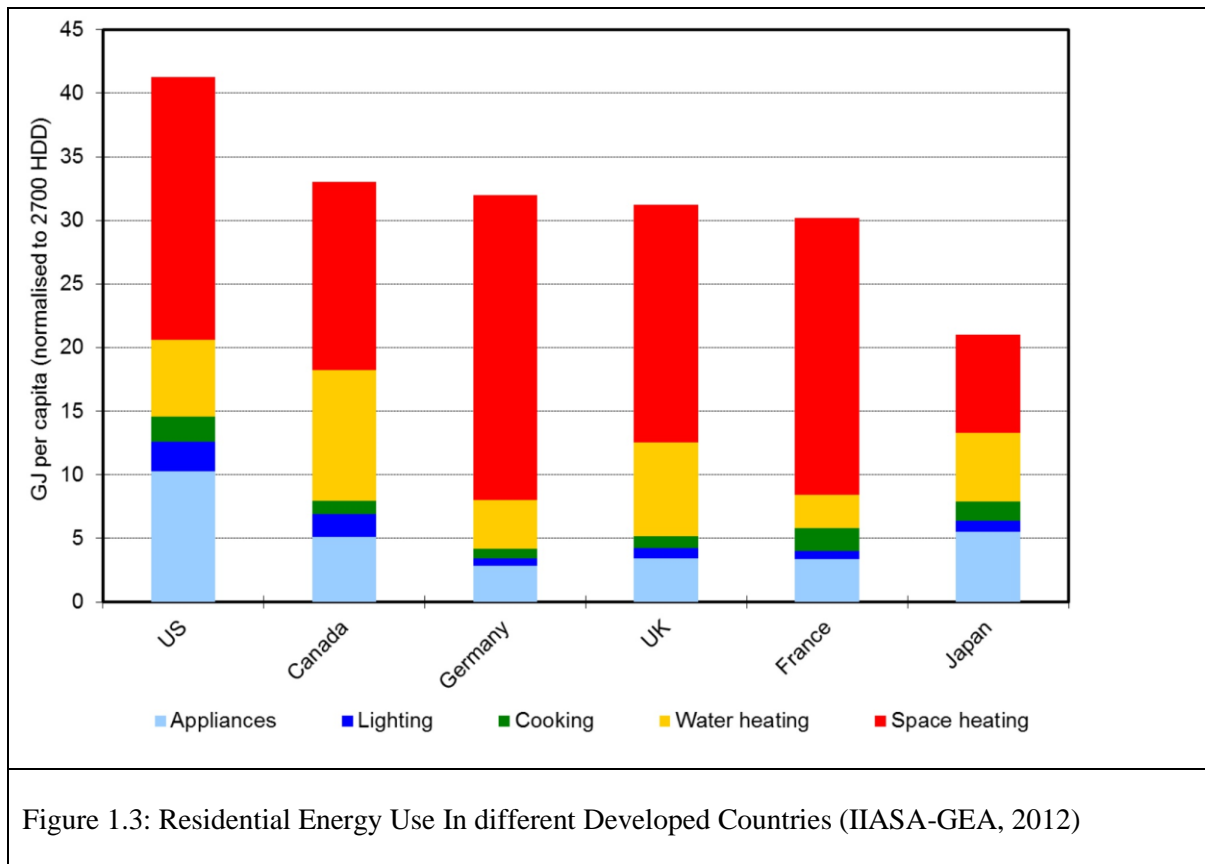


Figure 1.2: Residential and Commercial energy Consumption End-Usage (2011 Building Energy Data Book of U.S Department of Energy (DOE), 2012)



All of these energy demands represent the building energy load. Building load is categorized into heating loads (when building is too cold), cooling loads (when building is too hot), plug loads (running appliances), and lighting loads. These demands must be covered to keep building livable and occupant comfortable (ASHRAE, 2014).

Building energy consumption must be considered systemically. An approach to reducing the heating and cooling loads is to address the building fabric, in terms of its conductivity and air infiltration. It is also important to consider boundary conditions such as sun, climatic conditions, and wind during the design stage of a building. Typical carbon emissions mitigation strategies may include using renewable energy, or increasing the building efficiency to reduce the demand for energy. Increasing a buildings' energy efficiency needs to consider different principles such as shape, size, and orientation of buildings, size and orientation of fenestration, material properties and assembly of envelope, and size and orientation of rooms (Bergman, 2012; Kubba, 2012; ASHRAE 2014; UK BREEAM, 2014; LEED, 2014).

These principles can be categorised into two major categories of geometrical (sizes, shapes and orientations) and technical (properties of materials, heat flow, envelope assembly, etc.).

Selecting suitable shape and appropriate orientation for the building can save 30-40% of energy consumption (Elbeltagi, 2017). The geometrical design has traditionally been done by architects while mechanical engineers or other firms and professionals who are aware of energy and building science deal with the technical part.

The aim of this research is to evaluate the conditions of the design process for HEPB in the UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

1.2 Building Information Modelling (BIM) and Energy Efficient Buildings

The use of Building Information Modelling allows a building model to be developed and analysed in a number of ways, such as cost, time, clash detection and environmental performance (Azhar et al. 2008). The UK Government has identified BIM as a major driver for both building quality and productivity, both in the UK and Internationally.

BIM is the first truly global digital construction technology and will soon be deployed in every country in the world. It is a 'game changer' and we need to recognise that it is here to stay (HM Government, 2012, P2).

Kubba (2012) states that for designing energy efficient buildings, measuring performance expectations is necessary. Computer modelling tools can be employed for this task. These tools can be adopted in the design stage to inform a project's stakeholders the impacts of energy use in the primary stage of the process (Kubba, 2012). Some of the BIM's tools can help designers to predict energy consumption of buildings through energy modelling and performance analysis during design processes (Azhar et al., 2008; Succar et al., 2012; Wong & Fan, 2013; Anderson, 2014). Concerns and issues such as precision, ease of use, and how to use such tools are discussed in detail in the next section.

Azhar et al. (2008) discusses some of the most important functions and benefits of BIM, which are summarised as: a three-dimensional model can be easily produced before the construction phase for visualisation; a solid modeller can produce a shop drawing for fabrication; a review of a building is easily possible by referring to the model(s), such as a regulatory compliance review; any errors, leaks, defects, or evacuation plans, can be subjected to forensic analysis; designing spaces before and after completing a project; maintenance operation and renovation, as aspects of facility management, can be utilised by a BIM-based model; easy access to the number of objects used in the model, and their characters, can help in cost

estimation; time scheduling and preparing of orders for materials are achievable by using BIM for construction sequencing; parametric information in a BIM model can help in investigating, and therefore preventing, any clash and conflict between a building's components in the design phase.

Wong and Fan (2013) claim that BIM makes the achievement of sustainable design more possible. Projects in the UK, France, Germany, Norway, Sweden, Finland, and Australia have been completed by implementing BIM in the construction life cycle process. They have demonstrated that more sustainable buildings can be achieved by BIM implementation (Khosrowshahi and Arayici, 2012).

Much of these researches have made claims about the ability of BIM to support the development of environmentally sustainable buildings. However, in many of these studies there is a lack of clarity as to how this is achieved in terms of roles and responsibilities, clear definitions of sustainability criteria that can be achieved, and clear tools and processes. To achieve an energy efficient product as Anderson, 2014 mentioned '*a quick workflow from architectural model to energy model is needed which BIM promises this translation but has yet to deliver*'

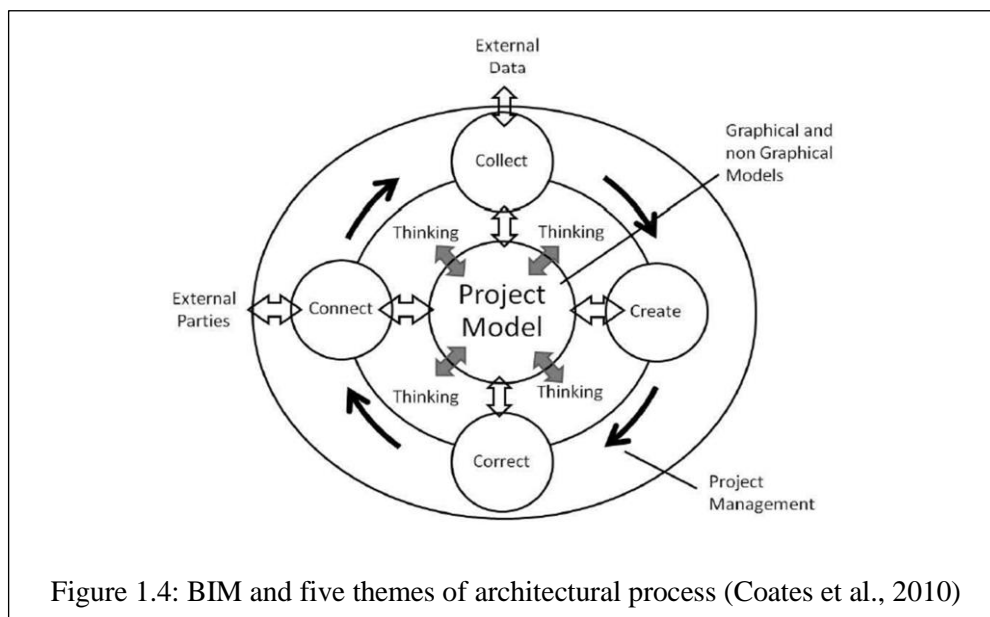
In this research, effort has been made to find the answer of these questions by assessing acceptability of BIM tools for reducing the gap between geometrical design and technical design, which is the focus and contribution to the knowledge of this study. Architects are often involved early in the project life cycle and are responsible for geometrical design, so this research is looking to this group as main targets for investigation. It seeks to answer a number of questions as to the potential use of BIM models and energy efficiency in the early design stage and how architects consider the sustainability issues in their work? What tools they are using? How familiar are they with BIM and its ability for performing different tasks and specially energy efficient product achievement? What are the biggest barriers for them for utilizing BIM in their work practice?

For an energy efficient product, smooth connection and communication between architects (geometrical designers) and energy related engineers (technical designers) are necessary for better coordination and cooperation. These kinds of coordination and cooperation need a novel efficient design process and engineering. BIM allows the potential for Concurrent Engineering (CE) and a more efficient process of design which is Set-Based Design (SBD) instead of traditional Point-Based Design (Lee et al. 2012). In an SBD process, the circular

process used for sending and receiving the results from designers and assessors at different times will be changed to a concurrent model. Then assessors have instant access to the design and can start their analyses and modifications in the same database. At the same time the designers can see the results of the assessment concurrently. Another important advantage of SBD is its potential to help designers to be able to work on variety of potential designs for comparing and selecting the best one based on the project requirements. In traditional PBD usually just one design is chosen and different solutions are applied and tested on it (Lee et al. 2012).

Coates et al. defined the architectural process within five themes (Figure 1.4):

“These domains are thinking, collecting (relevant data, information and knowledge), creating (abstractions, models, concepts and artefacts), correcting (reviewing, refining, verifying and validating) and connecting (transferring an understanding of the output to others)” (p.81).



The use of BIM to address energy efficiency presents a potential opportunity to better integrate architects into the process, particularly when early design decisions are being made. This research recognises that there are questions about roles, tools, processes and expertise that need to be more fully understood before BIM can be effectively implemented in this way.

1.3 Research Rationale

The research brings together some key bodies of knowledge to develop the question. These need to be addressed to fully understand the more specific question of how architects may use BIM tools to develop more energy efficient buildings.

- *Why environmentally sustainable buildings and, specifically, energy efficient buildings?*

Environmental buildings have been supported by accreditation methods such as BREEAM and LEED. These tools address wider sustainability in terms of providing best practice models. Here we will focus specifically on energy efficiency and address wider sustainability drivers as well as energy efficiency drivers.

Note: for this study, BREEAM refers to the “BREEAM UK New Construction, Non-Domestic Buildings, 2018” scheme. LEED refers to LEED BD+C New Construction scheme.

- *Why Building Information Modelling (BIM)?*

BIM has the capacity provide reliable, rich data in an integrated environment (database) for the design and analysis of buildings. In the initial stages of design, new BIM tools have the potential to enable architects to design an energy efficient building without the need for deep knowledge about the rules related to energy, solar radiation, airflow, lightening, etc. However, the process and issues that architects may find in practice must be explored.

- *Why the design stage?*

Design consists of a series of processes interacting with each other and the most significant decisions in this process are made with the help of existing information, simulations, and analyses. Specifically, early investment in the design phase in order to increase the performance of a building can bring significant efficiency in the operation phase.

In 2013, RIBA developed the previous Plan of Work with eight stages (0-7) and eight taskbars as the “the process of briefing, designing, constructing, maintaining, operating and using building projects”. This Plan of Work is considered the basis for effective management of the design stages. Phases 2 (Concept Design), 3 (Developed Design), and 4 (Technical design) are the main stages that include the architect. While in all phases, there are several check-points regarding sustainability issues, in the three stages of design the importance of decision-making, analysis, and checking are highlighted. For example,

In the *concept design*: “the environmental impact of key materials”; “formal sustainability pre-assessment and identification of key areas of design focus have been undertaken”.

In the *developed design (design development)*: performing full formal sustainability assessment. Reviewing the design to find the potential points for reducing resource use, particularly energy, and waste.

In the technical design (Detailed design): considering details to address airtightness and sequence of insulation; submitting all outstanding design stage sustainability assessment information; demonstrate agreed sustainability criteria for contributions to specialist subcontractors.

- *Why architects?*

Architects have significant role in design stage. Architects' familiarity with materials, forms, technical systems, and geometrical design make them well placed to be able to conduct a simplified energy analysis so that they can "play" with the design idea and receive quick feedback during early option development (Schlueter and Thesseling, 2009; Anderson, 2014). This research is designed to evaluate respondents' experience regarding HEPB design and BIM. There are two main reasons for this research to be undertaken in design and construction industry. The first is to understand what the existing knowledge and experience in designing for energy and building information modelling currently is. Secondly, to consider potential recommendations and guidance for architects who are willing to implement BIM in order to design for energy efficient buildings by using the knowledge of practitioners who had relevant experience.

The final recommendation is designed for firms and architects so that they can improve the efficiency of architectural design process through BIM capabilities in order to conduct non-advanced energy performance analysis.

- *Why UK and Canada?*

There are several reasons which motivated researcher to conduct his research in UK and Canada. Both countries are considered developed countries where energy consumption and related climate change mitigation are considered important policy issues, and BIM is considered a standard tool for the delivery of many buildings. The researcher is a Canadian resident but started his study as a full-time student in UK, therefore there was an aim to consider both countries for data collection to have more comprehensive data and also to be able to compare differences.

Problems Identification

The dependency of architects on other parties for BPA decreases the efficiency of HEPBs' design process. It causes a circular process where many repetitive data transfers are created.

Architects cannot see the impact of their changes in their design on energy performance instantly and they need to wait for the performance analysis results to come. For small projects and in the SME, the motivation is very low to get involved in this kind of process because of being time and cost consuming specifically in countries which there is a lack of enough attention to the energy related regulations.

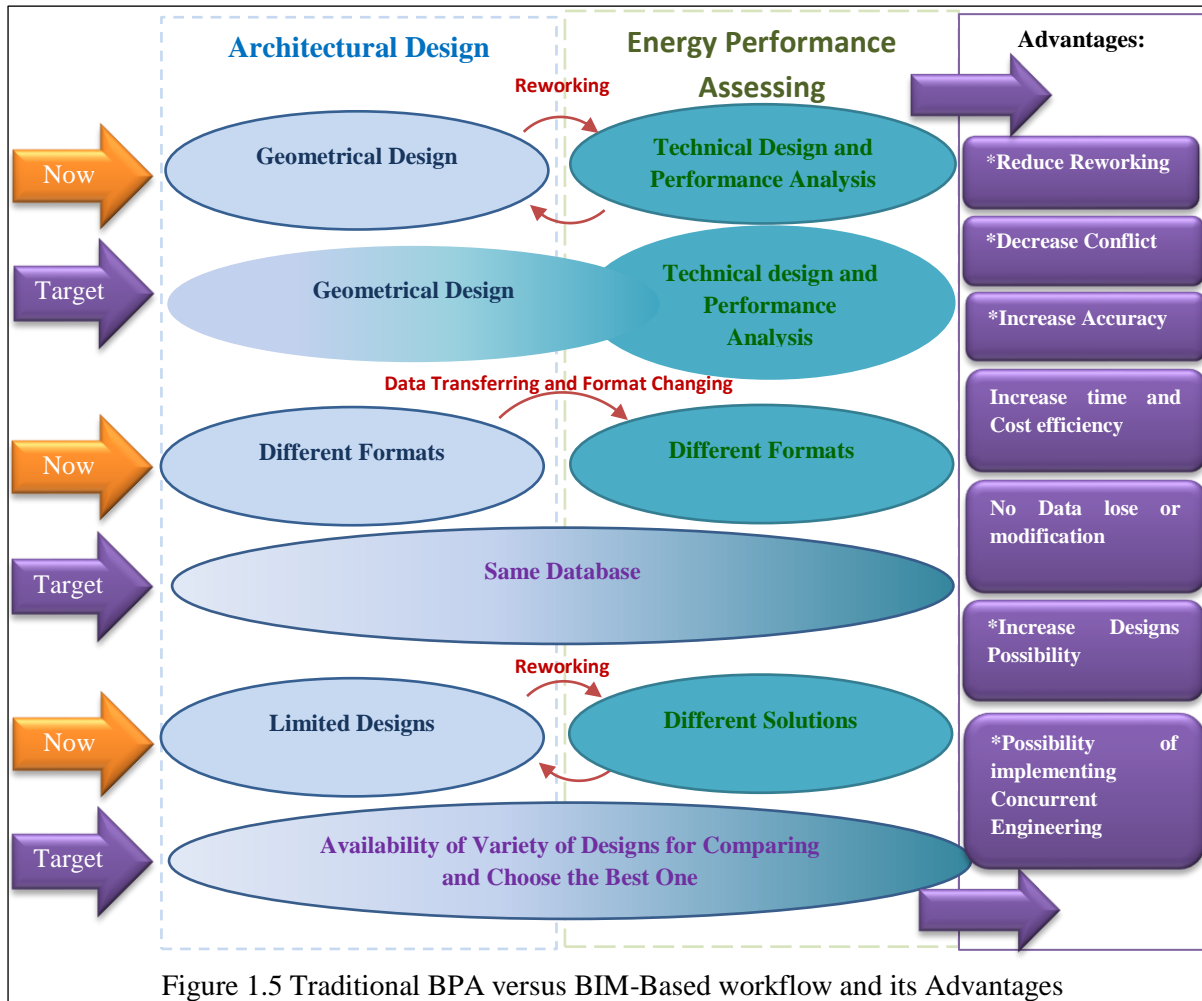
Architects may benefit from BIM tools to analyse their works from an environmental perspective. They need to know how BIM can be effectively used through an integrated process in order to facilitate the design to meet the sustainability indicators (Succar et al., 2012).

The main problems for designing sustainable buildings are identified as:

- Architects are the main designer involved in geometrical designs of buildings, but are almost detached from BPA despite the fact that building performance has a very close relation with geometrical design
- Detachment of architects from BPA has made a dependency on other organisations which causes that architectural designs to be caught in a repetitive process and these processes usually increase the time and cost.
- The point-based design process is still very popular especially in SME and small projects. This process might be replaced with a potentially more efficient set-based design process which leads to concurrent engineering. BIM can support this approach.
- The current process of BPA needs the transferring and, sometimes, translating of file formats which increase the possibility of losing data or difficulty of synchronising the format of files of architectural design to a readable format for analysis tools.

The aim of this research is to evaluate the conditions of the design process in UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools. Revit and GBS are considered in this study as Revit is the most popular modelling software in the market (Chelson, 2010; Becerik-Gerber and Rice, 2010) and GBS is the analysis engine which can be accessed in Revit.

In the Figure 1.5, the current relation between architectural design and building performance analysis is presented along with the required changes as target and the advantages which the changes can bring up.



As it is shown, in the current process, the geometrical design is detached from technical design and analysis, and each is conducted by different parties. Considerable information and data needs to be transferred between stakeholders for different analyses including performance analysis. There is the possibility of data loss or modification. Formats of created data need to be changed for other tools to be able to read them. By implementing BIM and its tools in this process, these risks can be reduced while they can provide more options for designs in a more efficient way.

Figure 1.6 demonstrates the concept of implementing BIM in the process of sustainable building design. Sustainability is a wide topic encompassing many facets of building design, so this study focuses on energy as a key sustainability issue.

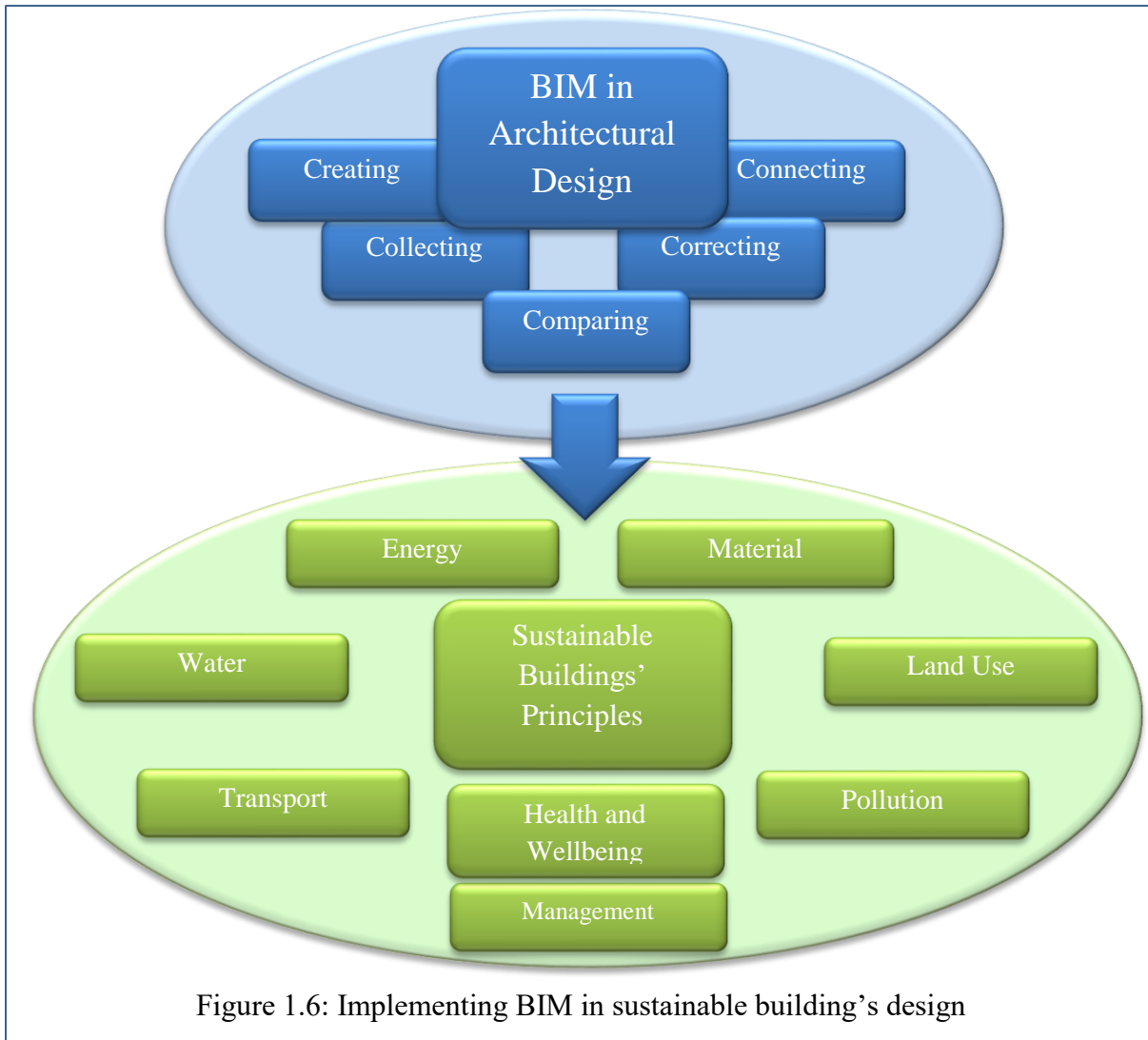


Figure 1.6: Implementing BIM in sustainable building's design

BIM can be utilized in architectural processes for different tasks. For designing HEPBs, designers need an appropriate tool for each related task. Autodesk Revit as one of the most popular BIM tools in architectural design can be used for almost all of these tasks. It is possible to use it for creating a simple concept to fully detailed models. In the versions after 2013, additional tools were accessible through the Insight 360 interface for collecting information. In the Insight 360, it is possible to compare different designs performance even in a concept model, for choosing the best orientation, size, and shape of a building or in detailed model for analysing a whole building energy performance with its all elements.

1.4 Research Design

In this section, a brief of the philosophical stand, approach, and technique which are considered for this study are discussed. Also, the Contribution to knowledge, Research Questions and Research Aims and Objectives are introduced.

1.4.1 Contribution to Knowledge

The contribution to knowledge of the research focuses around a better understanding of the specific barriers for the implementation and use of BIM energy analysis tools by architectural practices to which will be achieved through finding weaknesses in the current process of design and discovering potential solutions. While there is wider work on energy analysis there is currently a gap in looking at the potential for the use of tools during the design process and the specific issues that architects might find in their implementation.

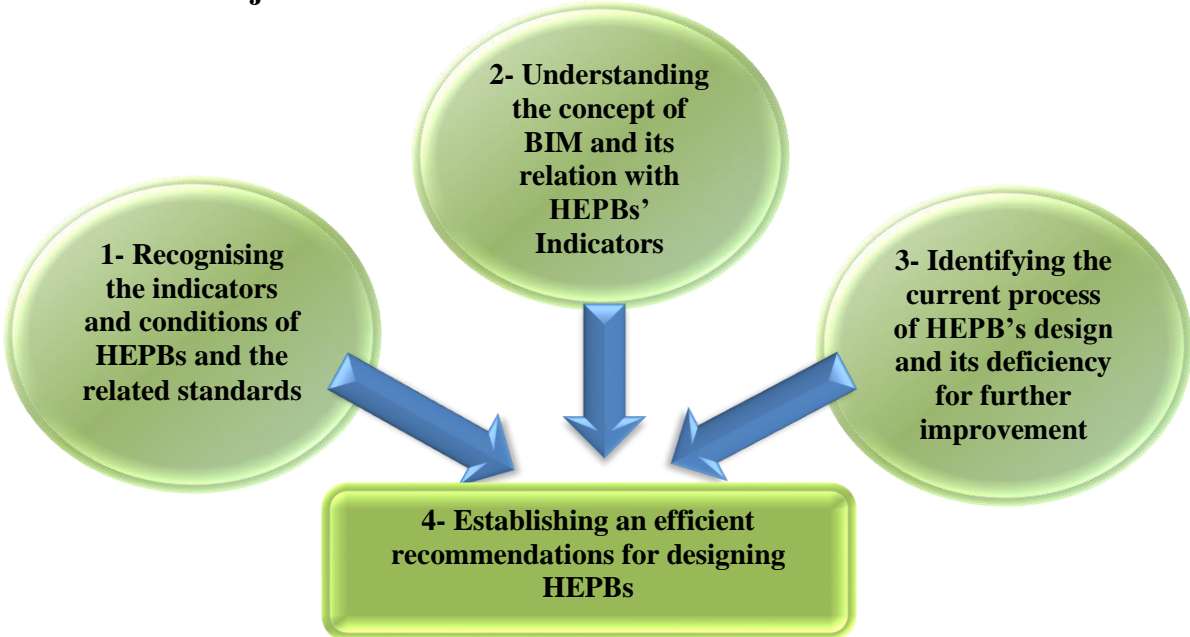
1.4.2 Research Question

How can architects use BIM effectively to manage the energy performance of buildings?

1.4.3 Research Aim

The aim of this research is to evaluate the conditions of the design process in UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

1.4.4 Research Objectives



1. To conduct a comprehensive literature review regarding green buildings', with a specific focus on energy consumption and High Energy Performance Buildings (HEPBs) design process.
2. To review literature about BIM and its tools to specify the relationship between BIM and HEPBs' design process.
3. To conduct a survey with architects in UK and Canada on the current process and knowledge regarding HEPBs design and BIM.
4. To establish recommendations for improving process of design to better enable designers to design HEPBs using BIM tools.

These following sections of the work are:

Chapter 2 – Literature Review: this section addresses the drivers for energy efficient buildings, the approaches to assess these buildings and how BIM tools may be used to undertake this analysis.

Chapter 3 – Methodology: this section highlights the selection and rationale for the method to address the identified research aims and objectives.

Chapter 4 – Development and Finding: this section presents the data and the analysis

Chapter 5- Discussion: in this chapter, main outcomes from this study are presented. This chapter covers the last objective of this research

Chapter 6 –Conclusion and Recommendations: this section outlines the next steps for the completion of this research.

1.4.5 Research Methodology

The aim of this research is to evaluate the conditions of the design process for HEPB in the UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

The two core concepts of BIM and the HEPB design process are considered in this research. Practitioners and firms may have different views and opinions with regards to each term and the relationships between them, based on their knowledge, experience and familiarity with these concepts. These firms may follow their own procedures or other standards for their work practices. Therefore, when designing a HEPB, different information, data, knowledge

and processes could be used in different firms based on factors such as project requirements, location, owner needs, and regulation. It may be possible to see this research with an interpretivists' perspective, because the opinions of people are sought. On the other hand the capability of BIM tools for conducting energy modelling might be seen as a concrete process which shows the objectivist- positivist aspects of the research. Energy efficient buildings and BIM are both defined and invented by humans and may have different meanings for different people. Based on this discussion, this research determines that some elements are quite objective while some other are open to interpretation. Therefore, pragmatism is sought as a suitable approach for this research and in the design of questionnaire. It helps to use specific assumptions for particular questions in the survey. A pragmatist perspective can combine both traditions which help to use different assumptions for different questions.

There are existing theories regarding the use of BIM to develop green buildings and, specifically, HEPBs, so phenomena will be observed through exploring awareness and processes of HEPBs' design, the position of BIM in the design process and BIM's potential for facilitating energy efficient building design. Therefore, this research takes an abductive approach.

A questionnaire (descriptive survey) is considered as the data collection technique for this research. Naoum, (1998) stated that, the descriptive survey is an appropriate technique for answering questions such as *how many? who? what is happening, where? and when?* Since this research is investigating current condition in design industry for implementing BIM in regard to designing HEPBs, the questionnaire includes questions that are started by "what?" "how much?" "how many?" "when?" and "who?". The questionnaire includes two kinds of questions: Closed questions which are designed to assess the current situation. Open ended questions are used to cover, expand and support respondents' opinion by their own words. Kothari (2004), discussed that open-ended questions can be complementary to multiple choice questions so that respondents can provide more details about their feelings and beliefs.

1.4.6 Limitation/ Scope

This work comes with its own limitations and scoping issues. In terms of defining the scope:

- Since this research looked to gather data from developed countries where BIM is common, it is more pragmatic to collect data from developed countries UK and Canada. Therefore the sample includes architects and companies which are involved in building

design in these countries.

- Although the results of this research may be applicable to retrofits and industrial buildings, the focus of this research is on the design of new construction residential and commercial buildings. This has been undertaken due to the application of BIM being more prevalent in new build projects and the architect having greater freedom to impact the energy efficiency of the design.
- For this research, the knowledge of experienced architects is used to understand the current conditions and readiness for implementing BIM strategy to perform performance analysis as well as providing recommendations to other less experienced practitioners.
- While there are wider issues concerning the application of BIM to address sustainability issues, this research focused energy as a major issue for building design. This was identified in the literature as one of the major areas where BIM tools may be applied where their current application by architects was limited.
- This research has been limited to the design of the envelope and passive design options, rather than detailed HVAC/ mechanical and electrical issues. Issues such as geometry, orientation, and glazing have been considered as issues to be modelled, rather than mechanical and electrical, which have been identified as issues for specialist consultants.
- Architects' understanding and application of building energy efficiency strategies are discussed in this research and investigated through a survey. This approach has been taken to understand the potential of using BIM tools for energy modelling by architects at the early stages of the design process.
- BIM has a different elements to consider with regards to its implementation; soft issues (related to people, culture and management) and hard issues (related to technology). There is an exploration in the literature of BIM's application to different tasks such as simulation, certification achievement, clash detection, code review, environmental analysis, and feasibility studies. However, this research focuses on its capability in improving the process of design by providing a reliable method of sharing data and using its tools for conducting simplified energy analysis by architects in the early design stages.

- Using BIM for energy modelling can create an issue of performance gap; a gap between modelled and actual energy use. However, while this issue is considered, we address the issue of benchmarking between early stage designs, rather than absolute performance. Therefore, this research does not deal with question such as, why there is a gap between analysis in design and real consumption. This research does not comprehensively deal with other factors which can affect the energy consumption in a building such as equipment and appliances, end use issues and certification standards, such as the Energy Performance Certificate.
- As following relevant building regulations or codes for energy consumption is mandatory in both the UK and Canada this research considers two credential standards of BREEAM and LEED to understand how it is possible to achieve performance beyond the mandatory regulations. Both of these best practice tools are considered as having stretching targets required for HEPB.

In terms of limitations;

- The scale of the sample is small – due to the difficulty of accessing participants, only 21 surveys were conducted. This may have implications for the generalizability of the results.
- The small nature of the sample against the wider population may mean that the survey is subject to some element of sampling bias. This does have implications in terms of being able to generalise the results.
- There are some issues with regards to the wider understanding of the sample in terms of establishing whether the sample is representative in terms of the types of people who did not respond to the survey – or non-response bias. There may be certain individuals, such as those with limited experience of BIM, who may not have responded due to the nature and content of the survey.
- Due to the difficulty of accessing respondents, the opportunities to pilot the questionnaire were limited. This creates a potential limitation around how respondents may have viewed the questions and how this may have influenced their responses.

Chapter 2.0: Literature Review

In traditional building design processes, which is still popular (specifically in SMEs), performance analysis is usually performed by engineers and other professionals after the architectural design stages. In this process, architects are affiliated with other experts to see the results of applying strategies that have been used to increase the building's performance in the design phase.

The aim of this research is to evaluate the conditions of the design process in UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

BIM may be considered to achieve this aim through the development of parametric models. BIM's ability to provide simultaneous analysis for multiple designs and optimizing them, along with the creation of a suitable platform for Concurrent Engineering, promises an improvement in design process of buildings.

Considering the benefits of this approach and issues with the current nature of the design process the following research question is proposed:

How can architects use BIM effectively to manage the energy performance of buildings?

There are two major concepts within this question, Building Information Modelling (BIM) and High Energy Performance Buildings (HEPBs). The literature review is based on exploring these two themes. It starts from reviewing the literature on sustainable buildings and buildings' energy performance. During the review the existing weaknesses and strengths in the process of HEPBs' design are explored. Potential solutions are investigated and BIM has been considered as one of these solutions which can be utilised in the process of HEPB's design.

The first part of literature review chapter deals with sustainability and high energy performance buildings to address the first research objective. It will start with the history and background of sustainability, its core elements and descriptions of performance. The importance of sustainable development is explained. As sustainability is a wide topic area, which has three main pillars (environmental, social, and economic), the environment has been chosen due to large scale issues around environmental sustainability, which are applicable at a global level. The literature review in this part has been narrowed to a more specific subject of "Energy", which is generally a central part of sustainability models such as LEED and

BREEAM and is often well-regulated in many developed countries. The concept of green buildings or HEPBs will be introduced, as well as the techniques that are required to design such buildings. Required knowledge regarding designing a high energy performance building such as heat flow, passive design (wind study and solar study), and building energy loads are reviewed in detail. The elements of a building which need to be considered such as walls and their layers, windows and their glasses, materials and their properties, awnings, and other components that could effect on energy use of the building are reviewed and explained.

The second part of the literature review deals with BIM. BIM's background and different definitions which come from different professionals' viewpoint are analysed and compared. Also, the conditions and ability of BIM in different levels of its maturity along with the key tools that drive the functionality of BIM are reviewed. Benefits, challenges and tasks which BIM can be used for in design and construction industry especially regarding sustainability task are discussed. The literature is narrowed to investigate the potential of BIM and its tools regarding HEPBs' design which include the ability of BIM that assist designers to be able to use their knowledge and analyse the results. As has been mentioned, in the first part of the literature review, required knowledge about HEPBs design and the components of a building which need to be considered to reach a HEPB are explained, the relation between them and BIM is the main body of the second part.

2.1 Sustainability and High Energy-Performance Buildings

This review starts from a general discussion about sustainability, its history and aspects, and then it is narrowed down to HEPBs' design and their importance for sustainable development. After introducing sustainability and its matters, sustainable buildings with their settings and energy efficiency are discussed.

2.1.1 Sustainability

Young (1997) defines Sustainability as “a measure of how well the people are living in harmony with the environment taking into consideration the well-being of the people with respect to the needs of future generations and to environmental conservation” (p. 136). He has compared sustainability to a stool which has three pillars of economy, society, and environment.

Based on definitions laid out in the Brundtland Report (1987), sustainable development considers welfare for current and future of human life with protection of natural resources and

the environment. Environment, society, and economy are three dimensions which must be addressed in an integrated manner – a failure to address one is a failure to address sustainability. Interlocking circles is one of the common ways (Figure 2.1) of showing this incorporation (Adams, 2006).

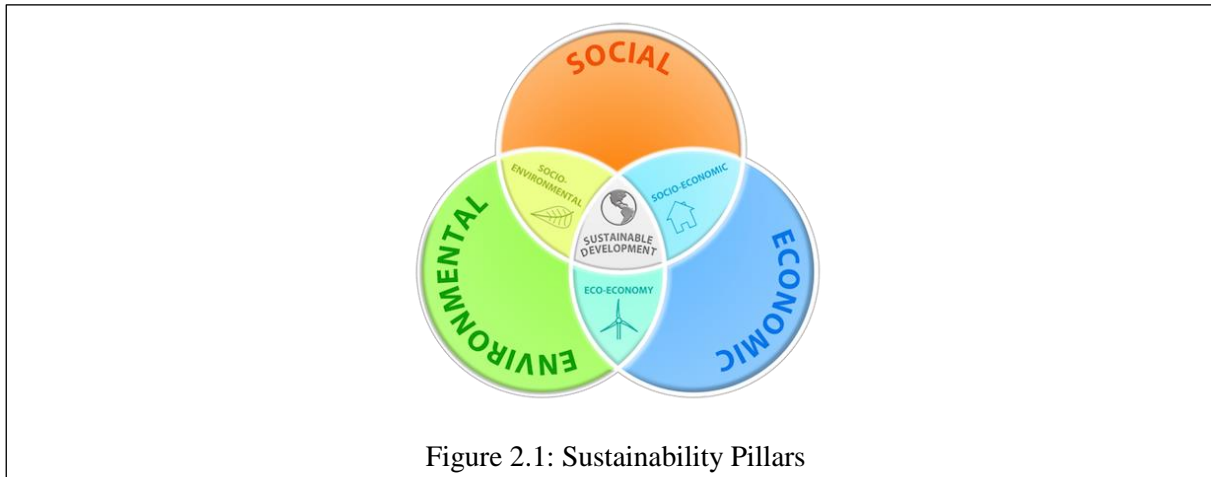


Figure 2.1: Sustainability Pillars

Society:

The UK Office of the Deputy Prime Minister (ODPM) (2003) defined sustainable society as: “A place for living and working for people’s now and future which is well planned, built and run to provide safe and inclusive place of opportunity and appropriate services for people.” Good urban development is based on the principles of sustainable communities (Xia et al., 2015). For developing a community, it is necessary that each of the local communities implement their own sustainable strategies (Yuan et al., 2003). Culture, accessibility, participation of all stakeholders, security, social integration, public utility, and responsibility are some indicators for having a sustainable society (Sanchez and Lopez, 2010).

Economy:

Adams (2006) argued that, economy has been created by society therefore it is something in which they all share. Series of rules or mechanisms are created by society in order to operate the economy. Economy and society have completely different concepts from the environmental pillar of sustainability which is not created by people. Goodland (2002) claimed that: “*the widely accepted definition of economic sustainability is maintenance of capital, or keeping capital intact*” (p.2). Doane & Mac Gillivra (2001) have described how a wide range of indicators such as interest rates, housing starts, investment, mortgage lending, productivity, employment statistics, and labour market can help to better understand sustainable economy.

Environment:

Robert Goodland (1995) defined environmental sustainability as: “*meeting human needs without compromising the health of ecosystems*”. Another definition from Ekins (2011) called it as “*the maintenance of important environmental functions*” (p.637). Ortiz et al. (2009) believed that the environmental pillar is focused on waste, damage, energy-consumption, greenhouse gas, pollution, waste generation, and resource management. Global Warming (GW) is one of the major global challenges (Cameron, 2012). In *December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal*. The deal aims to avoid dangerous climate change and keep global warming under 2⁰ C by setting up a global action plan (European Commission, 2017).

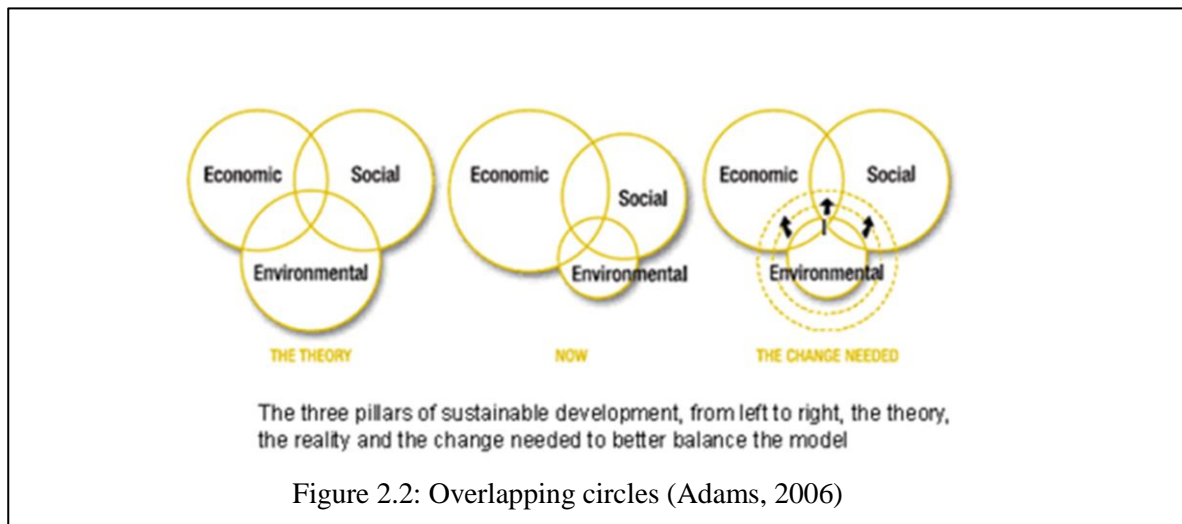
GW makes environmental problems such as increasing sea levels, expansion of deserts, and rainfall pattern changes. When high amounts of greenhouse gases accumulate in the atmosphere, the sun’s radiation is trapped and it causes that the temperature of earth to rise significantly. Human activities are identified as on the main reasons for global warming specially by burning fossil fuels and producing carbon dioxide. CO₂ is absorbed by plants but reducing forest areas means that earth cannot naturally control the levels of CO₂ (Sussi, 2006).

Sanchez and Lopez (2010) identified key indicators which should be considered when measuring environmental sustainability:

- Soil (ecological value, soil consumption);
- Water (consumption, saving, protection resources);
- Biodiversity (natural heritage, protection of fauna and flora, impact on the environment, footprint on ecology);
- Atmosphere (noise, odours, air quality, ventilation);
- Resources (optimisation, use of regional material, low risk materials, material with high durability, equipment with ecological label);
- Energy (consumption, renewable, efficiency, light pollution);
- Landscape;
- Risks (flood and droughts, climate change);
- And waste management.

(Sanchez and Lopez, 2010)

Sussi (2006) mentioned that, goals of sustainability are focused on issues such as determination of the quality of environment and humans' lives. These aspects support a development that is sustainable in social and economic threads and yet possess the capability of preserving advantages of a healthy environment long term. Vitousek et al. (1997) warn that the activity of humans is changing the earth more rapidly than was previously appreciated. Adams (2006) demonstrates that in the sustainability spheres, how economy and society have squeezed the environmental sphere (Figure 2.2):



Rhodes reported to the UK House of Commons in 2019, which, in the UK, the construction industry provides 2.4 million jobs and accounts for 6% of GDP.

2.1.2 Design and Construction activities

In the last ten years special attention has been paid to the environmental sustainability around the world. There is a particular consideration in countries to achieve 77% reduction in CO₂ Emission by 2050 in order to keep earth's temperature increase under 2°C (IEA, 2013; European Commission, 2017). As Zuo et al., 2012 mentioned that the construction industry is a very influential sector whose activities regarding building and construction are deeply involved with humans, environment and economy.

In the United States 31.5 million tons of waste is produced from construction activities annually, and with demolition waste representing nearly 40% of solid waste is the result of these works (Kubba, 2012). In the United State 39% of CO₂ emissions come from fossil fuels used by buildings (USGBC 2015) which can directly affect global warming and impact sustainable development.

From beginning of this century, the increasing the price of energy has meant that operating and maintaining buildings is becoming increasingly expensive. Now, owners and related industries have noticed resource consumption, pollution, waste generation and other impacts of buildings construction and operation. There has been consideration of appropriate strategies such as decreasing the negative impact on environment, by “establishing new eco-friendly goals”, following codes and guidelines for green and sustainable buildings such as Green Globe, BREEAM, and LEED (Kubba, 2012).

BREEAM, 2014 claimed that, it is the pioneer of building assessment method launched in 1990 and nearly 200,000 buildings are certified by it. Reducing the impacts of building’s life cycle on the environment; recognising buildings based on their benefits on environment; assigning a credible environmental rating for buildings; and improving the demand for green buildings are the aims of BREEAM. Some of the objectives of BREEAM, are to identify green buildings in the market; to guarantee the best practices which consider environmental matters in planning, design, construction and operation of building; to outline a strong and cost-effective performance standard; to make a competition in the market for providing cost-effective innovation methods in order to achieve environmentally friendly buildings; and increasing the knowledge of buildings’ stakeholders regarding the benefits of green buildings during building’s lifecycle. Management, health and wellbeing, energy, transport, land use and ecology, water, materials, waste, pollution, and innovation are the main areas (Appendix C) assessed in the BREEAM model (UK BREEAM, 2014).

2.1.3 Indicators of Green Building

Kubba (2012) defined Green buildings as: “*structures that are designed, built, renovated, operated, or reused in an ecological and resource efficient manner*” (p.26).

They are essential for our societies because they offer healthier buildings, more effective resource usage, decreasing negative effects on the ecology, improved productivity, and saving considerable cost during building’s life cycle. To achieve green construction and building, it is necessary to consider some principles such as:

1. Integrated Design;
2. Site Selection;
3. Water Efficiency and Conservation;
4. Materials, Resources and Waste Management;
5. Livable Communities and Neighbourhoods;

6. Indoor Environmental Quality and Safety;
7. Commissioning Operation and Maintenance;
8. Energy Efficiency (Building envelope; ventilation and air conditioning; heating; water heating; power and building power-distributed generation systems; lighting; other electrical equipment).

(Kubba, 2012; Bergman, 2012)

Considering these principles in the design and construction of a building helps the building to meet the criteria of sustainable design. These principles can influence each other, for example, the energy efficiency of a building is affected by other elements such as commissioning operation and maintenance, site selection, and material selection. While most important decisions regarding these principles are made during architectural design stage and this study focuses on energy efficiency. In the following section, first the architectural design process is introduced and reviewed in detail then the topic of energy in building is discussed.

2.2 Architectural Design Process

Since the intent of this study is to make a better integration between architectural design and building performance analysis, it is useful to first investigate the process of design and specifically the architectural design process. This process is reviewed with its shortcomings and potential improvements.

Krishan et al., (1998) liken design to a network in which different stages and parameters of developments are interacting with each other. Mather believes that design is not usually a linear process. This is a process which needs collaboration, flexibility and vision between various people who are involved in during the process (Mather, 2012). A linear architectural process is used as a traditional method, but after introducing computers into the architectural process, designers are able to examine the possibility of a large number of design alternatives, this has allowed the possibility of a non-linear design process (Grobman et al., 2010). Bahrainy, (2006) believes that process refers to a logical and purposeful arrangement of actions (Bahrainy, 2006 cited in Parsaee et al., 2016).

Miller, (2005) states that the word, “design”, can be used as noun which generally refers to some object, or verb. He believes that as a verb, design is the thought process. Lawson, 2006 introduces design as a process with different “spectrums”. On the one side, fashion design is located in a space which seems unpredictable and imaginative while on the other side an engineering design is located in a domain which seems more systematic and precise. Miller,

(2005) believes that, design is the activity of creation which is a sequence or set of thought-filled procedures and events. Product is the result of the design process which includes different activities such as thinking, communicating, drawing, modelling, constructing, etc. Thomas, (2010) considers “design” and “engineering design” and how a design project can be called an engineering design project. She believes that design is the critical part of many fields such as fashion design, architectural design, and graphic design. While creativity is the common element in any design project, an engineering design always comes with analysis, mathematics, and science. She states that involving the language of mathematics and laws of physics are the emphasized points in engineering design, which means designers are able to predict how their product will work and perform. These are necessary to prove that the final result is safe for humans. Lawson, (2006) identifies that, while any good fashion design needs considerable technical knowledge, good engineering design processes also requires considerable imagination and can have unpredictable outcomes. Parsaee et al., (2016) described, in a simple way, how a design is created. He believed that at the first step designers use their knowledge to understand the design problem then they are using their creativity to present the initial scheme on paper or screens.

2.2.1 Architectural Design

As an architect, Lawson, 2006 believes that architectural design is a three-dimensional design process and the environmental design field requires designers to produce products which are practically useful and well-functioning, while also being beautiful. Therefore, architectural design lies in the middle of the spectrum. The products of architectural design have great impact on quality of life of people. Any mistake can cause serious problems, costs or even life threatening situations (Lawson, 2006).

Architectural design processes contain different identifiable stages and each stage includes their specific activities. As mentioned, in traditional methods these stages are located in linear way, but in modern methods, many of the stages and activities are in interaction with each other during the whole process of design. Roozenberg and Eekels, (1995) introduced the primary model of the design process based on three activities of ‘analysis, synthesis, and evaluation’ (Roozenberg and Eekels, (1995) cited in Parsaee et al., (2016)). Lang, (2007) added two more stages and introduced 5 stages of ‘analysis, synthesis, prediction, evaluation, and decision for design process.

In the 2013 RIBA Plan of work, developed by Royal Institute of British Architects, there are 8 defined stages for the whole building life cycle. Four of them mainly cover the design process, which are preparation/planning, conceptual (schematic) design, design development, and technical design (RIBA, 2013). Coates et al., (2010) introduced 5 main activities of ‘thinking, collecting information, creating, correcting, and connecting for architectural design process.

By merging technology in the design process it is possible to add and introduce some activities like simulation and modelling to the design activities. These activities can be covered in different stages. Activities such: needs and problem definition, thinking and mind storming, data and information gathering, creating and implementing collected data, data and information analysis, correcting, and comparing must be conducted in a developed design process.

There is always a reason to start designing and different stages and activities must be conducted during the design stage. For example, for a building, different designs such as architectural, plumbing, electrical, structural and mechanical designs are required. Most of these designs need different analysis to make sure that the final product would work well and can meet the occupants’ needs. In the next section the stages and activities which are common in a design process are reviewed.

2.2.2 Process View of Design

Simon, (1982) states that design is a goal-oriented process in which the goals can be; removing needs, creating new useful products, and problem solving (Simon (1982) cited in Parsaee et al., (2016)). Mather, (2012) pointed out that design starts with the brief, which includes product requirements and owner needs. Thinking and mind storming are a permanent and inseparable activity in this process (Coates et al., 2010). Traditionally, 2-3 preliminary possible designs are prepared by architects in the schematic design stage based on the gathered data and information from the previous step. These designs are presented as concepts which include simple plans and elevations, basic envelope shape, general locations of the functions. The discussion meeting is concerned with selecting materials, establishing budgets and choosing an overall design strategy (BUILDLLC, 2008). At the developed design stage the concept design is further developed and all core design team members

include architects, structural engineers, and MEP engineers working together to complete the spatial coordination exercises. Architectural, structural, and MEP designs and building services are developed in this stage (RIBA, 2013). Therefore, in this stage the initial designs which are produced in the conceptual design are transformed into the detailed design which would be similar to the final product. Details for materials, assembly, appliances and related code information are merged in this stage (BUILDLLC, 2008). The RIBA Plan of Work, 2013 states the technical design stage is where technical definition of the project and the design work of specialist subcontractors is developed through further refining the designs of architectural structural and services.

2.2.3 Design and Energy

The importance of the design stage is obvious and, as Azhar and Farooqui, (2015) state, the most important decisions regarding a project are made during design stages. Increasing energy efficiency is one of the construction project needs which require related planning, data gathering, actions, modelling, and analysis during design process by architects and engineers. Understanding the design process can help to identify where issues of energy efficiency are explicitly engaged with in that process.

Early collaboration and coordination between engineers and designers is necessary to better understand projects needs and share the information, opinions, and ideas. Specifically for increasing the building energy efficiency, all parties who deal with geometrical design and building physics must have a good connection and communication to each other. Building geometrical design such as buildings' orientation, size and shape can have a big influence on the building physics and dictate the building's energy consumption. As architects are responsible for geometrical design, their knowledge, information, and decisions are very important. Engaging with the building performance analysis in the early stage of design, is away to improve the efficiency of whole building design process specifically regarding to increase efficiency of buildings energy consumption. This study has a comprehensive view on design process, therefore the most recent and new strategies and technologies such as Set-Based Design strategy (SBD), Concurrent Engineering (CE), and Building Information Modelling (BIM) which can help architects regarding to improve their works and specifically for increasing buildings energy efficiency are reviewed. The SBD process and its differences and advantages in comparison with traditional point-based design strategy are discussed below.

2.2.4 Point-based Design and Set-Based Design

Traditionally, designers prepared different concepts based on project definitions and client needs. Then one of those concepts will be chosen for further development. Development on the selected concept is continued until it meets all project needs. In this method designers have some limitation on changing the main structure of design and changing anything on design may need repeated work between different designers and engineers, because they are not in appropriate communication with each other. In each stage (point) the responsible engineers and designers are working just on their area of responsibility often lacking communication and coordination with other stakeholders. This method of design called Point-Based Design. Subek et al., (1999) categorised the traditionally PBD process into 5 stages of:

- 1- Problem Definition
- 2- Generating a Large number of design concepts
- 3- Primary analysis on designs alternatives to choose a single concept one for further development
- 4- Modifying, developing, and analysing the selected concept until it covers all product's requirements and goals;
- 5- Repeating the stage from 1 or 2 if the selected concepts cannot meet the requirements until the best solution is found.

Singer et al., (2009) identified that designing large products has inherent complexity, which the traditional design process cannot easily support. Designing these kinds of products requires a different approach in how to think about and manage the design. Set-Based Design (SBD) is a complex design method which was identified by Admiral Paul Sullivan in 2008 for improving the NAVSEA design and analysis tools. Naval equipment, such as submarines or warships contains very complex systems such as power generators, plumbing, mechanical parts, structural systems, and electrical equipment, all of which must work in collaboration with each other. Buildings also contain different complex systems like naval equipment, but with less complexity, therefore any method of design which can improve naval systems design may potentially be useful for building architectural designs.

SBD allows a designer to be able to process most of design efforts concurrently and detailed specifications are kept until their content is fully understood (Singer et al., 2009). Traditional Point-Based Design (PBD) can be replaced by SBD with design discovery.

The combination of a Set-Based design process and Concurrent Engineering is called Set Based Concurrent Engineering (SBCE). It can be introduced to replace the traditional design process which tends to reach to a solution quickly and develop that solution until it meets the objectives of design. In a SBCE process, a set of possible designs are considered at the beginning (schematic design) instead of one or two designs. Then they will be narrowed down filtering the weakest of them based on the project requirements until a final choice is reached (Subek et al., 1999) Therefore various alternatives are considered in a SBCE from the beginning, and assessed concurrently, which helps to reduce the repeating of post-progress calculation which are both time and cost consuming (Kang, 2008 cited in Lee et al., 2012).

Different and complex systems must work together in an appropriate way to create a building that is useable and comfortable for its occupants. Building must pass different tests such as structural analysis and performance analysis, which are applied using simulation tools. Buildings' energy consumption and performance is influenced by geometrical design and buildings' physics. Architects are responsible for geometrical design and mechanical engineers usually deal with building physics, particularly in the context of heating and cooling (HVAC) systems. Strategies like SBCE enable better collaboration between engineers and designers early in a project. The SBCE process requires an appropriate strategy like BIM with its tools because BIM can be used as an appropriate context. By modelling the information of project and sharing them in a database which all stakeholders have access to it, BIM provides smooth connections, collaboration, and coordination between projects' stakeholders include architects and energy specialist from early stage of a project.

Lee et al., (2012) identify that building systems have become more complex and SBD can help to improve the process of building design through reducing the rework, which is one of the main reasons for waste generation in construction projects and it frequently happens in PBD process. Lee believed that using BIM in the SBD process increases its efficiency in terms of obtaining optimal solutions and provides better cost, time, and safety.

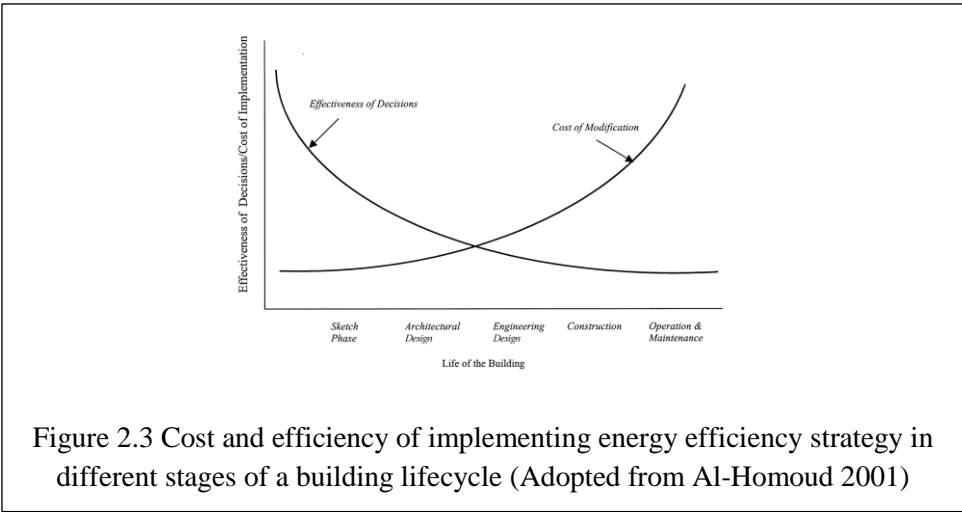
Architects benefit from BIM for modeling building architecture, initial energy performance analysis, and sharing designs with other designers and engineers for further development. BIM has been identified as improving the weaknesses of traditional processes that are used for design. Before reviewing BIM and its description and function, it would be useful to understand: what is the energy performance analysis, its importance and the current strategies that are used to reach to an energy efficient building, and the weaknesses. Therefore, energy

performance analysis and the stage of design that energy modelling is traditionally considered at, as well as weaknesses of the process and potential solutions are reviewed.

2.2.5 Importance of Design Process to Achieve a HEPB

In this section the importance of considering building energy performance analysis and modelling in early stage of design and its impact on design efficiency and final product is demonstrated.

The role of energy is significant in the building design process and most important decisions in this regard are made early in the process. Improving thermal performance and, consequently reducing energy consumption and greenhouse emissions, can be achieved through very careful decision making during the design of a building. Making decisions in the early stages of design has less cost in comparison with the later stages (figure 2.3) (Al-Homoud, 2001; Echenagucia et al., 2015). After the planning phase, the conceptual design phase is good time for implementing any ideas and integrating any sustainability factors, including increasing energy performance (Pacheco, 2012).



When project goals are identified early and properly balanced during the design process, a successful design objective will be obtained. It is important that interdependencies and interrelationships of project goals with all the building’s systems are analysed, appropriately implemented and coordinated concurrently from the early phase of any project. Such an integrated design approach is necessary to achieve a high-performance building (Prowler, 2014).

Elbeltagi, (2017) states that 30-40% of energy saving can be achieved just through selecting suitable shape and appropriate orientation for the building. Architects can test different design options very quickly to choose the best one; it can increase the efficiency of the final product which will then go forward to detailed analysis by energy modeler experts. Therefore, the sustainability goals of the project can be achieved in a more efficient way in terms of time and cost, if energy matters are considered at the early stage of design.

Sacks et al., (2004) pointed out the advantages of parametric modelling which allows operators be able to “*generate computer representation of objects not only as they look but also to define semantic relationships between the objects’ representations*”, allowing them to be easily created and edited”. They stated that, in parametric modelling, both geometrical relations and functional relation between components are defined, which means the function of each component and it’s interaction with another part, in terms of their functions, are defined. Therefore the parametric model can be used for different analysis such as structural, thermal, and acoustic. Hollberg, et al., (2018) discussed that parametric design allows the generation of many variants with less effort which, is a suitable method of testing different alternatives in the early stages of design.

USEOP, (2008) identify that to design a high energy performance building, well-developed methods and tools are needed for predicting, monitoring, and controlling building energy consumption. To reach to this goal, all a building’s complex component systems must be integrated during design to see building as a single durable good. It is because during a building’s lifecycle all of its components will perform together and interact with each other. Polesello and Johnson, (2016) stated that, an efficient building would not be achieved just through gathering and installing high-end technologies. Such a building requires a process in which design elements are first optimized and then the interrelationship and influence of various different systems and elements within the building and its surrounded area are re-assessed, integrated, and optimised as part of a whole building solution (Polesello & Johnson, 2016).

Specific data and information regarding buildings physics, climatological information, and thousands of engineering calculations and measurements methods are involved in predicting energy performance of a building (Tortellini et al., 2006 cited in USEOP, 2008). In the traditional architectural process which is still used by some architects and firms (especially SMEs), BPA is usually conducted by engineers or other experts after “developed architectural

design stage” (Schlueter and Thesseling, 2009). Architects rely on engineers to understand some of the buildings’ principal physics such as energy demand and building comfort (Anderson, 2014).

Al-Homoud, (2001) categorized the building energy analysis into two categories of “simplified energy calculations” and “detailed energy calculations”. Schlueter and Thesseling (2009) claimed that simulation and detailed analysis of building energy performance need expert knowledge, which in the early stages of design, is not often available. While architects are not usually familiar with all the necessary parameters to run an advanced performance analysis, they are knowledgeable about materials, forms, technical systems, and geometrical design (Schlueter and Thesseling, 2009), which potentially make architects well placed to be able to conduct a simplified energy analysis and evaluation of building energy performance. As Anderson (2014) stated, bringing performance analysis to the early design stages which architects are mostly involved in this process has great advantages for architects to “play” with the design idea and to receive quick feedback.

In 2008, USEOP pointed out to the BIM and its tools have the capability of optimising the building design and operation. Integrated energy modelling of advanced technologies is permitted through BIM’s tools which provide “what if” analysis and it makes designer to be able to improve the energy-related design parameters (USEOP, 2008).

As Kibert, (2013) identified that understanding how a building gains and loses energy is the first important step for designing HEPBs and increasing energy efficiency. While making the buildings airtight and installing insulation is necessary to increase their energy efficiency considering energy gain and energy lost in the buildings is necessary for balancing overall energy consumption. It may even be possible to have a positive energy balance for some parts of the time (Rode, 2012). In the next section the strategy for designing energy efficient buildings is reviewed.

2.2.6 High Energy Efficient Building and Zero-Energy Buildings Design

After understanding the process of design and importance of this process for design of energy efficient buildings and in identifying appropriate strategies to achieve an energy efficient building, nearly-zero or net-zero energy consuming buildings as examples of the most energy efficient buildings are reviewed.

Currently, increasing energy efficiency of a building and reaching zero or nearly zero energy consuming buildings (ZEB and nZEB) are very popular topics. To achieve to these kinds of buildings, it is necessary to start from planning, and then choose an appropriate strategy whilst following the codes and regulations, employing appropriate tools and techniques, implementing and installing efficient equipment. Familiarity with these techniques and strategies can help to understand how BIM and its tools can be utilised more effectively. In the literature, various techniques, methods and technologies to achieve a HEPB are presented. By considering the points below during design process, the major considerations when designing an energy efficient building will be addressed:

- Optimising building, orientation, shape and thermal mass;
- Considering appropriate insulation and high performance envelope;
- Providing renewable energy sources, such as wind, solar, and other alternatives instead of fossil based fuels source for energy consumers in buildings;
- Maximising use of passive features (natural sources) for lighting and ventilation by choosing high performance shapes and orientations in a passive design strategy.
- Employing modern technology for controlling, monitoring, and management of energy for thermal and lighting systems. Accurate automatic control system which are equipped with smart thermostat or motion sensors can reduce energy load in buildings;
- Modelling of buildings with their electrical and mechanical systems tools for optimising their performance at design stage.

(Kubba, 2012; Polesello & Johnson, 2016)

Griffith et al., (2007) believe that by integrating new technologies with the building design, 70% of CO₂ reduction can be achieved. Nowadays designers, engineers and scientist can apply strategies and technologies for designing and constructing nearly zero and net-zero energy consuming buildings. The term “nearly zero-energy building” (nZEB) is used for buildings which are very efficient in energy consumption. In recent years, specific attention has been paid to net-zero energy buildings. As an example, the EU Directive on Energy Performance of Buildings (EPBD) determined that all new buildings intend to be nearly zero energy buildings by end of 2020 (BPIE, 2011). There is a similar strategy in the US to reach new to market zero energy homes by 2020 (Sartori et al., 2012).

The Building Performance Institute Europe ((BPIE), 2015) defines a NZEB as a high energy performance building which requires a very low amount of energy for its needs and that energy must be produced from renewable sources. In the report from the U.S Executive Office of President ((USEOP), 2008), it is stated that significant reduction can be obtained through decreasing energy consumption in the building which enables buildings to operate only with renewable energy. These kinds of buildings are called net-zero energy buildings and are more self-sufficient and this will be achieved over a set time period and need developing and integrating new technologies in building design stage (USEOP, 2008).

Sartori et al., (2012) identified the following key factors for zero-energy buildings:

- Building system boundary: includes physical boundary (determines if renewable resources are on-site or off-site), balance boundary (determines which energy uses are considered for the Net ZEB balance), and a set boundary conditions such as functionality space effectiveness, climate and comfort.
- Delivered energy: imported energy by a building (kWh/y or kWh/m²y).
- Exported energy: Flowing energy from a building to the grids (kWh/y or kWh/m²y).
- Loads: building's energy demands (kWh/y or kWh/m²y).
- Generation: Generated energy from the building which can be different from what is exported based on energy consumption (kWh/y or kWh/m²y).
- Weighting system refers to the system which converts the physical units into the other metrics (for example accounting for the emission released to extract, generate, and deliver the energy).
- Weighted demand: combination of all delivered energy (summing all energy carrier multiplied by its weighting factor).
- Weighted supply: obtained by summing all exported energy (summing all energy carriers each multiplied by its respective weighting factor)
- Net ZEB balance: it is the condition which in that, over a period of time (usually a year) weighted supply covers completely (or more) weighted demand. ($|\text{weighted supply}| - |\text{Weighted demand}| = 0$).

ASHRAE, (2014) introduced a very comprehensive design guidance (Advanced Energy Design Guide) to achieve 50% energy saving. The principles can be used for office, commercial and residential buildings. The guidance includes the related strategies for different types of Climate Zones (CZs), and appropriate materials and building's components

for each climate zone. The guidance has been converted and summarised to the checklist boxes which is shown in Table 2.1. This checklist boxes helps designers to review the necessary design strategy for increasing building energy efficiency very fast based on the CZ that project is located on it.

Related Design Strategy	Climate Conditions						
	1-Hot and Humid	2-Hot and Dry	3-Mild and Humid	4-Mild and Dry	5-Marine	6-Cold and Dry	7-Cold
Driving forces are: Conduction, Solar loads through fenestration/Significant cooling loads/(*Removing moisture/Latent Loads)	*						
Driving Forces are: reducing heat gain in summer and heat loss in winter							
Driving Forces are: Heating and Solar control							
Driving Forces are: Heat loss through envelop/ Heating and cooling loads associated with ventilation							
Driving Forces are: Heat loss through envelope/ Infiltration/attention to heating and cooling loads							
Fenestration Area/Appropriate Orientation/Well Place Shading/Double Glaze Low-e Coating/ Cool Roof, Solar Reflective Roofs and Walls/ Appropriate Insulation/(*Reduce Risk of Condensation)			*				
Reduce Infiltration Through Upper Level Envelope							
Size and Position Of Windows for Solar Heat gain, Direct Solar heat and Glare Protection							
North Light (without Solar Content) Highly Recommended							
Internal or External High Shelves With Daylight Glazing Above (High VT) and View Glazing Below (Low VT)/Horizontal Blinds on View Glazing							
Check North of Building's East-West Line for Solar Heat Gain and Glare in Early Morning During Summer Months							
Considering Free Night Time Cooling to Precool Interior							
For Office buildings, Open Office Spaces Works Well on the North and South							
Direct or *Indirect Evaporative Cooler in the Ventilation/ Evaporative Heat Rejection System like Cooling Tower,						*	

Evaporative Condenser, Water Side Economizer							
Air-Side Economizer/Water Side Economizer/Most HVAC system work well							
Air Side Economizer							
Considering External Shading Devices Based on Zone's Potential for Storm and Hurricane							
Translucent Exterior Shading/Heating is almost always required							
Heating Elements in any Perimeter Zone/ Freeze Protection at All first Pass Coils in Ventilation air Handlers and Humidification/ Wall Drying System to Avoid Moisture Driven Into Wall Cavity							
Consider Ground source Heat Pumps (GSHPs) if Total annual Heating and Cooling is Well Balanced and based on ground Soil Conductivity							
Mixed methods of natural ventilation+ Radiant Passive Heating and Cooling or Passive Chilled Beams for summer peak during different seasons							
Reduce Conduction Through U-Factors of Envelope/ Avoid Too Much Exfiltration Through Façade/ Insulation Expand Into wall Cavity/ Installing high Quality Air Barrier to Reduce Infiltration/Demand Control Ventilation (DCV)							
*Must be Considered Just In the Specified Climate Zones							
Table 2.1: Related Design Strategy for Different Climate Zones							

By following this table, designers easily can improve related energy performance indicators in their designs and also they can use it to check if their design meets the indicators.

As mentioned, to increase energy efficiency of a building, the main goal must be to decrease building energy demand and consume energy in the most efficient way. There are three main strategies in this regards which are:

- 1- Employing sustainable resources such as natural elements for lighting, ventilation, heating and cooling instead of active system;
- 2- Preventing energy waste through buildings' envelope (high level of insulation and air tightness); and
- 3- Installing and using high energy efficient equipment and appliances.

(Kibert, 2012; ASHRAE, 2014)

While the third strategy is important for reducing building energy demand, the role designers and architects in this regard is not considerable and usually manufacturing companies deal with building's equipment and appliances. Therefore, the first two strategies are considered more comprehensively in this research. Shape, size and orientation of a building, its rooms and building envelope material properties have significant impact for using natural elements instead of active systems and preventing energy waste. By reducing building demand and installing clean energy generation such as PV panels or a wind turbine in the site, it would be possible that the weighted supply meets weighted demands.

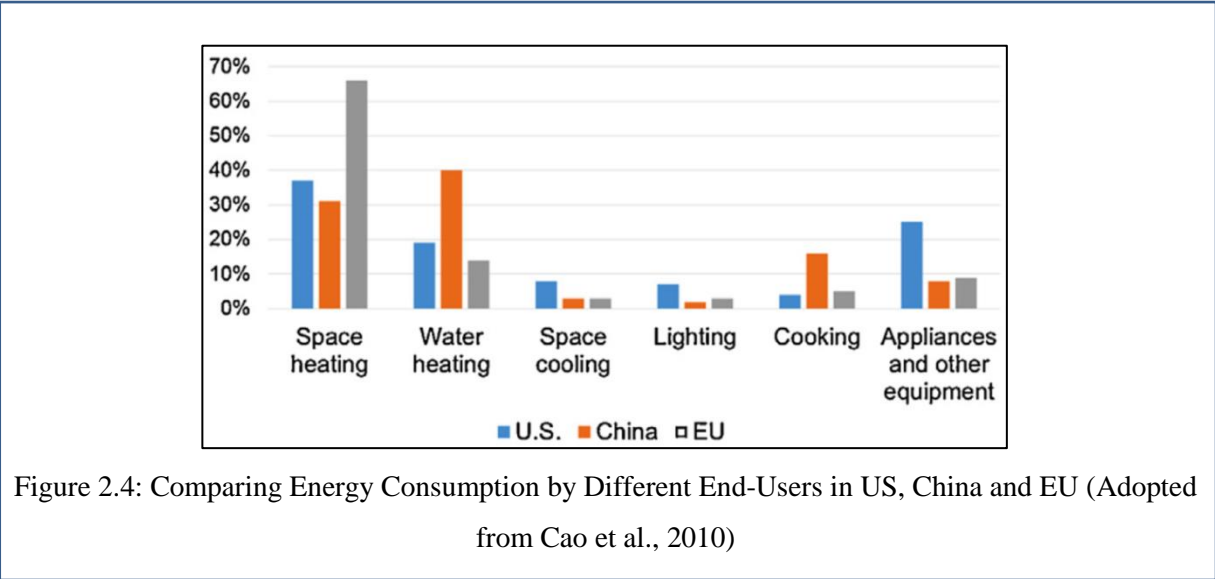
2.2.7 Building Physics (energy gains and losses in buildings) in HEPBs' Design

Buildings (residential and commercial) are a major energy consumer, consuming 31% of energy in a global scale and in comparison to transport, industry and other sectors (UNEP, 2016). In the US and EU approximately 40% of energy is consumed by buildings and they contribute 36% of CO₂ emissions (Sajn, 2016; Cao et al., 2016). Buildings gain and lose energy in different ways such as receiving solar heat energy or solar light, and losing energy through envelope via conduction and convection. As mentioned, understanding how energy is lost and gained in a building is the first step for increasing its energy efficiency (Kibert, 2013; Allouhi et al., 2015). There are also different end users in a building who may consume different amount of energy depending on how they use a building.

As discussed in section 2.2.5, reducing building energy consumption can be achieved by improving the efficiency of the building design process and through conducting building energy modeling and analysis at the early stage of design. It is important for designer to understand each end user and how much energy they consume, to work on that sector and increase its efficiency.

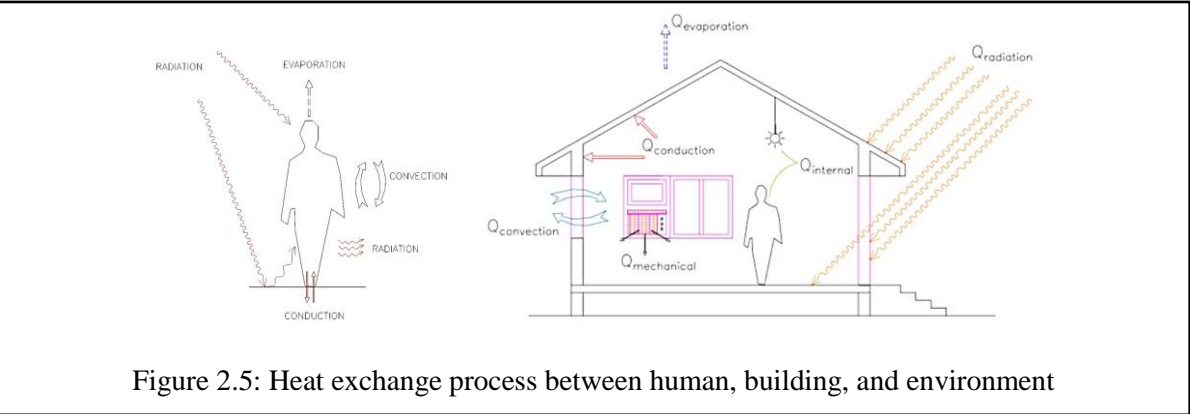
Energy is used in the building for different purposes such as cooking, space heating, lighting, space cooling, running appliances and electronic devices, and etc. Cao et al, (2010) compared building energy consumption by different end-users in US, China and EU, which is shown in Figure 2.4. In these regions, the largest portion of energy is consumed for space and water heating and after that by appliances, cooking and lighting. Based on the Building Energy Data Book, which is produced by US Department of Energy, in both commercial and residential sectors in the United States, space heating has the biggest share of energy consumption with 27% (commercial) and 45% (residential) respectively. Also, space heating contributes 21.3%

of all CO₂ emissions, which is the biggest energy end-user carbon dioxide producer (US DOE, 2012).



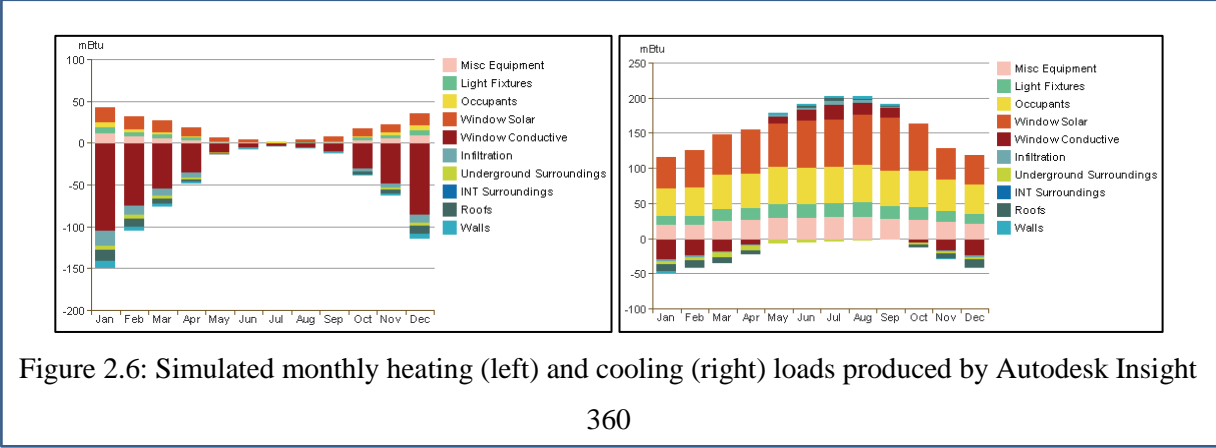
The combination of heating load and cooling load is called thermal load. There are two kinds of thermal loads, internal loads and external loads, which they have influence on building energy consumption. US DOE, 2012 defined building load as: “*Loads represents the thermal energy losses/gains that when combined will be offset by a building's heating/cooling system to maintain a set interior temperature*”. In order to design a high energy performance building, it is necessary to address the reduction of both internal loads and external loads.

Occupants’ activities have significant impact on building Internal loads; based on human activity they can produce 100-1600 watts of thermal energy (appendix F). All energy used for lighting equipment is transferred to heat directly or indirectly. As an example Figure 2.5 briefly presents the heat exchange between human, building, and environment.



A highly energy efficient building must have a very good lighting strategy which includes using daylight in maximum performance. Such a strategy has double benefits, first of all it

can reduce demand for energy for lighting and, secondly, it will produce less heat which reduces the internal heating load. Other sources of internal heating loads are friction in mechanical parts of equipment and electrical resistance (Kibert, 2013; Autodesk 2015). Figure 2.6 demonstrates a building’s internal and external loads in different months which are modelled by energy analysis interface of Autodesk Revit 2015.



Hens, (2016) believes that, outdoor and indoor conditions have a role same as the loads in structural mechanics and good understanding of environmental loads is necessary to ensure correct design decisions. Heat transfer from the outside environment, sun and earth introduce external thermal loads to the building by envelope. Heat can flow into/out of building through envelopes’ conduction, radiant energy from sun, air leaks or infiltration, and ventilation. Different temperature and humidity between outdoors and indoors have great effect on buildings load. Environmental loads have different parameters which are presented in table 2.2.

Inside	Outside
Air temperature	Air temperature
Radiant Temperature	Relative Humidity
Relative humidity	Vapour Pressure
Vapour pressure (partial water)	Solar Radiation
Air Speed	Under-cooling (Long wave radiation)
Air Pressure	Wind
	Rain and Snow
	Air pressure

Table 2.2: Environmental load’s parameters (Adopted from Hens, 2016)

Heating and cooling loads are fixed HVAC design and dictate the annual energy consumption in a building. These loads are directly influenced by air temperature which also has an effect on air, heat, and moisture load the envelope experience. Air temperature is measured by a thermometer which is installed 1.5 meters above ground level and under cover in an open field area (Hens, 2016).

2.2.7.1 Energy (Heat) Flow

Sensible heat and **latent heat** are two forms of heat flows. By changing temperature in a material, space or substance without changing the material phase, the sensible heat occurs. Latent heat occurs when heat flows without changing temperature but the material phase is changed (i.e.: from liquid to gas) (Pohl, 2011).

In general, sensible heat is transferred by conduction, convection (other kind of conduction), and radiation. Conduction occurs when a temperature gradient exists. Naturally, heat is moving from a point with higher temperature to the cooler zone in the same material or two attached materials. In convection, at least one of the materials is fluid. Therefore, the transforming heat between solid and the fluid is called convection which can occur freely (by gravity) or by force (with external pressure). Radiation is the other way of heat transfer which is the result of incidences of electromagnetic waves to the surface of materials (Böckh & Wetzl, 2012).

Every material which is used in a building has physical properties that determine their performances, such as:

- Thermal conductivity (K [BTU/hr.ft².°F]);
- Heat capacity (thermal mass); and
- Thermal resistance (R [ft².°F.hr/BTU])

Thermal conductivity depends on factors such as

- Density: generally light materials have low conductivity;
- Structures: conductivity of granular materials is lower than cellular material;
- Moisture: existing moisture in materials can increase the conductivity;

Temperature: usually by increasing temperature in lightweight, porous materials, the conductivity will be increased. Under steady conditions the rate of heat transfer (Q) is given by: $Q = U \times A \times [T1-T2]$. U factor/value is the thermal transmittance through components of building envelopes (Pohl, 2011).

$$U=KA/L$$

K: Thermal conductivity of material

A: surface area

L: thickness or length

T1: indoor air temperature

T2: outdoor air temperature

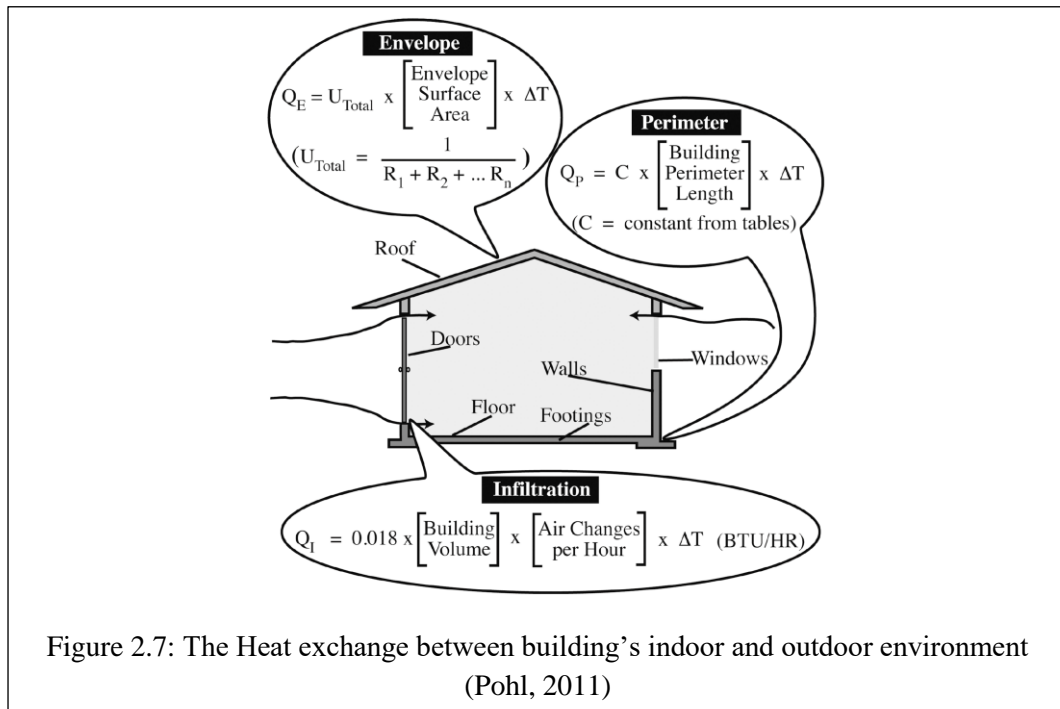


Figure 2.7 demonstrates the heat exchange between buildings surrounded area and different building envelope components such as wall, roof, windows, and floor. The characteristics of all elements in an assembly and all sensible modes of heat transfer (not latent heat transfer) have an effect on the U-factor, so it is an overall coefficient of heat transfer. The U-factor is only used for the envelope which is in touch with the air by both sides.

Thermal resistance or R- value ($R = 1/U$) demonstrates the ability of materials to resist heat flow which shows how effective they are as an insulator. For better insulation it is necessary to use higher R-value materials. For calculating U-factor of an envelope assembly, resistance of all involved components are summed together ($U = 1/\Sigma R$) (Pohl, 2011).

As an example, for an exterior wall (as a part of envelope): assume that in an area, 10% is occupied by 2x4 studs with R-4 and 90% is filled by fiberglass with R-14, the overall U Value is calculated as $(1/4 \times 10\%) + (1/14 \times 90\%) = 0.0893$ if it is converted to R-Value it gives: $(1/ 0.0893) = 11.2$. Table 2.3 can be used to estimate wall R-values based on the

temperature of inside surface of an exterior wall and outside temperature (it assumes that interior wall temperature is 70°F) (Chen, 2012).

Outside Temp (F)	Estimated R-Value									
	1	2	5	10	15	20	25	30	35	40
40	20.4	10.2	4.1	2.0	1.4	1.0	0.8	0.7	0.6	0.5
30	27.2	13.6	5.4	2.7	1.8	1.4	1.1	0.9	0.8	0.7
20	34.0	17.0	6.8	3.4	2.3	1.7	1.4	1.1	1.0	0.9
10	40.8	20.4	8.2	4.1	2.7	2.0	1.6	1.4	1.2	1.0
0	47.6	23.8	9.5	4.8	3.2	2.4	1.9	1.6	1.4	1.2
-10	54.4	27.2	10.9	5.4	3.6	2.7	2.2	1.8	1.6	1.4
-20	61.2	30.6	12.2	6.1	4.1	3.1	2.4	2.0	1.7	1.5
-30	68.0	34.0	13.6	6.8	4.5	3.4	2.7	2.3	1.9	1.7
-40	74.8	37.4	15.0	7.5	5.0	3.7	3.0	2.5	2.1	1.9

Interior wall T - exterior wall T

Table 2.3: Estimating wall R-Value based on outside temperature and interior wall surface temperature

A more accurate result for a wall construction R-Value can be calculated through: $R = (T_h - T_c) / (T_a - T_h) * 0.68 + 0.68$. In this formula, **T_h** is the interior temperature of an external wall, **T_c** is the temperature of outside air, and **T_a** is the indoor temperature. It should be noted that in this calculation only thermal conduction is considered, no radiation, no air leakage, therefore no condensation, and no convection losses are considered (Chen, 2012).

Heat capacity indicates the ability of a material to store heat per unit volume. Each material has density (mass of material/ unit volume) and a specific heat (for given mass of material it indicates need of heat to raise its temperature by 1°) which by multiplying them together the heat capacity is reached. Usually, material with high thermal capacity can reduce heat flow from outside to the inside. High thermal mass material can absorb heat from heat source (like sun) and retain heat when the source is gone (Pohl, 2011).

2.2.7.2 Sun and Solar Radiation:

Solar radiation is one of the most important parameters and it has considerable influence on building loads by providing heat and lighting, as well as energy that can be used for power generation. Therefore, it must be considered seriously during design stage when considering building energy efficiency.

When solar radiation hits a surface, it is converted to thermal energy (Cao et al., 2016) which means free heat gains (Hens, 2011). Managing solar radiation in an appropriate way can improve energy performance considerably. Solar radiation can also be used for generating electrical power by PV panels and hot water using Solar Water Heating (SWH) systems. Integrated system (Hybrid photovoltaic-thermal) which are a combination of PV panels and SWH can be introduced to improve the efficiency of PV panels by reducing their temperature through absorbing solar heat gain (SHG) with water (Cao et al., 2016). While SHG can reduce energy consumption in a building during cold seasons, converting solar radiation to thermal energy must be controlled in places that have hot summers through appropriate shading systems, otherwise additional energy is expended on cooling loads.

Some components of buildings, such as walls, doors, windows, ventilators, roofs, etc. are directly exposed to the sun. Solar contribution to the total inside thermal loads of a building depends on different parameters such as type, size and orientation of windows, wall area, ratio of wall/window (WWR) area that let solar radiation to come inside, and shading devices to avoid excess solar heat gains (Ralegaonkar & Gupta, 2010).

Hegger (2012) stated that, buildings that have less dependency on active systems have an advantage by using solar radiation in passive design, and this is the most effective and simple technique. He advised that, the following factors must be considered in order to improve efficiency to absorb and store solar heat and use daylight:

- Intelligent site selection, orientation, shape, mass, and placement of a building;
- Purposeful arrangement of windows; and
- Intelligent selection of walls' structures and materials.

By addressing these factors, a reduction in CO₂ emissions and heating demand will be achieved, as well as creating a more comfortable environment for occupants (Hegger, 2012). All three methods of heat transfer are involved in thermal transfer through windows in buildings. The dominant one is dependent on various factors, such as the external and internal temperatures, the time, the amount and angle of incidence that solar radiation that strikes the windows, and wind speed (Greenspec 2017; U.S DOE, 2017). The received amount of solar radiation depends on latitude and seasonal changes in the sun's angle of incidence. Also, insulation is a very important factor solar based strategy. By considering these factors building shapes are optimised toward massing, orientation, façade, and footprint, then

fenestration could be created (Bergman, 2012). United State Department of Energy (U.S DOE, 2013) has proposed the use of the following strategies together for a successful passive solar design:

1. Appropriately oriented windows: During the heating season, windows and other solar collector components should face within 30 degrees of true south and any other building or trees should not shade them between 9 a.m. to 3 p.m. each day. To avoid overheating during cooling season, the windows need an appropriate controller such as blinds.

2. Thermal mass: Material with dark colours and more density is suitable to absorb and store heat. Materials such as concrete, brick, stone, etc. can absorb heat from sunlight and retain it. Also, they are useful to absorb heat from the air to balance air temperature in the cooling season. While some materials like water are more efficient for storing heat, materials like masonry have a double advantage when used as structural materials as well as storing heat.

3. Distribution mechanisms: Absorbed heat from the sun may be used in indoor components to create flows to different areas of home by convection, radiation, or conduction. Distribution could be assisted by devices such as fans, but it is generally not provided when undertaking a strict passive design.

4. Control strategies: control devices such as thermostats which control fans, dampers and vents to allow or prevent heat flow, low-emissivity blinds, and awning may be used to increase efficiency of solar design. Also, overhangs on a roof can provide shade for windows of buildings in areas which have hot summer.

(DOE, 2013)

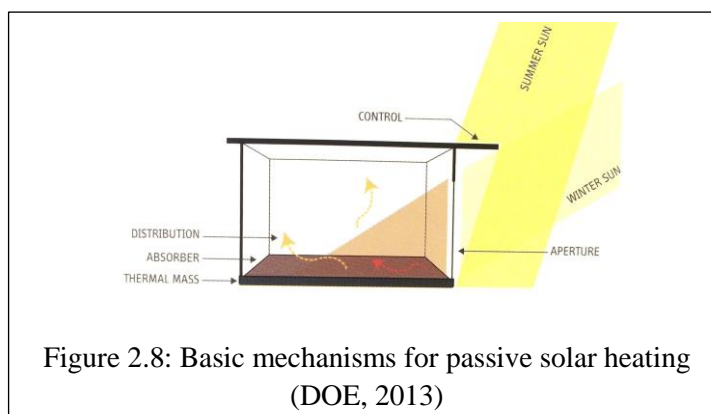


Figure 2.8 provides a summary of how solar radiation can be controlled in a building in order to use it as a natural energy source which provides free lighting and heating.

Choosing appropriate glazing and selecting the correct glazing properties are very important when using natural elements in an energy efficient design approach. Any opening that is installed in a building envelope is called fenestration, glazing are fenestrations which are covered by a translucent or transparent surface (such as a skylight or windows) (Autodesk, 2015).

Thermal conductance (U-value), Solar Heat Gain Coefficient (SHGC), Visible Light Transmittance (Tvis), Air Leakage, and Condensation Resistance are the most common factors for demonstrating glazing properties. The US National Fenestration Research Council have introduced a label to show glazing properties (Figure 2.9) (Bergman, 2012).

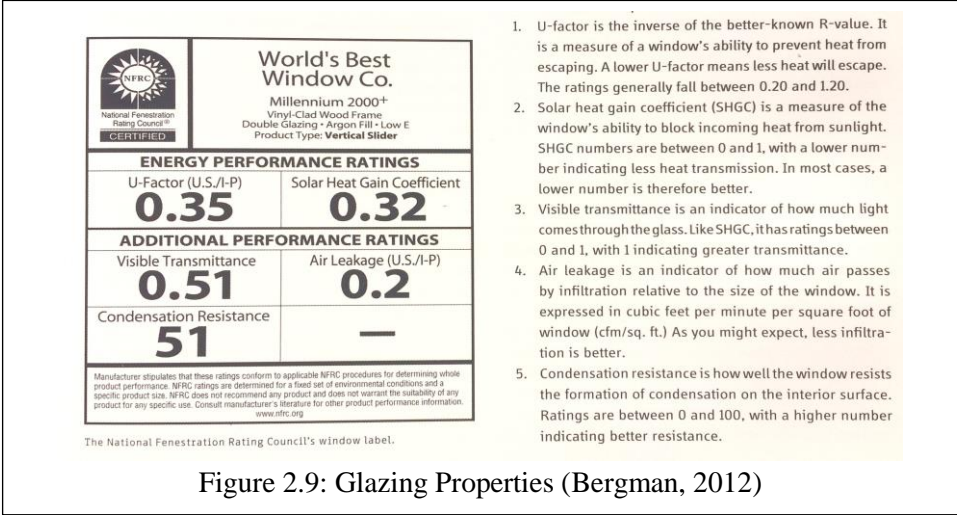


Figure 2.9: Glazing Properties (Bergman, 2012)

2.2.7.3 Wind and Air Pressure

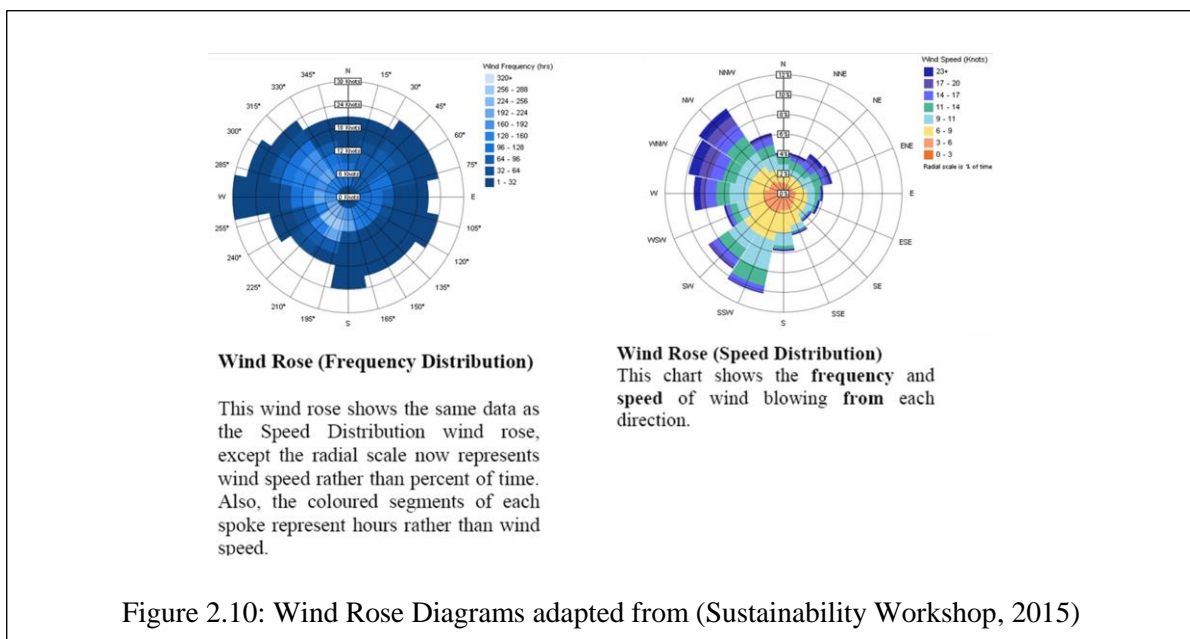
Wind is another effective natural element which should be considered to improve the energy efficiency performance of a building. It offers natural ventilation, transfers heat through convection and drives moisture, so it can cool both people and the building.

Chimney (Stacks), fans and wind cause different air pressure, which can act as the driving force causing air to come in and out the building, causing vapour transport, convective loops, and enthalpy displacement. Air movement can cause thermal transmittance, increased energy consumption, decreased sound insulation, and induce interstitial condensation. Wind speed

and related pressure coefficients along the building envelop dictate the pressure differences (Hens 2016).

Air flows from a point with high air pressure to the point with low air pressure. Wind has very similar behaviour to water because both are fluids. Wind is not stopped or blocked by buildings, but it will flow around the object and continues its direction, or is deflected. In a particular area wind patterns could be affected by environmental surroundings, such as other buildings, landforms and other objects which cause microclimates. It is possible to predict air flow by knowing some fluid “rules”, for example cold air is denser so it falls to ground and hot air rises from lower levels. In coastal areas, during daytime air flows from water to land and at night the process is reversed. Also, wind has similar behaviours in valley zones (blows uphill in day and downhill at night). Wind speed is also generally higher at higher altitudes (Wagner & Mathur, 2009).

A Wind Rose diagram describes wind behaviour (usual speed and direction in different times), so designers can use it for prediction and use of wind as a natural source in the most efficient way in their practices (Figure 2.10).



2.2.7.4 Relative Humidity and Vapour pressure

The ratio of water vapor in the air to its saturation is called relative humidity. The vapor pressure of a liquid is the pressure of the vapour resulting from evaporation of a liquid above it. Letcher (2007), p207, defined vapour pressure of a pure compound as “the pressure of

characteristic at any given temperature of a vapour in equilibrium with its liquid or solid form". Hens (2016) discussed that, usually there is no considerable difference between summer and winter regarding relative humidity. But vapour pressure differs significantly. However, the inverse may be true between day and night in mild climates. Moisture tolerance of building components and whole buildings are influenced by indoor relative humidity and indoor vapour pressure. While indoor environmental quality is affected by these two parameters, usually they are uncontrolled as a quantity except in specific rooms such as museums, computer rooms, surgical units, etc. which a stricter control is mandatory (Hens, 2016).

2.2.7.5 Long wave radiation

Earth loses its energy through outgoing long wave radiation. The typical wave length is located between 4 to 30 micrometres (0.0002 to 0.001 inch). The atmosphere is a selective radiant body which absorbs all incoming terrestrial radiant energy and emits only a fraction of it. The balance between the atmosphere, the terrestrial environment and the surface provides under-cooling. The combination of short wave radiation (insolation) from sun and long wave radiation from earth moderates the temperature of atmosphere and surface (Hens, 2011; Pielke, 2018).

A building usually interacts with all of these factors and their combination has significant influence on a buildings' energy consumption. Each of them has its own science and calculations for understanding their actual function and effect which requires specialists to address them. It may very difficult for architects to learn and apply this knowledge as well as their other design responsibilities, but understanding and implementing these factors can improve the architectural design. It helps them to understand the principal of energy analysis and how energy modelling tools work. All of the energy modellers and analysis software use these core principals and the users may be considered to have a good working knowledge in order to understand and apply them. In the next section energy modelling and different energy modellers are discussed more in detail.

2.2.8 Building Energy Modellers (BEMs)

In the previous section, the effective factors on a building's energy consumption, the interaction between buildings and environment, and a building's physics have been considered. In this section the practice of building energy modellers is considered. The review

includes the introduction and background of BEMs, their working methods, and their issues and challenges.

As discussed, an accurate energy analysis of a building requires lot of formulation and calculation, which without related tools and software can be difficult. As Anderson, (2014) stated, while formally, architects are not trained in the underlying calculations, these simulation tools can help architects begin to understand how their design decisions affect energy use. Also, building energy modelling tools can be used for different purposes such as green certification, code compliance, utility incentives, qualification for tax credits and real time building control (Roth, 2017).

2.2.8.1 Introduction and Background

The terms Building Energy Modelling (BEM), Building Energy Simulation (BES) or Building Performance Analysis (BPA) are applied to the tools and software which are employed to predict different aspects of buildings' performance such as energy consumption, indoor and outdoor air quality, acoustic performance, lighting, and etc. Some of the common programs used are: BSim, ECOTECT, DeST, Energy Express, DOE-2.1E, IES <VE>, eQUEST, Energy Plus, HEED, TRACE, and TRNSYS.

Initially, it is necessary to distinguish between modelling and simulation, Becker and Parker, (2009) pointed out that, while the words of simulation and modelling are used as synonyms, they do not have a same meaning. They believed that, description of some system is called a model, but for simulating a model, it must be described with mathematics. As an accurate definition in terminology, a simulation enacts, or instantiates, or implements, a model (Becker & Parker, 2009 cited in Clarke & Hensen, 2015).

The BRIS simulation program is one of the first buildings simulations, which was developed at Royal Institute of Technology, in Stockholm in early 60's. The temperature variation in a room is calculated by using a series of heat balance equations, solved through an iterative, finite difference method (Brown, 1990). Anderson, (2014) stated that, most of energy modelling programs are based on trade-offs, which means that one element is swapped for another to recognize the effects of an intervention. After testing many trade-offs, the analyst starts to realize how changing a single element can influence the system, then they can understand most effective energy use.

2.2.8.2 Working methods and categorisation

From 1960, lots of research has been conducting on BEM tools to make them richer and integrated which have capability such as: simulating heat and mass transfer in the building fabric, airflow in through the buildings, daylight analysis, and considering different systems and components in analysis (Clarke and Hensen, 2015).

Vecken et al., (2004) described that, in mid 1960s, first simulation has been introduced which in that simulation time has been considered as an independent variable. It was divided into three steps. In the first step, approximate techniques had been used to calculate building load. In second stage, the results of first stage were used as an input for HVAC system design. The results from the second stage were used to design the energy conversion systems. The interaction between the system and the building was often ignored in this method because of its sequential nature. Vecken stated that, time averaging techniques are used in the initial simplified building load models. In this method, transient thermal storage, convection processes, and radiation are roughly estimated through time-averaging techniques, which used internal heat gains over a period of time. Wilde, (2014) described how energy performance can be analysed at different levels based on time scale and duration. Annual energy consumption of the entire building for cooling and heating purposes is one of the most common approaches, but higher temporal resolution is available for monthly, weekly, daily, or even hourly studies and analysis (Wilde, 2014).

Clarke, (2011) described that, since many parts make the entire building, for building performance analysis the systemic approach must be considered, which is dynamic (*“parts evolve at different rates”*), non-linear (thermodynamic states effects on parameters), and complex (there are many *“intera- and inter part interactions”*). He believe that this system involves both hard (like transient energy flow) and soft aspects (like casual occupant interactions). As an example, Motuziene & Vilutiene, 2013 presented that age, number, and behavior of occupants have significant effect on building energy consumption.

As Crawley et al., (2008) discussed the whole building energy simulation programs are the core tools is the building energy field. These programs provide key indicators of building performance such as energy demand and use, humidity, temperature, and costs. Motuziene and Vilutiene, (2014) pointed out that energy simulation must be conducted in an integrated process, which considers the interaction and impact of all external factors and building

components. The whole BEM simulating energy consumption in a building is based on building physics, as explained in section 2.2.7. The input of BEM's tools are a description of a building's operation (lighting, schedules for occupancy, thermostat settings and plug-loads) and description of a building itself such as construction material, geometry, HVAC, lighting, refrigeration, renewable generation system configuration, water heating, controls, and efficiency of components (Motuziene and Vilutiene, 2014; Roth, 2017).

Anderson, 2014 discussed that based on the detail required and goals of the designers, there are three scales of building performance analysis. Single aspect analysis assesses a design for a single effective- solar irradiation, daylight, glare, airflow or so on. It is very fast and accurate while the Whole Building Energy Simulation (WBES) as a second scale needs two weeks or more to calibrate, and prepare the results because it considers almost all aspects of a building which influences energy consumption. The last one is the *Shoobox analysis* which is very similar to WBES, but usually working based on averaged data to account for mechanical systems. To limit the geometric size and simulation scope, they use boundary conditions. As an example in a shoebox simulation, the boundaries are imaginary walls without energy passes, therefore analysis only focus on limited facades which most heat transfer will happened in them.

Table 2.4 demonstrates the variety factors which are consider in a dynamic energy simulation.









	<p>Building Geometry</p> <p>A building's form is one of the primary factors that influence energy consumption. This includes its area, volume, layout, orientation, glazed areas, and shading – and is captured in an energy simulation using an Energy Analysis Model (EAM).</p>
	<p>Spaces & Thermal Comfort</p> <p>These spaces exchange heat with the outside environment and with each other (the dotted lines). An EAM that has discrete spaces that represent the air within a building (the pink boxes). A series of thermal comfort points are placed within these spaces (the dots).</p>
	<p>Surfaces & Heat Transfer</p> <p>These spaces exchange heat with the outside environment and with each other (the dotted lines). This heat transfer happens across surfaces of the model, abstracted from the geometry and representing the walls, roof, floors, and windows of the building (blue and green lines).</p>
	<p>Material Properties</p> <p>The behavior of the heat transfer across these surfaces is dictated by the materials (concrete, glass, insulation, etc). These affect the heating and cooling energy required to maintain comfort.</p> <p>Thermal properties considered include density, specific heat capacity, and conductivity. The properties of each surface account for the combined thermal properties of the layered building constructions.</p>
	<p>Building Systems</p> <p>A building's systems consume and produce energy to meet the building's and occupants' needs. These include:</p> <ul style="list-style-type: none"> • Heating, Ventilation, Air Conditioning (HVAC) • Lighting (Lighting Power Density = LPD) • Equipment (Equipment Power Density = EPD) • Water Heating (Domestic Hot Water = DHW) • Renewables that generate energy on site.
	<p>Loads from Occupancy & Exterior Conditions</p> <p>So far we've built-up a model that represents the building's spaces, surfaces, and systems. The other half of the modeling needed for energy simulation is the dynamic loads from people inside the building (based on building program assumptions) and the environmental conditions outside the building (based on climate data). How well will the building perform under these loads? These factors include:</p> <ul style="list-style-type: none"> • Heat and humidity from people (determined by how many people are in the space at different times, and what they're doing) • Set points, or the target temperatures of the spaces • Outside air temperature • Relative humidity • Wind speed and direction • Direct and diffuse solar radiation. • Infiltration assumptions
	<p>Heat Transfer Modeled Over Time</p> <p>Now that we know both the building's properties and the loads it will be subjected to over time, we can simulate heat transfer over time (usually an entire year, in hourly increments). This includes:</p> <ul style="list-style-type: none"> • Conduction (red arrows) • Convection (green arrows) • Radiation (yellow arrows)
	<p>Energy Use and Cost Predictions</p> <p>Finally, based on all that we've modeled and simulated, we can extract energy use and cost predictions. These energy use values are broken down by energy source (electricity, fuel) and also by end use (lighting, HVAC, etc). This can be translated to cost by multiplying predicted use with the predicted utility rates of each energy source.</p>

Table 2.4: The factors of a dynamic energy simulator (Adopted from Autodesk, 2018)

Swan and Ugursal, (2009) believed that energy consumption modelling can be grouped into two major categories of “top-down” and “bottom-up”. In the top-down approach, the buildings are considered as energy sinks. In this approach, there is no distinguishing energy consumption by separate end users. The advantages of top-down modelling are its dependencies on aggregate data, which are often freely available, and reliance on historical energy values. However, reliance on historical data can cause issues, as it does not have capability to adopt with related technologies which are developing continuously. Since there is absence of detail regarding end users’ energy consumption, it can lack of the ability to find the key areas which influence on energy consumption improvement. Alternatively, a high

level of detail regarding dwelling properties such as geometry, equipment and appliances, envelope fabric, climate properties, occupancy schedules, indoor temperature, and equipment uses are the common input data in a bottom-up model. Therefore, determining the energy consumption of each end-use is available in a bottom-up models which can help to identify the possible areas for improvement (Swan & Ugursal, 2009).

Adhikari et al., (2013) categorised the methods of energy simulation tools into static (does not consider the effect of time) and dynamic (considers the effect of time). Swan and Ugursal, (2009) divided energy simulation methods in two groups of statistical and engineering methods. They pointed out that historical information and method of regression analysis which are employed to attribute buildings' energy consumption to particular end-uses are statistical methods. The model can estimate the energy consumption of buildings when the relationships between energy consumption and end-uses are established. They stated that the engineering methods estimate the energy consumption of end uses based on heat transfer and thermodynamic relationships and/or power ratings and use of systems and equipment.

Adhikari et al., (2013) compared two simulation techniques (static and dynamic) for accuracy through the simulation analysis of two historical churches. Based on his research, while the dynamic software results are quite correct in comparison to real performance, the static software overestimates real energy consumption. As Clarke, (2011) stated, it could be because of that if all the effective factors (the description of a building itself and its operation) are not considered in a performance analysis, there would be a considerable gap between the results from simulation and real performance. Also steady-state analysis has some limitations for energy analysis of historical buildings such as: presence of standard climatic databases, complications of simulating buildings without heating, problems in modeling complex shapes, existence of established internal set point temperatures, ignoring lighting, and lack of understanding of the building's management (Adhikari et al., 2013). Currently, plug-ins in parametric design tools are rely on dynamic building performance simulation which provide results in more detail (Hollberg et al., 2012).

The accuracy of energy simulators is one of the popular topics in literature and as Menezes et al., (2011) stated the real performance of buildings is often different from what is predicted for them. In continue the difference between the results of energy modelling and measured performance which is called performance gap is discussed more.

2.2.9 Performance Gap

There are a considerable number of articles which identify that there is a difference between predicted energy performance of a building and its actual energy consumption (Menezes et al., 2011; Motuziene and Vilutiene, 2013; Wild, 2014; Marshal et al., 2017). As an example, when performance simulation is conducting for regulatory compliances the result can be five times lower than actual consumption (Carbon Trust, 2011 cited in Menezes et al., 2012)

Discrepancy between actual measurements and predicted consumption can have different reasons such as occupancy behavior, quality of materials and built, simulation tools, management and controls, and initial assumptions (Menezes et al., 2012; Motuziene and Vilutiene, 2013; Wilde, 2014). Each of these factors contains its own parameters. As an example, occupancy behavior includes gender, family size, age, awareness of energy issues, employment, socio-cultural belonging, price of energy, etc. This variety of factors means that predicting of energy consumption in a single family is potentially more difficult than an office building in which the occupancy schedule, number, time, quantity, and quality of comfort requirements may be viewed as more clear and predictable (Motuziene and Vilutiene, 2013).

Quality of materials, installation, procurement, and building are some of the major factors which impact on performance gap. Usually buildings' components are manufactured and tested in an isolated environment which does not consider them as a constructed fabric assemblies or a system. In 2014 ZCH had a review on "CLOSING THE GAP BETWEEN DESIGN AND AS-BUILT PERFORMANCE" report and categorised the factors which are influenced on performance gap during design stages, the factors are summarised in bellow.

- Concept design: Usually in this phase, there is lack of enough understanding about how early design decisions influence on a building energy performance.
- Detailed Design: Factors such as: insufficient knowledge and understanding within team, inappropriate integration between services, renewable, and fabric designs, thermal bridging and U-value calculation matters, and competency of Standard Assessment Procedure (SAP) advisors and assessors influence on the performance gap.

- Construction and Post construction: The factors which are influential on performance gap in this stage can be: Replacing components without consideration their energy performance, fabric's poor installation, inadequate installation or commissioning of services, site team does not care or have enough knowledge and skills regarding energy performance, Quality Assurance (QA) on site.

(ZCH, 2014)

The above factors usually are not considered during performance analysis and if they have occurred then they will increase the gap between the actual energy consumption and predicted energy performance.

In the introduction chapter it was mentioned that space heating has the biggest share in energy consumption of buildings in both residential and commercial sectors. Therefore, as Menezes, (2012) pointed out, the management and control of central equipment and HVAC systems have a considerable effect on energy consumption and inappropriate strategies can waste energy

The accuracy of the tools which are used for BPA has a significant effect on the performance gap. It was discussed in section 2.2.8, that there was a difference between the accuracy of steady-state and dynamic energy simulators. There are many of tools in the market for BPA purposes but as Menezes et al., (2012) stated out these tools can contain fundamental errors in equations that are used by the program. Marini et al., (2016) conducted a research calibration process by monitoring real data to reduce the performance gap. As an example, based on their results, the software is unable to capture detailed system dynamics and delay times. They stated that, while the calibration process can decrease the error gap considerably, the realistic behavior of a system is not accurately captured by simulated model.

While the energy modelers need to develop to improve the accuracy of models, they are very useful for comparing the performance of different design ideas at the early stages of the design. Also they are very helpful in understanding how any changes in geometrical design and/or systems would effect on energy performance of a building. Therefore designers still can benefit from the capabilities of these tools.

Crawley et al., (2008) conducted an investigation into popular simulation programs' specification and function which in the table 2.5 the summary of their results are presented.

Simulation tools	Specification	Function
BLAST	<p>Predicting Energy consumption, Energy System Performance, and Cost.</p> <p>Predicting Space loads (transmission loads, infiltration loads, internal heat gains, solar loads, and the temperature control strategy) air system simulation, and central plant</p>	Dynamic modelling by computing hourly space loads
BSim	<p>Popular for Energy and moisture analysis.</p> <p>Comprises: SimView (graphic editor), SimLight (daylight), tsbi5 (building simulation), XSun (direct sunlight and shadowing), NatVent (natural ventilation), SimPV (photovoltaic power), and SimDxf (import from CAD)</p>	
DeST Families (Residential, Commercial, Building Evaluation, Building Ratings, and Solar Buildings)	<p>Detailed analysis of HVAC system performance and building thermal routes.</p> <p>Functions: natural ventilation, weather data, Lighting, external shading, building simulation and analysis, and CAD interface.</p>	Hourly calculations for complicated buildings' heating/cooling loads, and indoor air temperatures.
DOE	Outcome from subprogram of loads are used as the input of simulation subprogram of Systems, Plant, etc. then their results become the input of subprogram of Economic.	Providing hourly weather information and predicting the hourly energy usage and cost.
ECOTECH	Possibility to create a comprehensive 3D visual architectural design and providing Performance analysis for energy, lighting, thermal, acoustic, shading, and cost expectation.	Real-time animation Of solar ray, and interactive acoustic providing real time update when changes happened to building geometry and material properties.
Energy Plus	<p>It is a “modular, structured code based” on the most popular capabilities and features of DOE and BLAST.</p> <p>Predicting more accurate space temperature which is key factor for design of system and</p>	Calculating loads at a user-specified time scale and sending the result for building systems simulation at the same

	plant sizing, occupant health calculation, and occupant comfort. Also provides better evaluation of moisture adsorption and desorption in building components, inter-zone air flow, radiant heating and cooling system, and realistic system controls.	time.
IES <Virtual Environment>	Has different modules for geometry creation and editing (ModelIT), thermal (ApacheSim), loads Analysis (AppacheCalc), component-based HVAC (Apache HVAC), shading visualisation and analysis (SunCast), natural ventilation (MacroFlo), 3D computational fluid dynamics (MicroFlo), model optimization (DEFT), radiance, lighting design (FlucsPro), building evacuation (Simulex), life-cycle energy and cost analysis (LifeCycle).	Evaluating building and system designs in details based on obtained information regarding environment.
Hourly Analysis Program (HAP)	Provide both detailed and summary of information regarding building, equipment and system performance. Providing comprehensive data for controlling and configuring terminal equipment and air-side HVAC systems. Also provides part-load performance models for packaged DX units, Split DX units, Chiller and cooling towers, and heat pumps. *DX: Direct Expansion air conditioning	Simulating hourly energy performance of a building to predict energy use and cost annually.
Table 2.5: Summary of Building energy simulation tools specification and function (Adopted from Crawley et al., 2008)		

As highlighted in Table 2.5, not all the simulation tools provide the same features regarding performance prediction. Some of them are just used for performance analysis (Like HAP) while others can be used for both geometrical design and performance analysis (like ECOTECH). Engineers and other specialists in the energy field are the most common users of tools that are designed specifically for energy modelling, while programs which provide geometrical design along with energy modelling can be used by both architects and energy specialists. Those softwares are equipped with interfaces which allow users to send and receive data to energy simulation engines.

Reeves et al., (2012) conducted a research on twelve BEM tools by assessing four major criteria which are: user-friendliness, interoperability, available out puts and available inputs

(Appendix L). Research is conducted through case-study and analysing performance of two buildings in university of Florida. The initial evaluation result from their study is presented in Table 2.6.

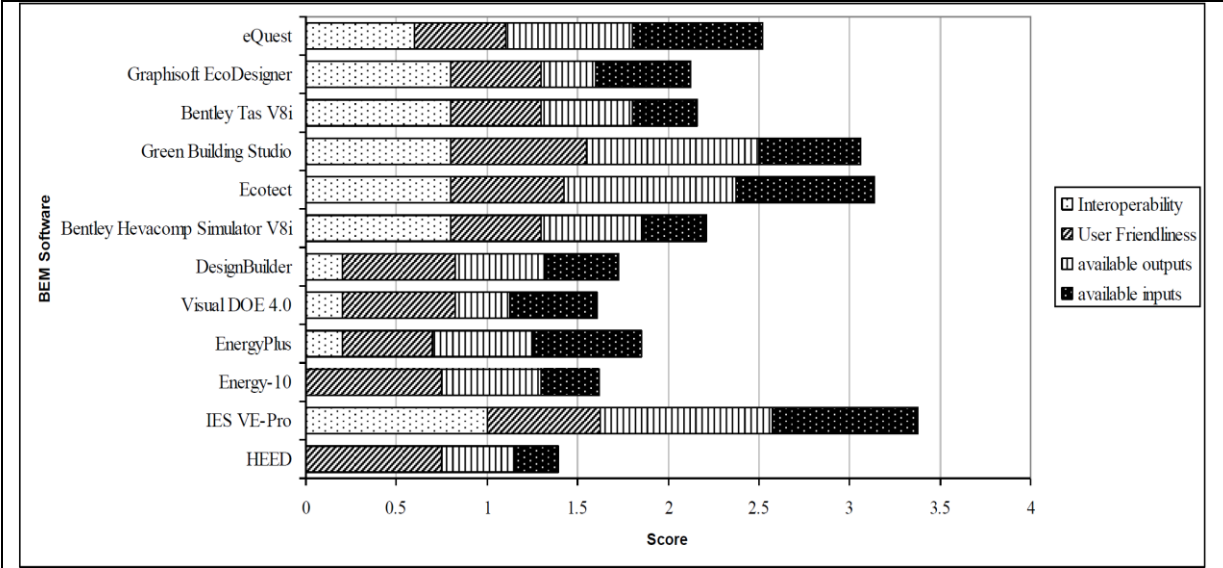


Table 2.6: Evaluation scores on twelve BEM tools adopted from Reeves et al., (2012)

The top three tools from the initial evaluation are selected for re-evaluation (Appendix M), which the result is presented in Table 2.7.

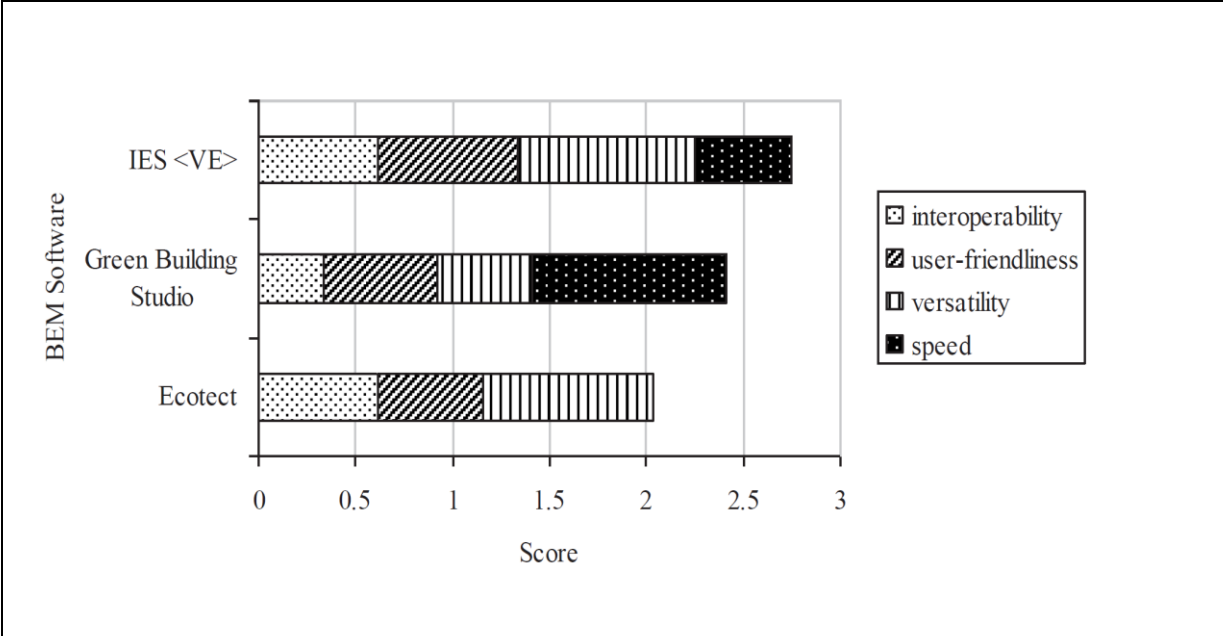


Table 2.7: Re-Evaluation Scores adopted from Reeves et al., (2012)

Reeves et al., (2012) conclude that IES <VE> was the most effective BEM tool, but selecting a tool can depend on different factors, such as how BEM will be incorporate into a design process, and how the operators intend to apply BEM. For example, to achieve faster results for comparing different designs, the GBS may be a more suitable tool.

GBS, 2018 claimed that, the integration of Revit with energy analysis was the first integrated whole building energy analysis solution in the market. The Green Building Studio is a cloud service which provides a building analysis platform for conducting whole building performance analysis through BIM tools. It uses the DOE-2 engine to provide water use, carbon emission, and energy use results (Autodesk GBS, 2018). DOE-2 is a *“freeware building energy analysis program that can predict”* building’s energy use and cost. Different parameters such as weather conditions, utility rates (provided by user), building layout’s detail, operational schedule, constructions, conditioning systems (HVAC, lighting, etc.) are used in DOE for hourly analysis and estimating utility bills (Hirsch, 2016).

Data structures such as Green Building XML (gbXML) which is created by Green Building Studio (GBS) and enables interoperability between engineering analysis and building design tools through facilitating the transfer of CAD-based building information. It provides fast and reliable transfer of building information to and from architectural and engineering models for very fast plan take-offs, therefore an affordable process for designing energy efficient buildings may be achievable. It has wide adoption by BIM vendors such as Trimble, Autodesk, Bentley, and Graphisoft (gbXML, 2018).

GBS, 2018 claimed that, variety of building features automatically are tested by it which considerably reduce the time of calculation. The ability to conduct whole building energy analysis is added to Autodesk Revit from 2013. Therefore, Revit users can use it as both geometrical modeller and energy simulator. It is possible to use it for initial energy analysis on a conceptual massing model which does not require room space object element and also can reasonably predict detailed whole building energy analysis based on the installed systems in a building (Autodesk GBS, 2018)

2.2.10 Summary

In the design and construction of a sustainable building, indicators such as water efficiency, energy efficiency, pollution, land use and ecology are considered. Energy efficiency is the currently considered one of the more important indicators, for a number of regulatory and financial reasons. To increase energy efficiency of a building, the main strategy must be to decrease building energy demand and consume the energy in the most efficient way. Reducing buildings' demand can be obtained through: 1- Employing sustainable resources such as natural elements for lighting, ventilation, heating and cooling instead of active system; and 2- preventing energy waste through buildings' envelope; and 3- installing and using high energy efficient equipment and appliances.

Shape, size and orientation of a building, its rooms and building's envelope material properties have significant impact for using natural elements and preventing energy waste. Figure 2.11 illustrates Buildings and Natural Elements Consideration in design stages. This diagram is generated based on a detailed review of different standards and other related literature. It contains two main steps. The first step which is highly dependent on collecting information about the site and natural elements and it is conducted during pre-design, schematic / conceptual design process. The next step is mostly involved in design development and detailed design process which includes the important influential factors on building's energy usage which must be considered for designing building's elements. After these steps, details can be used to design HVAC system, Mechanical, Electrical, and Plumbing (MEP) systems and other equipment incorporated. The diagram below assists designers in the review of all the necessary design considerations by following these steps. It may be used as a checklist along with other existing standards, guidance and building codes. It can be useful especially for designers who are involved in design because it is a very fast referral source which includes most of the influential factors on buildings' energy efficiency all in one place.

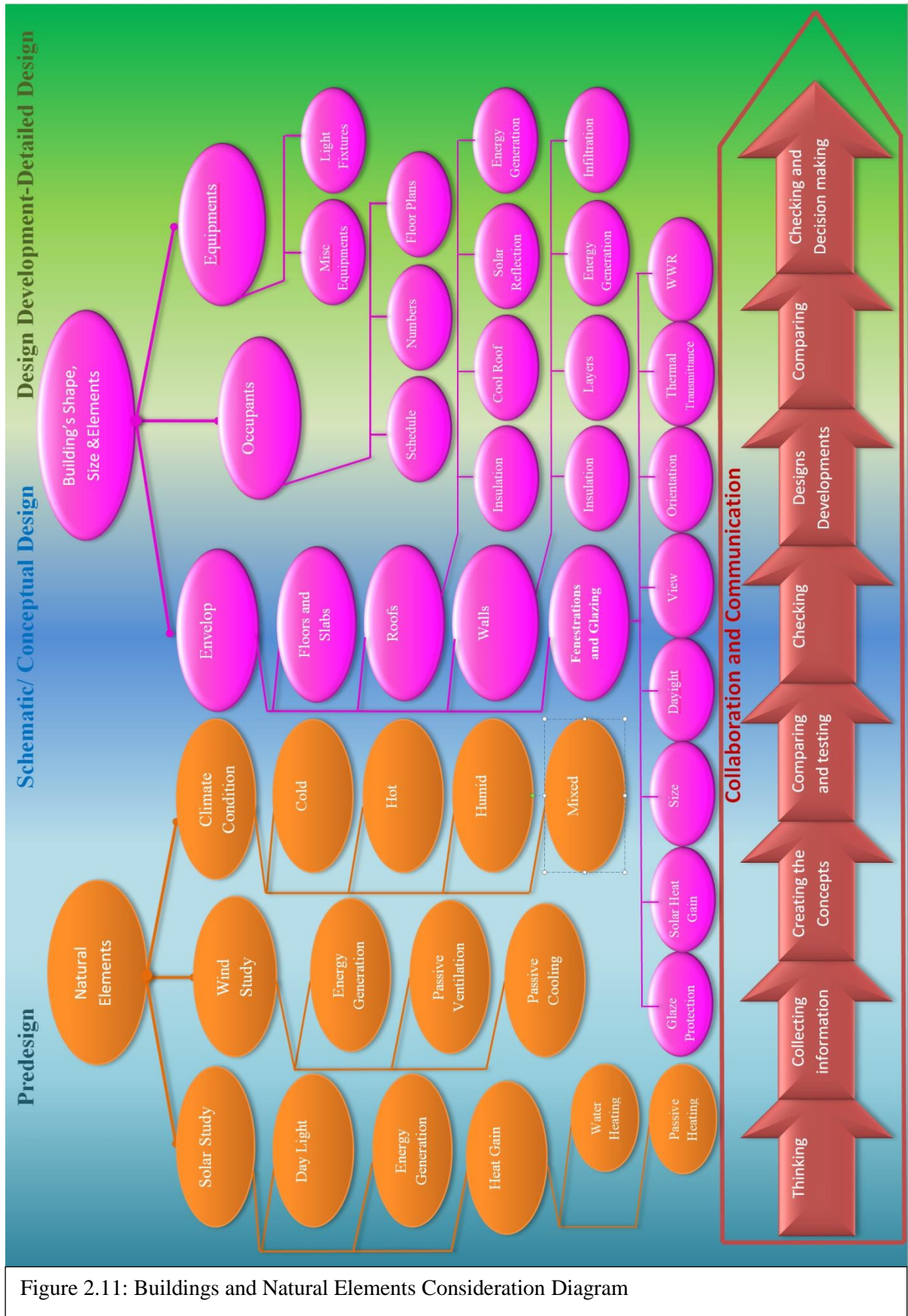


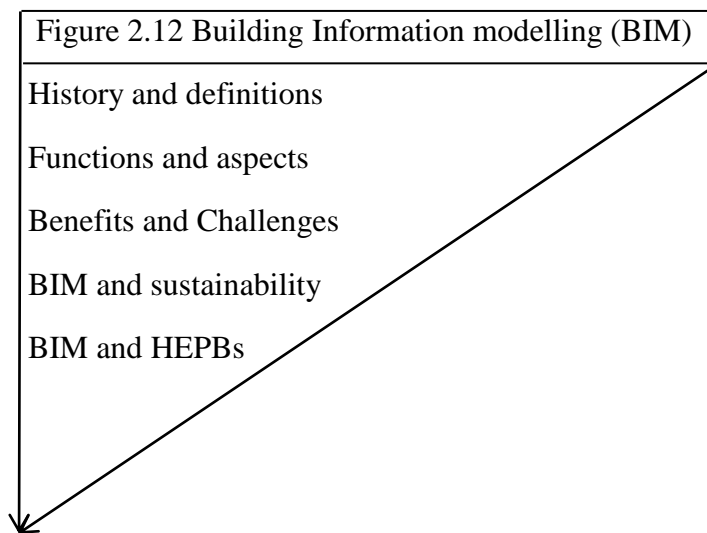
Figure 2.11: Buildings and Natural Elements Consideration Diagram

Three main natural elements which can have influence on building energy efficiency are sun, wind and climate condition (cold, dry, humid, hot, and mixed). These elements can have both positive and negative impact on building's energy demands. In an inefficient building they usually have negative impacts such as uncontrolled solar heat gain, or air infiltration. By implementing an appropriate design strategy, it is possible to use these natural elements to decrease building's energy demands or even achieve net-zero energy consuming buildings. As an example, controlling solar heat gain through installing shading systems and low e-coating glass on fenestration can reduce the building's heat demands in winter while providing lighting and subsequently energy demands.

To design a highly energy efficient building, a detailed knowledge of building physics and analysis is desirable. While most architects have appropriate knowledge regarding HEPB design and implementing their knowledge in their work, architects are usually dependent on other professionals in undertaking detailed analysis. The final analysis and certification will be conducted by registered assessors, but the engagement of architects in the performance analysis process has the potential to improve the efficiency of the design process and the final product. BIM with its tools may allow non-experts to quickly analyse the energy performance of buildings during the design process without having deep building physics knowledge. In the next section, BIM and its ability for conducting energy analysis or building performance analysis are discussed in more detail.

2.3 Building Information Modelling

This section provides an explanation and background to Building Information Modelling (BIM). BIM's tools and functions, benefits and challenges, and BIM's relation with sustainability and especially with HEPBs are reviewed in detail. Figure 2.12 presents the way of narrowing of relevant studies about this section.



2.3.1 History of Information Modelling

Smith (2010) claimed that modelling the information of a project has a history of more than 25 years in different industries, such as the automobile and aerospace industries, and it has been used in construction industry from the late 1990s.

Dave (2013) argued that features such as automatic drawing, parametric and intelligent components, 3D modelling, etc. are described by Aish in 1986 for construction practice (Aish, 1986 cited in Dave, 2013). The first mention of Building Information Modelling (BIM) was in 1992 by Nederveen and Tolman (Nederveen and Tolman, 1992 cited in Dave 2013).

2.3.2 Definitions and Explanation

There are several definitions of BIM in the literature. For a better understanding of BIM, some of these definitions are presented in Table 2.8. Characters of different definitions usually represent the viewpoints and the specified field of the authors. In each of them, the considered viewpoint is shown in bold.

Definition of BIM	Authors:
<p>BIM is <i>“An intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information — into an intelligent format that can be used to develop optimised building solutions with reduced risk and increased value before committing to a design proposal”</i></p>	<p>(Woo et al., 2010, p. 538)</p>
<p><i>“BIM (M) is a managed approach to the collection and exploitation of information across a project. At its heart is a computer-generated model containing all graphical and tabular information about the design, construction, and operation of the asset.”</i></p>	<p>(BIS, 2011, p. 91)</p>
<p>Eastman, Teicholz, Sacks and Liston (2011) are <i>“ used the term BIM to describe an activity (meaning building information modelling) rather than an objective (building information model).This reflects that BIM is not a thing or type of software but a human activity that ultimately involves broad process changes in design, construction, and facility management.”</i></p>	<p>(Eastman et al., 2011, p. xi)</p>
<p><i>“Building Information Modelling (BIM) is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets.”</i></p>	<p>(HMGovernment, 2012, p. 3)</p>
<p><i>“A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. The BIM is a shared digital representation founded on open standards for interoperability.”</i></p>	<p>National BIM Standard- United States (Retrieved 2015)</p>
<p>Table 2.8: BIM Definitions</p>	

The BIM's definition from Penttila, 2006 look appropriate for this research because it covers most aspects of this research:

BIM is a set of interacting rules, procedures and technologies that generate a methodology to manage the necessary data (in digital format) about a project and building design during its life-cycle (Penttila, 2006 cited in Succar et al., 2012, p. 121).

Krygiel and Nies (2008) argued that documentation methodology in design and construction industries is changed through the use of BIM by storing the set of design documents in an integrated database. All the data are interconnected and therefore makes a “parametric information model”. With this ability, any changes to a component in the model are instantly reflected throughout the whole project documentation.

Eastman (2011) claims that different activities such as construction, procurement activities, and fabrication can be supported by precise geometry and data in the generated models. The functions required to model the lifecycle of a project are accommodated by BIM. Also, BIM changes the duties and relationship between team members of a project. Saving time and cost with better quality are the results of more integrated activities in design and construction, which are some of the proposed benefits of BIM.

University research programmes and innovative software companies have matured BIM from object-based parametric modelling into suites of software programmes that are used widely in design and construction professions (Kenesk and Noble, 2014). These software programmes create accurate three-dimensional models (instead of traditional 2D views) which provide reliable visualisation of a project in all views and dimensions in any step of process. The advantage of parametric regulation is that it supports the alignment of design data and supports final models in having reduced geometric errors. BIM's tools can help to estimate costs and quantity of bills for lifecycle of a building. One of the very relevant advantages of BIM for improving sustainability in a project is that model could be used for energy analysis in design stage to simulate the project performance (Eastman, 2011).

In early stages of design, BIM makes it possible to track the process of construction. On-site visualisation tools help teams to understand what the space would look like when completed. The model can be used for quantity take-offs materials by contractor, and/or operating, managing, scheduling the materials and furnishing the facility by owners and operators. Sections, plans, details, elevations, and scheduling can be extracted automatically from BIM-

based model while the CAD-based model is an assembly of manually generated files which does not provides all of these options (Krygiel and Nies, 2008).

The different definitions for BIM state that BIM is not just software or tools. It is an abbreviation of Building Information Modelling, but it is possible to look at it as a way, an approach, or what this study prefers to call a “strategy”, which has been built on information. Therefore, BIM is considered as *information and computer based strategy* to simulate (modelling) designers’ desire virtually for better management of resources.

Information is driving force in this strategy which means designers and engineers are able to input their ideas by parametric drawing instead using traditional methods. By employing a set of mature BIM tools, each drawn component contains a considerable amount of information (parametric) in comparison with traditional systems like CAD which in that, the components were just images with information such as dimensions, colour and shape. Parametric modelling allows the designer to edit properties of each element of building in the model and extract different formats of data from the model for further actions and analysis.

2.3.2.1 IFC, IFD, and IDM

BIM creates an opportunity for various stakeholders in different parts of the world to be able to work on a project. For instance, the capability exists for a client and place of project to be located in the UK, but architectural design, structure design, and maintenance design (MEP) to be conducted in different countries. The result of each individual’s work can be seen and edited in a unified database. However, as languages and standards of different countries are distinct from each other, a series of standards are necessary for converging data. For this reason, BuildingSMART has developed IFC, IFD and IDM standards (Figure 2.13).

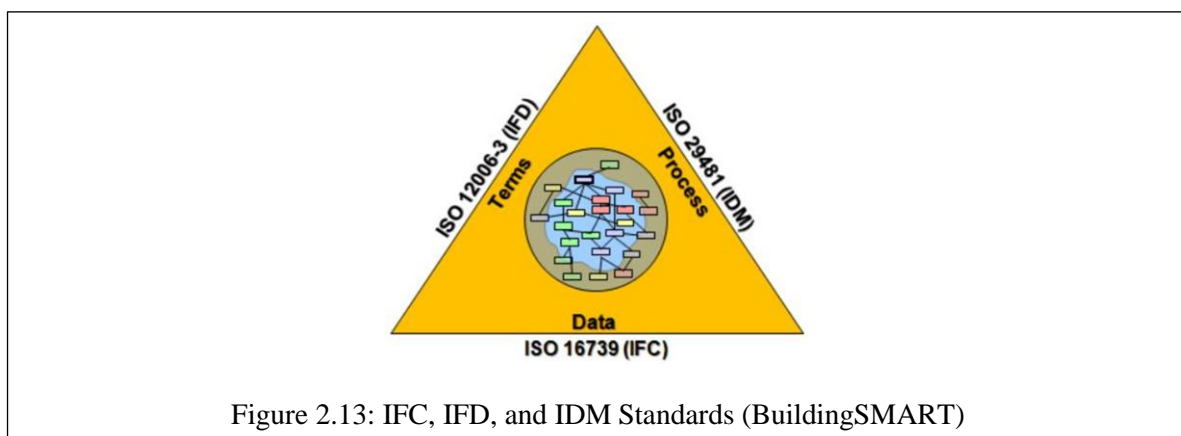


Figure 2.13: IFC, IFD, and IDM Standards (BuildingSMART)

Different items exist in the BIM schema and they need to be named and described to understand what they mean and do. The International Framework for Dictionary (IFD) has been developed to describe the meaning of names of items in a controlled definition and the units in which they could be stated. The Information Delivery Manual (IDM) is used to facilitate recognition and documentation of data exchange progressions and requirements. BuildingSMART has developed Industry Foundation Classes (IFC) as a standard for data storage and sharing in the capital facilities industry. The virtual demonstration of objectives, their relationship, attributes and inheritances in the capital facilities industry are defined in this standard (NIBS, 2007).

2.3.3 BIM Maturity

BIS (2011) considered 4 levels (0-3) for BIM maturity. The provided model of maturity which is shown in Figure 2.14 clearly demonstrates the level of competence expected for each stage. This model categorises the kind of technical and collaborative working to assist to a better understanding of the ‘processes, tools and techniques to be used’. Clients and their supply organisations can recognise their approach maturity based on this model index. Also, it aids as an organised educational progress over a period of time (BIS, 2011).

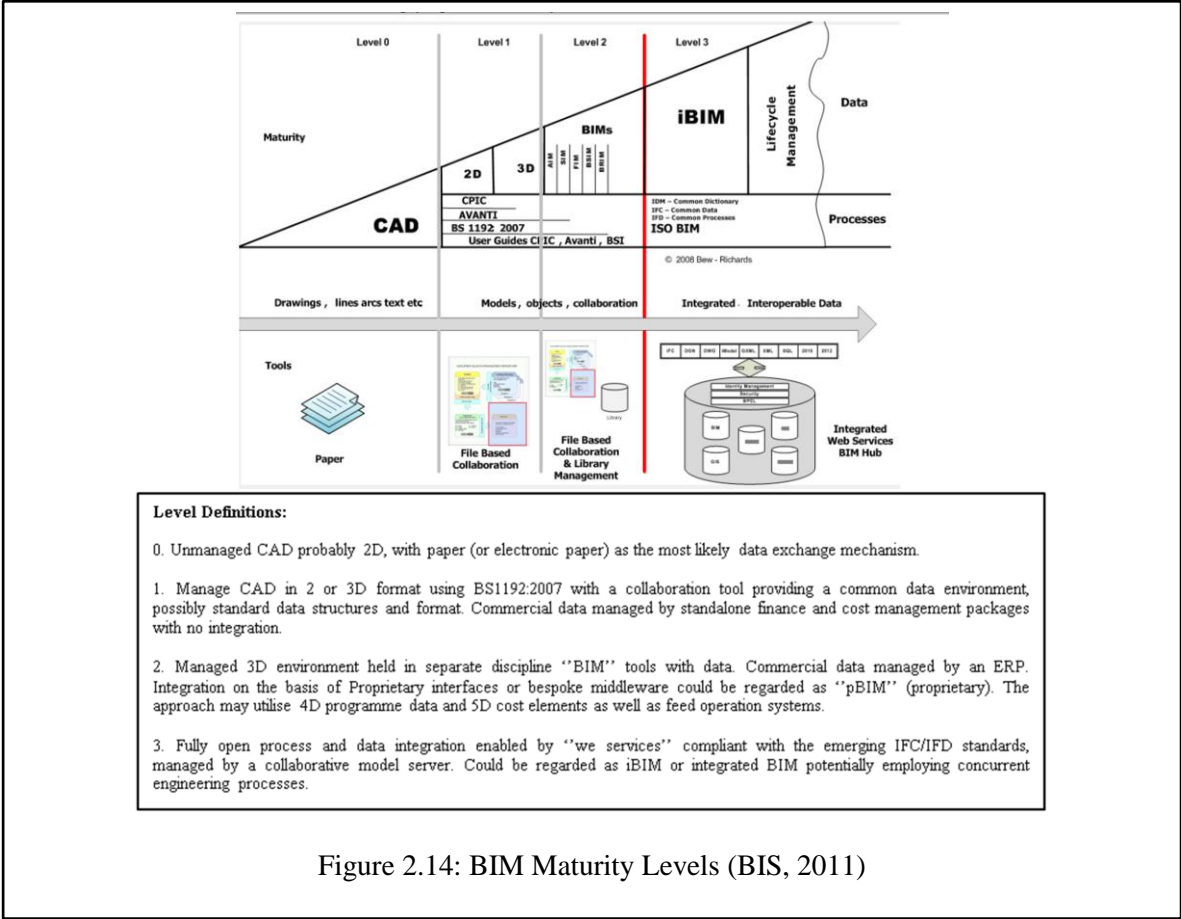


Figure 2.14: BIM Maturity Levels (BIS, 2011)

Information from mature BIM must be interoperable to support activities such as: Simulation, Virtual Design and Construction, Lean Construction, Deconstruction, Real Property Asset Management, Resiliency, Analysis, Integrated Project Delivery, Carbon Footprint, Building Green, Raw Material Consumption, Value Engineering, Preventative Maintenance, Environmental Stewardship, Life Cycle Costing, High Performance Buildings, Energy Conservation, and Sustainability (BIS, 2011).

2.3.4 BIM Function

Two approaches are considered for BIM function. One approach is about the relation between BIM and Humans (Soft Approach) and the second one is about the relation between BIM and the tools which are used for functioning BIM (Hard Approach).

2.3.4.1 Soft Approach

One of the most significant effects of BIM is integrating and harmonising the activities in a project. BIM's soft approach is about people and human activities. This approach provides a framework for better communication and coordination between the stakeholders in design and construction industry.

This approach comes from one of the existing points of views regarding the use of BIM in relation to human activity and BIM (ace BIM, 2012). BIM can provide a new method of collaboration with its tools to develop the communication between the involved teams in a project (Thompson, 2000; Eastman et al., 2011). As Jernigan (2008) mentioned, the 'BIG BIM' contains social development, software, hardware and business processes while the 'little BIM' is just about BIM tools.

2.3.4.2 Hard Approach:

As Jernigan (2008) mentioned, little BIM is the driver of 'BIG BIM' through BIM's tools, such as surface modeller and solid modeller. Different tasks could be conducted by architects, engineers, contractors, manufacturers, and any other stakeholders of a project through data from model/s which are accurately produced by BIM tools (Eastman et al., 2011). The results of research in United States demonstrate that visualisation, clash detection, and building design are the three most popular tasks which BIM is used for. Figure 2.15 presents the popularity of tasks that BIM is used for them (Becerik-Gerber and Rice, 2010).

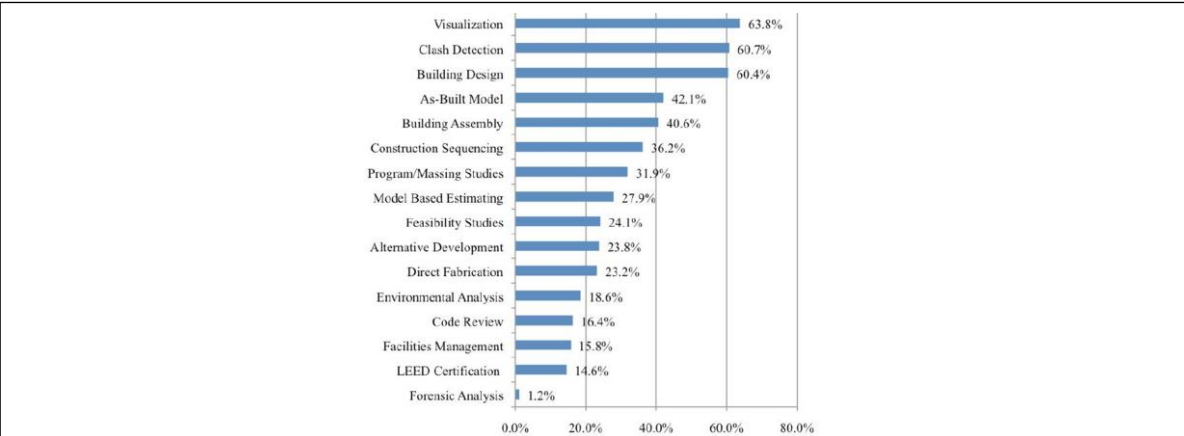


Figure 2.15: Tasks that are conducted by BIM's Tools in US (Becerik-Gerber and Rice, 2010)

BIM is a strategy which is based on information technology and needs appropriate software and hardware to implement. This digital-based strategy assists any project's stakeholder to create their idea virtually with all its components. Each component contains high levels of information which form properties, specifications, and characters of each element and at the larger scale, the whole project. Therefore, elements know what they are (door, windows, wall, etc.), what their function is, what their relation with other components is, and what each of them has been made from along with their properties' information such as R-Values, thickness, layers, etc.

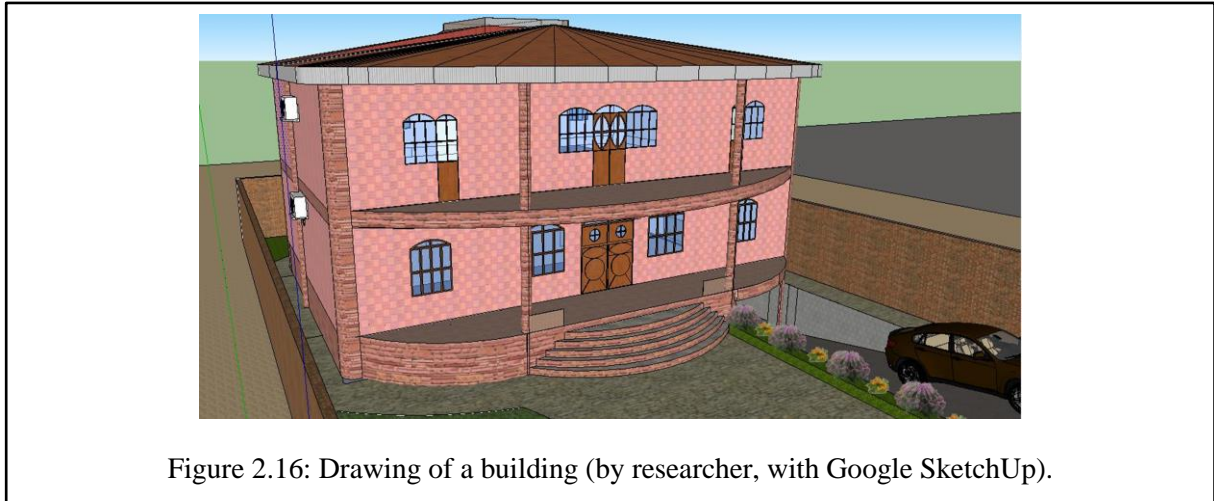
The ability to simulate people's design intention and to convert it to a simulation using digital data at any time provides a reliable way for better communication and coordination between project's stakeholders. In software such as Autodesk Revit, the operator can easily define a wall, for example, with its different layers based on the design requirements. Extracted data from the model can be easily transferred to other software for other analysis such as structural analysis or performance analysis.

Based on maturity level of BIM that is considered, different softwares with different capabilities are provided. There are two main groups of modellers in the industry, 'Surface Modeller' and 'Solid Modeller'.

2.3.4.3 Surface Modeller

Chelson (2010) believes that these kinds of modellers cannot support BIM completely, because they do not contain relational object-based information of components (Non parametric). The components in surface modellers are just collection of surfaces which can be used for collecting data regarding size, location, and three dimensional views. Google

SketchUp, WebEx, and OUMA Planning System are examples of this kind of software. Usually models which are generated in these softwares could be utilised for other applications in solid modellers. For example, Navis Works, as a solid modeller, can detect clashes in a model which is generated in SketchUp.



2.3.4.4 Solid Modeller

These kinds of software such as Autodesk Revit, Nematschek Vectorworks, Bentley Architecture, Gehry Technology's Digital Project and Graphisoft ArchiCAD are Object-Based Parametric modellers. Autodesk Revit (Architecture, Structure, and MEP) is one of the most popular solid modellers and has approximately 42% of the US market (Becerik-Gerber and Rice, 2010). In 'Parametric Assembly' that is used in recent architectural desktop, when the shape's parameters are changed, automatically the definition of assembly modelling will be updated. But the more advanced 'Parametric Object Modelling' lets the defined parameters of a shape to be linked to roles of another component. Therefore, any changes in parameter of one shape automatically impacts on the definition of the assembly and so the update sequence is automatically determined (Eastman et al., 2011). Visualisation with these modellers presents an accurate view of components and building (Sacks et al., 2004). However, Eastman et al. (2011) believe that BIM is more than visualisation, because the provided model/s by BIM contains "smart" objects that each of them consists of detailed data about itself and understands its function and connection to the other components in the model. These data could be used to extract an accurate representation of objects from model/s for manufacturing. Since all data of all components in a building are compared together in a united area (generated model), the interference points of parts are accurately controlled and checked to detect any clashes.

Editing, creating and defining semantic connections among computer representations within the modeller make it a very powerful tool to present functions of components' links, and geometric connections. Various analyses such as structural, acoustic, thermal, and environmental analyses can benefit from these functional properties (Sacks, et al., 2004). Adding the dimension of time in the 3-D model/s makes 4-D model/s that could be used for time-scheduling, construction sequencing and constructability. The BIM solid modeller proposes the ability to extract the quantity of objects used in the model with their characteristics. Also, making changes will automatically perform the related change to other object/s within the whole model. Therefore it becomes possible to add the cost as fifth dimension for estimating costs regarding any activity (Azhar et al., 2008; Chelson, 2010; Eastman et al., 2011).

Decrease in waste and improving resource efficiency in the lifecycle of a building which directly impacts on building sustainability could be achieved through BIM technology. The rich data that could be extracted from model could be used in energy simulator programmes such as Energy Plus, Virtual Environment, Ecotect, or inside the Revit energy analysis toolbar (Autodesk Insight 360) to estimate the energy use in a building at the primary stage (design) of project (Jernigan, 2008; Motawa and Carter, 2012).

Since meeting environmental aspects of sustainability and improving energy and resource efficiency in buildings by using BIM tools in design stage is the part of this research's goal, the ability of BIM to meet environmentally sustainable buildings or green buildings components will be investigated more in the following after BIM adoption section.

2.3.5 BIM Adoption

Adopting BIM, despite its purported advantages, has its own challenges. As Rogers (2002) stated in his research around the adoption of new innovations, people express different reactions to new processes and methods. These reactions usually come from different personalities, interests, experiences, knowledge, and motivations. These mean, BIM implementation may be slow, but will be accelerated after an initial period of growth, as highlighted in Rogers Innovation Adoption Curve, which indicates a normal distribution in the rate of adoption of a new innovation.

Organisations in AEC industry are usually categorised in Large, Small to Medium and Micro. SMEs refer to Small or Medium Enterprises which are the major constituent organizations in

this industry (Wu and Issa, 2012; Hong, et al., 2016). HM Government, (2012) suggested that both public and private sectors can get benefit from BIM adoption, therefore all organisations in the private sector or public sector may see benefit from the implementation of BIM. Wu and Issa, (2012) argued that intensive IT upgrading, which is required for BIM adoption has considerable cost, and most SMEs cannot afford it. Eadie, et al., 2012 discussed that, the size of the organisations is a significant factor for implementing BIM. They believe that adopting BIM in SMEs is easier than in large organizations, but only if they can afford the related costs associated with this change. The cost issue for adopting BIM in SMEs' is identified as a barrier, but on the other hand, due to the size of SMEs' projects which are usually smaller than projects in a large organization, the rate of BIM implementation can be faster in SMEs in comparison to large organizations. They recognised that large organizations need longer time to "complete and coordinate the transition of projects to BIM" because large projects require more time (Hong, et al., 2016). The UK NBS, (2019) reports that the majority of their respondents believe that BIM is not only for large organizations. The report shows that respondents in small practices (1-15 employees) have less confidence regarding their BIM knowledge and skills in comparison to medium sized (16-50 employees) and large practice (51+ employees). However, there is no significant difference regarding employees' confidence in their BIM knowledge and skills between medium and large size companies. Currently 81% of large companies, 80% of Medium practices and 56% of small firms in UK are using BIM. Perhaps, few small firms believe that they will be required to use BIM on all projects in future or their clients would ask for it (NBS, 2019).

The NBS reports shows, that while not all companies are using BIM, many of them, especially medium sized companies, who are the target for this research, are using BIM. Even in small firms (16-50) more than 50% of them are utilizing it. Therefore, this widespread adoption of BIM has the potential to create wider use cases, such as designing for improved energy performance. As discussed, there are some issues regarding BIM implementation which must be considered by both individual and the wider sectors in the design and construction industry. Overcoming these issues may help BIM's spread and its use to perform a variety of tasks, including those around sustainability issues.

2.3.6 BIM and Sustainability

Becerik-Gerber and Rice (2010) believe that BIM is not being used to address sustainability in buildings, despite its potential. Environmental analysis is an important process in building performance, but results of their research identify that only 19% of BIM users obtain high value from BIM for this analysis. Also, just 15% of their research respondents express that they used BIM for implementation of the Leadership in Energy and Environmental Design (LEED) standard in US.

Each standard can contain several different version of the standard within it; these may include various iterations of the standard as best practice develops, as well as different sectorial standards. Schweber, (2013) discussed that, there are 16 versions of BREEAM such as BREEAM for retail, offices, and education LEEDs, For this study, BREEAM refers to the “BREEAM UK New Construction, Non-Domestic Buildings, 2018” scheme. Also there are different versions of LEED such as LEED for healthcare, warehouse and distribution centres, retail, and LEED for schools. In this study LEED refers to “LEED BD+C New Construction, 2019” scheme.

BREEAM in Europe and LEED in North America are two of the most popular standards. Assessment of these standards is based on points that a project obtains from different areas. In the considered scheme of BREEAM, (2018) these areas are Management (maximum 11%), Health and Wellbeing (14%), Energy (16%), Transport (10%), Water (7%), Land use and Ecology (13%), Materials (15%), Waste (6%), and Pollution (8%) and innovation a 10% additional score. LEED, (2019) includes: Location and Transportation (Maximum 16 point), Sustainable Site (10 points), Water Efficiency (11 points), Energy and Atmosphere (33 points), Materials and Resources (13 points), Indoor Environmental Quality (16 points), Innovation (6 points), and Regional Priority (4 points).

Each of main categories includes different subcategories. Since this study deals with energy, the subcategories of energy in each standard are presented. BREEAM, (2018) demonstrates a timeline for each category assessment. The subcategories of energy assessment with the timeline are shown in Figure 2.17.

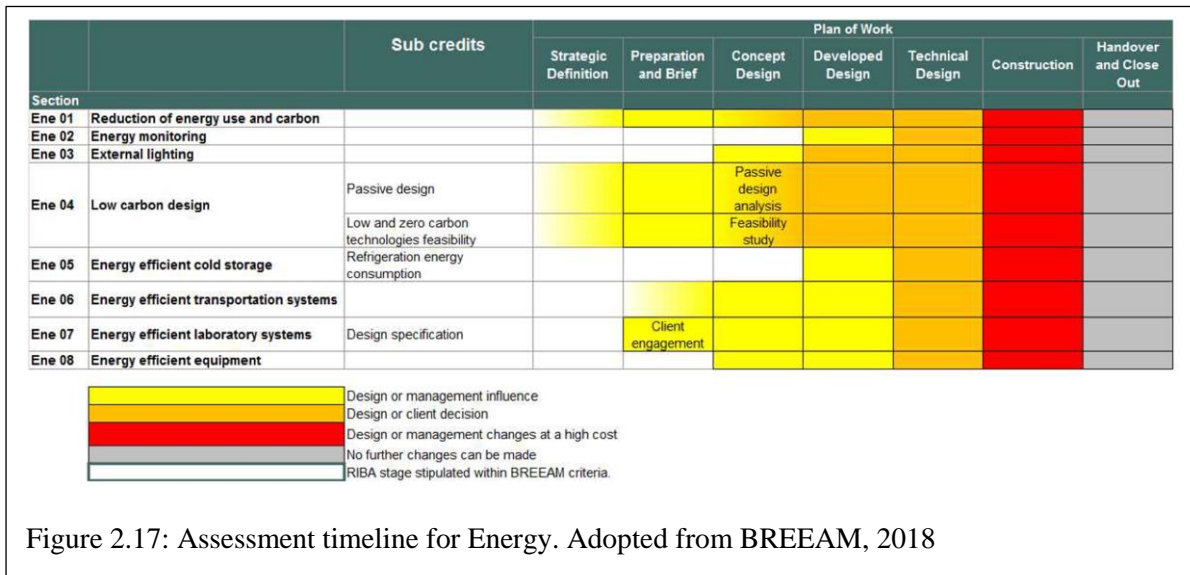
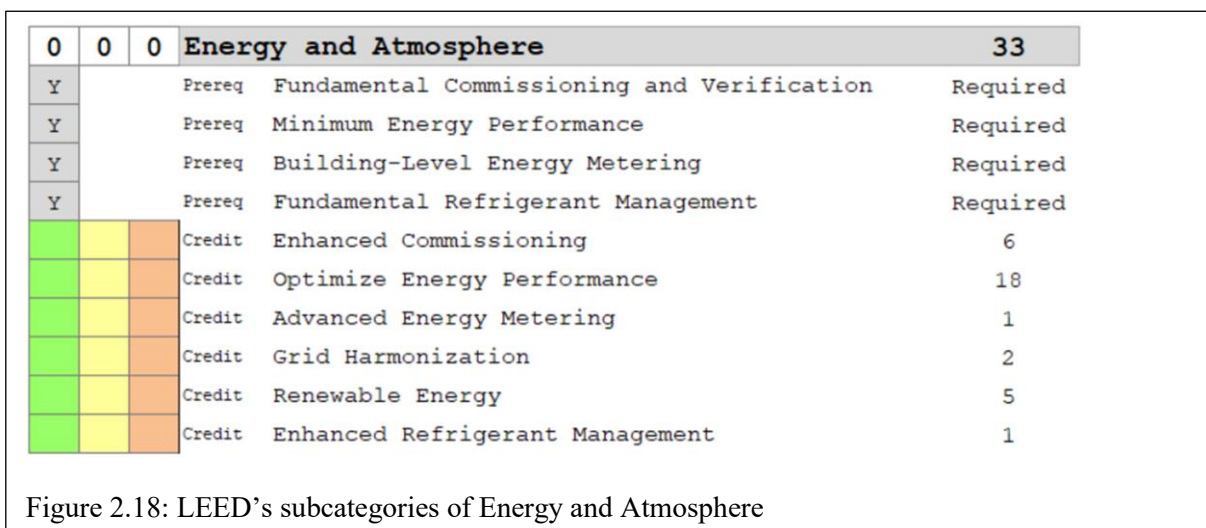


Figure 2.17 shows where each sub category must be considered in which stage of design and construction and by whom. Each of these subcategories has different credits, External Lighting: 1 credit, Low Carbon Design: 3 Credits, Energy Efficient Cold Storage: 2 Credits, Energy Efficient Transportation Systems 3 Credits, Energy Efficient Laboratory Systems: 5 credits, and Energy Efficient Equipment 2 Credits (BREEAM, 2018).

In LEED, there are 10 subcategories under Energy and atmosphere which are presented in Figure 2.18. Four of them are mandatory, while the others have different additional credit levels awarded (LEED, 2019).



Brophy and Lewis, (2011) identified that, for some clients, low initial cost is the most important issue, and such clients may look only to fulfil regulatory requirements, Part L of the UK Building Regulations, for example. They believe that this issue must be considered in

the architects-client contract because it is one of the responsibilities of architects to make sure that all aspects of sustainability are taken into account. Schweber, (2013) noted that, in the UK, some local authorities, through their planning standards, or Health Service Trusts, through their procurement rules, have changed their policy from requiring an assessment to obtaining a particular level of certification from BREEAM. The main purpose of these standards is to reduce the destructive effects of buildings on the environment. Clients would benefit from these standards by measuring, evaluating and reflecting the performance of their project in comparison to the best current practice (BREEAM, 2018). Alternatively, when a client would like to go beyond the regulation to meet the requirements of these standards, this may lead to a greater investment by the client, as more sustainable technology may be required (Dadzie, et al., 2018). As Bird and Hernández, (2012) discussed, there might be the “split incentive” issue for implementing these standards. As the economic benefit of reducing energy consumption is greater for the final consumer, in a project where the customer is not the end-user, there may be less incentive to invest more in order to obtain a certificate for these standards. Even if client is the end-user, usually s/he is interested in short-term return for his/her investment (Dadzie, et al., 2018). It should be noted that recently more attention has been given to buildings which obtained a certificate from one of the Green Building Rating Systems which means such a building may have more demand and consequently can be sold with a higher price to compensate the possible extra costs.

Azhar et al. (2011) claim that a total of 38 points (17 credits and two prerequisites) from LEED (equal to Silver of LEED) could be directly and or indirectly achieved through Autodesk Revit™ and IES Virtual Environment™. These points can be obtained in areas such as sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design process. Barnes and Castro-Lacouture (2009) have claimed that, with the help of Autodesk Revit, one prerequisite and 13 credits are achievable in LEED rating. A study by Wong & Kuan (2014) for achieving points in BEAM standard (Building Environmental Assessment Method) in Hong Kong has been conducted with the help of BIM. The result of this research shows that from maximum of 80 points of this standard, 26 points (Credits) can be supported through BIM and documents which are produced by BIM.

The numbers of research studies that have been conducted especially in order to obtain points from different standards by BIM are small and most of them that have been done are

conducted to obtain points for the LEED standard in the United States. There is a lack of sufficient research on achieving points in certification schemes in UK and Canada through utilising BIM. Azhar et al. (2011) claimed that BIM has a significant potential for interoperability with sustainable strategies to change traditional design practice to a new high-performance design approach. Results of a survey from 145 firms in design and construction industry in US indicate that sustainability analysis based on BIM tools has significant cost and time savings in comparison to the traditional methods (Azhar, 2010 cited in Azhar, Carlton, Olsen, & Ahmad, 2011).

The short list of potential analysis for predicting building performance based on BIM tools could be:

- Water resources, harvesting, runoff;
- Sound mitigation, acoustic;
- Fire evacuation, smoke modelling;
- CO₂ footprint, lifecycle assessment, energy consumption, thermal comfort;
- Ventilation;
- Glare, day-lighting, and electrical lighting.

(Donn, 2014)

Access to a comprehensive set of data about building's context, form, materials and technical systems are essential for analysing building performance in early design. A model that is produced by BIM has "rich" data for its components which gives the ability to analyse building performance (Schlueter and Thessling, 2008).

While different tools of BIM can be used for different performance analyses, this research focuses on the potential of BIM for energy performance analysis which can be conducted easily by architects and other involved designers who do not have deep knowledge regarding building physics.

2.3.7 BIM, BPA and Architectural Design

Enabling people to quantitatively understand how different designs impact on energy performance of a building is one of the main technical challenges for designing a sustainable building (Shen et al., 2012). Based on a survey which NBS conducted, 69% of respondents in UK were aware of and using BIM (NBS, 2019). Still, traditional CAD tools for modelling a building in order to have a sustainable design is popular among the rest of 31%. In the

traditional method, the related data can be extracted from CAD tools and entered into energy simulation tools such as EnergyPlus, IES Virtual Environment, or Ecotect. Thermal loads can be calculated in any of the analyses; the energy performance specialists run the thermodynamic principles which consider any statement to generate annual hourly thermal loads. Also, these simulation engines use different parameters in buildings such as climate response, thermal insulation, solar gain, glazing, shading, natural ventilation, HVAC system, air tightness, and thermal mass. The combination of all this information makes it possible for the software to simulate performance of a building. It is possible to claim that building energy performance analysis needs a large amount of different data related to the design, climate, building loads, environment, etc. which extracting them from traditional CAD-based practices is quite difficult, complex and could be lost easily during transfer to the simulation engines (Motawa & Carter, 2013).

The energy simulator applications can help us to understand the energy performance of buildings by providing a 3D visualisation (thermal, lightening, and acoustic) and performance simulation, beside diagrams and tables with quantitative data. Energy performance of buildings could be predicted by building energy simulation in the process of architectural design (Goldman & Zarzycki, 2014).

Arayici et al., (2012) identify some challenges in the architectural process and complexity in design process such as collecting accurate information at the right time from reliable sources, developing an iterative cycle for testing alternative design, the possibility of correction for better design solutions, and transferring rich data and information in reliable ways. They believed that BIM could help designers to facilitate these challenges in architectural practices' themes specifically in collecting, correcting, and connecting contexts.

BIM has a significant role in design processes because architects and engineers can easily present their intent through BIM. The distance between evaluative design decisions and building energy modelling is decreased through encoding information in parameters using BIM tools. Establishing the parametric relationship within the model depends on the ability of designer to define the volume, shape, and material properties of an internal environmentally conditioned space. In conceptual design the basic building plan, general appearance, orientation, massing, structural organisation, sitting, and programmatic layout are determined. During conceptualisation it is necessary to determine the simulation scope ('what to

simulate') from the buildings' data and how to analyse the results to enhance energy efficiency. The amount of solar radiation, energy consumption, daylight, and orientation of a building are effective threads in building performance which should be defined when assessing the design objectives. As an example, for establishing most efficient site location (whether the goal is to maximise or minimise solar exposure) it is possible to analyse different orientations of a building's primitive form on the site during conceptual design (Hemsath, 2014).

In order to prevent a failure of performance (because of slight changes in weather, use patterns and controls) in comparison to what has been assumed in design stage, the performance analysis should be conducted by considering the following:

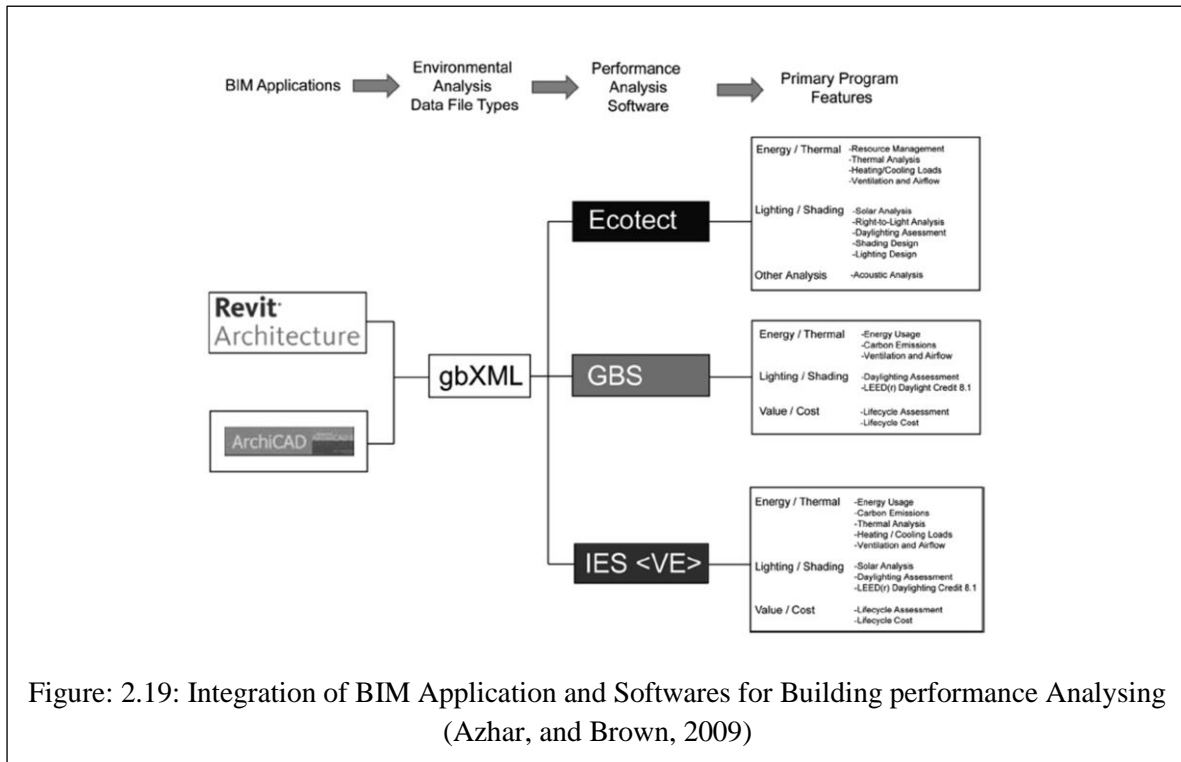
- Giving priority to quality in design rather than just minimum quantity (code);
- Designs must truly be responsive to the clients use plan for the building;
- The different design ideas should be tested to ensure that the final result is robust in different situations.

(Donn, 2014)

The performance simulation results can be influenced by the features in a model such as detail of materials, detail of external geometry, reflectance measurements, size and location of openings, glazing transmittance, room dimensions, fenestration's dimensions and size (Donn, 2014).

Usually, model/s generated by BIM already include information, such as building type, design features, weather files or project location, that they are necessary for performance analysis (Motawa & Carter, 2013). Some BIM tools like Autodesk Revit (versions after 2013) include the option of analysis inside the system (Autodesk Insight 360). These kinds of software could be used for modelling a building and analysing the energy performance of that building, both in the same application.

These utilities allows the designers to be able to compare different design options from a perspective of building performance quickly and choose the ideal one in early stages of project (Cho et al., 2010; Goldman & Zarzycki, 2014).



Parametric design methods allow the designer to control the relationship between objects of a building and discover design options. The model of a building that is generated by using physical parameters (e.g., weather) can make it possible to achieve optimal building performance by comparing design options through parametric simulation (Goldman & Zarzycki, 2014).

2.3.8 Autodesk Revit and BPA in Autodesk Insight 360

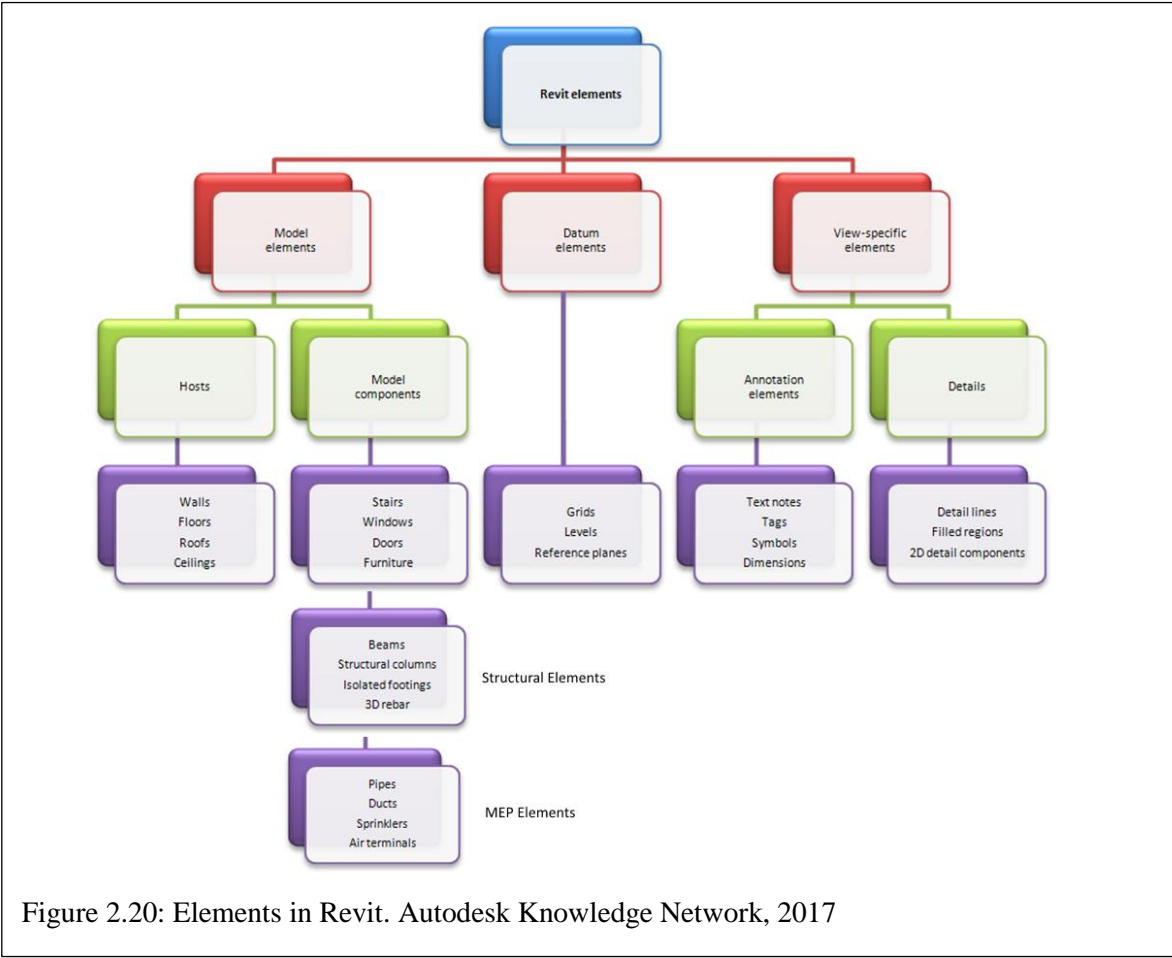
As it discussed in section 2.3.4.4, Revit is one of the most popular BIM's tool. NBS, (2019) researched the use of different BIM tools which shows Autodesk Revit with 46% is the most popular software for drawing.

Revit gathers data about building projects and coordinates this information across all other representations of a project when an operator is working on the building model. On Revit, any schedule, 2D and 3D view, and drawing sheet is a presentation of information from the same virtual building model. The parametric engine coordinates changes that are made anywhere in drawing sheets, model views, plans, sections, and schedules. 3 types of elements (also referred to as families) are used in Revit (Figure 2.20) (Autodesk Knowledge Network, 2017):

Model Elements: shows the actual 3D geometry of a building and its components such as doors, walls, windows, and etc. They are visible in applicable visions of the model.

Datum Elements: grids, levels, and reference planes are examples of datum elements which help to define project context.

View-Specific Elements: they are just visible in the views that they are placed at. Dimension is an example of this kind of elements. View-specific elements help to document or describe the model.



All projects stakeholders can access the shared results which are available in Insight 360. The design process can be approached by architects with an understanding of the elements that potentially leads to better building performance outcomes through integration with Revit and access to guidance from simulation engines and industry benchmarks. Workflows such as lighting analysis, energy cost range, energy plus cloud, and solar analysis are integrated by Insight 360. Capabilities of these tools provide a comprehensive approach to building performance (Egger, 2015).

2.3.9 Conclusion

Building Information Modelling (BIM) is considered as a computer-based strategy for managing data and information of a project. It is a methodology for sharing data and information in a reliable way. The higher BIM maturity, the more important and rich data and information can be extracted and shared. In a mature BIM, project information is modelled in a parametric way. In this way, each component, in addition to having information such as shape and dimensions, will contain its type of material, and its relationship with other components. Properties of elements can be edited and the relationship between components can be defined in the model. For example, the exterior wall is not just a shape. It contains very rich information such as, different layers which it is made from, the properties of each layer (such as R-Values), and also its relation with the other elements and components such as outside climate, door and windows. These rich data which can be extracted from a parametric modelling tool are useful for different analyses and modelling, such as energy modelling and other building performance analysis.

While BIM can facilitate different tasks such as Simulation, Clash Detection, Code Review, Environmental Analysis, etc. during the design process but all these capabilities are not fully exploited by industry. Some of BIM's capabilities which are less used are Building Performance Analysis (BPA) and energy modelling. Designers and engineers can benefit from information like solar study data, which can be extracted from BIM tools such as Naviswork or Revit. Since the model is a parametric model, it can be exported to other tools which are specifically designed for energy analysis. It is possible to conduct an energy analysis inside tools such as Revit. Therefore, architects can see the energy performance of their building in the early stage of design without depending on external expertise. Although performance gaps issues do create some considerations, there is a capability to benchmark different designs. Additionally, architects would be able to see how their changes on design can influence on the energy consumption of a building. While advanced performance analysis is not expected from architects, they are deeply involved in geometrical design of a project which has considerable influence on energy consumption. Therefore, Architects can use the simplified energy analysis with a basic knowledge of building physics to improve the efficiency of the process of design and subsequently the efficiency of a project. Supporting energy modelling being undertaken by architects and bringing performance analysis into the early stages of design requires familiarity with two major pillars which are design for energy

and BIM. Practitioners familiarity with the content of each of these topics such as process of design, requirements for designing energy efficient building, passive design strategy , gathering information about natural elements, buildings' physics, BIM's Capabilities (tasks), BIM tools, and relation between BIM and HEPBs are necessary. This study investigates the current situation in design and construction industry to evaluate conditions for employing BIM for energy analysis in early stage of design. In the next chapter the methodology which is employed for this research is discussed in detail.

Chapter 3.0 Research Methodology

The lack of involvement of architects in the process of building performance analysis is highlighted in the literature.

The aim of this research is to evaluate the conditions of the design process in the UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

BIM promises to provide a simple way to carry out energy performance analysis by designers, where they do not need to have specialized knowledge. Based on the literature, as discussed in the previous chapter, these kinds of tasks which BIM tools can be used for have not been sufficiently considered by design professionals.

This research will try to find the points which need to consider for development in the design process and provide a series of recommendations for architects so that they can improve the efficiency of architectural design process through BIM capabilities in order to conduct non-advanced energy performance analysis. To achieve this aim, this research is designed to investigate the current process of architectural design and, specifically, the methods for addressing energy issues and the position and ability of BIM in this regard. In this research the potential solutions and recommendations from experts for implementing BIM in the process of HEPB's design and methods of increasing building's energy efficiency are explored.

Collis and Hussey (2009) have defined research as: *“A systematic and methodical process of enquiry and investigation with a view to increasing knowledge”* (p.3).

Ghuri and Grønhaug (2005) have referred to research as a systematic means (logical relationship) that people employ in order to gain information and increase their knowledge. Any research should include one or more research questions that must be answered in the research and must be complemented by a set of objectives which the research must address. Generally, a researcher faces an interconnected ‘multi-stage process’ that includes:

1. Determining and formulating a topic;
2. Literature review;
3. Research design;
4. Data gathering;

5. Data analysis and writing up (Ghauri and Grønhaug, 2005).

It should be noted that in any research, the literature review is not a separate stage which starts sometime between research processes and finishes before any other stage. The literature review is an ongoing activity which starts in the beginning of any research study during the development of a research proposal and will continue alongside all activities of the research process. Most of literature review has been conducted at the beginning of research to learn more about the background knowledge regarding the research topic and finding out the gap in the knowledge. Then, as it has been mentioned, the research design will be started which refers to research methodology or the methodological framework. There are a variety of approaches to design and conducting a research. Saunders et al. (2009) compared the structures of research to the structures of an onion with six layers (Figure 3.1).

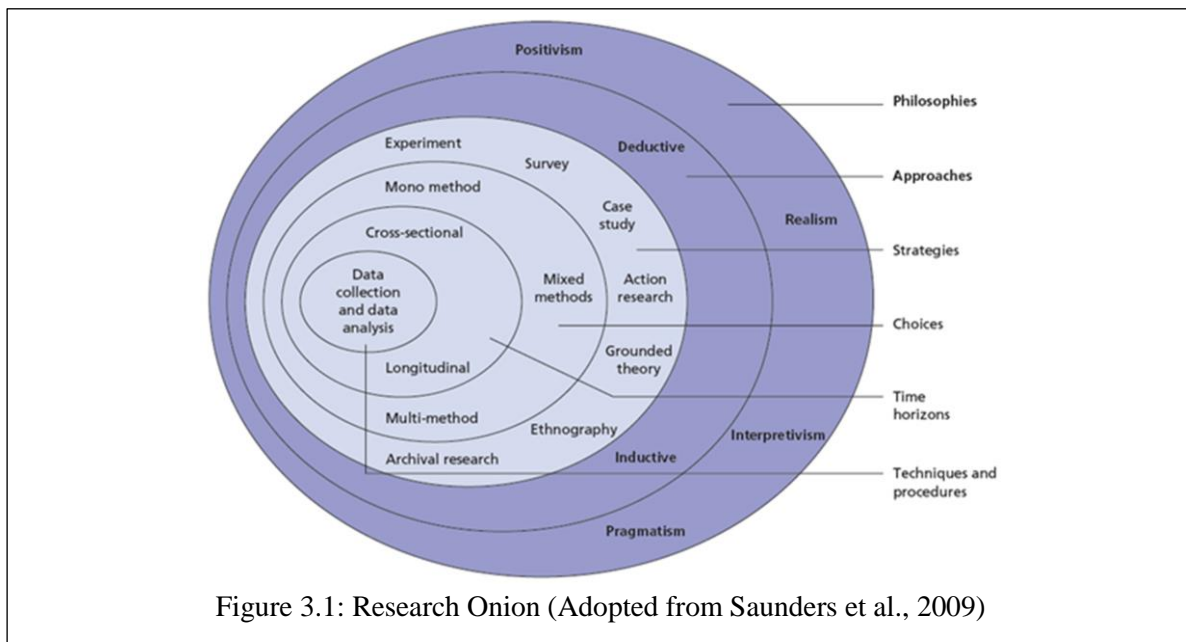


Figure 3.1: Research Onion (Adopted from Saunders et al., 2009)

Any researcher needs to investigate each layer from the outside in to formulate his research design. It will help the researcher to clearly understand his position in terms of philosophical assumptions and approaches then choose the best strategy, methods, and techniques for gathering and analysing data.

3.1 Research Philosophy

Saunders et al. (2009) state that research philosophy demonstrates the relationship between the ‘development of knowledge and the nature of that knowledge’. Each researcher has

important assumptions which make up his/her research philosophy. These assumptions concern the way which researcher views the world.

Philosophical Assumption	What it is about?	Paradigm Continuum	
		←	→
Ontology	What assumptions do researcher makes about the way in which the world works?	Objectivism	Subjectivism
Epistemology	What is acceptable knowledge about the specific area of study?	Positivism	Interpretivism
Axiology	What roles do researcher values play in research choices?	Value-free	Value-biased

Table 3.1: Assumptions and paradigm of research philosophy

Collis and Hussey (2009) explain that there are five philosophical assumptions: ontological, epistemological, axiological, rhetorical, and methodological. However, they state that the first three are interrelated and common assumptions (Table 3.1), while the other two have complementary roles.

3.1.1 Ontology

The ontological assumption refers to a way of looking at the nature of reality. Is it an objective nature or a subjective nature? **Objectivism** considers reality as external to the human and reality imposes itself on an individual. At the other end of the continuum is **subjectivism** which does not consider reality to have an independent status. Subjectivism (constructivism / idealism) proposes that the perceptions of social actors create social phenomena (Burrell and Morgan, 1979; Saunders et al., 2009). As an example if the “role of management in an organisation” is the title of a research and researcher has an objectivist view then researcher may say that all managers must follow their job descriptions which describe their duties, and then they are a part of a formal structure management which is similar to in all organisations. But the researcher may have subjectivist view if he believes that the objective aspects of management are less important than the way in which the managers make a connection between their own individual meanings to their jobs and the way that those jobs should be performed by them (Saunders et al., 2009).

3.1.2 Epistemology

The epistemological assumption relates to what the researcher accepts as valid knowledge. This involves an investigation of the relationship between the researcher and what is researched. Positivism and Interpretivism represent the two extremes within epistemological approaches. **Positivists** believe that knowledge is only those phenomena which are validated through measuring, observing and positive verification (Collis and Hussey, 2009). Quantitative methods are usually used in this approach. On the other hand, **interpretivists** believe that there is no separation between people themselves and what they know (Coates 2013). The interpretivists state that beliefs decide what should be considered as facts (Smith, 1983, cited in Collis and Hussey, 2009). Interpretivism claims that the world can only be understood through the points of views of people who are directly involved in the actions which are to be studied (Burrell and Morgan, 1979).

Rogers (2006) counts three key tenets for the constructivist researcher and paradigm:

- 1- Knowledge is not what is discovered, but is rather constructed;
- 2- A variety of different knowledge is constructed by people;
- 3- The person who creates knowledge then gains power.

3.1.3 Axiology

Saunders et al. (2009) argue that axiology studies judgments about values of researcher opinion. The researcher's values have a significant impact on the credibility of the research results. An interesting idea which comes from discussion of axiology provides the possibility to the researcher of writing his/her own statement of personal values regarding the research topic

The parties who the researcher has contacted with also have the ability to use this statement of values. If these values have a very significant role in interpreting results, then the research is located in the **value-biased** part of the axiological continuum. However, if the researcher is independent of the data, then the research is conducted in a **value-free** manner. Table 3.2 demonstrates a summary of these three assumptions paradigms.

There are other assumptions between main assumption in Ontology (objectivism _ subjectivism), Epistemology (Positivism _ Interpretivism), and Axiology (Value-free _ Value-laden) which are presented in Table 3.2.

Objectivism ←	Ontological Assumption				Subjectivism →
Reality as a concrete structure	Reality as a concrete process	Reality as a contextual field of information	Reality as a realm of symbolic discourse	Reality as a social construction	Reality as a projection of human imagination
Positivism ←	Epistemological Assumption				Interpretivism →
To construct a positivist science	To study systems, process, change	To map contexts	To understand patterns of symbolic discourse	To understand how social reality is constructed	To obtain phenomenological insight, revelation
Value-Free ←	Axiological Assumption				Value-Laden →
Man as a responder	Man as an adaptor	Man as an information processor	Man as an actor, symbol user	Man as social contractor, the symbol creator	As pure spirit, consciousness, being
Table 3.2: Research assumptions and paradigms (adopted from Morgan and Smircich, 1980; Saunders et al., 2009)					

Saunders et al., (2009), pointed out that pragmatist would be a suitable position for researcher who thinks that in practice it is not realistic to choose just one of the extreme positions. Pragmatism argues that the research questions determine the epistemology, ontology, and axiology of the research. They state that if it is not possible to clearly understand the adopted position in the research questions therefore pragmatism may be used to address variation in research ontology, epistemology, and axiology and make it possible to engage with both qualitative and quantitative methods (mixed methods) within one study.

3.1.4 Justification for Research Philosophy

The aim of this research is to evaluate the conditions of the design process in the UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

BIM and HEPBs' design are considered as two subjects that the research aims to investigate their current relation and potential ways to develop the relation between them. Therefore, this research is divided into two parts. The first part deals with the architectural design process, with a focus on energy efficiency, and the second part with BIM, specifically the energy performance analysis tools available within BIM for conducting BPA. In the first part, efforts have been made to investigate: the process of architectural design with its shortcomings and potential solutions for improvement, the methods for increasing building performance in energy consumption with the available tools and their pros and cons. In the beginning of the second part the current position and usage of BIM in the design and construction industry is investigated. Then the relation between BIM and energy performance analysis is determined and BIM capability for conducting non-advanced energy modelling is investigated. Prior to these steps, the researcher is independent from the data and he just trying to investigate the current scenario in each of the subjects. During this study, the researcher is making efforts to recognise the relation between BIM and high energy performance architectural design through practising with relevant software, literature and survey. This has helped to understand and make the foundation for the remaining investigation to see how BIM can facilitate design of HEPBs. Therefore, the second step of investigation in each part includes some beliefs and views of researcher to the knowledge and phenomena. Effort has been made to avoid any bias and prevent dictating those views by careful research design for the data collection in this research (see Section 3.6). Also, efforts has been made to test the existing theories regarding the ability of BIM to obtain green building indicators specially HEPBs based on literature and result of questionnaire, so phenomena will be observed and measured to provide credible data. Table 3.3 demonstrates the considered assumptions for this research.

Assumptions:	Ontology:	Epistemology:	Axiology:
Considered in this research:	Nature of reality is objective. Exists independently of human thoughts and beliefs or knowledge of their existence (realism), but is interpreted through social conditioning (critical realism)	Observable phenomena provide credible data and facts. Insufficient data means inaccuracies in sensations (direct realism). Alternatively, phenomena create sensations which are open to misinterpretation (critical realism). Focus on explaining within a context/s	Research is not undertaken completely in a value-free way; the researcher is biased by world views, cultural experiences and upbringing. These will impact on the research

Table 3.3: Considered assumptions for this research (adopted from Saunders, et al., 2009)

To achieve the aim of this research, understanding the potential of using BIM for designing a high energy performance building is required. The research is not just looking at a single topic (BIM or HEPBs design). Based on the knowledge, experience and familiarity, different practitioners and firms may have different views and opinions on each topic and the relation between BIM and HEPBs design process. They may follow their own procedures or other standards for their work practices. Therefore, when designing an energy efficient building, different information, data and knowledge and processes could be used in different firms based on varying project requirements, location, owner needs, regulation, etc. It may be possible to see this research with an interpretivists’ perspective, because the opinions of people are sought. On the other hand the capability of BIM tools for conducting energy modelling might be seen as a concrete process or structure which shows the objectivism-positivism aspect of the research. Even if we accept the definition of energy efficient building and BIM ability and capability as solid topics, they are defined and invented by humans and may have different meaning for different people. As an example in chapter 2, Table 2.8 presents different definition of BIM which are coming from different views of person who defined it. Based on the research question, aim, and objectives, pragmatism is sought as a suitable approach for this research and in the design of questionnaire. It helps to use specific assumptions for particular questions in the survey.

3.2 Research Approach

After determining the philosophical assumptions of the research, next step is the determination of the research approach as the second layer of research onion. As Saunders et al., (2015) highlights, use of theory is a part of starting any research which may or may not be made clear in the design of the research. The researcher's awareness about the theory at the beginning of the research indicates which research approaches, deductive (theory testing), inductive (theory building), or abductive (modifying an existing theory) must be employed. Therefore, three main approaches are reviewed to find the suitable one for this research.

3.2.1 Deductive: Testing Theory

Yin (2003), states that in deductive research existing knowledge (theory) is investigated. 'Deduction is theory-driven' and preconception is the basis of the deductive approach (Rogers, 2006, p.83). In this approach, existing theoretical structures and pre-developed concepts are tested through empirical observation by the researcher. Based on the existing theories, the researcher generates one or more hypotheses and then tests the result through conducting data collection and analysis. The objectivist and positivist paradigms can include the deductive research approach (Losee, 1993).

3.2.2 Inductive: Building Theory

Rogers (2006) states "*induction is a process of drawing inferences from observations in order to make generalisations*" (p.82). In an inductive approach, there are no preconceptions about data collection and analysis. Objective data are gathered by the researcher to produce knowledge in order to establish regularities. The researcher's mind is clear from any prejudices in order to obtain the objective nature of facts. It is possible to generate hypotheses through induction but this approach cannot test them, therefore the deductive approach is mandatory for testing. The four main steps that form the inductive approach are observation, analysis, inference, and confirmation.

3.2.3 Abductive

Saunders et al., (2015) stated that, instead of moving from data to theory (induction) or theory to data (abduction) combining both and moving back and forth in an abduction approach.

This approach starts with the discovering of a fact and then investigates for an acceptable theory to explain how this could happen. In an abduction approach the researcher collecting the data to explore a phenomenon, explain patterns, and identify themes to create a new or modify an existing theory which will be tested through additional data collection (Saunders et al., 2015).

3.2.4 Justifying this Research Approach

Saunders et al. (2009) believe that for inductive approach, small sample of subjects is more suitable while in deductive approach, a large number seems more appropriate. They suggest that if the researcher is looking to understand “what is happening” rather than “why something is happening”, it may be more proper to undertake research deductively rather than inductively. Also, they believe that based on their experience, deductive approach can be quicker.

Deduction Approach	Induction Approach	Abductive Approach
<p>Moving from theory to data.</p> <p>Scientific principles</p> <p>When explain about common relations between variables is required.</p> <p>The application of controls to ensure validity of data.</p> <p>The collection of quantitative data.</p> <p>The operationalization of concepts to ensure precision of definition.</p> <p>Researcher independence of what is being researched.</p> <p>A highly structured tactic.</p> <p>The requirement to select samples of plenty size in order to generalise conclusion.</p>	<p>A close understanding of the research context.</p> <p>Obtaining an understanding of the meaning humans attribute to events.</p> <p>A more flexible arrangement to allow changes of research emphasis as the research developments.</p> <p>The collection of qualitative data.</p> <p>Less concern with the need to generalise.</p> <p>Researcher is part of the research progression.</p>	<p>Modifying of generating new theory based on an existing theory.</p> <p>Testable conclusions are generated based on known premises.</p> <p>Interactions between the general and specific are used for generalising.</p>

Table 3.4: Major differences between inductive and deductive approaches (adopted from Saunders, et al., 2009)

There are many theories which describe the ability of BIM to facilitate sustainable building design. However, it is not clear, what the relation between BIM and HEPBs actually is? What is the current process in the design and construction industry regarding design of high energy performance buildings (HEPB) and where the BIM position is in this regard? This research is looking at how BIM can increase the efficiency of the design process by increasing awareness of architects about BIM ability for conducting non-advanced energy analysis which means that architects are able to see the real time impact of their changes to the design on the energy consumption of a building. The structure of this research is based on the existing theory regarding BIM's abilities for designing energy efficient buildings without having deep knowledge regarding building science. These will be investigated through finding the current process and awareness about energy efficient buildings design, position of BIM in design and construction industry and looking for its potential for facilitating energy efficient building design. Therefore, this research takes an abductive approach.

3.3 Research Strategies

As Robson, (2002) pointed out, choosing the research strategies is the first step of turning a research question into a research project. Saunders et al., (2015) discussed that, while the way a researcher selects and approach to answer their research question, which is influenced by research philosophy and approach, the research question determines the choice of research strategy, data collection techniques, and analysis process. Therefore, after revealing the philosophical assumption and approaches of the research it is time to take a look at the third layer of research onion and determine the research strategies. There are different kinds of strategies that the researcher can choose to apply. The most important of these strategies are introduced below.

3.3.1 Experimental

Robson (2011) stated that the experimental strategy is designed to study the relationship between variables. In this strategy, the independent variable is manipulated purposely to observe its effect on the dependent variable. Experiments tend to be used in explanatory and exploratory research to answer 'how' and 'why' questions (Saunders et al., 2009).

3.3.2 Surveys

Surveys are a popular strategy in research and studies about business and management. They are commonly aligned with the deductive approach. Researchers use the survey strategy to

answer questions such as what, where, who, how much, and how many. This strategy brings exploratory and descriptive tactics to research. Through this strategy the researcher may be able to collect a large amount of data from a large population in an economical way (Saunders et al., 2009). The survey strategy allows researchers to collect primary or secondary data from a sample which is a subset of a population. The researcher can then analyse the data obtained statistically in order to generalise the outcomes to the whole population (Robson, 2011).

3.3.3 Case Studies

In a case study, the case could be the situation, group, organisation, individuals, or whatever it is that researchers are interested in (Robson, 2011). He has defined case studies in this way:

Case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence. (Robson, 2002, p. 178)

There are some characteristics of this strategy. The case study is seen as an approach or stance rather than a method. In this strategy specific cases are studied, from which it may be possible to generalise the results. Usually, when the relationship between context and phenomenon is not clear, a case study focuses on exploring this. Usually case studies are considered as qualitative. However, there are some views that case studies can be used with both qualitative and quantitative data collection methods (Robson, 2011).

3.3.4 Action Research

The philosophical assumption associated with action research considers the research and researcher as parts of the social world, which is constantly changing. It is used in applied research to discover an effective system of bringing about conscious change in a partially controlled situation. The main goal of action research is to enter a particular environment, and to then make efforts to manipulate and change regulation in that environment to discover the results (Collis and Hussey, 2009).

3.3.5 Grounded Theory

Robson (2011) states that generating a theory that is related to a specific situation is the function of the grounded theory strategy. During the study, especially regarding processes relating to the people involved, actions, and interactions, the theory is 'grounded'. Grounded

theory can be seen as both a strategy for conducting research and a specific style of analysing that the resulting research data. Robson (2011) discusses the existence of many claims that this strategy offers the best coordination for qualitative research, but there is no reason that quantitative methods cannot be used with this strategy. Some characteristics of this strategy are mentioned below:

- It provides clear progress for generating theory in research;
- It offers the possibility of flexible research but in a systematic and coordinated way;
- It provides specific processes for analysing qualitative data;
- It is useful in applied areas of research, especially when the selected theoretical approach is not clear;
- Some versions notices that some theoretical ideas and assumptions should exist before starting the research;
- Original (as problems in using grounded theory): It is not possible to start a research without some pre-existing theoretical ideas and assumptions (as assumed in some versions of grounded theory research)
- The systematic approach of grounded theory has problems with the inductive style of flexible study;
- It may be difficult to decide on the saturation times for categories or on when the theory is appropriately developed (Robson, 2011).

3.3.6 Ethnography

Ethnography consists of ‘ethno’ + ‘graphy’ which mean descriptions of people. The researcher is involved with people, their society and their customs, and uses socially obtained and shared knowledge to realise the ‘observed patterns’ of people’s activity. Participant observation is the main method of data collection, through which the researcher becomes completely involved by becoming a full member of the group being studied. Since this needs a long period of time for observation and collection of data, it is therefore not a suitable method for a researcher who is faced with limitations in time (Collis and Hussey, 2009).

3.3.7 Archival Research

Texts which are accessible in printed and/or database form are the most common documents for archival research (Flick, 2009). Literature includes books, newspapers, magazines, and other written resources, which are the most well-known written documents. Other documents

such as television programmes, films, photographs, and so on are considered as non-written resources for archival research (Robson, 2011).

Archival resources should be considered as a means of communication. When this strategy is used, the researcher should think about the answers to three questions. First, who has prepared these resources? Second, what was the aim of gathering these documents? And third, for whom were these resources prepared (Flick, 2009).

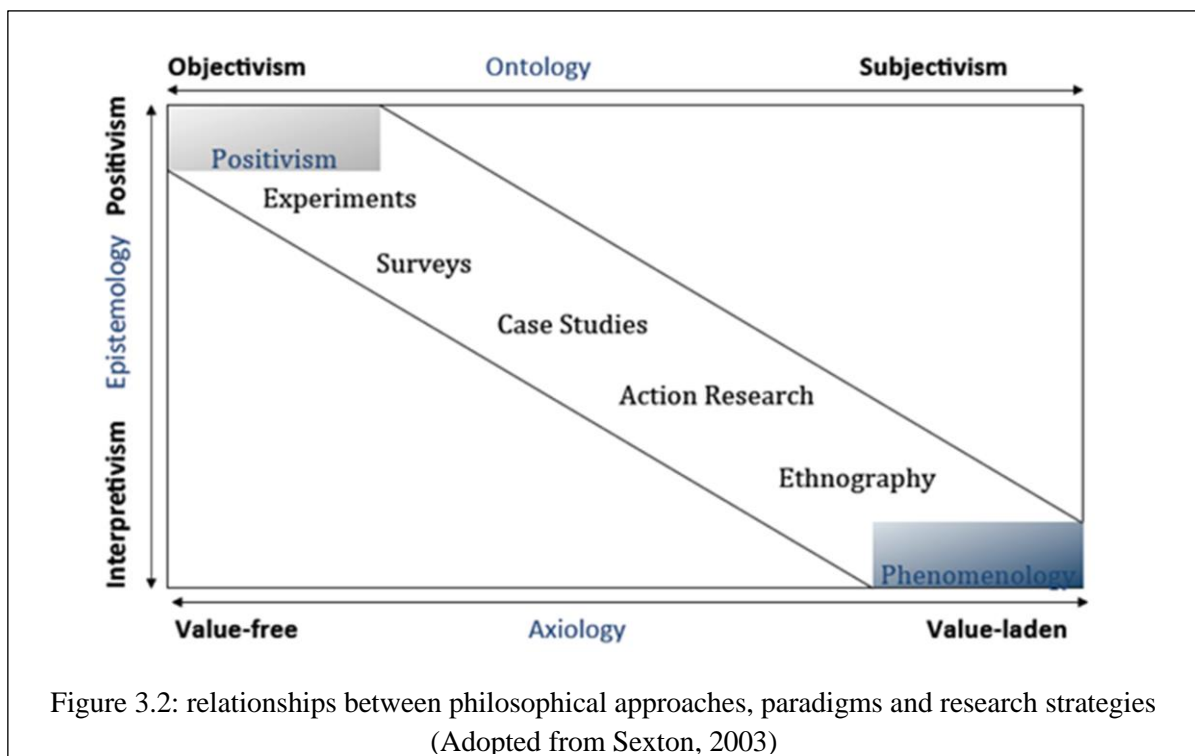


Figure 3.2 demonstrates the relationships between philosophical approaches, paradigms and research strategies. Since one of this research’s focus is to improve the process of energy efficient building design through involving architects in the process of energy modelling with BIM potential capabilities, this research addresses questions such as:

What is the current process of HEPBs design? What are the shortcomings? How much awareness is there about BIM and process of HEPBs design amongst architects? Who is responsible for different tasks? And other questions which are used in the questionnaire. Based on these descriptions, it sought that the best matched strategy for this research is survey which is good to answer questions such as what? Who? Where? How many? How much?

As figure 3.2 shows, the experimental strategy is located in the traditions of positivism, value-free, and objectivism continuums and survey strategy which is chosen for this research tends to these points. Ethnographic strategies are located on the other side of continuums and after that action research strategy tends to value-laden, subjectivism, and interpretivists elements.

3.4 Research Choices, Methods

Qualitative and quantitative methods are the most popular methods used for research. While quantitative methods deal with digits and numbers, qualitative methods deal with interpretation of words and phrases. Saunders et al. (2009) stated that any data collection method such as questionnaires and the related analysis procedures like chart, graphs or statistics, which provide numerical data, are used as a synonym of quantitative data collection techniques and analysis. On the other hand, the techniques like observation, interviews and data analysis that are used for producing non-numerical data which are usually produced by the qualitative techniques.

Gubrium and Holstein (1997) have likened qualitative research to learning a language. This method involves a series of techniques that use various terms to define the world. Denzin and Lincoln (2003) have described qualitative research as a substitute action through which observation is brought to the world. According to this view, the world is established and transformed through a series of interpretive material practices. These materials could include records, field notes, photographs, conversations, and interviews. The researcher employs data which are based on personal experience, life stories, interviews, observation, experimental material, visual material, documents, cultural products, history, and which describe the usual moments or problems of someone's life.

Empirical studies or statistical studies are two common designs for a quantitative research which are traditionally used to conduct behavioural and psychological science investigations. Pre-test, post-test design, experimental studies, and quasi-experimental studies are samples of quantitative designs studies where randomisation, variable control, and measures of validity and reliability are required for generalising the result from a sample to the population (Newman and Benz, 1998).

Both the quantitative and qualitative data collection and analysis have their own weaknesses and strengths. Recently, attention has been given to the mixed method approach which both

qualitative and quantitative methods of data collection and analysis are employed (Smith, 1981 cited in Saunders et al., 2009).

Saunders et al., (2009) discussed about the variety of research choices and their difference regarding data collection techniques and analysis:

- 1- **Mono Method:** Just single data collection technique and analysis which can be qualitative or quantitative would be employed in this method
- 2- **Multiple Methods:** In this method, more than one data collection and techniques would be used for data collection and analysis. The technique can be just qualitative or quantitative and researcher cannot mix both together.
- 3- **Mixed Methods:** Both Qualitative and Quantitative data collection and analysis are used in this method. There are two subdivided approaches in this methods:
 - **Mixed-method research:** qualitative and quantitative data collection and analysis progresses are employed as techniques one after the other (sequential) or at the same time (parallel). In this approach the qualitative gathered data will be analysed qualitatively and quantitative data obtained will be analysed quantitatively
 - **Multi-method research:** qualitative and quantitative data collection techniques are combined together as well analysis procedure. *This means that researcher may take quantitative data and **qualitise** it, that is, convert it into narrative that can be analysed qualitatively. Alternatively, researcher may **quantitise** his qualitative data, converting it into to numerical codes so that it can be analysed statistically.*

Saunders et al., (2009), pp. 152,153

By implementing the mixed-method in an appropriate way it is possible to overcome some weaknesses of each technique by the strengths of the other one. Bryman (2006) mentioned some advantages of the mixed methods such as:

- **Triangulation:** Employing more than one data collection technique and analysis traditionally are considered to corroborate research results.
- **Offset:** combining qualitative and quantitative techniques is a useful strategy to offset any possible weakness of each to draw on the strengths of both.

- Completeness: a more comprehensive account of the area of research can be gathered by researcher with different aspects of an investigation.
- Process: while quantitative technique supplies structures in social life, the sense of process is provided by qualitative research.
- Explanation: combination of qualitative and quantitative research is useful for explaining and understanding the generated data by the other.
- Instrument development: developing questionnaire and measure items by a qualitative research.
- Credibility: The accuracy of findings can be improved by employing two techniques.
- Context: when there is unrecognisable relationship between variables in a survey (quantitative approach), the qualitative research may provide contextual understanding.
- Confirm and discover: the capability to generate hypothesis by qualitative techniques and test them by a quantitative research in a single study.
- Diversity of views: discovering the relationships between variables by quantitative research while the qualitative research is explaining the meanings among research participants.

In this research the mixed method is considered but emphasises is given to the quantitative aspect. Both qualitative and quantitative data collection techniques are employed in a questionnaire which has 3 different classes of questions. The questions which are completely closed are designed for quantitative analysis. Two kinds of open question (completely open answer question and semi closed question which has predefined answers and a space for other replies) are considered as complementary. These approaches are mainly located in qualitative techniques.

3.5 Research (Data Collection) Techniques

After a researcher has outlined their plan of the research and selected method or methods of research, then appropriate research techniques which are matched to their research design and strategies must be chosen. Observation, interviews, and questionnaires are the three of the most common data collection techniques which each of them have their own characters, advantages, and disadvantages. These techniques are introduced and discussed further below:

3.5.1 Observation

Observation can be conducted in two different areas. It can be conducted for activities in a completely natural environment, or in a controlled area such as a laboratory, where controlled experiments could be conducted in order to achieve results (Angrosino and Perez, 2003). Flick (2009) has considered observation as a major method for obtaining first-hand data for qualitative research. It allows the researcher to investigate how real events happen and/or function. He believes that sometimes a researcher needs to use all of his/her senses, including sight, touch, smell, taste, and hearing, in the observation field. Hughes (2002) claimed that, for any social study through observation, the researcher must be completely in personal contact with a social group in order to investigate actions of the group members.

3.5.2 Interviews

The interview is one of the most powerful methods for understanding people's feelings (Fontana and Frey, 2003). They believe that asking questions and obtaining answers is more difficult than it seems. Dingwall (1997) suggests that researcher must make interview enough attractive to encourage sample for responding. The researcher must recommend topics to the interviewee and search for the most appropriate responses. Saunders et al., (2009) counted three common main categories of interview, which are the structured interview, the semi-structured interview, and the unstructured interview.

- **Structured interviews:** In the structured interview a series of predetermined and standardised questions is used. The researcher reads the questions and then records the answers in a standardised schedule, which usually has pre-coded answers. The researcher should read questions as they are written, without any change in tone and voice. The structured interview is a tool for collecting quantifiable data and is therefore aligned with quantitative research methods
- **Semi-structured interviews:** Different questions and themes are compiled into a list which can vary from interview to interview. The researcher may omit some of the questions in specific interviews, depending on the specific organisational framework that is faced in relation to the research topic. Sometimes the researcher may need to add more questions in order to explore the research question and objectives. Audio-recording and perhaps note taking are necessary for recording the data
- **Unstructured interviews:** This is an informal method. The researcher uses unstructured interviews to understand in depth about the broad context in which

researcher is interested. They lack any predetermined list of questions, but the researcher should have clear ideas about the topic or topics that he wants to explore. The interviewee can freely talk about beliefs, behaviour, and events in relation to the area being studied. In this method, the interviewee's perceptions guide the conduct of the interview. Therefore, these interviews have two characteristics; they are 1- in depth and 2- non-directive.

(Saunders et al., 2009)

3.5.3 Questionnaires

Saunders et al. (2009) believe that the questionnaire is a general term which includes all data collection techniques for obtaining individual answers through predetermined questions. Questionnaires can include telephone questionnaires, structured interviews, and online questionnaires. In the survey strategy, the questionnaire is the most widely used data collection technique and it tends to be used in descriptive research. It allows the researcher to obtain responses from a large sample through asking the same set of questions to respondents in an efficient way.

Kothari (2004) counted several benefits for a questionnaire as a technique for data collection:

- It allows the researcher to be able to achieve large responses in broad geographical areas with low cost;
- Interviewer bias does not have any effect during data collection;
- There is enough time for the respondent to think and answer the questions;
- has better chance to reach respondents who are not easily approachable;
- Can expect more reliable and dependable results because of possibility to make a large sample from universe.

On the other hand, there are some considerations regarding this technique such as low rate of response, can just be used when respondents are educated, possibility of ambiguous or omission in replies, low control after dispatching the questionnaire, and it is more time-consuming in comparison with other techniques.

3.5.3.1 Question Sequence

Kothari (2004) introduces some points which can help to keep the questionnaire moving smoothly and clear:

- Easier questions must be at the beginning and followed by more advanced questions
- For increasing respondent's motivation and cooperation, the first questions have vital roles.
- Questions should not be hard to challenge the respondent mind, or looking for their very personal character and wealth.
- Each question should clearly present its relation to the previous and next question.

In this research these points are considered carefully in order to design the questionnaire as a technique of data collection. In the next section, the reasons for choosing questionnaire as research technique for this study are discussed.

3.6 Justifying the Research Techniques for Data Collection

In this section, the characteristics of questionnaire and its suitability for doing this research are discussed. How to design an appropriate questionnaire and the process of designing questionnaire for this study are addressed in this section.

3.6.1 Questionnaire Design

When producing and realising attitudinal and realistic information, the questionnaire has been suggested as an appropriate technique by Ackroyd and Hughes (1992). Since, in this research the first goal is to investigate the current situation and process of high energy performance buildings therefore questionnaire has been chosen as the best data collection technique for this research. For covering other objectives of the research, combination of exploratory and descriptive survey questionnaires was thought as the best option for collecting primary data.

The descriptive survey aims to answer questions such as, *how many? who? what is happening, where? and when?* (Naoum, 1998). An exploratory study is valuable for finding out '*what is happening; to seek new insights; to ask questions and to assess phenomena in a new light*' (Robson, 2002:59).

The questionnaire used in this study is designed based on two main questions of: what? and why? The first one is looking to find the current scenario and potential solutions while the second one exploring for reasons. For this research the close ended questions are designed for descriptive study to recognise the current situation. They have been used to find the answers of questions such as:

- What is the current process in design space between architects and design firms and companies evaluating high energy performance buildings' design?
- What is the level of awareness in the sample with regards to, sustainability indicators and their importance? Related standards? Related knowledge? Building performance analysis? and Building information modelling?
- What is the position of BIM in the process of energy efficient buildings design?
- Who is involved in the process of analysing building energy performance?
- When is the energy performance analysis in the design process considered?

The open ended questions are designed for the exploratory elements of the study and they are considered to achieve broader and additional insight about the matters which they have been investigated by descriptive questions. As Saunders et al. (2009) mentioned the exploratory study is useful for clarifying and understanding the problems. In this study they are used to answer of questions such as:

- What are the barriers?
- What is the relation between BIM and HEPBs?
- What are the most usages of BIM tools?
- What are the appropriate solutions?

Except demographic section with 5 questions, the questionnaire has two main parts. The first part deals with sustainability, its criteria and standards, and HEPBs indicators and index with 15 questions. The second part attends to the BIM and its tools with 10 questions. In each part the exploratory study will be used for critical evaluation to achieved information regarding:

1. the existing problems for architectures to bring performance analysis in early design stage;
2. Ability and potential of BIM and its tools for conducting different tasks and specifically regarding to BPA.

Open ended questions provide more room for the respondent to cover, expand and support their opinion by their own words. Because the investigation on current process and situation in design and construction industry is one of the research targets, it was thought that the open ended questions can help much in this regard.

“For instance, multiple-choice questions constitute the basis of a structured questionnaire, particularly in a mail survey. But even there, various open-ended questions are generally inserted to provide a more complete picture of the respondent’s feelings and attitudes.” Kothari (2004, p.103)

3.7 Questionnaire Structure and Process for This Study

In this research, except demographic part, the questionnaire is designed in a way to have two parts which each part deals with specific topic. The first one is divided into two sections, the section one of part one deals with “Sustainable Design Tools”, while the second section of part one contains the questions regarding “Designing for Energy Efficiency” and the second (last) part contains is about “BIM and Tools for Sustainable Design”. In the each parts, the general and easy questions are included which are followed by more specific and complex questions. All questions in each part stand in a category which each question has a clear relation with the previous one and the respondent can easily recognise the narrowing and relationships between the questions in each part. All questions are structured, definite, concrete and pre-determined. Each part starts with close ended questions which are very easy to answer and respondents can easily choose one of the pre-determined answers. After them, the second group of questions are semi- closed questions which provide the alternative way of response. In these questions respondents can choose one or more (in some questions) pre-defined answers or just state their own ideas in the provided space. At the end of each part respondents are invited to provide their own words without any limitations. There is hope that with this structure for the questionnaire, the researcher can achieve considerable information even if some hard questions will not be answered and if they have been answered then more comprehensive results will be obtained. In the whole data collection, effort has been made to avoid any irrelevant or personal questions.

3.7.1 Pilot Study

For this research the pilot study has been done through sending the questionnaire to friends and colleagues who are involved in design and construction industry. They are asked to present their opinion about:

- Length of questionnaire
- Clarity of questions and answers
- and appropriation of structure of questionnaire

The results from the pilot study demonstrate that the questionnaire was clear enough and has an appropriate structure. The most mentioned matters were about the length of the questionnaire which the respondents believed that it is a long questionnaire. Also, respondents claimed that answering most of the questions needs special knowledge regarding BIM and HEPBs which means that it is suitable for professional practitioners.

3.7.2 Sampling

When the population is large, therefore, it is not logical and affordable to collect data from all of cases. Even if it would be possible to collect data through census but it doesn't necessarily mean that it provides more useful results in comparison with collected data from a sample which is a good representative of entire cases. Population is a full set of cases which the sample is taken from them. If survey on entire population is impracticable for the researcher and s/he has limitation in time and budget for surveying all cases then he must consider to make a good sample for his study (Saunders et al., 2009).

There are two kinds of sample designs, which are the non-probability sampling and probability sampling. In the non-probability sampling the particular units of population have been chosen purposively. In this kind of sampling design the researcher chooses the sample based on some reasons and his/her personal element can have effect on sample design. Therefore, in this kind of sampling design researchers must always be aware of bias. Probability sampling which is known as random sampling provides equal chance to each member of the universe for selecting and participating. The sample can have the same characteristics and composition of population if on average the sample chosen is a random one. For this reason, the best method of choosing a representative sample is the random sampling (Kothari, 2004).

Some of the popular complex random sampling designs are: Systematic Sampling, Stratified Sampling, Cluster Sampling, Area Sampling, Sequential sampling and Multistage Sampling. In this research the combination of systematic sampling and cluster sampling in geographical areas are employed and developed.

Practitioners who are involved in architectural design are the main target for data collection regarding investigating the current situation and position of high energy performance building design. Beside of this investigation, the research is looking to find out the potential solutions

for bringing building performance analysis to the early stages of design. Therefore, practitioners who are involved in building performance analysis and building information modelling are the other important people for recruiting. In this study the population include all experienced architects, building performance assessors and BIM specialists. They are usually working in architectural firms or medium and large construction companies.

While there is an expectation that all stakeholders in design and construction industry can benefit from the result of the research, the main target are architectural designers. The research intends to help architects who are detached from energy performance analysis. Even by considering a specific country such as UK or Canada, there are still a considerable number of architects. While it is not possible to approach all of them for data collection, the questionnaire can help to obtain appropriate results by making a good sample which consists of competent practitioner. Consequently, the sample expects to be a good representative of population.

In this research the universal set is all architects, designers, and engineers who are involved in architectural design and building performance analysis. The population refers to who are specifically involved in architectural design and building performance analysis and BIM. To make a good sample from UK, the registered architectural companies which their information is available from RIBA are considered. For Canada where the researcher is living, Royal Architectural Institute of Canada (RAIC) is the database used.

There is no definite answer for the required sample size (Kelly et al., 2003). While more responses promising more accurate and reliable results but, since this research study needs more specific knowledge and experience about HEPBs' design and BIM therefore it effects on sampling size and response rates. It is expected that not all architects or firms be aware about BPA and BIM. Saunders et al. (2009) suggested that 30% is the likely response rate which can be expected for conducting survey by Email. There are other risks such as sampling errors which can be reduced by increasing the number of samples. 25% response rate is considered for acceptance from practitioners to participate in the survey therefore a total of 400 invitations will be send to both UK and Canada chosen samples. A very similar research regarding "sustainable practices in residential projects" is conducted by Kristen Hlad in 2009 in Florida US. She distributed 150 Questionnaire to the companies and firms and received 16 responses in total (Hlad, 2009).

The list of the largest construction companies in the UK is obtained through “the construction index” database (www.theconstructionindex.co.uk, 2016). The list contains 100 top companies and random sampling has been employed to choose 70 of them which have provided their email for communication (kind of systematic sampling). Most populated cities usually mean more demands for design and construction, the architectural firms were chosen from the RIBA database based on a local geographical search. 160 of companies were chosen from London as a capital city and Greater Manchester as a capital of northwest region. The remained 70 architectural companies are selected from most populated cities in other UK regions. For Canada 60 architects have been chosen from RAIC database and 40 construction companies have been selected from on-site magazine (<http://www.on-sitemag.com/features/top-40-contractors-by-revenue/>) to send the questionnaire. The sample contains the architectural companies from different cities around the nation which has conditions below:

- is a member of RIBA and RAIC (registered)
- Has experience in architectural design for residential or commercial buildings
- Has national and international experience.

One month after sending the invitation emails and attached questionnaire file to architectural firms in UK and architects in Canada, no responses were received, which required a review of the research strategy. A decision was been made to conduct the survey through a mixture of online questionnaire and paper questionnaire delivered in person. Firms and companies which are located in the city of Toronto, Canada and Manchester, UK have been chosen. From the sample which includes 65 members in total (20 members from Manchester and 45 members from Toronto) **in total, 21 responses are received**. More information is provided in the next chapter, “Development and Findings”.

3.8 Limitations of the Study

Usually there are different kinds of issues and difficulties for conducting a research which researcher must recognise them. Some of them can affect to the research progress and create some limitations. In this section, main limitations and difficulties which researcher has been faced to them are discussed.

3.8.1 Availability of Funding

Cost is a very important factor for this research. For this study, researcher is self-funded and does not receive support from any institution or government. For balancing the time and cost, sending questionnaire by email has been considered as the first option because it is the most economical option. If this option does not lead to a sufficient response rate, the next option would be focusing on Toronto as the city in which the researcher is living, and visits firms and companies in person to conduct the survey.

3.8.2 Time Resource

Receiving the results from respondents can take a long time. Preparing appropriate questions, waiting to receive the results, and analysing open ended questions can take considerable time. On the other hand, sending the questionnaire, and analysing close ended questions which are the main structure of the questionnaire (most questions are close ended) enable the researcher to save time. Also, since it is the only technique which is considered for primary data collection for this research, therefore, it is expected that the researcher can stay on the planned schedule and finish his research on time.

As mentioned, to reduce the risk not covering the scope of research by one technique, the researcher has developed a comprehensive questionnaire which includes multiple choices and open ended questions. Multiple choice questions provide fast, and accurate responses which are easy to handle and easy to answer and analyse.

3.8.3 Precision Required

There are arguments regarding accuracy and precision of each technique of data collection. As mentioned above, any of research techniques has their own advantage and disadvantages. These four factors have sometimes conflict with each other. For example, while in interviews the accuracy will increase by increasing the number but it will usually consume more time and money. The questionnaire technique has been chosen because of its ability in balancing these four factors. To decrease the risk of sampling error which is an inaccuracy in the collected data, increasing the samples along with providing different classes of questions (close ended, semi-close, and open answer) are considered. In questionnaires, there is very limited control after dispatching or sending questions. Therefore, there is risk that some respondents do not respond at all or answer just some questions. BIM is a relatively new strategy in the design and construction industry, it is not expected that all respondents have

familiarity with it. Also, based on literature review it is possible that just a few architects may be aware of building performance analysis. The questionnaire has been designed in a way that if any of those matters exist, at least the researcher can find the reasons and the potential solutions by interpreting other responses from architects who could overcome to the issues.

3.9 Research Process Diagram

Figure 3.3 briefly shows different stages of this research, and how the research is designed and how it addresses to the research’s issues, in what method and with what action.

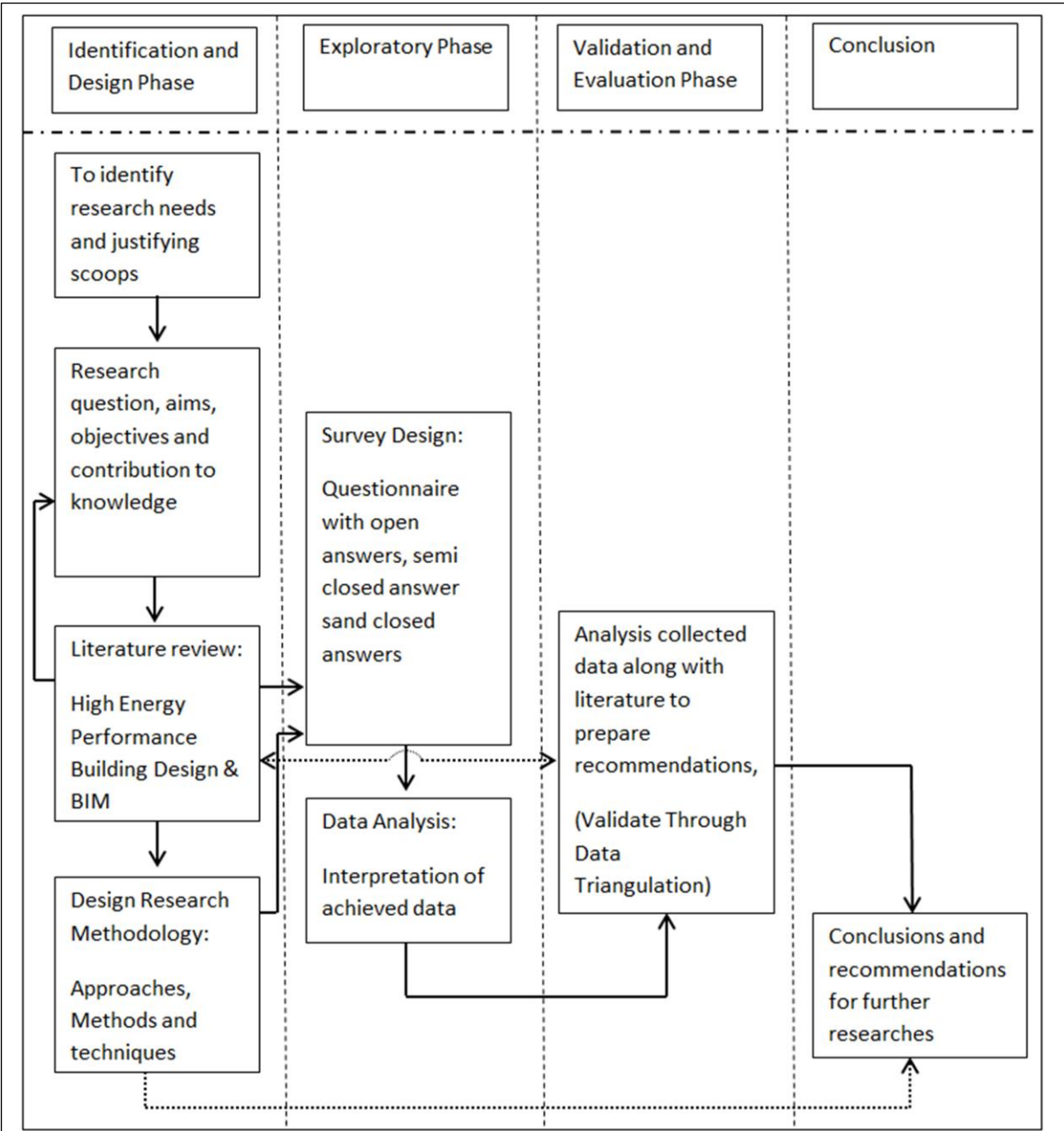


Figure 3.3: Research Process Diagram

Chapter 4.0: Developments and Findings

The questionnaire is designed to address the research question “*How can architects use BIM effectively to manage the energy performance of buildings?*” Questions are designed to cover the third research objective and partially address the second and fourth research objectives.

As discussed, the survey is chosen as the research technique for this study which has 4 sections. Questions are organised from initial to more specific.

- The first part investigates the background of respondents. It includes the respondents’ experience and education. This information is asked for two reasons, first comparing the responses from respondents who are educated and have work experiences in different countries. Second, for using the respondents’ answers who has long time experiences in developed countries to find the shortcomings in process of HEPBs’ design and using their provided recommendations.
- The second section is investigating respondents’ familiarity about existing sustainable design tools and standards. Investigating the current process of energy efficient buildings’ design process is one of the research goals. Therefore, evaluating respondents’ awareness about major credential standards in the countries which survey has been conducted is considered.
- The third section identifies the current processes of architectural design and energy efficient building design, are explored at both the individual and organizational level. At an individual scale, respondents’ awareness of passive design techniques and energy modelling are investigated. The stages of the architectural design process in which performance analysis is taken into consideration, tools and information which are needed to design an energy efficient building, the extent of architects’ involvement during energy performance analysis and existing barriers and challenges are investigated in organizations (firms and companies).
- The last section of the questionnaire deals with BIM, it starts from general questions to evaluate existing familiarity about BIM and the tasks which can be done by BIM’s tools. It continues with more focus on energy and performance analysis.

The results demonstrate the viewpoints of respondents about their use of BIM tools, their accuracy and user-friendliness for building performance analysis, their use in supporting a passive design strategy and existing barriers when using BIM's tools. The questionnaire evaluates respondents' experience and familiarity regarding the research main topics (design for energy and BIM). These questions are discussed for two main reasons. The first is to understand what the existing knowledge and experience in designing for energy and building information modelling. Then as a second, is to allow us to consider potential recommendations and guidance for practitioners who are willing to implement BIM in order to design for energy efficient buildings.

Developing the research methodology, preparing the questionnaire and seeking ethical approval started in October, 2016. In early March, 2017 the ethical form has been sent to the panel and on early April the ethical approval was received. When all the required documents were ready including the research ethical approval, 400 emails were sent for inviting participants from both the UK and Canada to take part in this research. This was met with limited success. Therefore, a decision was made to change the data collection technique and visit the firms in person.

Key results from the survey demonstrate that:

- 1- Respondents' demographics have a considerable influence on how respondents answer the questions. Respondents from developed countries are more familiar with the importance of energy and BIM. The city and location which respondents work can effect on the methods which they use. For instance, in high-rise cities, wind behaviour is considered more.
- 2- There are significant claims of familiarity with LEED and BREEAM, but when discussing the details, the respondents were often not familiar with the detail.
- 3- Architects are aware of how to access to the required data and information which they need for designing an energy efficient building. They are familiar with passive design techniques and methods for improving their design performance. While architects claim that they are familiar with basic building physics principles which are required for BPA, they are very dependent on external engineers and experts to analyse their design performance.
- 4- While architects can use basic performance analysis to compare their design's performance and save time and cost, there is disconnect between the architects and

BPA. They are not familiar with the existing tools, software and methods for conducting BPA.

- 5- BIM is a popular tool with architects, but they are using it mostly for visual design tasks, such as simulation, 3D design, etc. while other aspects of BIM, which may be used for performance analysis and for improving the efficiency of design process and the final product, are not widely used for these activities. A lack of familiarity with the tools is the biggest challenges in this regard.

After an initial description about how survey is conducted, the employed techniques, and response rating are discussed in the next section (4.1). In continue (from section 4.2 until end of the chapter) more comprehensive details from questionnaire and findings are presented.

4.1 Data Collection techniques and Response Rate

For Canada, the Royal Architectural Institute of Canada (<https://www.raic.org/members-directory>) database has been used to recognise architectural firms in the Greater Toronto area. For UK, the Royal Institute of British Architects (RIBA) database has been used for recognising architectural firms and companies. Contacting all firms and companies in person is almost impossible because of time and cost issues. Also, not all of recognised firms are involved in buildings' architectural design. Others are involved in different areas such as urban design, consulting, interior design, and etc. The approach of both an online questionnaire and paper questionnaire delivered in person was used. Firms and companies which are located in the city of Toronto, Canada and Manchester, UK have been chosen to visit first. From the sample which includes 65 members (20 members from Manchester and 45 members from Toronto) in total, 21 responses are received of which the majority are from medium and large companies. Surprisingly, even in large firms there are one or just a few practitioners who have enough knowledge to answer the questionnaire. Some companies did not answer the questionnaire because they were not familiar with the research subject. Others declined to answer the questionnaire because of other reasons such as being busy or lack of interest.

In the next section the results from the questionnaire are presented based on the questionnaire structure. At the beginning of each section a summary of why this section is included is discussed. It includes the details such as number of questions, purpose and aims of the questions in each section.

4.2 Questionnaire Section One - Demographics

DeFranzo, (2012) discussed that, when questionnaire is considered as data collection technique, the researcher needs to assess asking questions from whom? Also he needs to know how to breakdown obtained data into meaningful groups of respondents. These assessments are based on demographic information which describes survey respondents and characteristics such as gender, education, occupation. Demographic data helps to divide the respondents to importance subgroups for comparing them and also adjusting differences among them (Griffith et al., 1999; DeFranzo, 2012).

The first section of the questionnaire includes five questions to identify the identity, educational and work experience background of respondents. Also this information is used for coding the results. They are important because:

- 1- They can increase or reduce the value of the respondents' answers to the rest questions. For example the answer of a person with lots of experience in architectural design or who has work experience in different developed countries can be more significant in compare to a person with few years' experience.
- 2- They can open different windows to see the different views of architectural design process, Energy efficient building design, and BIM from people in different countries with different experience and educations.
- 3- The answers from people with more experience and/or high educational level are considered important for some of the opened answer questions to use their knowledge and experience as suggestions and guidance.

The questions in this section are:

- Name: refers to given name and/or surname of the person who is responding to the questionnaire.
- Location: Countries and/or cities which respondent is working now and previously.
- Main Role: refers to respondents' main responsibility in his/her career such as senior designer, BIM manager, etc.
- Education: the highest academics degree which is achieved by respondent.
- Experience: refers to number of years which respondents are worked in his/her specific field.

The respondents' details are made anonymous for ethical reasons therefore coding system are used to present the respondents (Table 4.1):

Respondents:	Location	Main Role	Education	Experience
GM- 01	Toronto	VC Manager	Civil Engineering	18 years
NP-02	Toronto	Design Manager	Master of Arch	-
PK-03	Toronto	-	-	-
JP-04	Toronto	Architect	Master of Arch	23 Years
GL-05	Toronto	Senior Architect	Master of Arch	30yrs Toronto 10yrs New York
RF-06	Manchester	Lecturer in Energy Efficiency	PhD in Building Physics	-
KV-07	Toronto	Architect, Project LEAD	Master in Architecture	8 Years Canada 2 Years Netherland
RA-08	Toronto	Virtual Construction Coordinator	MSc BIM Management	2 Years Canada 1 Year Venezuela
JP-09	Toronto	Research Manager	-	18 Years Canada
MK-10	Toronto	Construction Coordinator/ BIM modeller	MSc in Construction Management	3 Years
DG-11	Manchester	Architect	MSc in Architect	-
KA-12	Toronto	BIM Manager	BSc in Architect	7 Years Canada 2 Years South Africa
PB-13	Manchester	Architecture Assistant	Architecture Technology	4 Years UK
AA-14	Manchester/Jordan	Civil Engineer	MSc Construction Management	11 Years
HS-15	Manchester/Iraq	Architect and Lecturer	PhD in Architect	24 Years

MC16	England	Architects	Master	20 Years
HL17	US	Planner/Designer	Master	+20 Years
JP 18	US	BIM Manager	PhD	6-10 Year
MOU 19	UK/Nigeria	Architect	MSc	11-20
GW 20	England	Design Engineer	MSc	6-10
SPS 21	England/Middle east	Engineering	MSc	1-5
Table 4.1: Respondents Background				

4.3 Questionnaire Section Two - Sustainable Construction

This section is about assessing the respondents understanding of the key principles of designing sustainable buildings through focusing on one of important aspects of sustainability; energy. BREEAM and LEED are two of the main standards regarding sustainability and are widely used in UK and North America, as these are the two major locations that survey has been conducted these are the certification schemes that are discussed. Since one of the objectives of this research is to conduct a survey with architects in UK and Canada on the current process and knowledge regarding HEPBs design, respondents' familiarity and awareness of these two popular standards are evaluated through this section questions.

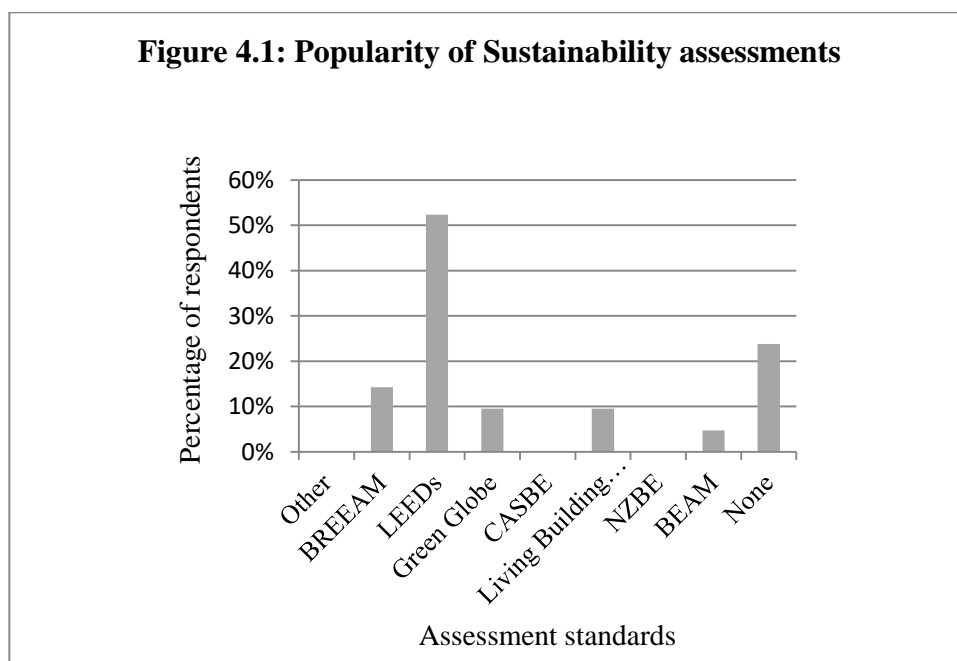
This section is designed to evaluate the respondents' familiarity, awareness and knowledge of sustainable design tools and standards such as BREEAM and LEED. The result of the first question demonstrates that respondents' familiarity with the criteria of environmental sustainability. This section includes 4 questions which evaluate the respondents' familiarity with general criteria of a sustainable design. Then the results explore the respondents' awareness about existing standards and their contents, also the result of these questions will be compared with the other questions in continue for further analysis. It must be noted that questions in this section deal solely with respondents' experience and knowledge individually and do not investigating their firms and companies.

1) How familiar are you with existing sustainability standards' content and methods of assessment such as BREEAM and LEED?

This question is designed to assess the use of existing standards. The results of this question show how many respondents have familiarity with existing standards and their content. Also the results of this question will be used to compare with questions in continue for further evaluations.

Results show that 24% of respondents declared that they have average familiarity and 33% (19%+14%) of the respondents indicated that they have **high and very high familiarity** with these certification standards and content of the sustainability standard in their country. It shows that most respondents (57%) have an average or more than average awareness about the existing standards. Since these tools and standards include very useful information regarding how a building can meet the requirements of their certificate, familiarity with them is important.

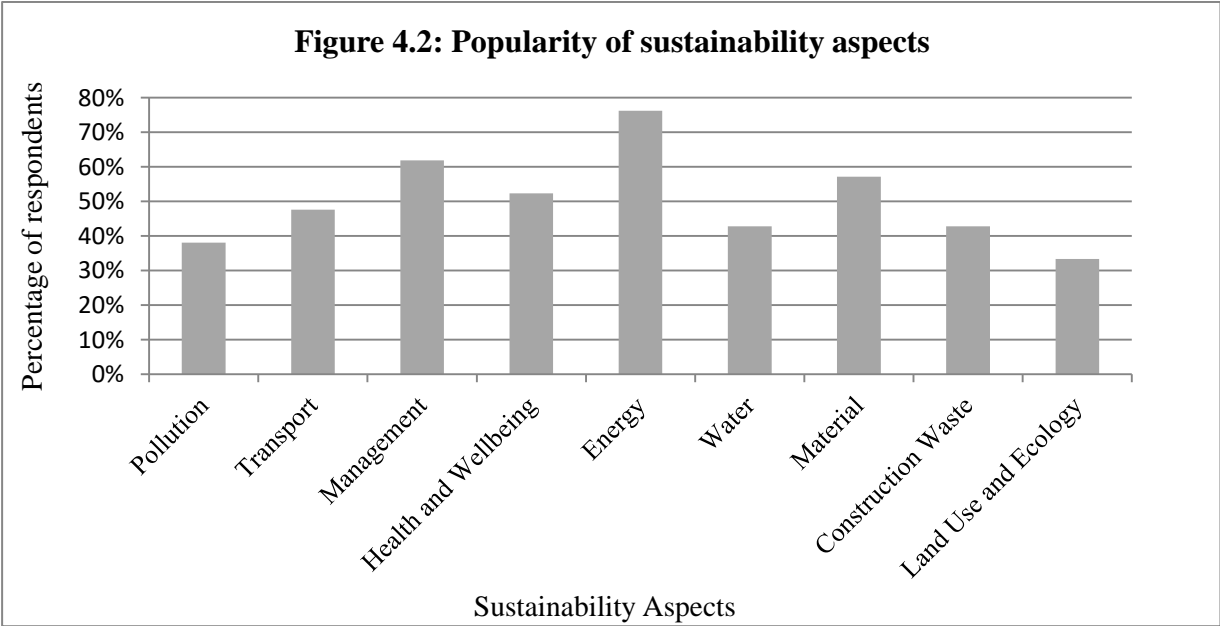
2) Which sustainability assessments do you commonly apply to your projects (Can choose more than one answer)?



76% of the respondents declared that the project that they were involved in could obtain the certificate from different existing standards. Between these respondents, LEED is the most popular standard, more than 50% of practitioners stating they had projects that they commonly applied the standard to. After LEED, BREEAM is the second most popular standard which practitioners use. It may be because most respondents were from North America and after that UK, and these countries are the place which LEED and BREEAM have been created and developed respectively. Canada Green Building Council (CAGBC) has licence from US Green Building Council to use Canada LEED.

While there are different building wellness standards such as WELL, Healthy Building, Green Star, CASBE, Living Building Challenge and etc. but based on the results, LEED, BREEAM, BEAM and Green Globe are the standards which companies commonly apply to their projects.

3) Which of the following factors do you consider the most important when considering the development of your projects? (Can choose up to 3)?



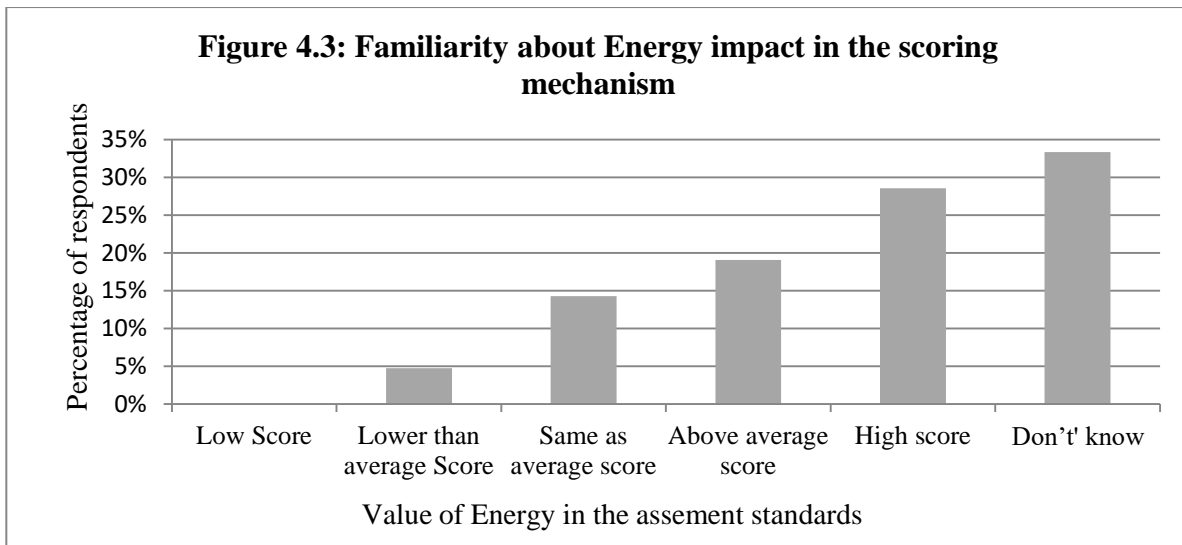
This question investigates the detail of the standards and evaluates respondents’ familiarity with the standards’ main themes. BREEAM headings have been used for categorisation for this question because it is the pioneer sustainability standard, although these criteria can be closely matched to other standards, such as LEED.

The results from this question demonstrate how much attention has been given to the content and each criterion of existing standards by the architects. It shows which of the sustainability indicators is more popular and has more value based on the respondents' view point. It must be noticed that BREEAM is a weighting-based model which means different value is considered for each aspect and it can possibly effects on respondents' attention to specific aspects.

Energy is the most popular theme that practitioners declared that they are familiar with. 76% of the respondents claimed that they consider it in their work practice. After energy, management with 62% and materials with 57% are the most considered aspects which respondents declared that they are familiar with. As an accreditation method, in UK BREEAM, (2014) energy alongside health and wellbeing both with 15%, have the biggest weight in comparison to the other aspects. Attention to energy has been increased, because In UK BREEAM, (2018) the weight has been increased to 16%. Also in LEED V4, (2019) energy has the maximum scores (between 31-35 scores based on the project) which can be achieved through in comparison to other aspects. Therefore, it is possible that respondents may pay more attention to energy due to the weighting within the models.

There may be other reasons for the attention which is given to energy in media, particularly as linked to global warming.-It should be noted that these aspects can influence to each other as an example material insulation effects on energy consumption. As mentioned in previous paragraph, reducing energy consumption has the biggest scoring weight in standards such as BREEAM and LEED, which means that they may get more attention from respondents. The answer from next question would help to understand if more attention to these aspects are coming from the weighting system or it may have the other reason.

4) What impact does energy efficiency have in the scoring mechanism of BREAM or LEED?



It is discussed in previous question that energy has the biggest weight in comparison to other aspects in the BREEAM and LEED (as the main considered accreditation methods in this research). This question is asked for two reasons, first, evaluating the respondents' awareness about the importance of energy in comparison to other aspects and, secondly, to compare their answer for this question with previous questions to see if they claim that they are familiar with the standards and their content; are they really aware about the importance of energy in them? Therefore their answer to this question can be used to validate their previous response.

Based on the previous question, while energy with 76%, is the most popular aspects among the respondents, Just 29% of the respondents knew that the energy has the biggest credit in comparison with other aspects. Based on the answers from the last three questions, while more than 50% of the respondents claimed that their project could obtain scores from LEED and they are aware of the content of the standard, just the respondents who had "High" or "very high" awareness (Q1) about the standard's scoring know that energy has the highest weight. Comparing the answers of question 3 and this question shows that awareness about weighting system cannot be the only reason to pay more attention to energy. Therefore, it may have other reasons such as the attention which is given to reducing energy consumption and the impact of fossil fuel on built environment in media and/or national regulation. This result may indicate that architects who are involved in designing buildings have to pay more attention to the content and details of wellbeing building standards. Familiarity with the methods of their working and the importance of different aspects in those standards can help designers understand what the requirements are, how they can achieve them, and which aspects has how much weight (is more important). By considering these issues during the

design stage, there is a hope that the architectural design shows a good performance when energy analysis is conducted and can meet the requirements the certificates standards. Therefore, a more efficient design process can be achieved which there is a less works repetitions in it and earning scores and certificate from credential standards would be more achievable.

As mentioned in chapter 1 and section 2.2.5, it is possible for designers to address energy performance in design into two main categories:

1-Geometrical design including: design boundary, shape, location, position of building based on wind and sun behavior, which all can effect on the energy demands in a building.

2- System design including HVAC systems and other controllers and mechanical and electrical systems, which are designed to manage the energy consumption in a building.

While system design is the responsibility of energy specialists, such as mechanical engineers, the geometrical design is the architects' responsibility. As Anderson (2014) stated, architects decisions regarding geometrical design have a large influence of buildings energy demands. While in some project, architects may not have control over the system design, particularly where there are external advisors. However, if their familiarity of energy modeling works, it may improve the energy efficiency of final product.

This research is about improving energy efficiency of buildings through involving architects more in the process of energy design. BIM, with its tools, provides a good platform for both geometrical design and system design. As Schlueter and Thesseling, (2009) stated, while architects may not familiar with all the necessary parameters to run an advanced energy performance analysis, it is proposed that if they improve their knowledge regarding energy design for the basic performance analysis it may improve the performance of their product.

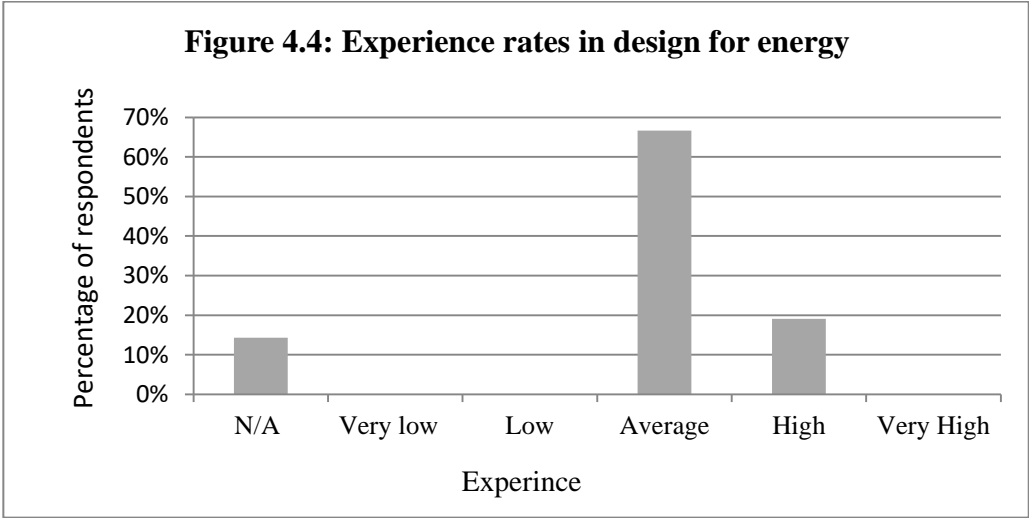
One of the objectives of this research is to identify the current process of HEPBs' design in UK and Canada, as a subcategory of this objective these four questions in section two are designed to evaluate practitioners' awareness and familiarity with energy issues and the related standards and tools. Awareness about importance of energy is one of the potential prerequisites in applying the tools in a design context. The first four questions draw a general view regarding existing awareness in design and construction firms about standards such as BREEAM and LEED, their content, and the importance of each element. This possibly demonstrates that, while practitioners are aware of the importance of energy in standards,

their familiarity about details is not as strong. The existing awareness and familiarity of the design process for energy issues are evaluated through next section, which contains more specific questions regarding energy efficient building design. Therefore, the next questions deal with energy efficiency understanding and investigate the current process of energy efficient building design.

4.4 Questionnaire Section Three: Designing for Energy Efficiency

Section three of the questionnaire discusses how energy efficiency is considered in the architectural design process. This section includes questions which deal with both respondents’ experience and knowledge individually and also the processes and experiences within firms and companies in which they have worked. Questions in this section deal with issues such as the methods and strategy which respondents employ in their design for increasing building energy efficiency, stages which energy performance analysis is conducted, who is responsible for energy performance analysis, tools and sources regarding design and analysis of HEPBs, and existing barriers and solutions for designing energy efficient buildings.

5) How would you rate your experience in designing for energy?

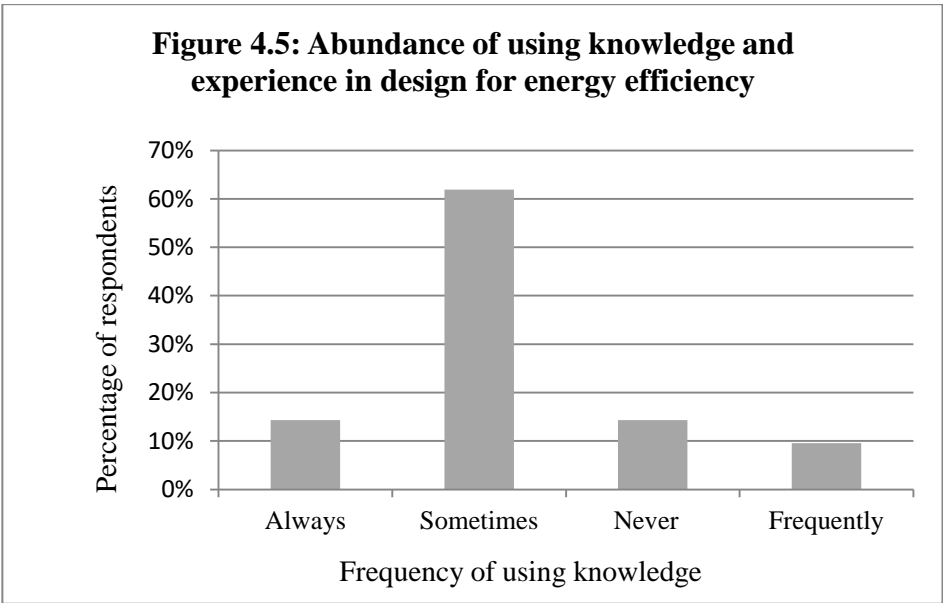


Generally, an understanding of passive techniques and a working knowledge of building physics are needed when designing an energy efficient building. Building physics is largely about the application of thermodynamic rules, as discussed in section 2.2.7. Question 5 looks to evaluate the respondents’ experience and knowledge specifically regarding designing for energy efficiency. As discussed, operating energy modelling tools requires knowledge regarding climatological information, building physics and engineering calculations and

measurements methods (Tortellini et al., 2006 cited in USEOP, 2008). A simplified energy analysis may be conducted by architects who are knowledgeable about geometrical design, materials, forms, and have an initial knowledge about building physics and technical systems. This question is evaluating this prerequisite among the respondents and, therefore, the answers will show how much awareness exists in this regard between designers for employing building energy modellers.

The survey shows that 67% of the respondents have average knowledge and 19% of them have high awareness about the design for energy. As discussed in the literature review and based on what Schlueter and Thesseling, (2009) stated, familiarity of architects with materials, forms, technical systems, and geometrical design can help in conducting basic performance analysis. While this kind of analysis may not provide a detailed energy model, it can help architects to modify and develop their geometrical design based on the results of the analysis. This can lead to a better design which may meet the required indicators of a HEPB in a more efficient process when the architectural design goes for system design (including HVAC and other system related to energy) and advanced energy modelling. Therefore, the result of this question possibly indicates that having enough awareness about buildings' physics (design for energy) as one of the prerequisite of conducting basic energy analysis exists between designers

6) How often do you employ your experience in designing for energy efficiency in your projects?



Having knowledge about a topic and applying that knowledge are two separate issues. While previous questions evaluating respondents' knowledge about design for energy efficiency, this question assesses how often they use their knowledge when designing energy efficient buildings.

As identified in section 2.2.8, designing for energy efficient buildings requires preparing and solving mathematical equations that often require specialist knowledge. However, current software tools are designed to facilitate designers through solving those kinds of problems. While 86% (67%+19%) of the respondents claimed that they have average and high awareness of thermodynamic rules, just 14% of them declared that they always use these rules on their work practice. 62% of the respondents declare that "sometimes" they use their knowledge. This may indicate that having a knowledge or tool is not enough while employing that knowledge is important as well.

7) When designing for energy efficiency, which do you consider being the most important passive design techniques (can choose more than one answer)?

Not used Sun Wind Precipitation Climate Conditions Other, Such ...

As discussed in the sections of 2.2.6, 2.2.7.2, 2.2.7.3 in the literature review, the natural elements including climate conditions, sun and wind behaviours influence of buildings energy demands. In appropriate passive techniques, natural elements can be used to provide parts of a building's energy demand. For instance: using solar energy for lighting, heating, and power generation, or using wind for natural ventilation and energy generation. Therefore, this question is designed to find out which of these passive techniques are more important among practitioners.

There is a view that inexperienced or new designers, design firms and companies who are willing to improve their design through employing passive techniques will know that they must pay attention to which passive design techniques they should use. Software companies which are involved in producing software for building design can use these results to understand the needs of design market to provide related software and tools. Designers can benefit from tools and software which can be used for visual tasks, while also providing reliable data and information about natural elements, and even performance of the design. It should be noted that Autodesk Revit has these features with interfaces for performance analysis.

All architects stated that they consider at least one or more natural elements in their design practice. Solar is the main element considered, which 76% selected. After that, wind (52%) and climate condition (43%) are in second and third place. The next question is a complementary question for this one because in the next question the method of employing these natural elements have been asked.

8) Please briefly give examples of the types of passive design solutions you employ?

This was an open response question which is a complementary question to the previous question. This question looks deeper into the types of passive design techniques which are employed by the respondents. Therefore, analysis of this question's answers can be used as an initial guidance for designers who are intend to use passive techniques in their work practices. In the demographic question, the amount of experience, the location and main role of respondents are asked. The reason behind this question is to use the experience of experienced respondents and comparing their answers based on their role and the different locations which they are working. 40 % of the participants answered this question and they are the respondents who answered the previous question and declared that they consider one or more natural elements in their work. Except one of the respondents who had 8 years' experience in architectural design field other respondents who answered this question have more than 10 years' experience. The results from the respondents' answers and the description analysis are:

- In Manchester, transferring the design of project to the dynamic simulation tools is used to simulate the interaction between project and natural elements behaviour. Such an analysis provides the loads which the natural elements push to the building.
- Studying about wind and sun behaviour around the projects' location and use passive design principles whenever possible to reduce energy loads on buildings. Also, these elements are considered to improve occupants' comfort which refers to using natural lighting, preventing extra exposure from solar radiation, and ventilating buildings' interior naturally.
- Wind studies at street level and top of the building are being conducted for projects in Toronto. Shadow movement plans are studied for December, March, June and September. Sometimes shading devices and high-performance low e- coating glasses are considered. Low e-coating glasses filter the ultraviolet light (it fades the covering materials like fabric and wall surface) and infrared lights (are transferred to heat when

strike to the surface) and just let the visible light passing through the glass inside the building.

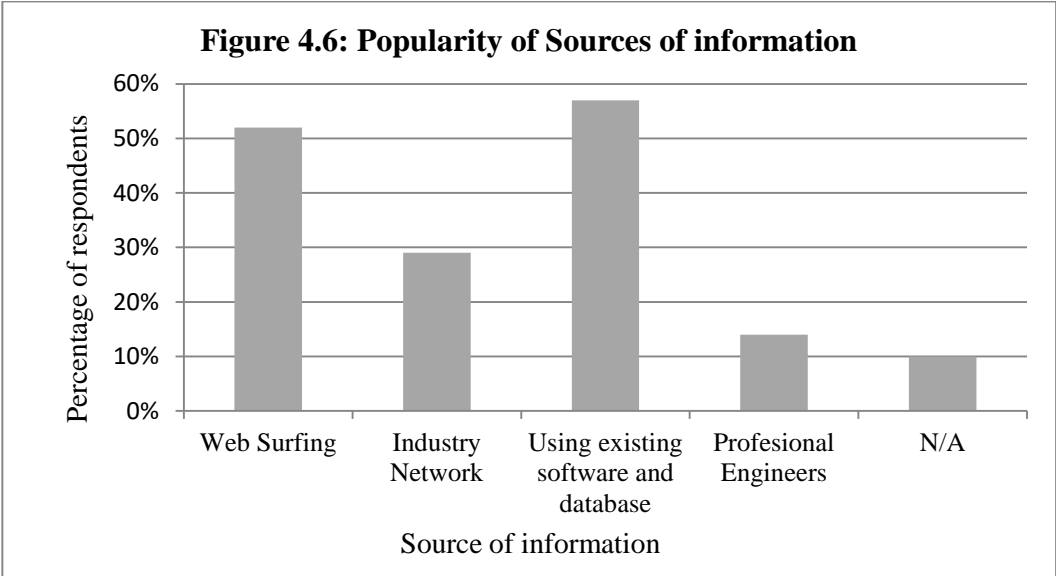
- Studying the solar energy for passive heating in winter and wind behaviour for passive ventilation.
- Solar studies are conducted to measure and investigate solar heat gain and providing sun shading devices for necessary parts of buildings. Wind studies help to predict the ventilation capacity from windows and other fenestration.
- Employing strategies regarding the difference of angle of sunlight in winter and summer. It is valuable to use the solar lights on the most optimised method through providing shading device which could be static shading like a balcony or flexible shading like exterior curtain canopy (45% of windows height for shading length). Wind studies are conducted for two reasons usually, one for passive ventilation and the second one for investigating the pressure of wind on building for structural analysis.
- Considering fabric is the first approach for some designers. They believe that appropriate fabric (for example maximizing insulation) can protect building from natural elements such as climate conditions (heat and cold). Therefore it reduces the energy requirements to cool or heat the building.
- Orientation and Microclimatic conditions can effect on building energy demands. Shades and wind which can be produced from tall building can increase the energy consumption for lighting or heating.

Answers from the demographic questions and this question indicate differences which are driven by respondents' experience or locations. They pay more attention to specific criteria given their individual context. For example, in Toronto, which is a high rise city, more attention is given to wind studies. Results also show that architects give more consideration to energy and passive techniques when compared to the other respondents who are involved in other roles such as BIM modeler or Visual Construction (VC) manager.

Based on the answers, solar radiation is the natural element most considered by designers and after that, wind. Managing solar radiation and light is one of the most important strategies for using this natural element for lighting and heat-gain. Also, solar energy can be used for electricity generation with photovoltaic panels which was mentioned by only one respondent. Also, these two natural elements are very important for designing passive buildings (near zero energy consuming buildings). Simulating and analysis of sun and wind behavior and how

they interact with a building are necessary to use these natural elements in the most efficient way. Using high performance materials such as low-e coating glasses for fenestration which allows light to pass but reflects heat is the other important strategy for increasing buildings' energy performance.

9) What is your priority source of information (such as wind and climate conditions) while developing your designs (can choose more than one answer)?



As mentioned in section of 2.3.7 in the literature review, there is complexity in design process such as accessing and obtaining accurate data from reliable sources in the right time and transferring obtained data and information in a reliable method (Arayici et al., 2012). For new designers who intend to design an energy efficient building, it is necessary to know how and where they can access to the required information on the tools and techniques of passive design. Therefore, the result of this question identifies the most popular sources of required information for energy design. 90 % of the respondents answered this question. Using the existing software and databases (57%) and web surfing (52%) are the most popular source of information. After these, industry networks (related organisations) located which 29% of respondents referred to it for obtaining their required information.

The results demonstrate that, many practitioners are still looking to networks (industry and web) to obtain their required information. Motawa and Carter, (2013) discussed that how commonly the data and information regarding a building is fragmented and they stated about the essential of a platform for integration. This question mainly deals with finding required data, their use and transmittance. In comparison with using software that provides

information about environmental conditions such as wind-rose or solar studies, searching in the web and networks is potentially more time consuming and not as actionable. Motawa and Carter, (2013) stated that while further development is still required for using BIM to increase energy efficiency, design data from BIM model can be transport easily to the simulation tools through gbXML and IFC. Some BIM software such as Revit are very integrated and have tools which provide the capability of gathering required data and transferring them to the required information, such as a solar study, in a same database which the geometrical design is modeled and energy analysis can be conducted. Therefore, designers do not need to search for the data in other sources (web, networks, etc.) and transferring them for energy design calculations or to other related tools.

10) Do you find it difficult to access information to help you develop energy efficient designs?

This question is designed to evaluate the ease of access to information needed as one of the important factors for designing an energy efficient building. 48 % of the respondents which included all responses from architectural firms believed that accessing information on issues such as solar behaviour or wind and climate conditions is not difficult.

The result shows that, almost half of respondents do not have problem in accessing the required information necessary to develop energy efficient designs. However, this means half of respondents have some difficulties accessing the required information. In comparison to the previous question, it might be that they are not familiar with the existing tools and their abilities.

11) What do you believe are the biggest challenges for architectural practitioners in delivering high energy performance buildings?

This question is designed as a complementary question to investigate the challenges which designers are faced by. This is an opened answer question for obtaining practitioners opinion regarding the existing challenges for architects in order to design an energy efficient building. It may possible that some factors are not mentioned in previous questions, which in this question respondents can address them. Also, the answer of this question describes the challenges that designers are faced with regarding the design energy of efficient buildings.

Right client: There are wide number of activities that BIM and design practitioners have to do, having the right clients who care about energy and are ready to pay the extra cost to allow

them to properly study and design the buildings to meet energy performance targets is important. The client must prioritise these issues in their design for designers to respond.

Budget: Designing high energy performance buildings usually needs extra time and cost. Some time it needs to hire a specialist or organisation for design HEPBs and conducting BPA. Also, HEPBs usually have more costs for owners of projects during design and construction phase.

Tools: It is necessary to standardise appropriate software and tools for conducting energy performance analysis.

Knowledge: many designers did not feel they had enough knowledge about building physics to know how a building interacts with its surrounding area and environment, thermodynamic rules, energy flow inside the buildings, and etc.

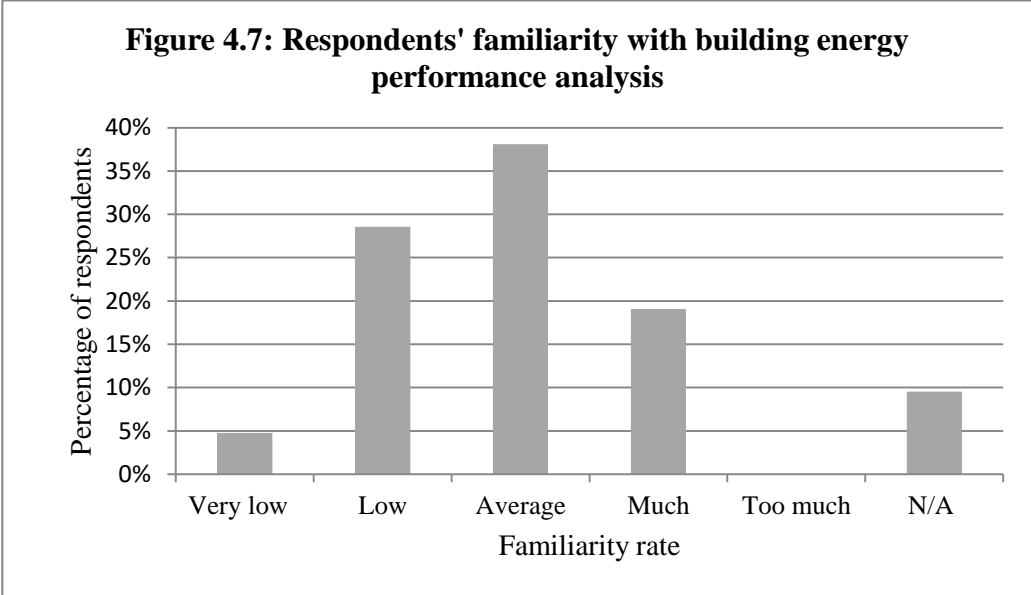
Assessment: Being able to adequately assess a project/option's impact in a timely and meaningful manner.

Dependency: While architects consider sustainability matters in their work practice, they are dependent on other professions, engineers, consultant, and firms for accessing the necessary information and analysing the final product.

From the results, it is possible to categorise the challenges into two categories which one can consider as either external or internal. External factors are where the designer does not have much influence on the factor and it depends on other people. The main external factor is the owner of a project, i.e. who is paying for the project and it is important that s/he cares about sustainability matters to encourage the architects to design a HEPB. Internal factors refer to the challenges that designers can have influence on and they are more directly dependent on designers to solve them. Having the right tools is considered the main internal challenge which includes knowledge, software, and any other equipment that is necessary for designing an energy efficient build. As identified in section 2.2.8 in the literature review, appropriate tools are necessary to access the required information, operating related softwares, conducting analysis and simulation and saving time by avoiding complex mathematical work, and having smooth and reliable connections between all stakeholders. Architects have to be equipped with tools so that they can study and obtain the required data, design and simulate their ideas to meet project objectives, and analyse different options and impact. With

appropriate tools and knowledge, architects' dependency to third parties can be decreased and the efficiency of HEPBs' design process can be increased through saving time and money.

12) How would you rank your familiarity with building energy performance analysis?



The next questions deal with the respondents' familiarity with energy performance analysis (EPA). This question is designed to evaluate existing familiarity between practitioners regarding EPA knowledge. The results demonstrate that half of the respondents had above average familiarity with EPA.

If initial familiarity with EPA considered as the foundation for further knowledge development regarding energy simulation and based on the results which shows more than 57% (38%+19%) of architects (all have more than 10 years' experience and in developed countries) have average and more than average familiarity about EPA, therefore possibly, at least half of experienced architects in developed countries have kinds of readiness to implement BPA or EPA in their work practice.

13) If you have ever been involved in a project where analysis of energy performance were conducted, in which stage it has been done?

This questioned is included for two reasons, first is to understand the current conditions within the sector and to identify which of the design stages are considered most appropriate for energy analysis. The second purpose of this question is to use the experience of

experienced designers who are involved in a project which EPA is conducted for presenting to new designers and firms who are willing to conduct EPA in their work practices.

For this question, the RIBA plan of work, which was introduced by Royal Institute of British Architects (RIBA) in 2013, is used as the model of design stages. This model includes 8 stages from 0 to 7. Stages from 0 to 4 are mainly about the works before construction phase. Phases of 2 (Concept Design), 3 (Developed Design), and 4 (Technical design) are the main three phases which mainly deal with design, have been chosen as the answers of this question.

These Three stages have been adopted to provide answers which are equivalent to: Concept Design = Concept Design, Developed Design = Design, and Technical Design = Detailed Design.

Q13																					
Concept Design	57.14%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	All stages	19.05%
Design	71.43%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Concept Design and Design	19.05%
Detailed Design	28.57%			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Design and Detailed Design	9.52%
N/A	9.52%	1																		Just Design (Development)	23.81%
Other (please specify):																				Just Concept Design	19.05%
																				N/A	10.00%

Table 4.2: Result Analysis of question 13

Since EPA can be conducted in more than one stage of design, respondents can choose more than one answer for this question. 90% of sample answered this question. In general, Design is the most popular stage for conducting EPA which 71% of respondents have selected this stage. 19% of respondents declared that, EPA has been conducted in all three stages of design. 19% have selected two stages of Concept Design, and Design. 19% of respondents have declared that, EPA is usually conducted just in Concept Design and 10% have selected the Design and Detailed Design stages.

As discussed in section of 2.2.5, while energy performance analysis can be run in all stages of design, the most accurate result can be achieved when EPA is conducted in each stage of design based on the project needs and available data and information. From the early stage of the design, which is conceptual design, performance analysis can be conducted when selecting the optimum shape, location and orientation of the project based on wind and solar studies and their effects on the project. Moving from the Conceptual to Detailed Design, more advanced analysis can be conducted. Useful results can be extracted from the analysis in details design stage which in that all details and changes have been implemented on the project. Anderson, (2014) pointed that the most important benefits of conducting energy

analysis by architects during all design stages is that they can see the effects of their decisions about a project at the real time without waiting for receiving the results of analysis from energy specialist.

14) In the projects which you are involved, who is usually assigned to conduct Energy Performance Analysis?

This question is designed to find who is responsible for conducting the EPA and how much architects are involved in conducting the EPA. As discussed in section 2.2.5, architects are responsible for the geometrical design which has significant impacts to a building's energy consumption. Selecting an appropriate orientation and shape for a building can save 30-40% in energy consumption (Elbeltagi, 2017). Anderson, (2014) claimed that "*Architects are uniquely positioned to affect passive strategies in their designs. They need to have the means to evaluate design decisions to take advantage of this*". He discussed how architects involvement with EPA can increase the efficiency of their work and also the final product.

Based on the results, mechanical (HVAC) engineers and practitioners are the most involved in conducting the energy performance analysis (57% of the respondents have checked the related box). 33% identified "registered assessors" as the second group who are mostly involved in performance analysis. Just 14% of architects declared that they are involved in EPA while at least most of them declared that they have good knowledge regarding building science which is enough to conduct simplified analysis.

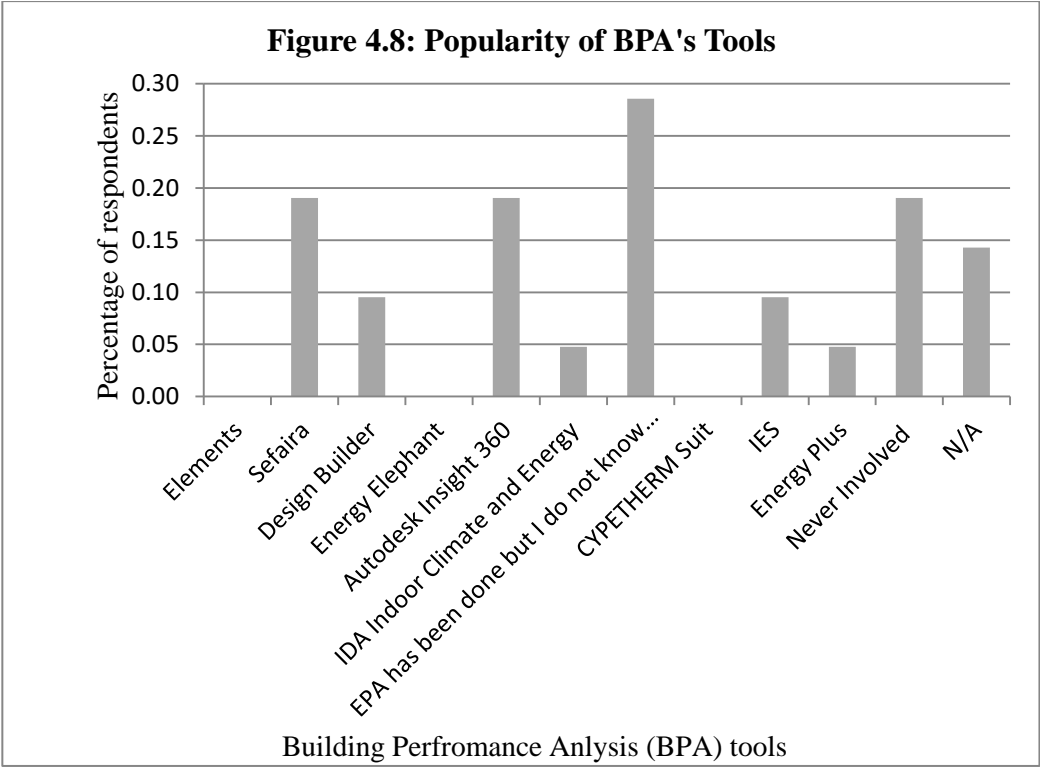
Note 1: In this Study, registered assessors are persons who have a certificate from a recognised organisation for assessing the performance (engineer, architects or technician who have learned and attended to specific course about energy efficient building or have certificate from recognised national accreditation body).

Note 2: Simplified Analysis refers to analysis which is conducted based on shape, forms, layout, etc. and does not consider all details such as mechanical, HVAC, etc.

Based on the results, most respondents stated that they are dependent on other people for EPA, which may show that most architects are possibly excluded from EPA processes. Comparing the answer of this question with the question number 12 indicates that while the practitioners have appropriate knowledge regarding EPA, it seems they were less likely to apply their knowledge. While in this study it is not exactly asked why they are not using their

knowledge to conduct performance analysis, but maybe an inference might be drawn by combining the answers of questions 11 and 25. When they have been asked to describe the barriers for delivering HEPBs and using tools and software in this regard, they mentioned issues such as: unfamiliarity about the existing tools which can help them, and the lack of motivation which possibly comes from their concern about time and cost. As stated they have not been asked to say, why they do not use their knowledge for conducting BPA therefore there is no any certain answer for this “why” in this results.

15) If you have ever been involved in projects that BPA has been done, which software/s is usually used?



This question is attempting to identify the most common tools which are currently used for Building (energy) Performance Analysis. Knowing the most popular tools may mean that those tools are more reliable and accurate in comparison to others. Therefore, new or inexperienced practitioners who are willing to use the B/EPA tools would be able to identify specific tools. In the section of 2.2.9, the function and specification of some popular building energy simulation tools are presented.

19% of respondents stated that they never involved in a project which EPA is conducted. 29% of respondents declare that, while EPA has been conducted but they are not aware of tools employed. The rest of the respondents identified Autodesk Insight 360 and, after that, Sefaira

as the most used tools for EPA. The dynamic modelling tools, Energy Plus and Integrated Environmental Solutions (IES) were less popular.

Autodesk Revit is one of the most common tools in design and construction industry, which provides different options such as architectural, MEP, and structural design and modelling. As discussed in section 2.2.9, Revit is equipped with interface of Autodesk Insight 360 (version 2013 and after) to connect to the GBS cloud and uses the DOE engine for conducting energy performance analysis. Sefaira, as introduced in its website is “collaborative, *cloud-based software that combines an engaging, easy-to-learn interface with validated industry-standard analysis engines*”. Sefaira is a parametric analysis tool which is used to compare different designs while a design is still evolving. It performs analysis of carbon emissions, renewables, energy consumption, and thermal comfort. It is also possible to conduct real-time daylight and energy analysis by Sefaira on the model which is transferred from Revit or SketchUp (Sefaira, 2019).

The results from the second section of the questionnaire present a view of the existing conditions in the design area. As the literature indicates (section 2.2.5), it seems still that architects, who are highly involved in geometrical designs, are not involved in energy design. However, more attention has recently been given to buildings as an expensive, complex system. “High performance” depends on criteria such as management, design, construction, and materials; predicting performance of a building in early design stages can save time, money and lead to a better product.

Results indicate that architects might be considered to have an appropriate knowledge regarding passive design strategies, especially with regards to sun and other climatic conditions. Based on the responses, many of architects state they have knowledge regarding design for energy (building physics), which is prerequisite for conducting energy analysis but they are almost detached from such an analysis.

Based on the results, it may be possible to conclude that most of architects are not familiar with existing tools that they can use them to undertake performance analysis during the design period. While respondents do not have issues regarding access to required information which may help them to develop energy efficient designs, they identified that they are limited by issues such as time and cost. performance analysis might be considered as a special field which requires advanced knowledge regarding building physics and energy modeling and must be performed by energy expertise or related engineers. However, as discussed in the

literature review, section 2.2.5, since architects are knowledgeable regarding building shapes, materials, forms and geometrical design, they may be able to conduct a simplified energy analysis if they have initial knowledge regarding building physics (as discussed in section of 2.3.7) and related tools and software. Recently, more attention has been given to Building Information Modelling which is considered as an approach or strategy for data and information management in this research. It is discussed in the related section of 2.3.3 and 2.3.4 in literature how a mature BIM approach can facilitate different tasks such as visualisation, forensic analysis, performance analysis and etc. In this regard, the next section is designed to evaluate the acceptance of BIM and its tools between practitioners. There are many claims in literature about the BIM's potential regarding its ability to support the design of an energy efficient building. Therefore, the next section discusses practitioners' familiarity and experiences of BIM, its tools and related tasks which can be conducted by BIM.

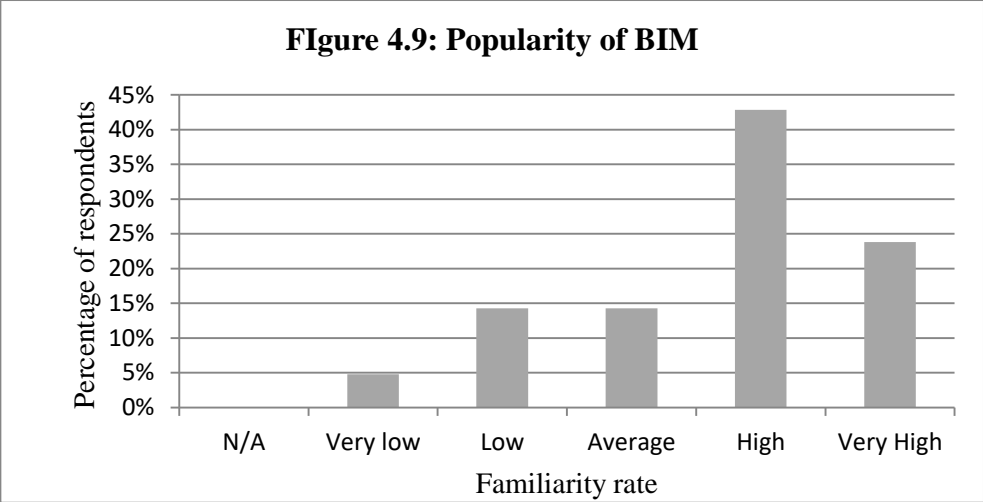
4.5 Questionnaire Section Four: BIM and Tools for Sustainable Design

Section 4 of the questionnaire is concerned with BIM and its functions, specifically regarding energy efficient building design. While section 3 includes questions which were related to the firm or company that respondents worked in, this section focuses on the individual's (practitioners') experience and knowledge with regards to BIM. This section begins with general questions to evaluate the respondents' awareness of BIM, its tools and the tasks for which BIM is used. While questions of this section mainly deal with practitioners' familiarity and experiences regarding BIM and its tools, two main categories of questions are included in this section. The first category is designed to evaluate the existing acceptance and popularity of BIM and its tools, specifically regarding energy efficient building design. The second group of questions is designed to identify the opinion of experienced designers as a potential source of guidance and recommendations for new designers /firms or any other designers and firms who are willing to develop their design process in order to design an energy efficient building.

The final section of the questionnaire narrows down to more specific topics of BIM's potential for design and analysis of energy efficient buildings. There is consideration of the tools for performance analysis, their accuracy, and user-friendliness. Revit's potential for designing an energy efficient building design, and the existing barriers for utilising BIM tools are discussed. Some of the questions in this section, which located at the end of the section, required more advanced knowledge and experience about BIM and its capabilities. The

responses from these kinds of questions can be used by other architects who may utilise BIM for BPA during the design process. Therefore, the results will be used for preparing the BIM-based recommendations for designing HEPBs’ design which is one of the objects of this study.

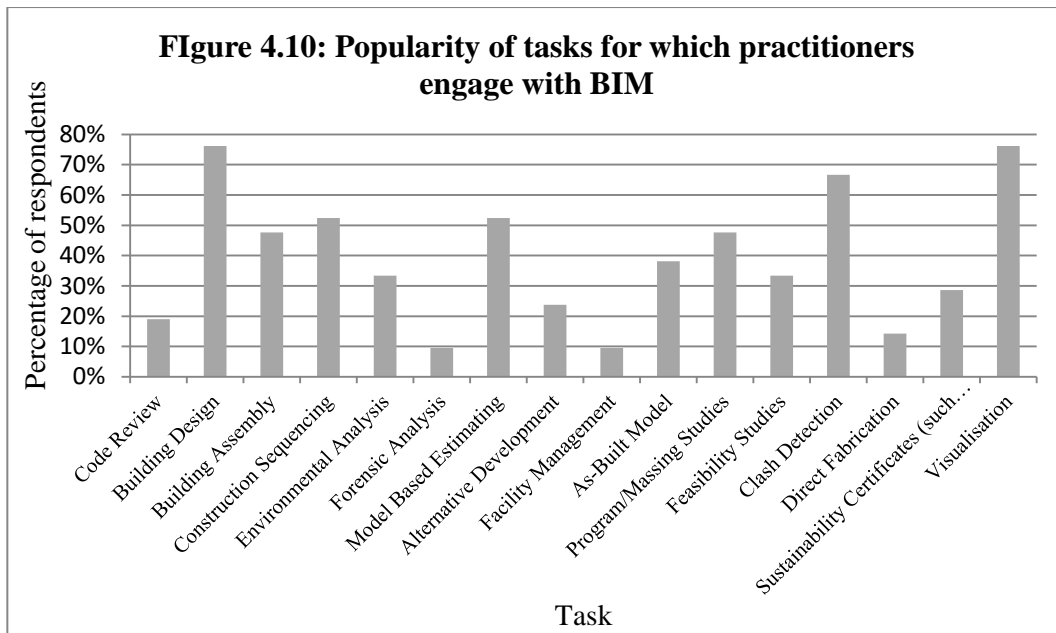
16) How would you rate your experience with Building Information Modelling (BIM) tools?



Since this research is exploring BIM as a potential way for practitioners to use their knowledge about building physics and conduct initial building performance analysis, BIM familiarity among practitioners is important. This is a simple question which is designed to appraise the existing familiarity with BIM, without identifying any specific tasks for which BIM can be used. Therefore, the results show a general overview about the respondents’ familiarity with BIM.

All respondents answered this question. 67% (including all architects) claimed that they have high or very high awareness of BIM. Result shows BIM is not a new concept for most practitioners.

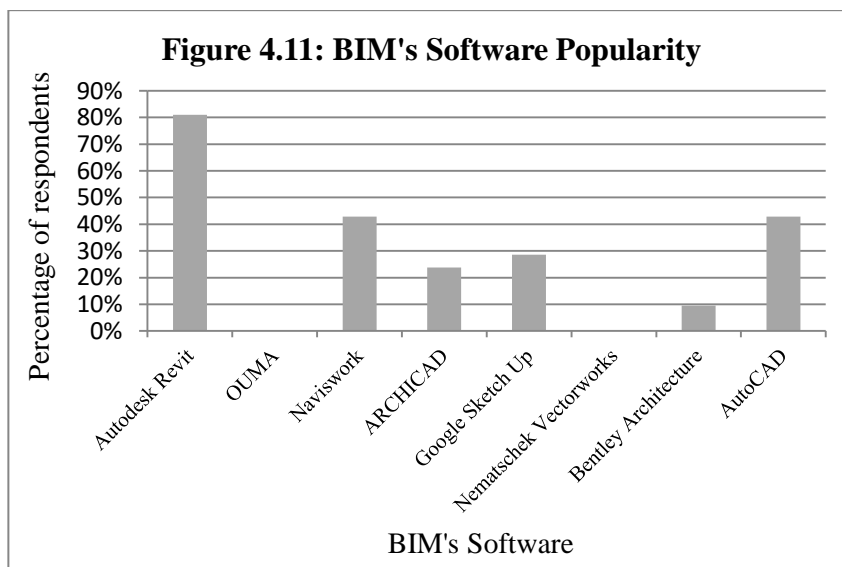
17) If you have ever used BIM for any of the tasks below on your work, Please indicate which of the following tasks has been done by BIM in the project that you are involved (Can choose more than one answer)?



This question is designed to more specifically find which BIM's tools are most commonly used by practitioners. Specifically, this question's result demonstrates the popularity of BIM's capability for environmental analysis and sustainability certification, which are directly related to the building's energy consumption.

Respectively, the most popular tasks which BIM is used for are: Visualisation (76%), Building Design (76%), Clash Detection (67%), As mentioned in the section 2.3.4 and based on the results, it seems that BIM uses are still quite narrow when compared with available functionality. The two aspects of environmental analysis and sustainability certificates appear to be not heavily used. .

18) Which one of the (software) do you use most often (can choose more than one answer)?



As mentioned in the section of 2.3.2, BIM can be considered as an approach or strategy for information management which is highly dependent on the tools and software that are designed in this regard. Therefore, any firm or designer who intends to use BIM, they need to know what tools and software are available with the BIM software. Knowing which tools are most commonly used by designers is useful to evaluate its capabilities specifically regarding energy analysis.

Autodesk Revit (81%) and, after that Naviswork (43%) along with AutoCAD (43%) respectively, are most popular tools which respondents declare that they are using most often. It is important to note that AutoCAD cannot support all identified aspects which are mentioned in Q17. It is not possible to conduct most of these tasks with AutoCAD because of the lack of parametric design capability. However, Autodesk Revit is a parametric design tool which provides interfaces for structural analysis through Robot Structure or energy analysis through Insight 360. Autodesk Revit and Naviswork are both parametric modellers' tools that are popular with practitioners, and as widely discussed in the literature, there are lots of advantages in parametric modelling for conducting different tasks. Since different parameters such as sun behaviour, wind, shape, size, and building orientation influence on building energy consumption, parametric modelling is required for more accurate energy analysis.

19) Do you ever employ any of the listed tools for Building Energy Performance Analysis (BEPA) purposes (Can choose more than one answer)?

This question specifically is designed to evaluate the respondents' experience regarding BIM tools which can be used for energy analysis. A list of software highlighted in the literature review section 2.2.9 formed the basis of the responses for this question. The option of "other" is provided so that if the software which respondents are using is not in the list, they can introduce it. Most of respondents (57%) have never employed any BPA tools. Autodesk Insight 360 and Sefaira are used by 19% and 15% of respondents respectively. After them, Design Builder is used by 14% of respondents. Comparing the results from this question with the previous question which showed that 81% of respondents are familiar with Autodesk Revit suggests that most Revit users are not using the available interface of Insight 360 in this software and GBS engine.

20) How do you rate the user-friendliness of building performance analysis tools?

This question is designed to assess the perceived user-friendliness of BPA tools based on practitioners' opinions. 50% of respondents who answered this question believe that BPA tools (include all tools that they are using them) have low and very low user friendliness and the other half believe that they have average user-friendliness. This, perhaps, suggests that BPA tools are not still easy enough to learn and use by practitioners. User-friendliness may increase the motivation of users to employ such tools. Software companies which are developing these kinds of tools may need to pay more attention to this point.

21) If you have ever used any tools for energy performance analysis, how do you rate them based on their accuracy and reliability?

This question is designed to evaluate accuracy and reliability of energy modellers' tools based on the respondents' opinions. Although most of respondents are designers, they are not energy professionals, but have some experience in their firms regarding design for energy and energy analysis. 75% of respondents who answered this question claimed that the accuracy of BPA tools is average. It means they cannot predict the real performance of building very accurately and the real scenario in operational phase could be different from the model analysis in design stage.

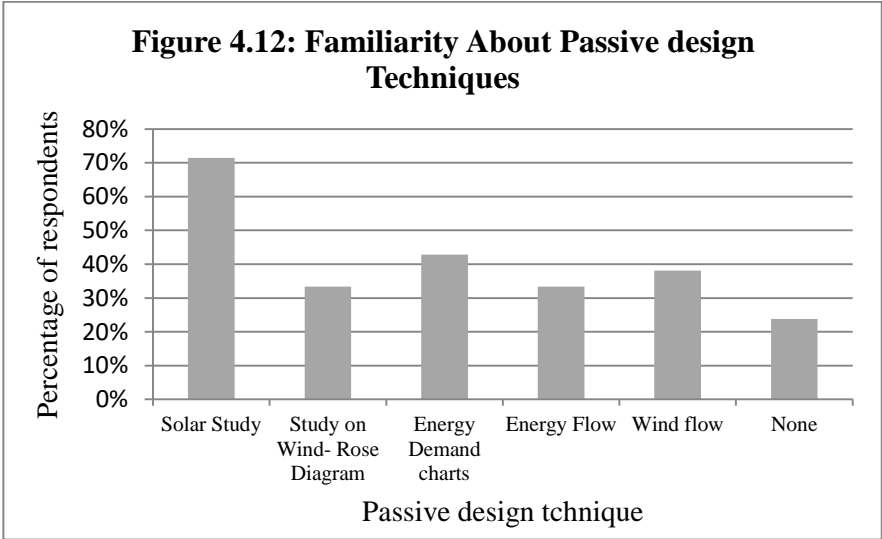
In the literature, section of 2.2.9, issues regarding the accuracy of BPA tools are addressed and the result from this answer shows that this is still an issue in design for energy. That means while this tools are starting to be used by designers, software developers need to work on their product to increase their accuracy and reliability. As mentioned previously, these tools can have value when comparing different designs. It must be noticed that like cars' fuel consumption, buildings energy consumption is not just about how it designed. The users' behaviour has a significant impact on their consumption. People temperature comfort zone, their culture and other factors which are difficult or impossible to predict by a specialist or tools can influence on building energy consumption. Subsequently, those factors can increase the difference between what is expected and what is really consumed in a building.

22) Which tool/s you consider as the most accurate and reliable?

This question is designed to investigate the suggested tools for BPA based on its accuracy and, identifying the perceived benefit of tools in use.

42% of respondents answered this question and between them, 75% identified that Autodesk Insight 360 has average accuracy for predicting building energy performance. Therefore, it is possible to claim that while there is no very accurate tool for energy analysis, in comparison to the other tools, Autodesk insight 360 is the most accurate one in the view of the sample.

23) Please indicate which of the techniques below are you familiar with and have ever used in any projects



This question has very close relationship with question 7 in the first section. While question 7 is designed to find which natural elements designers consider as the most important ones, this question is looking for the methods which designers employ when considering their low energy design. Solar had been chosen as the most popular natural element to consider and, based on the result, a solar study is the most popular technique which is a confirmation of the importance of sun as the most considered natural element with 71% of respondents using a “solar study” technique. After that, “wind-flow” and “energy demands charts” are the second popular techniques between designers and then, “energy flow” and study on “wind-rose diagram” are both less widespread in their use.

While the combination of wind-rose diagram and wind-flow can improve the design for energy, the wind-rose analysis diagram is the least popular approach. Studies about wind flow and wind-rose diagram are important to choose the best shape and orientation of a building based on the wind direction and what designers desire.

24) If you follow any steps, framework or guidance in order to design high energy performance buildings, could you please briefly introduce it (please indicate the steps and tools that are being used)?

This is an open answer question which is designed to collect experienced respondents suggestions, opinions and recommendations for designing an energy efficient building. Therefore designers who intend to increase their design efficiency would know which steps are the most popular in the current design area.

The employed principles which respondents mentioned to them are:

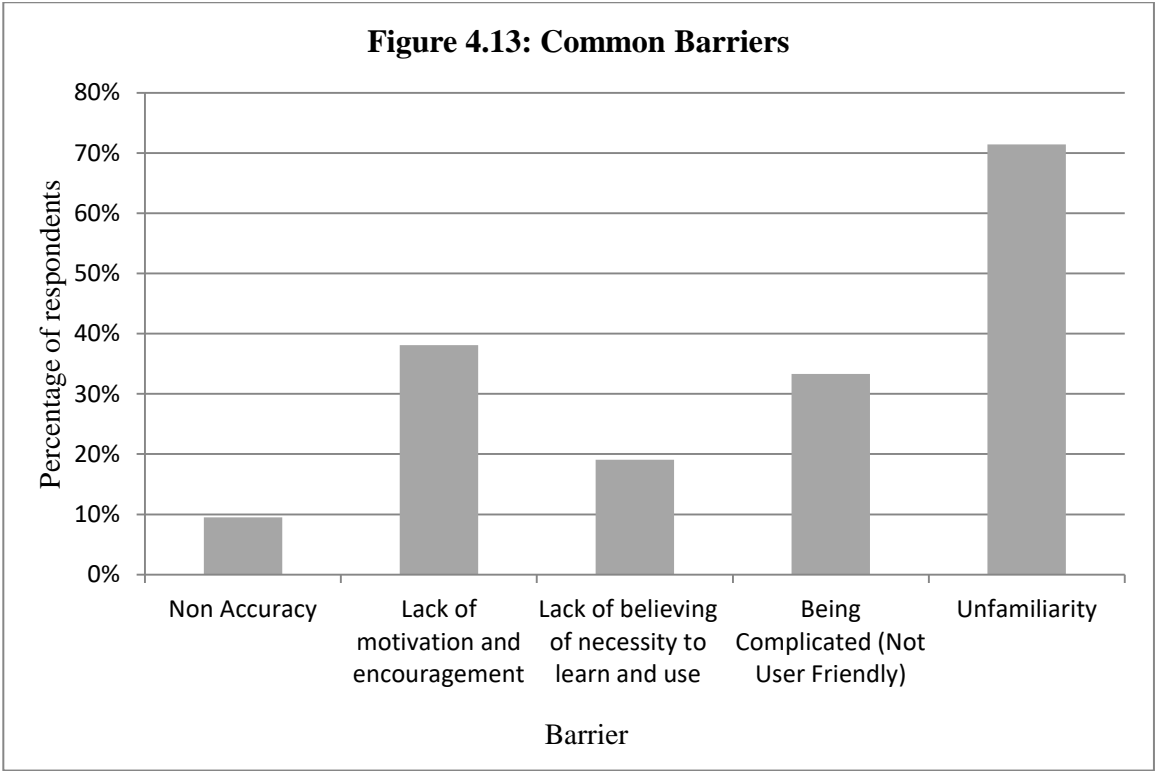
- Trias Energetica: This strategy includes 3 main concepts; first of all it encourages the designers to reduce building demands for energy by avoiding waste and implementing energy saving strategy. Next, designers must consider passive strategies which guide them to use renewable energy like Sun and Wind instead of fossil fuel. Last concept suggests using the energy which is produced by fossil fuel in the best efficient way.
- First of all the building must be designed without any equipment and system in it. The performance analysis is conducted on this design then based on the results of analysis and obtaining the proven of necessity for adding equipment and system, they will be added.
- Canada Green Building Council
- LEED
- National building regulation and codes

Based on the results, most designers prefer to follow the existing standards and tools such as LEED, Canada Green Building and other national regulations which are prepared by national governments. They are widely used by designers and engineers in design and construction industry. Trias Energetica has been developed in 1979 by the Urban Design and Environment study group at Technickal University of Delft. It is three steps guidance, when energy efficiency is considers in building sector. The three steps in the strategy are: reducing the demand for energy, using sustainable sources of energy, and using fossil fuel in a most efficient way (EURIMA, 2018). One of the respondents has noticed to this strategy. No-one mentioned to any specific framework or guidance which was prepared by an individual people or organization. One of the respondents briefly described how he is conducting

performance analysis first without considering any equipment and system installed, then based on the result he adds required systems and equipment.

While in the standard such as LEED or BREEAM there are lots of suggestions and guidance for increasing the efficiency of the design, they mostly focus on the final product with all equipment and system for analysis and certifying them. Based on the answer of this question and question number 13, performance analysis is not just for certifying. It can be used in different stages for gathering required information about a project and understanding the project requirements for increasing its performance.

25) What do you believe are the most common barriers for architecture practitioners to use software and tools (like Revit) for studying, analysing, and designing high energy performance buildings?



This question is designed to identify the challenges which designers are faced with when conducting energy modelling. This question is similar to question 11, both of which are investigating the barriers and challenges for practitioners when designing energy efficient buildings.

All respondents answered this question. 80 % of them choose the provided answers and 20 % mentioned other barriers such as:

- Lack of Time and Cost Support
- Never was their responsibility to conduct such an analysis
- Don't Want to incur the liability

75% of respondents checked “Unfamiliarity”, which shows it is the biggest barrier. After that “lack of motivation” with 35% and “being complicated” with 35% are next. The combination of answers from this question and question 11 indicate that unfamiliarity, being complicated and not user-friendly, lack of the knowledge, and time and cost considerations are the biggest challenges for practitioner in dealing with building science and energy modelling.

In continue a conclusion from the result analysis which includes main out comes are discussed.

4.6 Conclusion and Main Outcomes

The third objective of this research is to conduct a survey with architects in UK and Canada on the current process and knowledge regarding HEPBs design. This objective is covered in this chapter (4). Questions in the survey with the answers from respondents are presented and analysed. Based on the structure of questionnaire and results, four subjects are extracted. These subjects contain the summary of the results analysis from the survey and main outcomes which are discussed in continue:

4.6.1 Respondents' Background

At the beginning of research the demographic questions are considered when assessing a respondents' opinion as guidance. There was an assumption that answers from respondents with more experience and higher education may provide a reasonable source for recommendations. There was also a consideration of respondents in different countries or cities to see potential differences of approach to design. The location which respondents have worked has an important impact on how they respond. While 75% of respondents had experience in developed countries such as UK, US, EU and Canada, the others' work experiences were in the developing countries such as Turkey, Iraq, Jordan, and Nigeria. All the respondents who have experience in developing countries have post-secondary degrees from developed countries. The results shows that the respondents who just have degree in a developed country may have the same knowledge regarding energy efficient design and BIM but they use their knowledge less than respondents who has both experience and degree in a

developed country. It may be because of the lack of suitable background and context, terms and conditions, regulations and lack of enough attention to these subjects in those countries.

Regarding design for energy efficient building, the results demonstrate that in the different locations, practitioners pay more attention to the different issues based on the city forms and weather conditions. As an example, respondents who are working in cities such as Toronto which has a considerable number of high-rise buildings, they pay more attention to the wind and its behavior at the top and bottom of buildings.

Results show that practitioners who have more experience in a developed country generally will have more experience of the design of energy efficient buildings. They are also more likely to have been involved in the process of energy efficient building's design, but appear to have less experience of BIMs energy modelling and simulation tools. Analysis of younger respondents in developed countries and who have less experience indicated that they have good knowledge regarding BIM and design for energy buildings, but they were not directly involved in the process of energy modelling.

4.6.2 Certification Standards

There are different certification standards such as BREEAM, LEED, Green Globe, and BEAM. They are widely used in different countries as an assessment method and assigning a credible environmental "label" to buildings. They are designed to reduce the negative impact of buildings on environment through providing knowledge and information of design and construction stakeholders about different building elements such as material, energy, and land-use. Therefore, familiarity with these standards and understanding how they work as an assessment method can be useful for practitioners who intend to design a sustainable building. Section two of the survey addresses this subject and investigates the existing general knowledge and awareness, the importance of each factor, and more specifically the position of energy elements in certification standards between practitioners.

The analysis of this section shows that, while most of respondents had claimed that they have more than average familiarity of the standards such as BREEAM and LEED, including being directly engaged in projects with the certification, detailed question about the weighting of different elements identified that just 30% of them were aware of the impact of energy issues on the final score. The results demonstrate that energy is the most popular issue identified by practitioners which at first indicates this view could be because of the weighting system, but when the answers of other questions regarding the importance of each element were analysed,

it shows that many of practitioners were not aware of the values within the weighting system in these standards and the value of energy in comparison to others.

Therefore, more detailed knowledge of the common certification standards may be needed by practitioners. It is true that certified assessors are assessing the buildings, but understanding how the certified standards are designed and what are the important points can be useful for practitioners who are involved in design and construction field.

4.6.3 Design for Energy

In the third section of survey, two factors of 1-individual awareness and readiness of practitioners, and 2-the organizational awareness and readiness regarding design for energy are evaluated. There was an aim to use the experience and knowledge of experienced designers and firms to provide recommendations and suggestions. Both design and analysis factors regarding design for energy are considered in the survey.

4.6.3.1 Individual Awareness

Regarding energy efficient building design, two factors which required individual knowledge and awareness are considered,

1- The design for energy includes thermodynamic rules and analytical process.

Results from questions which are designed to evaluate the respondent's awareness of design for energy (largely about thermodynamic rules and passive design techniques) show that most practitioners say they have average and more than average awareness of these issues. Architects are mostly involved in geometrical design, which has considerable influence on thermodynamic behavior of the building. Therefore, familiarity with thermodynamic rules and building physics can be very useful. Based on the results, less than 15% of respondents "always" use their knowledge of building physics during their design practice. This lack of using the knowledge can be for different reasons. While it was not directly asked why they do not use their knowledge for design for energy, the answers from the other question about the barrier for design for energy shows that factors such as:

- Complexity of required analysis and unfamiliarity about with tools and software
- Defined roles and responsibilities within the project team
- Lack of client demand.

However, 60% of respondents declare that, “sometimes” they use their knowledge in the energy efficiency element of their design work. This may show a potential for architects’ to use their knowledge more often.

Maybe this goal can be achieved through introducing the importance and effect of using design for energy knowledge and conducting energy analysis to architects. This can be more effective by providing appropriate tools and software which can facilitate design for energy and related analysis. Supporting architects financially and through regulation and developing their roles and responsibilities need to be considered as well.

2) Passive design strategy:

Regarding passive design techniques, results show that solar, wind and climatic conditions are the main issues considered by architects. Natural elements have considerable impact on different aspects of a building, such as structural, architectural and HVAC designs. They must be considered to manage occupants’ comfort by providing natural lighting, solar heating, and natural ventilation, shadow movement and solar heat gain during specific times of the year. Wind studies are required for structural design especially when the project is a high-rise building. Additionally, wind and solar energy can be used for generating power on site to provide part or full energy demand of a building. Capability of power generation through natural elements such as photovoltaic panel or wind turbines were mentioned by 5% of respondents which can show the lack of enough attention to these options.

Same respondents (50%) who explained about the type of passive design solutions declared that accessing required information about natural elements is not difficult but it seems that is not an easy task for others. Results show that using software and Web surfing are the most popular sources. For experienced designers who explained about the type of passive design solutions which they used, the software and databases are the first priority source for accessing to the required information about natural elements.

4.6.3.2 Organizational Scale:

Architects are deeply involved in the process of design and, based on the survey, it seems they equipped with appropriate knowledge and awareness about the design for energy techniques. But, results show that most of them are detached from the related analysis which means they are dependent on other professions to see how their design is performing. Results

show that in the design and construction industry, mechanical engineers usually conduct energy analysis.

The detailed design was expected to be the most popular stage for conducting energy analysis because of availability of all details, which can influence on the analysis. However, results show that design development is the most popular stage. 50% of respondents are aware about the tools and software which are used in the process of design for energy analysis. 20% of respondents were never involved in a project which BPA is conducted. 30% of respondents declared that they were involved in projects which BPA is conducted, but they don't know what software and tools have been used. It may show the lack of engagement with this element of the process. Performance analysis does not appear to be defined as a responsibility for architects, but as they are generally involved in all design stages from concept to detail, and their decisions have considerable impact on the results analysis, therefore their involvement in energy modeling and analysis can increase the efficiency of the work process and final product.

4.6.4 Building Information Modelling

According to the results of the survey, BIM is widely used and understood among practitioners, especially in developed countries. However, not all its features are used by the designers. They generally used BIM for geometric design, clash detection and simulation. Using the capability of BIM for performance analysis is not very popular between practitioners. Based on the results, there are some issues such as:

- 1- Respondents who have experience with BIM tools believe that the tools are not accurate enough and not user-friendly, issues which must be considered by software developers.
- 2- Advantages of using the non-advanced performance analysis during design by architects is not considered enough. These advantages may need to be introduced to new architects by educational organizations, and for graduated architects through seminars and periodical retraining programs.
- 3- Introducing and explaining the advantages of using BIM especially its capabilities for increasing performance of the product to owners and clients. Then encouraging owners for investing in project which are designed and modeled through BIM tools by governments other organizations which are responsible for regulations and rules.

For new designer and other firms and companies which intend to employ BIM tools, based on the result Autodesk Revit and Naviswork are two most popular tools between experienced designers. None of the energy analysis tools are selected as very accurate, but Autodesk insight 360 which can be accessed by Autodesk Revit has been chosen as the most reliable and accurate one in comparison to other tools for predicting the energy performance of a building. Based on the results, since practitioners are familiar with BIM, the powerful parametric design modellers (BIM tools), can be considered as an appropriate platform for engaging architects more with BPA.

In this chapter, results from survey are presented in four sections and the results have analysed and interpreted. In the next chapter, the results of the survey are combined with those of the literature reviews and discussed in detail.

5.0: Chapter 5 - Discussion

In this chapter, all the outcomes of earlier chapters are woven together to show how this study addresses the research objectives, specifically the last objective of the research, which is: “To establish recommendations for improving process of design to better enable designers to design HEPBs using BIM tools”.

The reasons for turning to this research are discussed in detail in chapter one. There is a brief discussion of the research question and the reasons that have encouraged the researcher to conduct such research. Then, the main findings of this research are presented based on the results of the questionnaire as well as a discussion of how the relevant literature is reflected in the results.

5.1 Revisiting Research Question, Aims, Objectives, and Rationale

This research is designed to answer the following question:

How can BIM be used effectively to increase the efficiency of the design process and manage the energy performance of buildings?

This question and the following findings are at the core of the research, forming all of the previous sections of this study.

The statement from Anderson, (2014) about the detachment of architects from energy performance analysis (EPA) encouraged the researcher to explore the question. The research was developed with no prejudice about the potential role of architects in designing buildings with optimal energy consumption. The researcher needed to be familiar with the architectural design process and the position of designing for energy in this process. Also, he needed to identify the role of the people who are involved, the tools which are in-used and architectural processes in order to design a sustainable product. The literature review helped develop a good understanding of these issues. But there were other questions which need to be answered such as:

- Are architects detached from EPA?
- Is architects involvement in EPA significant? Why?
- Can architects’ decisions influence which principles of an energy-efficient building are applied?

- What kinds of requirements are necessary to improve energy consumption in a building based on architects' responsibilities?
- What are the barriers for architects to address the energy matters in their designs?
- What is the role of BIM in improving architects engagement with EPA?
- How familiar are architects with the possible BIM solutions?

Again the literature review has helped to find parts of the answers to these questions, to answer the questions more comprehensively, the researcher decided to investigate the design and construction field through a survey. Therefore sub-questions are created from these leading questions, and the questionnaire has been borne based on all of them.

The next section covers the conclusion from literature and result analysis among with some recommendations.

5.2 Main Findings

This section discusses about the themes which are the representative of main findings from survey. In each theme, the issues are explored and series of recommendations are discussed. In this section, the main findings of this study are divided into three main sections. They are standards and policy, professional issues and individual issues. The themes associated with each of these parts are discussed further in the commentary.

5.2.1 Standards and Policy

Globally, there are different voluntary certification standards such as LEED, BREEAM, BEAM, and Green Globe for assessing compatibility buildings meet environmental performance indicators for delivery and performance. BREEAM is the pioneer standard which originated in the UK and is widely used in European countries such as UK, Germany, Spain, Norway, and Sweden. It is the second most recognized standard that survey respondents apply to their projects. The most popular standard applied in design and construction project of the sample is LEED. It is a US-originated standard which is widely used in North America. Canada Green Building Council provides the Canadian version under USGBC license. All respondents who were in Canada and the US are declared that they are familiar with LEED. Unfortunately, these credential standards are not very popular among those who have spent most of their professional lives in developing countries. When it comes to the familiarity with the content of these standards, energy is chosen as the most popular one. Further questioning about the details as to how the standard is applied shows that even

respondents from developed countries are not fully aware about the details such as the application of the weighting system. Therefore, even in developed countries, more attention is required about details of regulation and energy certificate programs between practitioners.

Just following the related existing regulation, such as Part L of the UK Building Regulations, to meet environmental issues to meet the minimum requirements does not seem to be enough. Even in developed countries, encouraging practitioners to explore existing stretching standards in certification schemes in detail is highly recommended. Periodical training courses are recommended to familiarise and update architects with the contents of the available standard in each country.

5.2.2 Standards for BIM

UK standards for BIM, such as BS 1192 and PAS 1192, provide a framework for the application and use of BIM within construction projects, including the design process. Therefore, these documents along with internal procedures and practice provide a path for implementing BIM processes and software, including Bentley's AECOsim and Autodesk Revit (Mc Partland, 2017; eBIMc 2019). The BS 1192:2007 is the third edition, which was published in 2017 as a “collaborative production of architectural, engineering and construction information code of practice”. As described in the standard, it is a methodology for managing production information, distribution and the quality of construction generated by CAD or other systems through a disciplined procedure for collaboration (BSI, 2007). Building SMART Canada (BSC) was established to participate in the development of international BIM standards as a representative for the Canadian market, and is the recognised owner of the Canadian BIM Standards (Building SMART, 2019). The ISO 19650 is the international standard for BIM, which has been developed based on the BS 1192-2. Both the ISO 19650-1 and ISO 19650-2 were developed by the ISO technical committee to create an international framework, which provides an opportunity for collaboration in the industry amongst projects and national borders (Naden, 2019). However, this research neither deals with the BIM standards. Investigation about the BIM standards and their effects and values for utilising it with relation to its increase in building energy efficiency, can be conducted in further work and research.

5.2.3 Sector Level Issues

The sector issues refer to issues which arise under the processes and organizational environment of the workplace. It deals with issues related to the design of HEPBs that may

mean architects do not play as much of a role in some of them, and are more influenced by other factors such as customers, government and laws. These issues are discussed in this section. However, there are also issues that architects have a significant role to play in them and their role as well as their individual skills influence to the whole sector. These issues are discussed in next section.

5.2.3.1 Client Demand

In this research, the word "client" refers to someone who wants a building that has been designed and constructed. A client can be a person, group of people or even government. "Client demand" means what they want from design and construction teams. The client of a construction project is not necessarily the end-user of that building. For example, usually, the customer or entity that wants to build a commercial building or high-density residential project is not the end-user. These kinds of projects may have diverse end-users. In such projects, the capital cost is often traded off against the operational cost. In other words, client's interests stand against the interests of the end-users. This is one of the reasons that there is not much desire among clients to invest in increasing energy efficiency and is known as a split incentive (Bird and Hernández, 2012). Increasing the energy efficiency of a building usually requires more investment in the design process, and especially the construction phase. This is also true for other topics, such as the use of new strategies such as BIM. Using a strategy of BIM and exploiting features such as clash detection, feasibility studies, model-based estimating, and construction sequencing can help reduce client cost and save time while providing end-user benefits such as the automatic generation of facilities management information.

Client demand is one of the main issues that respondents have identified as driving the demand for low energy buildings and the application of BIM. When respondents were asked about the barriers of using BIM for performing EPA, the lack of motivation and encouragement was cited as the second biggest problem after the lack of familiarity. Requests to use BIM tools in the design and construction of a project and supplying related costs by client can be a great encouragement for designers and architects. In the national BIM report which is released by National Building Specification (NBS) in 2019, "No client demand" was cited as the biggest barrier for implementing BIM in construction projects. The report noted that, in their research, 65% of respondents mentioned to the "No Client demand" as the barrier for using BIM (NBS, 2019). Possible solutions may be: Introducing and familiarizing

customers with the benefits of new strategies and tools, changing the content of contracts and enacting related laws through governments, and providing incentives for using these strategies.

5.2.3.2 Contractual and Liability Issues

Architects may be reluctant to have new responsibilities imposed on them. As some have pointed out, "we have a lot of work to do" and "it has never been our job to perform EPA" and " we don't want to incur the liability". As discussed in section 2.2.5, the purpose is not to impose a new task to architects for which they incur its liability. Rather, the goal is for architects to accomplish their primary task, which is the geometric design of the building with higher performance. Also, BIM models may help them to interact and collaborate with other building performance professionals leading to more robust design solutions. It may be necessary to make changes in contracts and look at allocating assignments for each designer. For example, architects should be asked to perform simple performance analysis on their designs prior to sending it to the relevant experts. It should also be noted that the analysis performed is solely to improve the geometric design and that the responsibility for controlling the performance of the building does not lie with the architect.

5.2.3.3 Design for Energy Practices

An energy-efficient building requires multiple tasks to be undertaken in the period of design, such as gathering data and information, planning, reviewing codes and standards, sharing ideas and plans, as well as being knowledgeable about designing an energy-efficient product, creating models, and testing them. Architects have a significant role during the period of design, conducting many of these tasks that decide ultimate energy performance. The geometrical design of a building which includes size, shape, and orientation is the architects' responsibility. These specifications are important when passive techniques are considered and they have a considerable effect on the building energy loads. Few architects (less than 20%) have much experience with designing for energy efficiency and most of them have an average experience in this regards. On the other hand, less than 15% of architects who are experienced in design for energy declared that they always use their knowledge. This group of respondents includes architects who declared that they have experience with this issue.

This research has not asked why they do not always use their knowledge. Possible reasons for this may include that they feel their knowledge is not sufficient, or to follow the relevant

codes is enough, or there is no client demand. The majorities of the respondents are aware of the value of natural elements (sun, wind, etc.) in passive design and, more specifically in developed countries, know where to access to relevant data and information. 71% of respondents said they were familiar with and used at least one technique associated with the evaluation of natural elements, but only 40% of respondents have suggested ways to interact with natural elements. Exploring the answers of these questions shows that while it is not difficult to access natural element data and information, converting this data into comprehensible information and applying them to evaluate their effects on the project is not an easy task for most architects. To this end, architects need skills such as working with existing tools and software, transferring data and interpreting them. The next section deals with this issue.

5.2.3.4 Skills for Design for Energy

Regarding design for energy, two subjects are considered, 1- passive design techniques and 2- evaluating (analysing) design performance based on energy consumption. The first skill required to have relevant knowledge such as passive design techniques, familiarity with the building's physics, obtaining the necessary data and familiarity with factors affecting the energy consumption of the building. This issue was discussed in the previous section 5.2.3.3.

The next step is to use this knowledge and data, which requires related skills such as understanding and interpreting solar or wind studies. These studies show their impact of these natural elements to the building and they can be used for increasing the efficiency of energy consumption. Given that the geometrical design of a building has a direct effect on how it interacts with natural elements. The above studies help to determine the optimum geometrical design based on the needs of the building and the effect of natural factors to reduce energy demand. Between 41% of respondents who declared that they know how to study at least one the natural elements, the solar study is the most popular one. However, as discussed, few of them are applying this knowledge in projects.

After examining the effects of natural elements and optimizing the design based on the obtained information, knowledge of the HEPB's design, and following existing codes and standards, the next stage is building modelling. Energy modelling helps designers to predict design performance after construction. Although, according to literature and other research, modelling tools do suffer from “gaps” between designed and as built performance, they can still provide good feedback on how design changes affect energy consumption. This feature is

especially useful for comparing different designs and choosing the optimal design. Unfortunately, there is not much knowledge among architects about building energy modelling. Less than 20% of respondents claimed to have much knowledge about this skill. Most architects have never even participated in the EPA process and are not even aware of the tools used for this purpose.

Although it is not expected that architects will replace the specialist consultants that normally have responsibility for EPA, some basic familiarity with this skill could help them design high-performance buildings. In particular, this capability is accessible through BIM software, such as Revit which is popular among architects. Familiarity and engaging architects with EPA can help them better understand what goes into the process of developing a high performing building. So an efficient and smooth design process will be achieved which in that there is a better understanding among stakeholders. It also helps that the geometric design that is sent for technical design has less need to be sent back and have changes made.

5.2.3.5 Process Issues

The survey data suggested there were a lack of architects' involvement, as well as little interest of architects regarding their involvement in EPA confirming the statement made by Anderson, (2014) regarding the detachment of architects from building performance analysis processes. Based on the survey results, there is a little familiarity with the relevant BIM tools and their features by architects. A lack of motivation of architects to know what tools or software are used for EPA can be one of the reasons, but this unfamiliarity may show a shortcoming in the process of design. If an architectural design is sent for BPA, should the architect not be aware of the result and details of the analysis? As discussed earlier (Section 2.2.3), it seems the traditional design process in which activities are performed sequentially is still very popular. Additionally, connection, communication, and cooperation between different sectors who are involved in the process of design and analysis possibly are not well structured. This research did not investigate these issues through first-hand data collection, but the literature review identified potential solutions for these problems through introducing new approach and strategies such as Set-based design, concurrent engineering, and BIM which are discussed in, sections 2.2.3 and 2.2.4.

The importance of the design process to build the right product is imperative. Buildings as the final production of the design construction process are no exception. Conducting more

research may help to investigate the current processes of designs in the design and construction industry to recognise the deficiencies and potential solutions. Based on the results of this research, it might be considered that in some of the construction industry there are weak connections between the designers and the various sectors involved with a construction project, and if this is not the case, this connection is not appropriate and efficient to drive a more integrated design process. As discussed in section 2.2.4 a combination of a clear BIM strategy linked with an approach such as set-based design with concurrent engineering (SBCE) could potentially make a platform through which a design team considers a set of possible designs instead of one and conducting activities in parallel instead of series (step by step). Such a platform requires very efficient connection, communication, coordination, and cooperation between different designers and sectors and BIM can have a significant role in this regard.

It may be recommended that architects (as geometrical designers) and energy specialists (as technical designers) work together from the early stages of a project. Instead of creating a design and working on different versions of it, maybe it is better to consider various options of designs and working on them iteratively until the optimum design is achieved. This should be supported by a BIM-based platform for sharing data, information, designs which all of them have access to it to share their opinions and see the results. This platform can help designers and energy specialists to work together concurrently, therefore if architects make a decision, other practitioners including energy specialists can be aware of the decisions and the effect of the decision on the product can be analysed and evaluated. In this way, architects do not need to send their design to the energy specialist and wait to receive the results. This traditional method has its difficulties such as repetition, possibilities of losing data, and possibility of format incompatibility. All of these can be time consuming, and potentially lead to misunderstandings and conflict. Eastman et al., (2011) discussed that fragmented traditional facility delivery methods may cause the possibility of conflict among members of a project, the possibility of delay and rising cost. However, the effects of these difficulties may reduce if all practitioners share their work in real-time in a platform where all formats are compatible, and all practitioners have access to it. Figure 1.5 in chapter one compared the traditional method versus BIM-Based method and demonstrating these recommendations and the advantages.

5.2.4 Individual Issues

Individual issues refer to issues that are more directly related to architects' ways of functioning as a person. These include issues that affect how architects work individually. For example, academic background and place of earning experience can be named.

5.2.4.1. Skills, Education and Training

In general, it seems there is more awareness about design for energy efficiency in comparison to BIM, which may be because BIM has only recently been considered in design and construction industry in terms of its wider capabilities, with many capabilities not used at the highest level (as identified in Level 3 UK based) by all practitioners. For example, based on research which has been conducted by NBS in 2019, in UK, 71% and in Ireland 65% of respondents declared that, level 2 is the highest level which they have reached (NBS, 2019). While BIM may be better understood by designers in developed countries, just a few of its capabilities are commonly used by practitioners. Of the tasks which can be conducted by BIM, visualisation and building design are the most popular, while other tasks such as environmental analysis and sustainability certificate analysis are generally not considered.

Lack of familiarity of architects with relevant skills is the major problem for both issues of conducting EPA in the architectural design process and employing BIM in this regard. This issue can be addressed through educational programs in universities and colleges for new students or via retraining course for current practitioners. Such courses need to address the requirements for designing a HEPB, including the process and tools along with the capability of BIM in this regards. Keeping the connection between students who graduate in developed countries, with their institutes and attending to related seminars can help them to maintain their knowledge.

5.2.4.2. Developed vs. Developing Countries

Comparing responses from practitioners who have experience in developing countries with practitioners who have degrees and work experience from developed countries shows the second group have more awareness of designing for energy efficiency and the potential role of BIM. Practitioners who have a degree and work experience in developing countries are more familiar with designing for energy efficiency and BIM's role. This may be due to issues such as: existing regulations, codes and terms, better accessibility to data and information, better educational system, familiarity and understanding the importance of energy efficiency between government and people. For example, Melchert, 2007 concluded that having

regulation and standards in developed countries regarding sustainability drive the industry to address energy use issues in buildings. Wu et al., 2018 discussed that, in general the ratio of Research and Development (R&D) input in GDP in developed countries is higher than developing countries. They believe that more research means better responses to the issues of energy efficiency.

5.2.4.3 Locational Factors

Analysing respondents' answers with regards to the locations in which they work shows that the climatic conditions and layout of the cities in which they working have a considerable impact on their prioritisation of how interact with climate factors. Sun and wind are the most popular natural elements among all respondents which architects in different locations have interacted with them in different ways. In section 2.2.7.2, it has been noted that Hens, 2011 and Cao et al., 2016 have discussed how to use the sun's energy to provide heat and energy, as well as how to control it to avoid excess heat on the building.

Practitioners who are working in Canada have emphasized its weather condition. Having very cold seasons in most parts of Canada causes that architects in Canada pay more attention to Solar Heat Gain (SHG) in comparison to solar shading which is mentioned mostly by respondents in the UK. Generating power through solar panels is only mentioned by respondents in the UK. However, the number of sunny hours in the city of Toronto (2066 hours) is higher than Manchester (1416 hours) (Current Results weather and science facts, 2019). That means there is potentially a greater capacity for PV to generate solar power in Toronto. However, power generation by PV panels in UK is almost 4 times more than Canada (13000MW in compare to 3040 MW) (nrcan, 2019). Energy costs in Canada are lower than in England. Electricity is almost 10 times cheaper in Canada (call me power, 2019). Also it should be noted that, the UK population is more than twice that of Canada.

There is also a slightly different approach to wind in the two countries. In the United Kingdom, natural ventilation has been mentioned, while high-altitude and street-level wind studies are a major modelling issue in Toronto. As mentioned, the main reason for this can be because of Toronto's urban layout, much of which is covered by high-rise buildings.

5.2.4.4 Use of Software

Today, software is an integral part of the design process. Designers use them to perform a variety of tasks such as drawing, calculating, multidimensional design, and analysis (architectural, structural, performance). As a result, being confident and familiar with related software capabilities can save both time and cost when conducting tasks. Concerning software usage, a few points have been highlighted by this research. The survey results show that many architects are unfamiliar with the existing software used to undertake building energy performance analysis. While, in relation to BIM, only some of its tools such as Revit and Naviswork, are widely known. Consequently, there is a lack of comprehensive understanding regarding all the capabilities these tools can offer. Notably, according to the literature review, BIM can be applied for various tasks such as Program/Massing Studies, Building Assembly, As-Built Model, Clash Detection, and Code Reviews. Mainly, Visualisation, Building Designs, and Model Based Estimations are the most popular tasks conducted using BIM among architects. Given that architects have specific tasks and are not expected to perform those of mechanical and structural designs, familiarity with some of these capabilities could support them to perform their tasks better. For example, it was noted that one of the problems mentioned by respondents regarding not being involved in the energy performance analysis process was a lack of familiarity with the tools available for this purpose. Moreover, some BIM tools like Revit, allow designers to access other features such as EPA and further powerful design elements. Nevertheless, these features remain unused by many architects. In addition, there are concerns about the software including its lack of accuracy and user-friendliness. Among the respondents who had experience of utilising the EPA tools, most of them believed that the results were inaccurate and the software was not user-friendly. Therefore, whilst educating architects with software capabilities can be achieved with the help of training and workshops, increasing the accuracy and user-friendliness should be considered by the developer companies.

5.3 Key Issues and Recommendations

By reviewing the answers given, the barriers that the respondents pointed out regarding EPA and the use of BIM tools (in this case for architects), included: Insufficient related knowledge and experience, being complicated, inaccuracy and poor user-friendliness, client demand and financial support, as well as a lack of interest in being involved. As discussed above, some of these barriers may gradually be remedied with the help of reforms to educational systems,

related laws and regulations, the development of contract content and their defining responsibilities. At the same time, it seems that a platform where the BIM strategy is implemented with the aim of engaging architects with EPA would be helpful. This could be a potential BIM based platform for designing HEPBs, which contains two levels; macro and micro. The macro-level can be considered as the main architectural design stages, such as concept design, design development, and detailed design. Whereas, the micro-level would be the procedures, which are processes that go through all the design stages. These processes include collecting, creating, connecting, and correcting which are introduced by Coates et al., (2010).

5.3.1 Macro Level (Stages)

The macro-level is a sample of the BIM-based energy-efficient building design process, which is prepared based on the literature review, and survey analysis. This process is related to design, modelling and analysis of an energy-efficient building, where architects have the primary role. The Autodesk Revit is considered as the main BIM's tool and Figures 1.4, 1.5, Table 2.1, Diagram 2.1, and Appendix J are the main basis of this process.

Stage One: Concept Design

- A set of concepts are created;
- Accessing to required data and information about natural elements through available tools such as Insight 360;
- Wind impact and solar movement are conducted based on the architects' knowledge, passive techniques and guidance from standards such as LEED or BREEAM (Appendix J);
- Creating general shapes (masses), and determining orientations of the project;
- Conducting simplified energy analysis through available tools such as Insight 360;
- Selecting most efficient concepts for further development.

Stage Two: Design Development

- Based on the passive techniques, guidance and standards such as BREEAM and LEED (refer to Table 2.1 as a sample), developing a set of concepts with more details about the building's envelope, shape, size, orientation, number of floors, size and location of fenestrations, etc.

- Conducting performance analysis through related tools such as Insight 360 to compare designs and select the most efficient one (being connected to energy specialist and engineers and using their knowledge and guidance can be useful).

Stage Three: Detailed Design

Concurrent working between architects, energy specialists, and other engineers who are involved in the technical design is vital during this step. This process includes:

- Sharing a set of developed designs with technical design engineers and energy specialists;
- Conducting advanced energy analysis by energy specialists and engineers;
- Providing required corrections on architectural design;
- Selecting the most efficient design for designing equipment such as PV panels, cooling, lighting and heating systems.

5.3.2 Micro Level (Processes)

Part two of the literature review (section 2.2.5), focused on the importance of decision making regarding the design aims (specifically regarding design for energy), deciding at the early design stages and the role of the architects. In sections 2.2.6 and 2.2.7 of the literature review, the requirements for designing an energy-efficient building are addressed. In chapter one, there is a discussion about the design process and its central themes, which included collecting data and information, connection and communication, creation, test and correction. These themes can be applied in parallel (Figure 1.4) or back and forth connection. The two themes of creating and testing/correcting are mainly related to the architects' involvement in energy modelling. This research studies these fundamental themes for designing energy-efficient buildings and the role of BIM. Further details about each theme follow:

Collecting Data: to create an energy-efficient building, designers deal with two main fields of design; geometrical and technical. In the traditional design process, which is still prevalent, usually these two designs are conducted by different specialists and engineers during various stages and not concurrently. In this process, architects conducting geometrical design at the early stages and at the middle or late stage of the process, mechanical engineers or other specialists conduct the technical design based on a performance analysis of the architectural drawings.

Both the geometrical and technical designs have a considerable impact on the energy consumption of a building. However, even in a modern concurrent engineering process, first the geometric structure is designed subsequently any other analysis and technical design can be conducted. As described in section 2.2.6, reducing the energy needs in buildings (energy load) is one of the critical principles of HEPBs or Zero-Energy building design. There is an opportunity to address this principle in both the geometrical and technical design. For instance, in the technical design, energy demand can be decreased by using highly efficient equipment along with the installation of sensors, and in geometrical design through the selection of the most optimum size, shape and orientation of a building and its rooms. A building with appropriate envelope and airtightness, which is designed in a way that allows natural elements to provide all or part of its needs for lighting and ventilation, would require less energy for heating, cooling, lighting, ventilation and other purposes. Architects are mainly involved in this matter, and their decisions have a considerable impact on further designs. Therefore, familiarity with natural elements such as the sun and wind and their interaction with buildings are necessary to efficiently use passive techniques.

Whilst half of the architects (respondents) stated that the collection of related data and information about natural elements is not a difficult task, for the rest, it was deemed difficult, especially for practitioners in developing countries. This is partly due to a lack of access to the sources, where they can find the required data and information. For any practitioners who are keen to understand which sources are used by experienced architects to achieve the required details on natural elements, the results show that the software and web along with industry networks are still the most popular sources for architects to collect their required data and information.

After the required data is collected, it must be transferred to a format that can be used to evaluate their impact on a project. The solar study is an example of this kind of evaluation. While these sources may provide accurate data, transferring data to the model to evaluate their effectiveness and use them for different purposes, such as the solar study, could cause some difficulties such as data loss. Therefore, the use of related tools like Skelion, SolarPro, Autodesk Ecotect, and IES are recommended to extract information about the natural elements along with relevant analysis. In addition, tools like Ecotect and IES <VE> are samples of BIM tools, which are compatible with other BIM tools, like Revit and ArchiCAD. This compatibility is a great advantage to avoid losing data during the transference stage or format changes.

Creating: as mentioned previously, the four themes of collecting, creating, connecting, testing and correcting can be applied in both back and forth connection. Collecting information is the requirement of creating, but it does not mean that collecting information will stop during creation, rather that it will be continued to enhance the creating. Architects are deeply involved in creating by sketching first drafts, creating concepts, and simulating building models, which are all related to building geometrical aspects. BIM's tools, such as Revit and Naviswork, are prevalent in the field of design creations. Creating advanced energy models requires professional knowledge about building physics and thermodynamic rules, which are not expected from architects. However, a simplified energy model would be created on a building by architects. As discussed in section 2.2.5, improving the efficiency of the model as much as possible through simplified energy modelling, which can be conducted by architects, can increase the effectiveness of the design process and final product.

However, the capability of BIM's tools in this field is perhaps not considered enough by architects. In addition to the advantages of accurate, secure, and fast methods of data transportation between BIM tools, which can be used for advanced energy modelling by specialists, software like Revit enables architects to collect and evaluate the effects of natural elements such as the sun and wind on their design in the same platform. The sun and wind are two of the most popular natural elements, which architects consider for passive techniques. Solar study and wind-rose diagrams can be created during the design period from the concept until detailed design stages to evaluate sun and wind behaviour in a specific location. Although most practitioners pay more attention to the sun and solar study in comparison to the other natural elements, as the sun is a crucial element because of its ability to provide free heat, light and power generation, more attention is required for the study of other natural elements such as the wind. Wind-rose diagram can be created by providing project locations to the related tools such as GBS.

Nearly 85% of practitioners have claimed that they have average or above average knowledge in designing for energy efficiency. Architects can use their knowledge and experience to create different models using tools such as Revit and Naviswork. Also, they can benefit from existing guidance, which is provided by BREEAM, LEED and other certification standards for sustainability, to understand how to use the collected data to create an energy-efficient product. Based on the results, energy efficiency is one of the most critical factors for practitioners in design. However, more attention to the details of certification standards is required. Most experienced architects and large companies are trying to achieve higher scores

and better certification for their products using these standards. The consideration of natural elements and their uses in decreasing building loads has a significant impact on energy consumption. While, modelling the behaviours of natural ingredients aids the study of their effects on the project. The consequences must be managed more efficiently through project requirements, existing codes and following guidance like LEED and BREEAM, and the use of detailed knowledge. Even though most practitioners declare that their familiarity about design for energy is average or above average, only a few of the practitioners proclaimed that they “always” use their knowledge about designing for energy efficiency. Most of the respondents admitted that they only use their knowledge “sometimes”. This issue may require further research and investigation. However, there are many different reasons can be named, including a lack of interest, insufficient familiarity about the tools and software which architects can use, and time and cost consumption.

In an efficient design process, a combination of collected information about natural elements, project requirements, knowledge of design for energy, and the following of codes and standards would lead to the creation of a set of plans. These plans would then require further corrections through different tests for more improvements.

Connection and Correction/Testing: As during the process of design for energy, the themes of connection and correction/testing have an advanced interaction with each other, these themes are discussed together. After collection of the required information and the creation of model/s, it is then time for testing and correcting. Since this research deals with energy matters, all discussions are around the design for energy. However, other aspects of design or sustainability can also be replaced by energy aspects. In most traditional and current design processes for energy, testing is addressed by energy specialists, while architects may only become involved in the correction part. As discussed previously, an energy analysis can be categorised into either “simplified” or “detailed or advanced” methods. As advanced techniques require advanced knowledge, it is the responsibility of the specialists, who can be either mechanical engineers or energy specialists. However, a simplified analysis can be conducted by an architect with existing tools such as Autodesk insight 360. Even if these tools are not entirely accurate, architects can compare design sets in a fast way. This means that they do not need to send the model to an energy specialist and wait for the results. At each stage, architects can benefit from this analysis in terms of iteratively testing their geometric design options. Currently, it may be viewed that architects are not involved enough in any testing and analysis regarding energy. According to the results of the study, nearly one-

third of the respondents did not even know what tools are used for performance analysis in a project in which they were involved. This may show a lack of interest or insufficient appropriate connections between the designers and energy modellers/ specialists. Even if the architects become more involved in the process of energy analysis and modelling, a proper relationship between them and the energy engineers is required in order to share information, ideas, designs, and the results during the design period. Consequently, based on the literature, in sections 1.2 and 2.2.4, the capability of BIM for better, smoother, and more reliable connections among the stakeholders may help and benefit architects and energy specialists when conducting both geometrical and technical design concurrently in an efficient way.

For a simplified energy analysis, some initial information and knowledge about building physics are necessary. As discussed, in all stages of the design, the impacts of solar and wind on a project can be studied. Whilst for this current situation, the develop-design step is the most well-known design phase for conducting an energy analysis, performing a simplified-energy analysis is possible at all three main stages (concept design, design development, and detailed design). In these stages, it is possible to conduct a simplified-energy analysis for evaluating and comparing the effects of different parameters on building energy consumption. For example, the parameters such as the buildings' shape and orientation in concept design; the position of the rooms, windows and doors in design development; and the exact size of fenestrations, materials and layers of envelope in detailed design.

Based on the literature review and the respondent's answers, Autodesk Revit is one of the most popular software packages used by practitioners. For tasks which can be conducted by Revit, its capability for designing, modelling and simulation are noted. Also it is possible to access to GBS engine through Insight 360 through Revit from 2013. Most respondents are not familiar with this option, and among practitioners who are familiar with it, they believe it has average accuracy. However, its lack of user-friendliness for energy modellers is a key issue mentioned by most practitioners. Therefore, these matters of usability and accuracy need to be addressed by software developers. Furthermore, there are other barriers towards the implementation of BIM for energy performance analysis by architects. They include unfamiliarity about conducting an energy analysis and BIM capability in this. Additionally, there is a view that there was insufficient time and a lack of extra support costs which reduce the motivation for architects to get involved in the process of energy modelling.

5.4 Summary

Based on the literature review, BIM can facilitate a simplified energy analysis for architects. However, this differs from the obtained survey data, so it is hard to conclude whether BIM has this capability or not. As most respondents declared that they are not familiar with this capability and have never utilized BIM for this purpose. Nevertheless, as the survey was mainly designed for evaluative purposes, the results from the questionnaire provide an overview of the situations and conditions in the design industry that can be useful. While some of the shortcomings, deficiencies, and opportunities to address these issues have been discussed in detail in this study.

In a summary, the critical parameters required for the design of HEPB using BIM tools by architects in the early design stages based on the results of the study are:

- The results from questions 1, 2, 3, and 4 show that there is an acceptable awareness and readiness to deliver HEPB using BIM tools, including understanding the importance of energy, credential standards such as BREEAM and LEED, and the role of BIM in achieving these awards.
- By considering answers from questions 3, 4, 5, 6, 7, 8, 23 and 24 it is identified there is an appropriate level of knowledge around the design of HEPB or net-ZEB amongst architects.
- Responses to questions 8, 9, and 10 state that for most architects (especially in developed countries) accessing and obtaining the required data and information from reliable sources (specifically wind and solar behaviour) is achievable.
- The results from questions 11, 12, 14 and 23 indicated that technical detail and information around issues such as solar studies or wind study analysis were not easily accessible to the respondents.
- Analysing answers of questions 16, 17, and 18 shows that, possibly there is a readiness to expand the use of BIM capabilities regarding early stage HEPB design. There is a good awareness amongst architects about the use of BIM and its wider capabilities in general.
- This is countered by responses to questions 15, 19, 22, and 25, which look at energy analysis tools specifically. The responses indicate that most architects still are not familiar with energy analysis tools and software within the BIM platform.

- By considering answers from respondents to questions 15, 17, the responses show that method of communication and connection between designers, engineers and other stakeholders dealing with energy performance in the design phase may need to be improved.

The main outcome of this questionnaire indicates that while architects are well acquainted with the principles and indicators necessary for the design of HEPBs, their familiarity with related assessments and analysis need to be enhanced. Some of the issues which may help in overcoming these barriers are:

- No previous involvement in BPA, so architects think it is not related to them;
- BPA can be time and cost consuming; which owners of the project may not support;
- Unfamiliarity about the tools and software, which can utilise BPA for architects.

To improve and resolve these issues, one solution would be to add related courses to academic programmes related to design for energy and the capabilities of BIM, as well as conducting retraining workshops for graduated practitioners, which can help to eliminate or minimize issues related to unfamiliarity. As knowing how to perform a simplified analysis of performance with existing tools can have a positive effect on both costs and time. Additionally, clients and owners can be encouraged through rewritten codes and design processes, or by offering incentives such as tax cuts to pay the fees that may be imposed due to the implementation of BIM for increasing building energy efficiency.

Chapter 6.0: Conclusion

In order to conclude what has been achieved from this study, it is necessary to review the research question:

How can BIM be used effectively to increase the efficiency of the design process and manage the energy performance of buildings?

As well as the aim of the research:

The aim of this research is to evaluate the conditions in the design process in UK and Canada and develop a series of recommendations to better enable architects to address energy efficiency in the early stages of the design process by using BIM tools.

Energy-efficient buildings and BIM are two major themes in the research question and the aim of the research with architects as the main targets for investigation. Both the literature review and survey are designed based on these two themes. In this chapter, a summary of the work carried out in this research will be presented. In addition, this chapter will provide an overview of the research outcomes and how the research aim and objectives have been addressed. Furthermore, its contribution to knowledge and its limitations are discussed. Subsequently, based on what has been achieved in this research, a series of recommendations for further works are provided.

6.1 Conclusion on Literature Review and Research Methodology

In chapter one, a summary of energy-efficient buildings designs and BIM and how they relate to each other was discussed. Then a rationale relating to these two issues as the focus of this research was outlined. Subsequently, the research question and its aim and objectives were identified based on these two themes.

Chapter two reviewed the literature in two sections: the first part referred to drivers for energy-efficient buildings while the role of BIM was covered in section two. In the first part, the concept of sustainability, its indicators and the importance of energy as a major pillar of environmental performance were described. It also described the role of buildings in energy consumption and the environment. After that, the process of architectural design was discussed in detail, as well as the importance of this process for being effective and the role of architects. Furthermore, the significance of making decisions about enhancing building performance in both the early stages and design phase was highlighted. Passive homes were

then introduced along with the role of natural elements and the importance of studying them to meet part or all the building's demand for energy. Moreover, a summary of the knowledge required to design energy-efficient buildings including how to reduce a building's demand, and energy modelling were outlined. The final part of this section reviewed the background of performance analysis, its tools and related issues including the performance gap.

In section two of Chapter two, BIM was introduced, including various definitions and what this research considered BIM to be. As follows: *BIM is a set of interacting rules, procedures and technologies that generate a methodology to manage the necessary data (in digital format) about a project and building design during its life-cycle* (Penttila, 2006; cited in Succar et al., 2012, p. 121). Issues related to it, including existing standards, how it operates at various stages of its development from stage zero to three (based on the UK's BIM-maturity levels), its approaches including the soft and hard approach, and tasks that can be performed with the help of BIM tools were all discussed. Finally, BIM's relationship to increasing energy efficiency in buildings was described which included how to use it to enhance the performance of the design process, whilst obtaining the information needed to design energy-efficient buildings, as well as performing EPA.

While chapter three helped to formulate and understand the philosophy of the research. The previous section discussed issues related to increasing energy efficiency in buildings and the role of BIM in this regard. It also outlined the way to research these issues, including the different philosophical stances, the research approaches, the research strategies and the data collection choices and techniques, as well as reviewing the data analysis techniques. Then based on the nature of the research's aim and objectives, the philosophical stance and the research approach were identified along with selection of the appropriate strategy, data collection techniques and analysis.

6.2 Overview of Research Outcomes

The importance of involving architects in the process of designing energy-efficient buildings and EPA was identified. The extent of the architects' readiness for this purpose and what issues and challenges were faced was also acknowledged in this study. These outcomes are discussed in the following two sections; Energy-efficient building designs and BIM in design for energy.

6.2.1: Energy-Efficient Building Designs

In relation to what is relevant at the design stage, a variety of parameters such as designer skills and knowledge, standards and regulations, tools, and processes, all influence the energy-efficiency of the final product. Two main themes are considered in this regard which are; design and analysis. In the design section, designers review project requirements, collecting necessary data and information, then based on the documents and existing codes and regulations, they apply their knowledge (sketching). At the analysis stage, the performance of what has been designed is analysed for different purposes such as energy performance, which is the subject of this study. Designing mechanical parts of a building such as HVAC and lighting has a direct connection to the geometrical structure of the building. Ultimately, the more the building needs can be met through renewable (natural) resources, the less energy use will be needed, thus reducing building demand is the core of increasing energy efficiency. In the building's geometrical design, architects are the main actor but unfortunately in the analysis section, their role fades away. The survey results and the literature review, both confirm detachment of architects from the EPA. While this may not be the architects' responsibility, section 2.2.5 discussed the potential benefits of architects being involved in performance analysis. This detachment is due to several reasons such as low request, a lack of interest to take responsibility, deficiency in the design process, insufficient knowledge, and a lack of familiarity with the tools. Architects, especially in developed countries, are almost prepared to be involved in the design for energy. As most of them are familiar with the relevant standards and knowledge and know from which resources they can obtain the related information to make a sustainable design. Although in terms of performance analysis, more preparation is required among architects. There is initial knowledge but it is not being fully exploited and there is little familiarity with the related tools and processes.

6.2.2 BIM in Design for Energy

BIM is used by architects at various maturity levels, for instance in large companies its capabilities at level two or even three are used by some experienced architects, whilst in small companies and developing countries, BIM's capabilities at level one are used. Overall, there is considerable acceptance and familiarity among architects regarding BIM. But while most of the definitions given to BIM refer to its ability to promote collaboration and coordination among stakeholders, most architects have only used it as a tool to perform tasks such as

simulation and modelling. Even among the tasks that can be performed by BIM, some capabilities, including performance analysis, are less popular. Moreover, there are barriers among architects when using BIM tools associated with the design of energy-efficient buildings. Keeping architects away from the performance analysis process, possibly due to deficiencies in the existing design processes and regulations, has made them unfamiliar with the tools available and how to use them. Consequently, there is little desire among architects to get involved in the performance analysis process, with the main reason being the lack of familiarity with the tools and related issues. Other barriers include the low accuracy of these tools and their complexity, as well as a lack of interest in achieving responsibility, and time / cost considerations.

6.3 Answer to Research Question

This section attempts to summarize the answer to the research question based on the data obtained. First, the research question needs to be read:

How can BIM be used effectively to increase the efficiency of the design process and manage the energy performance of buildings?

The required prerequisites for this purpose are:

- 1- The value and benefits of being more involved in the process of design for energy, especially when performing an energy analysis by architects at the early stage of design should be outlined.
- 2- With the help of BIM modifications in the design process, this should allow for better connection between architects as the main designers of building geometry and experts in designing technical sections related to energy consumption and energy modelling.
- 3- Some changes to existing contracts and laws can help encourage architects to be more involved in the performance analysis process, whilst maintaining the role of the relevant expert as the main person in charge.
- 4- Increasing architects' motivation through responsibility to perform EPA with no obligation with regards to result and providing possible costs.
- 5- The capabilities of BIM must be introduced well, in order to obtain the necessary data and study such as wind-study or solar-study for design for energy and energy-performance enhancement.

- 6- The capabilities of BIM to transfer and share design files between other tools, along with the capabilities of other tools to perform performance analysis require more attention.

6.4 Contribution to Knowledge

In summary, what make this research unique are the following points:

- 1- It attempts to find weaknesses in the current process of design and discover potential solutions regarding more efficient products.
- 2- It attempts to involve architects, as one of the most influential designers in any construction project, into the process of performance analysis to improve the process of design and the final product.
- 3- It attempts to look for real fields of practice to compare and understand the current conditions about BIM, the desire for employing it, and the challenges of using it, specifically regarding the design and analysis of energy-efficient buildings.

Notably, the importance of design processes and the role of architects in achieving an energy-efficient product are apparent and several researchers and articles discuss this. However, this research has a unique approach to the process of design and the actors. In overview, it first attempted to examine the typical design processes based on a literature review and then to compare them with what is going on in the field of practice through a survey. Therefore, the strengths and shortages in the current process were examined. However, this research is not just about finding strengths and weaknesses and looking for possible solutions to the shortcomings. In this study, improving the performance of the whole process of design through existing tools and strategies was considered. There is a unique approach in this study that does not only see architects as sketchers but also seeks to emphasise their role and effect in the production of high-performance products by adding a part of the analysis process to their tasks. Currently, most architects are not involved in the process of performance analysis, even though there are available tools to aid and encourage this.

Also, there are many articles about BIM, most of which claim to highlight its many capabilities. However, what is going on in the world of action has been less studied. Tips include focusing on questions such as: Are all these features in use? Which one is most used? What is the reason for some of these capabilities to be unemployed? But what this research exclusively focuses on are the claims made by BIM that it enhances the performance of the

entire design process, as well as assisting architects to engage in the performance analysis processes, in addition to the design process.

6.5 Limitations of the Work

Like any work, this research has faced some limitations and difficulties. With the primary limitation being the number of responses received. From the second attempt of data collection, in total Twenty-one responses were received from the sample, which included 65 members. Even in the returned responses, some of the questions in each part were not fully answered by all the respondents, this could be because the research deals with two terms; “BIM” and “Energy-efficient buildings” and possibly not all respondents are familiar with both of them and the relationship between them. The study and conducting of data collection in two foreign countries (the UK and Canada) with few connections in either can be considered as one of the reasons which affected the number of received responses. However, even if the data collection was conducted in the researcher’s home country (as a developing country), possibly, better results could not be expected. Again, this could be attributed to the lack of familiarity regarding the terms of “BIM” and “Design for energy” between practitioners, based on the responses obtained from practitioners who had experience of working in developing countries.

6.6 Recommendations for Further Work

Some areas, such as the design process, BIM implementation, and the capability of BIM for conducting different tasks, requires more study and research. In addition, research about methods which could increase motivation and encourage architects to get involved in the process of energy analysis and utilize BIM for other tasks where their decisions influence them, is recommended. Finally, Cased-study through Ethnography and/or Action Research about BIM being used to design energy-efficient buildings may help to understand its capabilities in this regard.

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Appendix A: Attended Sessions

- 1- Learning English for Academic Purposes (LEAP) Higher
- 2- Application of Case Study Research
- 3- Workshop: Being in the room: can buildings ever be smarter than the people who use them
- 4- Workshop: 'Achieving a low carbon future: a peoples' energy revolution or a government programme
- 5- Online course from Autodesk: Building Performance Analysis
- 6- Introduction to Research Methodology
- 7- How to Reference Using Harvard APA
- 8- Preparing for the interim assessment and internal evaluation
- 9- Workshop: Getting the benefits of BIM for small architectural practices
- 10- MSc Class: BIM Level 2 Suite
- 11- MSc Class: BIM's Tool and Parametric Modelling
- 12- MSc Class: Interoperability, IFCs, Data Exchange & Open Standards
- 13- Training Autodesk Revit
- 14- Attempting to online course which leads to BPA certificate is obtained
- 15- Session regarding Ethical Approval achievement
- 16- quantitative research methods
- 17- Session regarding PhD Assessments
- 18- Mixed Methods Research

Appendix B: Research Progress and Schedule

Schedule														
	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	30-33	33-36	36-39	39-Viva
Introduction	Grey	Grey												
Literature Review	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive	Olive
Methodology				Red	Red	Red								
Interim Assessment				Blue										
Data Collection					Purple	Purple	Purple	Purple	Purple					
Internal Evaluation								Light Blue						
Data Analysis							Orange	Orange	Orange	Orange				
Validation										Pink	Pink	Pink	Pink	
Writing -UP				Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green

Introduction: preparation, overall Views, aims and objectives.

Literature review: Detailed review on articles, journals, books, reports and all valid written data.

Methodology: Methods, techniques, and philosophical assumption that are employed in the research.

Data Collection: Preparing question for gathering the primary data for the research (submitting Ethical approval form).

Data Analysis: sorting, thinking and analysing on the achieved data.

Validation: Validating the result through appropriate method of validation.

Appendix C: BREEAM aspects

Section	Assessment issues
Energy	Water
Reduction of CO ₂ emissions	Water consumption
Energy monitoring	Water monitoring
Energy efficient external lighting	Water leak detection and prevention
Low or zero carbon technologies	Water efficient equipment (process)
Energy efficient cold storage	Waste
Energy efficient transportation systems	Construction waste management
Energy efficient laboratory systems	Recycled aggregates
Energy efficient equipment (process)	Operational waste
Drying space	Speculative floor and ceiling finishes
Transport	Materials
Public transport accessibility	Life cycle impacts
Proximity to amenities	Hard landscaping and boundary protection
Cyclist amenities	Responsible sourcing of materials
Maximum car parking capacity	Insulation
Section	Assessment issues
Travel plan	Designing for robustness
Land use and ecology	Pollution
Site selection	Impact of refrigerants
Ecological value of site/protection of ecological features	NO _x emissions
Mitigating ecological impact	Surface water run-off
Enhancing site ecology	Reduction of night time light pollution
Long term impact on biodiversity	Noise attenuation
Health and wellbeing	Management
Visual comfort	Sustainable procurement
Indoor air quality	Responsible construction practices
Thermal comfort	Construction site impacts
Water quality	Stakeholder participation
Acoustic performance	Service life planning and costing
Safety and security	Innovation
	New technology, process and practices

Appendix D: BREEAM rating benchmark

BREEAM Rating	% score
OUTSTANDING	≥ 85
EXCELLENT	≥ 70
VERY GOOD	≥ 55
GOOD	≥ 45
PASS	≥ 30
UNCLASSIFIED	< 30

The BREEAM rating benchmark levels enable a client or other stakeholder to compare an individual building’s performance with other BREEAM rated buildings and the typical sustainability performance of new non-domestic buildings in the UK.

In this respect each BREEAM rating level broadly represents performance equivalent to:

1. Outstanding: Less than top 1% of UK new non-domestic buildings (innovator)
2. Excellent: Top 10% of UK new non-domestic buildings (best practice)
3. Very Good: Top 25% of UK new non-domestic buildings (advanced good practice)
4. Good: Top 50% of UK new non-domestic buildings (intermediate good practice)
5. Pass: Top 75% of UK new non-domestic buildings (standard good practice)

Appendix E: BREEAM Certificate and assessment stages

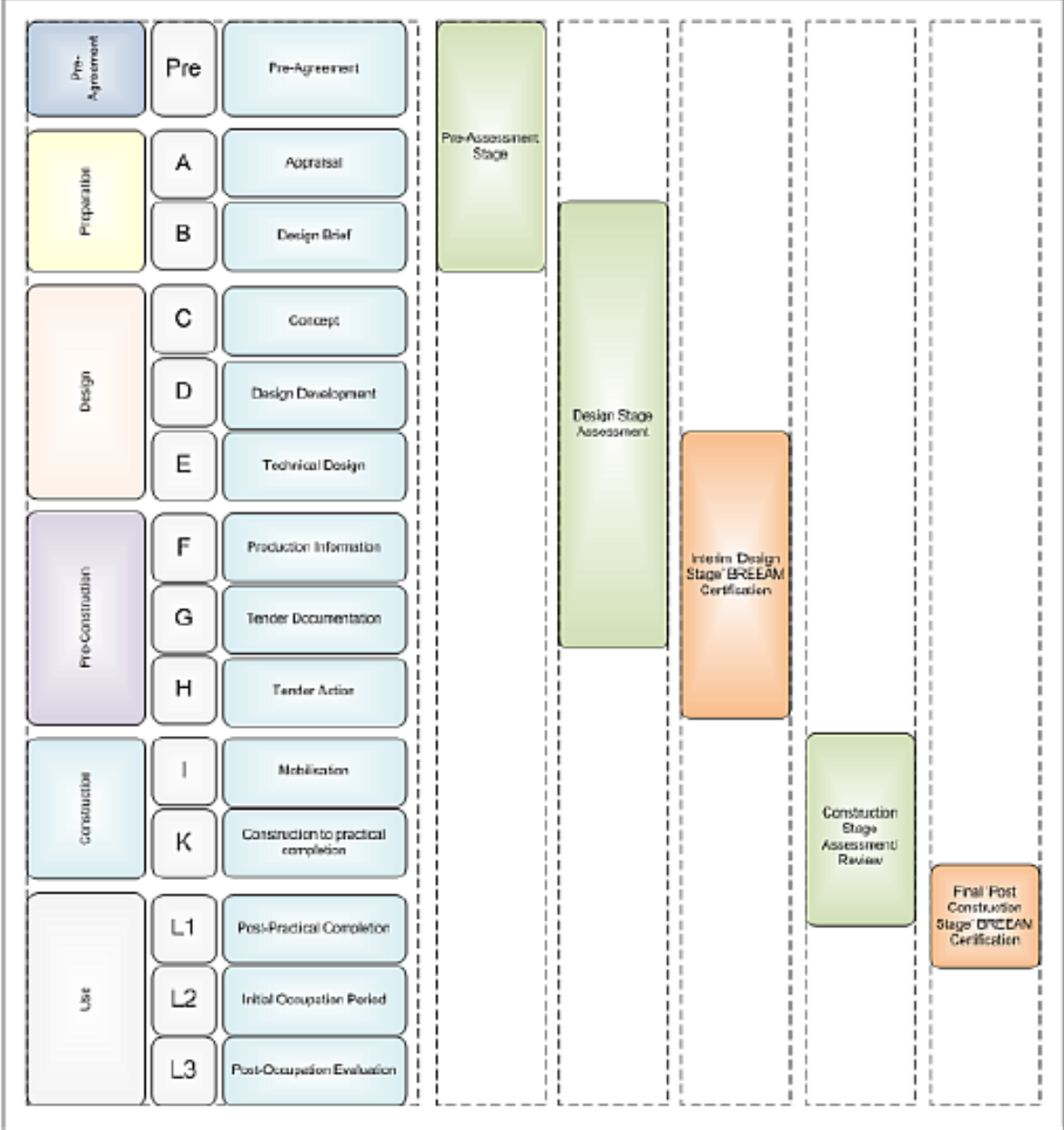


Figure 1: BREEAM assessment and certification stages and the RIBA Outline Plan of Works

Appendix F: Thermal energy production through human activities

Activity	Watts
Sitting	100
Standing at ease / Conversation	130
Eating meal	130
Strolling	160
Housekeeping	175
Heavy work (e.g. carpentry)	270
Fast walking / Hiking	400
Long distance running	1,000
Sprinting	1,600

Table values from Starner, T. and Paradiso, J.A., "Human Generated Power for Mobile Electronics," in Piguert, C. (ed), Low-Power Electronics, CRC Press, Chapter 45, 2004.

Appendix G: Relationship between BIM-Based Sustainability analyses types and LEED Credits

Relationship between BIM-based sustainability analyses types and LEED® credits.

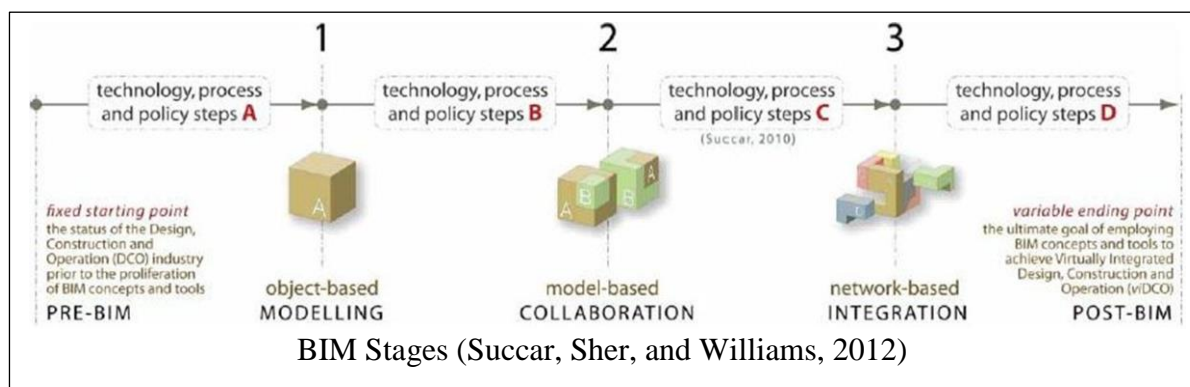
Sustainable analysis types with relationships to LEED®-NC credits (ver. 2.2)	LEED® Points	Sustainable design related analysis types						
		Energy analysis	Daylighting/solar analysis	Acoustic analysis	Material documentation	Value/cost analysis	Site analysis	Water use
LEED® Credits	LEED® Points							
Sustainable sites	Max. 14							
Construction activity pollution prevention	Required							
Site selection	1		▲				▲	
Development density and community connectivity	1							
Brownfield redevelopment	1							
Public transportation access	1							
Bicycle storage and changing rooms	1							
Low-emitting and fuel-efficient vehicles	1							
Parking capacity	1							
Protect or restore habitat	1							
Maximize open space	1							
Stormwater quantity control	1							
Stormwater quality control	1							
Reduce heat island effect – nonroof	1						●	
Reduce heat island effect – roof	1						●	
Light pollution reduction	1	●	●				●	
Water efficiency	Max. 5							
Water efficient landscaping	2						●	●
Innovative wastewater technologies	1							●
Water use reduction	2							●
Energy and atmosphere	Max. 17							
Fundamental building systems commissioning	Required							
Minimum energy performance	Required	●				●		
Fundamental refrigerant management	Required	●				●		
Optimize energy performance	10	●				●		
Renewable energy	3							
Enhanced commissioning	1							
Enhanced refrigerant management	1							
Measurement and verification	1	●, ◆						
Green power	1					●		
Materials and resources	Max. 13							
Storage and collection of recyclables	Required							
Building reuse – existing walls, floors and roof	2				◆			
Building reuse – existing interior nonstructural elements	1				◆			
Construction waste management	2							
Materials reuse	2							
Recycled content	2				◆			
Regional materials	2				◆			
Rapidly renewable materials	1							
Certified wood	1				◆			
Indoor environmental quality	Max. 15							
Minimum indoor air quality (IAQ) performance	Required							
Environmental tobacco smoke (ETS) control	Required							
Outdoor air delivering monitoring	1							
Increase ventilation	1							
Construction IAQ MGT plan – during construction	1	●						
Construction IAQ MGT plan – before occupancy	1	●						
Low-emitting materials – adhesives and sealants	1				◆			
Low-emitting materials – paints and coatings	1				◆			
Low-emitting materials – carpet systems	1				◆			
Low-emitting materials – composite wood and agrifiber	1				◆			
Indoor chemical and pollutant source control	1							
Controllability of systems – lighting	1							
Controllability of systems – thermal comfort	1							
Thermal comfort – design	1	●	●					
Thermal comfort – verification	1	●	●					
Daylight and views – daylight	1	●	●					
Daylight and views – views	1	●	●					
Innovation and design process	Max. 5							
Innovation in design	4					●		
LEED accredited professional	1							

▲ Pre-design stage, ● Design stage, ◆ Construction stage.

Appendix H: BIM Maturity

“BIM Maturity refers to the quality, repeatability and degree of excellence within a BIM Capability” (Succar et al., 2012 p.124). Succar et al. (2012) described that the capability of BIM is the basic ability to do a mission or deliver a BIM service. Three stages in bellow have defined the BIM capabilities which are: stage 1 (Object-Based Modelling); stage 2 (Model-Based Collaboration); and stage 3 (Network-Based Integration). Improvement maturity from lower to higher indicates:

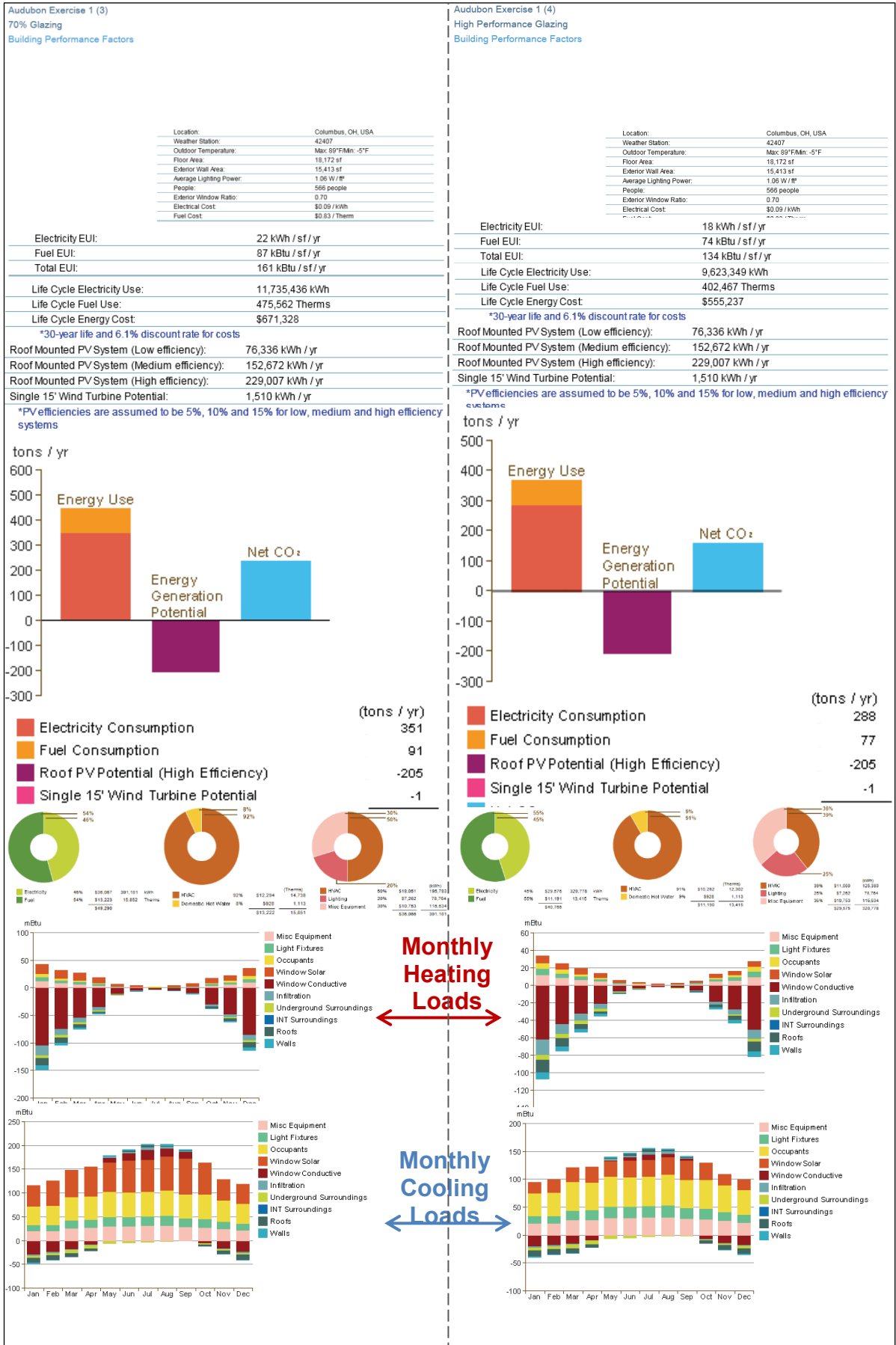
- Enhancing the control in consequences;
- Better prediction about costs, goals, and performance;
- Improving efficiency to achieve defined goals; and
- Better ability of management to intend new and advance targets for improving performance (Lockamy and McCormack, 2004 cited in McCormack, Ladeira, & Oliveira, 2008).



Appendix I: Tabular BIM Capability Maturity Model

<i>Maturity Level</i>	<i>A Data Richness</i>	<i>B Life-cycle Views</i>	<i>C Roles Or Disciplines</i>	<i>ITIL Maturity Assessment</i>	<i>D Business process</i>	<i>F Timeliness/ Response</i>	<i>E Delivery Method</i>	<i>H Graphical Information</i>	<i>I Spatial Capability</i>	<i>J Information Accuracy</i>	<i>K Interoperability / IFC Support</i>
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No ITIL Implementation	Separate Processes Not	Most Response Info manually re-	Single Point Access No IA	Primarily Text No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Initiation	Few Bus Processes Collect Info	Most Response Info manually re-	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Limited Awareness	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Full Awareness	Most Bus Processes Collect Info	Limited Response Info Available In	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Limited Control	All Business Process(BP) Collect Info	Most Response Info Available In	Limited Web Enabled Services	NCS 2D Intelligent As-Built	Spatially located w/Full Info Share	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	Full Control	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	Limited Integration	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	Full Integration	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas &	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-cycle Roles Supported	Limited Optimization	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netocentric SOA Based CAC	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Full Optimization	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netocentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full	All Info Uses IFC's For Interoperability

Appendix J: Performance comparison of two kind of potential design



Appendix K: RIBA Plan of Work 2013



The RIBA Plan of Work 2013 organises the process of briefing, designing, constructing, maintaining, operating and using building projects into a number of key stages. The content of stages may vary or overlap to suit specific project requirements. The RIBA Plan of Work 2013 should be used solely as guidance for the preparation of detailed professional services contracts and building contracts.

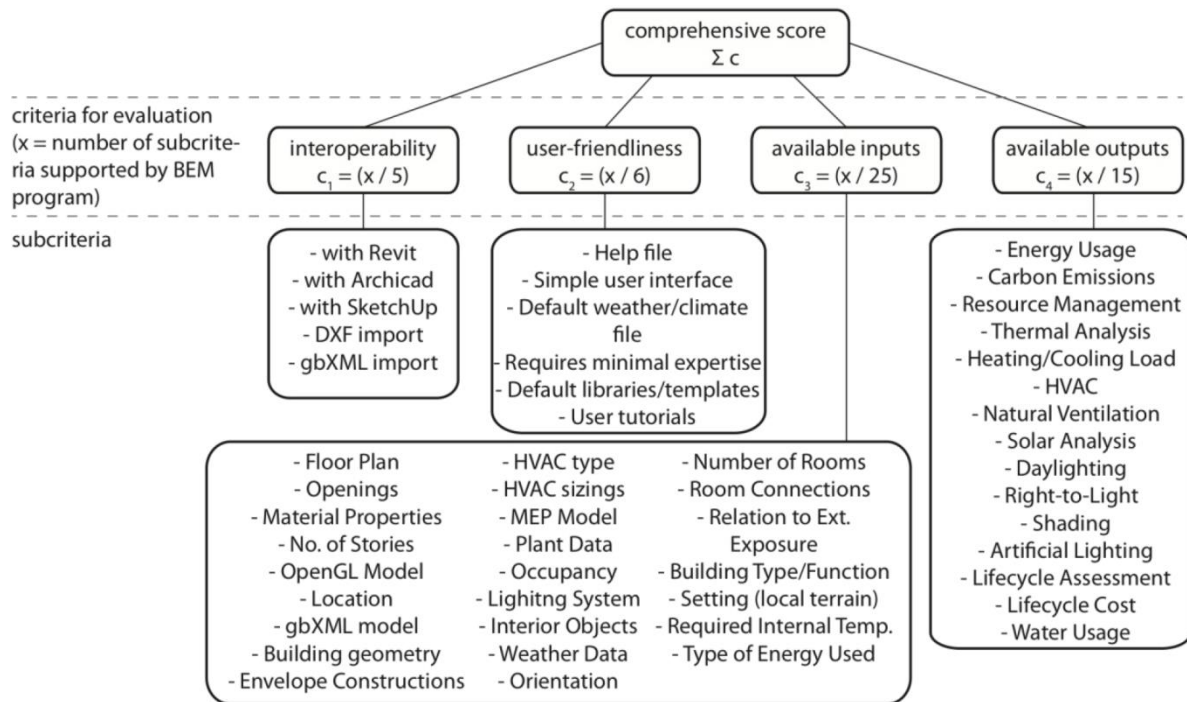
www.ribaplanofwork.com

Stages	0	1	2	3	4	5	6	7	
Tasks	Strategic Definition	Preparation and Brief	Concept Design	Developed Design	Technical Design	Construction	Handover and Close Out	In Use	
Core Objectives	Identify client's Business Case and Strategic Brief and other core project requirements.	Develop Project Objectives, including Quality Objectives and Project Outcomes, Sustainability Aspirations, Project Budget, other parameters or constraints and develop Initial Project Brief. Undertake Feasibility Studies and review of Site Information.	Prepare Concept Design, including outline proposals for structural design, building services systems, outline specifications and preliminary Cost Information along with relevant Project Strategies in accordance with Design Programme. Agree alterations to brief and issue Final Project Brief.	Prepare Developed Design, including coordinated and updated proposals for structural design, building services systems, outline specifications, Cost Information and Project Strategies in accordance with Design Programme.	Prepare Technical Design in accordance with Design Responsibility Matrix and Project Strategies to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with Design Programme.	Offsite manufacturing and on-site Construction in accordance with Construction Programme and resolution of Design Queries from site as they arise.	Handover of building and conclusion of Building Contract.	Undertake In Use services in accordance with Schedule of Services.	
Procurement *Variable task bar	Initial considerations for assembling the project team.	Prepare Project Roles Table and Contractual Tree and continue assembling the project team.	The procurement strategy does not fundamentally alter the progression of the design or the level of detail prepared at a given stage. However, Information Exchanges will vary depending on the selected procurement route and Building Contract. A bespoke RIBA Plan of Work 2013 will set out the specific tendering and procurement activities that will occur at each stage in relation to the chosen procurement route.			Administration of Building Contract, including regular site inspections and review of progress.	Conclude administration of Building Contract.		
Programme *Variable task bar	Establish Project Programme.	Review Project Programme.	Review Project Programme.	The procurement route may dictate the Project Programme and may result in certain stages overlapping or being undertaken concurrently. A bespoke RIBA Plan of Work 2013 will clarify the stage overlaps. The Project Programme will set out the specific stage dates and detailed programme durations.					
(Town) Planning *Variable task bar	Pre-application discussions.	Pre-application discussions.	Planning applications are typically made using the Stage 3 output. A bespoke RIBA Plan of Work 2013 will identify when the planning application is to be made.						
Suggested Key Support Tasks	Review Feedback from previous projects.	Prepare Handover Strategy and Risk Assessments. Agree Schedule of Services, Design Responsibility Matrix and Information Exchanges and prepare Project Execution Plan including Technology and Communication Strategies and consideration of Common Standards to be used.	Prepare Sustainability Strategy, Maintenance and Operational Strategy and review Handover Strategy and Risk Assessments. Undertake third party consultations as required and any Research and Development aspects. Review and update Project Execution Plan. Consider Construction Strategy, including offsite fabrication, and develop Health and Safety Strategy.	Review and update Sustainability, Maintenance and Operational and Handover Strategies and Risk Assessments. Undertake third party consultations as required and conclude Research and Development aspects. Review and update Project Execution Plan, including Change Control Procedures. Review and update Construction and Health and Safety Strategies.	Review and update Sustainability, Maintenance and Operational and Handover Strategies and Risk Assessments. Prepare and submit Building Regulations submission and any other third party submissions requiring consent. Review and update Project Execution Plan. Review Construction Strategy, including sequencing, and update Health and Safety Strategy.	Review and update Sustainability Strategy and implement Handover Strategy, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of 'As-constructed' Information. Update Construction and Health and Safety Strategies.	Carry out activities listed in Handover Strategy including Feedback for use during the future life of the building or on future projects. Updating of Project Information as required.	Conclude activities listed in Handover Strategy including Post-occupancy Evaluation, review of Project Performance, Project Outcomes and Research and Development aspects. Updating of Project Information, as required, in response to ongoing client Feedback until the end of the building's life.	
Sustainability Checkpoints	Sustainability Checkpoint – 0	Sustainability Checkpoint – 1	Sustainability Checkpoint – 2	Sustainability Checkpoint – 3	Sustainability Checkpoint – 4	Sustainability Checkpoint – 5	Sustainability Checkpoint – 6	Sustainability Checkpoint – 7	
Information Exchanges (at stage completion)	Strategic Brief.	Initial Project Brief.	Concept Design including outline structural and building services design, associated Project Strategies, preliminary Cost Information and Final Project Brief.	Developed Design, including the coordinated architectural, structural and building services design and updated Cost Information.	Completed Technical Design of the project.	'As-constructed' Information.	Updated 'As-constructed' Information.	'As-constructed' Information updated in response to ongoing client Feedback and maintenance or operational developments.	
UK Government Information Exchanges	Not required.	Required.	Required.	Required.	Not required.	Not required.	Required.	As required.	

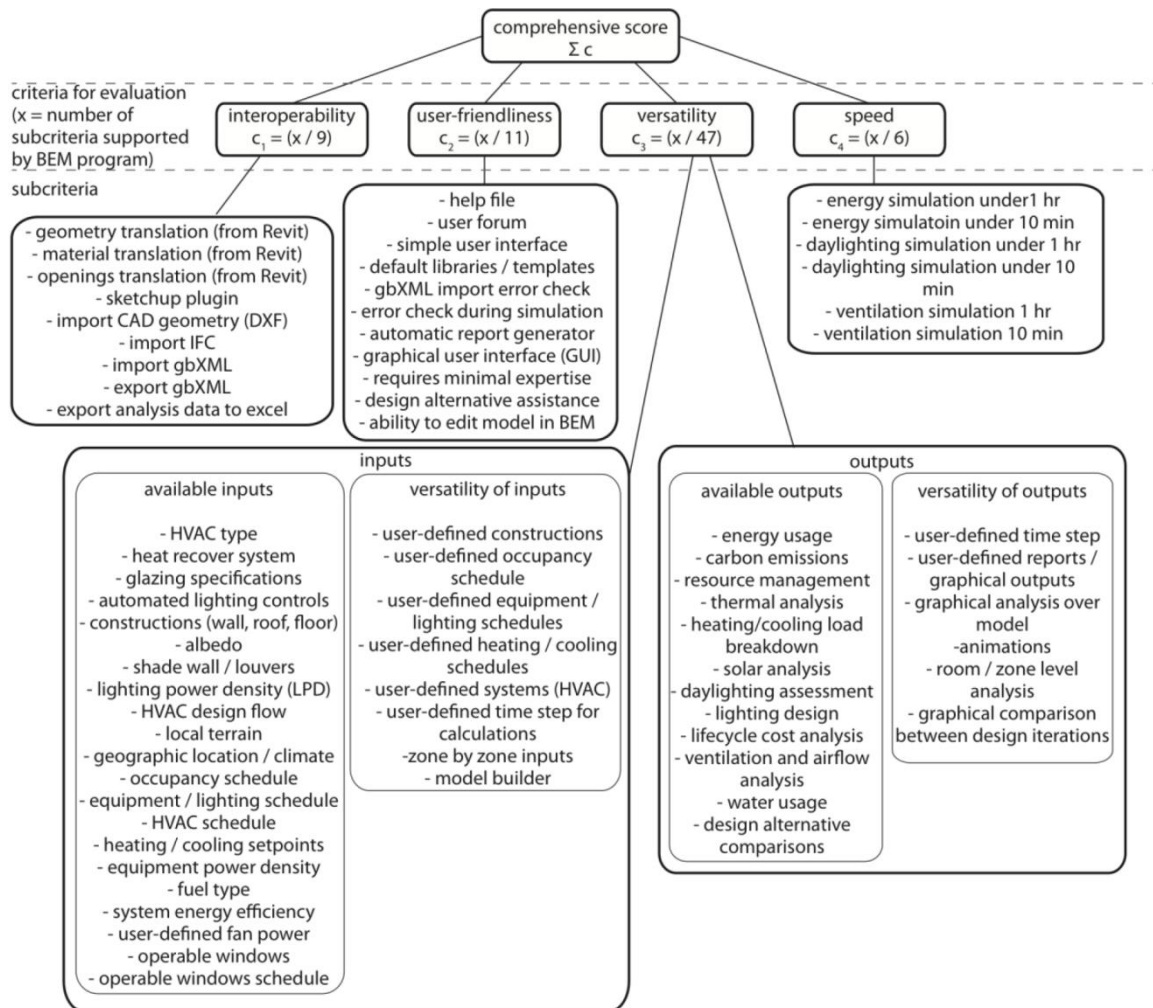
*Variable task bar – in creating a bespoke project or practice specific RIBA Plan of Work 2013 via www.ribaplanofwork.com a specific bar is selected from a number of options.

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Appendix L: Initial Evaluation Scoring system



Appendix M: Re-evaluation scoring system



Appendix N: Questionnaire



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Questionnaire:

Building Information Modelling (BIM) Position and Value in High Energy Performance Buildings' Architectural Design

Researcher: Mojtaba Karjalian Chaijani

Supervisor: Dr. Sara Biscaya

Co-Supervisor: Dr. Paul Coates

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Tel (Canada): 001 647 525 1364

Research Overview:

This questionnaire is part of a research study for a PhD degree. The aim of this research is to investigate the current processes and existing barriers for designing high energy performance buildings beside Building Information Modelling (BIM) functions and its tools. Collected data will be used to provide possible solutions for conquering existing barriers and guiding architectural practitioners so that they can design high energy performance buildings easier.

Instruction and Policy

- Any Identity and Addresses will remain confidential.
- All the provided data will just be seen by the researcher, supervisor, and co-supervisor.
- Data collected will just be used for this research topic and the articles which may be extracted from this research.
- All collected data will be anonymous, coded and kept in password protected PC and/or University of Salford f: Drive which just the researcher can have access to them.
- Best effort has been done to create non –intrusive questions. For best results, participants are asked to answer all questions but they may refuse to answer any question, which they are not comfortable to answer.
- Research participants can withdraw from research at any time and ask for their data not to be used and to be destroyed even after the data has been collected.
- This survey has a total of 32 questions which include close ended questions, semi close ended questions and open answer questions which responses are vital and

valuable for the research under scope. For the Open answer questions, a text box has been provided so that participants can write their opinions.

- Some questions are divided into more questions in a table to make them easier for answering. Some questions can have more than one answer. Such questions are usually indicated in a (bracket).
- There is a standard consent form which indicates your rights. I would really appreciate if you please read, fill, and sign the form at the beginning of the questionnaire.

Key Words: Sustainability, High Energy Performance Building, Building Performance Analysis (BPA), Building Standards (BREEAM, LEEDs, BEAM, CASBE, Green Globe, etc.), Building Information Modelling (BIM), Autodesk Revit.

Section 1 – About You

Name:

Location:

Main Role:

Education:

Experience:

Section 2 – Sustainable Design Tools

This section is designed to identify your familiarity with sustainable design tools and standards, such as BREEAM and LEED.

1) How would you rate your experience with sustainability assessments such as BREEAM and LEED?

N/A Very low Low Average High Very High

2) Which sustainability assessments do you commonly apply to your projects?

None BREEAM LEEDs Green Globe CASBE

Living Building Challenge NZBE BEAM Other: ...

3) Which of the following factors do you consider the most important when considering the development of your projects? (Can choose up to 3)?

Pollution Transport Management Health and wellbeing Energy

Water Material Construction Waste Land Use Ecology None

4) What impact does energy efficiency have in the scoring mechanism of BREEAM or LEED?

Low score

Lower than average score

Same as average score

Above average score

High score

Don't know

Section 3 – Designing for Energy Efficiency

This section is design to understand your experience in designing your projects energy efficient buildings. Also this section helps to explain the current process of energy efficient building design and identify the existing challenges and barriers for designing an energy efficient building.

5) How would you rate your experience in designing for energy efficiency?

- N/A Very low Low Average High Very High

6) How often do you employ your experience in designing for energy efficiency in your projects?

- Never Sometimes Frequently Always

7) When designing for energy efficiency, which do you consider to be the most important passive design techniques (Can choose up to 3 options)?

- Not used Sun Wind Precipitation Climate Conditions

Other, Such ...

8) Please briefly give examples of the types of passive design solutions you employ?

Please text here:

9-What is your priority source of information (such as wind and climate conditions) while developing your designs?

N/A

Web Industry Networks Using existing software and database Other sources such as
.....

10- Do you find it difficult to access information to help you develop energy efficient designs?

No Sometimes Yes

11- What do you believe are the biggest challenges for architectural practitioners in delivering high energy performance buildings?

Please text here:

12- How would you rank your familiarity with building energy performance analysis?

N/A Very low Low Average High Very High

13) If you have ever been involved in a project where analysis of energy performance were conducted, in which stage it has been done (can choose more than one answer)?

Concept Design Design Detailed Design Other (please specify):

14) In the projects which you are involved, who is usually assigned to conduct Energy Performance Analysis (Can choose more than one answer)?

Never involved in such projects I do not Know Architects
 Mechanical (HVAC) Engineer/Practitioner Registered Assessor
 Other (Please specify):

15) If you have ever been involved in projects that EPA has been done, which software/s are usually used (Can choose more than one answer)?

Never Involved Elements Sefaira Design Builder
 Energy Elephant Autodesk Insight 360 IDA Indoor Climate and Energy
 CYPETHERM Suit EPA has been done but I do not know the employed tools
 Other (Please specify):

Section 4 – BIM and Tools for Sustainable Design

This section is designed to assess your use and understanding of BIM tools. The results of this section will be used to identify your familiarity about BIM and its capabilities in general and more specifically regarding design an energy efficient product. Also this section is designed to understand the existing challenges and barriers regarding to implement BIM in design practices.

1) How would you rate your experience with Building Information Modelling (BIM) tool?

N/A Very low Low Average Good Very Good

2) If you have ever used BIM for any of the tasks below on your work, Please indicate which of the following tasks has been done by BIM in the project that you are involved (Can choose more than one answer)?

Visualisation Code Review Building Design
 Building Assembly Construction Sequencing Environmental Analysis
 Forensic Analysis Model Based Estimating Alternative Development
 Facility Management As-Built Model Program/Massing Studies
 Feasibility Studies Clash Detection Direct Fabrication

Sustainability Certificates (such as: LEED, BREEAM, etc.)

Other (please Specify):

3) Which one of the software do you use most often (can choose up to 3)?

AutoCAD Autodesk Revit OUMA Naviswork

ARCHICAD Google Sketch Up Nematschek Vectorworks

Bentley Architecture Other (please specify): ...

N/A

4) Do you ever employ any of the listed tools for Building Energy Performance Analysis (BEPA) purposes (Can choose up to 3)?

No Autodesk Insight 360 Sefaira Design Builder

Energy Elephant IDA Indoor Climate and Energy Elements

CYPETHERM Suit

Other: ...

5) How do you rate the user-friendliness of building performance analysis tools?

N/A Very Low Low Average Good Very Good

6) If you have ever used any tools for energy performance analysis, how do you rate them based on their accuracy and reliability?

N/A Very Low Low Average Good Very Good

7) Which tool/s you consider as the most accurate and reliable?

Please text here (can use back of the page):

8) Please indicate which of the techniques below are you familiar with and have ever used in any projects (Can choose more than one answer)?

Wind flow Solar Study Study on Wind- Rose Diagram Energy Demand charts

Energy Flow None

Other (please specify):

9) If you follow any steps, framework or guidance in order to design high energy performance buildings, could you please briefly introduce it (please indicate the steps and tools that are being used)?

Please text here (can use back of the page):

10) What do you believe are the most common barriers for architecture practitioners to use software and tools (like Revit) for studying, analysing, and designing high energy performance buildings (Can choose more than one answer)?

Unfamiliarity Lack of Accuracy Lack of motivation and encouragement

Lack of believing of necessity to learn and use Being Complicated (Not User Friendly)

Other: