Responding To Building Energy Analysis And Performance With Building Information Model (BIM)

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***Abstract*—One rapidly evolving process that has been envisioned to support building energy performance analysis is the Building Information Modelling. Given the ability of Building Information Models to serve as a multi-disciplinary data repository, this dissertation seeks to explore and exploit the sustainability value of Building Information Modelling/models in delivering buildings that require less energy for its operation, emits less CO_2 and at the same time provides a conducive living environment for its occupants. This paper's objective was achieved by a critical and extensive review of literature covering the following areas: (1) building energy consumption, (2) building energy performance and analysis, and (3) building information modeling and energy assessment. Literature cited in this paper show that linking an energy analysis tool with a BIM model helped project design teams to predict and create sustainable construction projects. To buttress this finding, an in-depth analysis was carried out on completed BIM integrated construction projects, including the Masdar Headquarters project, where it was established that BIM-based energy analysis helped the design team achieve the world's first 103% positive energy building. Based on the research findings, it was concluded that linking an energy analysis tool with a BIM model helps to expedite the energy analysis process, provides more detailed and accurate result as well as delivering energy efficient buildings. The study further recommends that the adoption of level 2 BIM and the integration of BIM in sustainability/energy analysis should be made compulsory for all projects irrespective of the method of procurement (government funded or otherwise) or its size.**

***Keywords*—Building Information Modelling, Building energy performance analysis, Sustainability, Energy efficiency.**

1. INTRODUCTION

The world's climate is changing; recent weather data clearly shows that the climate of Scotland has changed significantly over the last 50 years. According to [1], the mean annual temperature of Scotland increased by 0.5°C between 1914 and 2004, and by 1°C between 1964 and 2004. In addition, the report [1] also captured that:

a. Average precipitation increased by 20% between 1961 and 2004 with an almost steady summer precipitation and an increase of almost 70% in winter precipitation in Northern Scotland;
b. The number of winter days with snow cover has reduced by 25%, with snow season starting late and finishing early each year;
c. The average number of sunshine hours recorded each day is lowest in Northern Scotland. However, the average number of sunshine hours in all three regions of Scotland (North, West and Eastern Scotland) has increased by a small percentage since 1961.

The changes in the world's climate have been attributed to anthropogenic activities. Studies has also shownthat40% of the UK's energy consumption and carbon (CO_2) emissions come from the way our buildings are lit, heated and operated [2] [3]. Whilst there have been constructive efforts to reduce energy use and carbon emissions by buildings, the best of these efforts are not yet good enough to meet the full potentials of creating high performance green buildings [4]. With the above trend and in order to cope with the projected climate change brought about by the effect of green house gases, countries around the world (including Scotland) are investing in energy saving techniques in order to reduce building energy use and carbon emission [3]. For example, as a sequel to various global agreements on sustainability including the Kyoto Protocol made under the United Nations Framework Convention on Climate Change (UNFCCC), the Climate Change (Scotland) Act 2009, sets an interim target of 42% reduction in greenhouse gas emissions from the 1990 baseline by 2020 and at least a reduction of 80% lower than the 1990 baseline in 2050 [5].

In 2002, the European Parliament and Council approved the Building Energy Performance Directives. Amongst the focus of the EPBD is the:

- Establishment and implementation of a methodology for the calculation of the energy performance of buildings, taking account of all factors that influence energy use;

- Minimum energy performance requirements for new and existing large buildings;
- Energy performance certificate for buildings in operation;
- Mandatory inspection of boilers, heating systems and air-conditioning systems

In addition to these regulations, voluntary best practice programs such as the BREEAM, LEED and GreenStar have been establish to act as "pathfinders, paving the way for the mainstream to catch up by highlighting lessons and stimulating markets for innovative products and methods" (Exeter, 2011). Many factors have been identified to affect the energy use and performance of buildings; however, [3] believe that the building envelope plays the most significant role. [6] opined that "an accurate assessment of the envelope thermal performance will aid optimal sizing of systems for comfort and efficiency".

[3], argued that "buildings designed with energy-saving considerations have the potential to achieve 50% to 60% energy savings during their lifecycle. Similarly, [7] believes that in order to meet with the EU's ambition of nearly zero-energy buildings, "one key is using the appropriate building modeling methods, considering the relevant engineering interdependencies, especially in early phases, to support the design process and the involved design experts".

Different methods and models have been exploited by architects, planners and engineers to assess the performance of building envelopes in order to increase their energy efficiency. According to [8], "building performance is measured by using mathematical calculation models. [9] identified the: (1) automating, (2) visualising, and (3) geometric/functional relationship capacities of mathematical models and computer aided design (CAD) including 3D CAD and Object-Oriented CAD (OOCAD) systems as greatly helping users to assess and evaluate building performance. However, these systems lack data: (1) sharing, (2) exchange, and (3) interoperability capabilities; and has led to failures during energy performance assessments [9]. Buttressing this, [10] argued that the typical 2D and 3D CAD models are incapable of wholly evaluating building energy performance via the overall thermal transfer value (OTTV) due to their inability to interpret design information. In view of this, [8] summarized and confirmed that: "holistic performance assessment is not considered in any of computer-aided architectural design (CAAD)".

1.1 Justification of the Study

Global warming and its consequential climate change are threatening the very existence of mankind. These changes have been attributed to anthropogenic activities and they greatly affect a building's energy use, carbon footprint, indoor climate as well as leading to sick buildings. [11] provides an insight into the impacts of climate change on buildings. Their studies identified the following major impacts of climate on buildings: (1) flooding, (2) swelling and shrinking of soils affecting foundations, (3) wind actions causing dynamic structural loading by pressure forces, and (4) driving rain leading to weathering. Similarly, [12] further identified: (5) increased over heating and air-conditioning load, (6) increased greenhouse gas (GHG) emission, and (7) increased costs due to carbon or GHG charges, as significant impacts of climate on buildings.

In order therefore to reduce the negative effects of the aforementioned factors on buildings, there has been different consensus amongst built environment professionals/regulatory bodies on the need to design and construct energy efficient buildings. The conventional method of building energy analysis however provides little opportunities to wholly evaluate the relative energy performance of alternative designs as well as opportunities for information sharing [9]; [10]. Similarly, [13] believes that since the energy analyst constructs an energy/thermal model from drawings, the probability of misinterpreting the 2D/3DCAD information is high and this may lead to an inaccurate energy assessment. Whilst there have been many research in the area of building energy performance analysis, few of these research have exploited and integrated a BIM model in their energy analysis process [10]; [9]., [14]; [4]; [8]. Similarly, on the limited research in Building Information Modelling and energy performance analysis, there is little information available on the extent to which Building Information Modelling enhances the energy performance of building.

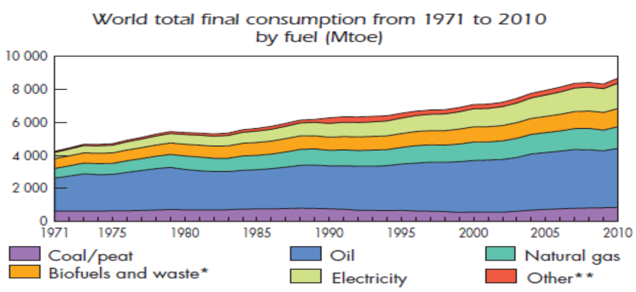
This research therefore seeks to establish the degree to which linking a BIM model with an energy analysis software/tool will help deliver energy efficient buildings. In addition, and with the UK government's ambition to adopt level 2 BIM for all publicly procured projects from 2016, this research also seeks to demonstrate the sustainability value of Building Information Modelling in delivering energy efficient buildings.

2. LITERATURE SURVEY ON BUILDING PERFORMANCE AND ENERGY ANALYSIS

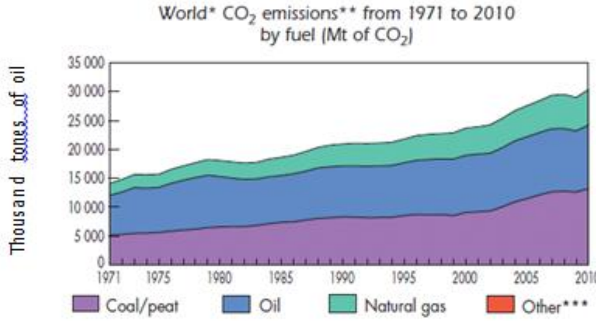
The current trend in world energy use has raises serious concerns over the supply difficulties, exhaustion of energy and heavy environmental impacts [15]. According to the International Energy Agency, total world energy consumption increased by over 46% from 4,672Mtoe to 8677Mtoe between 1971 and 2010(Figure1);with the amount of carbon dioxide emissions(CO_2)during this period increasing by over 48% from 15,637Mt of CO_2 to 30,326Mt of CO_2 (Fig. 2). With the current climate change and its consequential global warming, demand for energy globally is soaring. Global energy outlook shows that energy demand will continue to be thirstier. According to the [16], "global energy demand will increase by over one-third in the period of 2012 to 2035. Similarly, The British Petroleum (2013) predicts that global primary energy consumption will grow by 1.6% per annum over the period of 2010 to 2030, adding 36% to global consumption by 2030. Whilst it is outside the scope of this research to validate the authenticity of these statistics, the predictions are however frightening.

More worrisome is the fact that the global carbon dioxide emission is directly proportional to the amount of energy used. World population growth and economic development has been identified as factors contributing to global energy demand. [15] analysed the relationship between energy consumption, economic development and population growth. They opined that urbanisation, globalisation, improvement of living conditions in emerging regions and the development of communication networks, promote developed nations' lifestyle and raise energy needs to consumption patterns that, without doubt, will exhaust fossil fuels and produce serious environmental impact [15]. The situation is confirmed in China, for example, where over 210 million people rural inhabitants migrated to the urban areas between 2002 and 2012 (See Fig. 3). In the United States, the population of urban dwellers has been rising steadily from79.4% in 2011 to over 82% in 2011. Similarly, urban share of population in the United Kingdom has steadily increased only by a small fraction from 78.72% in 2001 to 79.64% in 2011 (See Fig. 5). Meeting with the needs of these urban dwellers thereof represents tremendous challenges and much pressure on energy, as considerable resources are needed to invest in urban public utilises, infrastructures and services including housing, water supply, roads and bridges [17].

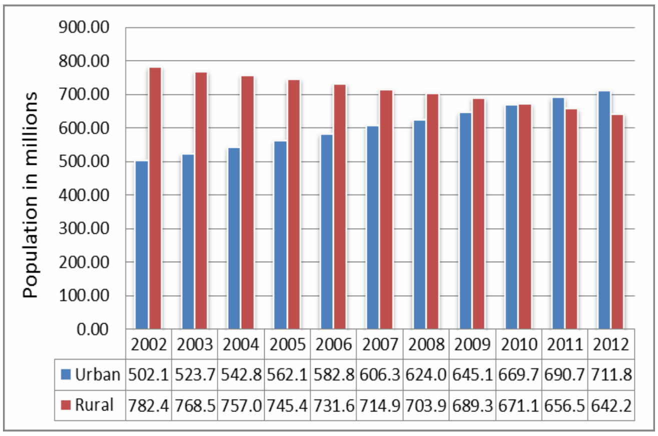
Recent statistics released by the Department of Energy and Climate Change shows that the total UK overall primary energy consumption in primary energy terms (fuel obtained directly from natural source) was 203 million tonnes of oil equivalent (See Fig. 6). The domestic sector accounted for about 20% (38.8 million tonnes of oil equivalent) with majority of energy spent on space heating. Interestingly, this figure is the lowest level of UK primary energy consumption since 1984 [2]. Improvements in energy efficiency of electrical appliances as well as energy efficiency of buildings have been identified as factors helping the UK to reduce total domestic energy consumption.



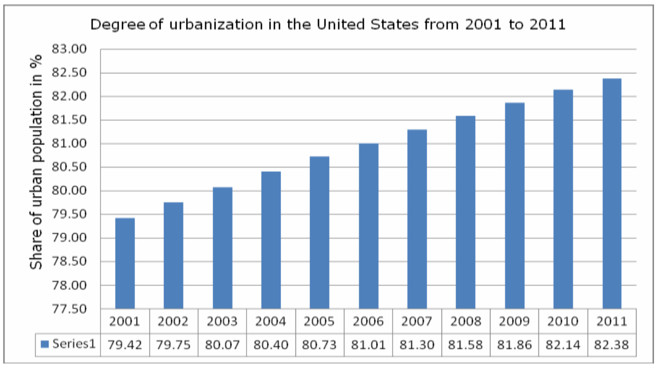
Source: IEA, 2013
Fig 1: Total World Energy Consumption



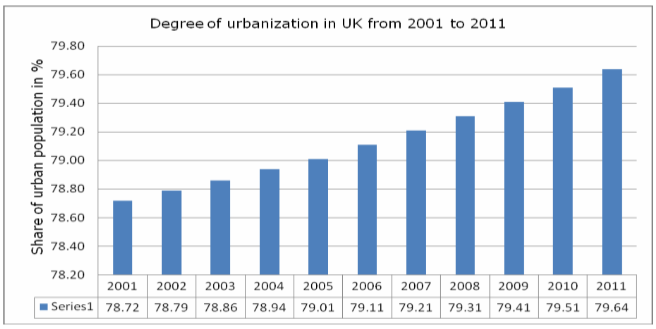
Source: IEA, 2013
Fig. 2: World Carbon Dioxide Emissions (CO2)



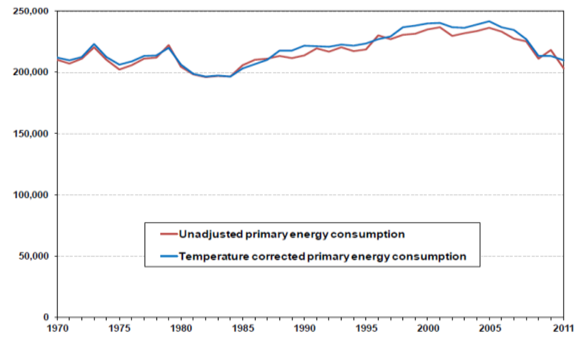
Source: Statista, 2013
Fig. 3: Degree of urbanisation in China from 2002 to 2012



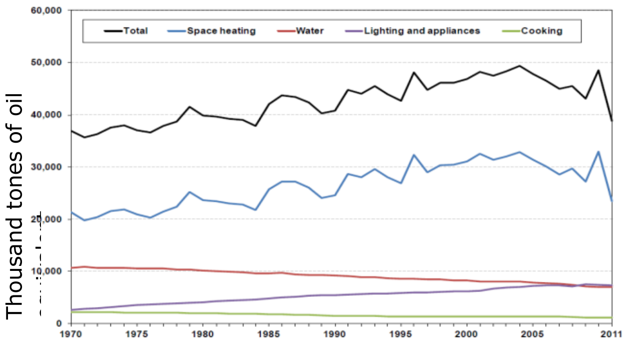
Source: Statista, 2013
Fig. 4: Degree of urbanization in the United States



Source: Statista, 2013
Fig 5: Degree of urbanization in the United Kingdom (2001–2011)



Source: DECC, 2013
Fig. 6: Total primary energy consumption, unadjusted and temperature corrected, UK, 1970 to 2011



Source: DECC, 2013

Fig. 7: Domestic final energy consumption by end use, UK 1970–2011

2.1 Building Energy Consumption

Energy consumption in buildings primarily serves to make the indoor environment conducive and habitable; these come by ways of space heating, cooling, domestic water heating, lighting, ventilation and appliances. However, the energy uses of buildings are disproportionate and it's a function of many factors: time, type, size, weather and seasonal variation as well as occupants' behavioural patterns. Urbanization, as a factor has been covered in preceding sections. [15] believes that "growth in population, enhancement of building services and comfort levels, together with the rise in time spent in side buildings, have raised building energy consumption". Similarly, [18], whilst studying the role of occupant in household energy consumption identified two major factors affecting building energy use:

- Direct factors and (2) indirect factors. Whilst direct factors includes climatic and physical housing variables, occupant choices and behaviour; indirect factors relates to household disposable income. Table 1 shows an overview of major factors affecting building energy use. The energy use associated with buildings in the UK is enormous. A critical analysis of the trend of total domestic energy consumption between 1970 and 2011(Fig 6 and 7) shows that [2]:

a) Domestic energy consumption in 2011 was over 38.9 million tonnes of oil equivalent, with 60% of these were used for space heating while water heating, lighting and appliances accounted for 18, 19 and 3% respectively;

b) Domestic energy consumption in 2011 was 20% lower than in 2010. This is attributable to lower temperatures in 2010 which led to an increase in demand for space heating, as well as the promotion of energy efficiency measures in homes.

Table1: Major Factors Affecting Building Energy Use

S/n	Variables	Description
1	Climate	Heating degree-days Cooling degree-days
2	Building	Floor area (m^2) Number of windows Properties of the building envelope Type of building Year of construction
3	Occupant	Number of occupants Total income
4	Equipment	Type of space heating equipment Type of space cooling equipment Frequency
5	Occupants' Behaviour	Number of heated rooms Average temperature setting Frequency Number of cooled room

Adapted from Steemers and Yun, 2009

2.2 The Building Envelope

As stated earlier, the building envelope mediates between the internal and external environment by forming a barrier to heat, light and air, and so must be carefully designed to achieve high-performance [19]. [19] further presented that the optimization of the building envelope from three viewpoints: (1) construction, (2) form, and (3) double façade. Whilst construction optimization is focused on the selection and varying of building materials based on their properties and form optimization is concerned about varying building shape and sizes, double skin façades employs two layers of skin to improve the performance of the building envelope [19].

[10] identified the evaluation of the building envelope via the Overall Thermal Transfer Value (OTTV). The overall thermal transfer value (OTTV) is a measure of heat gain into a building through the building envelope. The theory of the OTTV is based on the assumption that the envelope of a building is completely closed and comprises of two values: (1) Envelope Thermal Transfer Value (ETTV) and Roof Thermal Transfer Value (RTTV) [20]. Whilst the ETTV is a measure of the heat transfer through the walls or envelope of the building, the RTTV is concerned with the heat transfer through the roof of the building.

[20] provides the main objectives of the OTTV as including: (1) the development and implementation of energy efficient design protocols and relevant design tools, (2) establishing energy management benchmark and development of best practices system for various building type, (3) suggestion of ways to improve energy efficiency in building, and (4)

encouraging climate responsive building planning and design.[21] identified four different methods of calculating the OTTV. They include: (1) the ASHRAE90A-80 method, (2) the equation derived by Chow and Chan, (3) the Hong Kong Code of Practice, and (4) using data generated from computer simulation by TRACE 600.

2.3 Building Energy Performance Analysis

The term building performance analysis refers to the various assessments and evaluations conducted to determine a building environmental performance and include such contextual analyses as: solar, thermal, ventilation, day lighting, building massing, site orientation as well optimization of a building's HVAC systems [22] . Building energy analysis seeks to predict the usage profile and cost of energy consumption within buildings in order to provide opportunities for improvements [23]. These improvements come by ways of making energy conscious decisions at the conceptual design stage which helps the team detect and reverse the energy-efficient defects in the construction process [9], [8]. [24] provides a rational for building energy analysis. He opined that building energy analysis is carried out to achieve the following:

- Evaluation of alternative designs, systems, subsystems, components;
- Allocation of annual energy budgets
- Compliance with energy standards
- Economic optimization

Buttressing this, Galloway *et al.* (2012), whilst carrying out a case study analysis of the energy performance of a building opined that "post occupancy evaluations of many different types of buildings has shown that there are large gaps between the design and actual performance". The European Union Building Energy Performance Directives provides a methodology for the calculation of energy performances of buildings. This method shall include at least the following aspects:

- Thermal characteristics of the building (shell and internal partitions, etc.).These characteristics may also include air-tightness;
- Heating installation and hot water supply, including their insulation characteristics;
- Air-conditioning installation;
- Ventilation;
- Built-in lighting installation (mainly the non-residential sector);
- Position and orientation of buildings, including outdoor climate;
- Passive solar systems and solar protection;
- Natural ventilation;
- Indoor climatic conditions, including the designed indoor climate.

[9] identified the following factors influencing the energy performance of buildings: (1) climate, (2) design, and (3) occupants; Cong *et al.* (2010) expounded on the design factors as including: building sites, orientation, envelope configuration, HVAC system functions. Buttressing this, [22] while arguing that the conceptual design phase energy analysis provides the design team with first order magnitude feedback about the impact of various building configurations on annual energy performance, opined that the building energy analysis must take account of the following as input data [22]:

- Building geometry including the layout and configuration of spaces;
- Building orientation;
- Building construction including the thermal properties of all construction elements including walls, floors, roofs/ceilings, windows, doors, and shading devices;
- Building usage including functional use;
- Internal loads and schedules for lighting occupants, and equipment,
- Heating, ventilating, and air-conditioning (HVAC) system type and operating characteristics;
- Space conditioning requirements;
- Utility rates;
- Weather data.

2.4 Building Information Modelling and Energy Performance Analysis

Building performance analysis is typically performed after the architectural design and construction documents have been produced [22]. In the traditional process, the building geometry information is extracted from the architectural drawings which depict the architect's view of the building. Thereafter, the building energy analyst uses this information to define the thermal view of the building. This definition is subjective and it's dependent on the knowledge, skill and experience of the energy analyst. Different building energy analyst will therefore generate differing thermal view [25].

According to [22], the most effective decisions related to the sustainable design of a building can only be made in the design and preconstruction stages. Literature has it that due to the lack of continuous analysis of building performance, the traditional approach leads to an inefficient process of retroactively modifying design to achieve agreed set of performance criteria [8]. [26] identified this as the problem of "solitary information island". They further opined that the detachment of energy saving technology from building design, as evidenced in the traditional approach, present real problems to energy performance analysis.

Recent advancement in construction informatics now addresses the complex problem of integrating building energy performance analysis and building design. In order to do this, access to a complete set information that defines a building such as form, materialization and technical systems in necessary [8]. One rapidly evolving technology that has been envisioned and demonstrated to support building energy performance analysis is the Building Information Modelling [27], [8];

[10]. Building Information Modelling has the ability to serve as an independent, multi-disciplinary data repository, which provides new opportunities and approaches on integrating performance analysis into design possible [8].

[28] proposed the development of an Energy BIM. They believes that since the early stages of the design process is characterized by limited information which may affect energy performance analysis, a simple Energy BIM can be developed which will enable a 'sketch' to be made of the building energy performance. [28] further expounded on the Energy BIM as a combination of data from a building information model (BIM) with additional information such as building use, HVAC system details, building spaces and occupancy level, which can be used to produce repositories of simulated building and systems performance, the complexities of which will, by necessity, vary according to the building's lifecycle [28].

The contribution of BIM to sustainable design and performance analysis is demonstrated from the perspective of integrated project delivery and design optimization [29] [30]. [30] further sees the visualization and day lighting capabilities of BIM as contributing to sustainable design and energy performance evaluation. [30] provide a summary of the potential of BIM in sustainable design and energy analysis. They include:

- Building orientation (to select the best building orientation that results in minimum energy costs)
- Building massing (to analyse building form and optimize the building envelope)
- Daylighting analysis
- Water harvesting(to reduce water needs in a building)
- Energy modelling (to reduce energy needs and analyse renewable energy options such as solar energy)
- Sustainable materials (to reduce material needs and to use recycled materials)

Buttressing Krygiel and Nies' submission, [27] highlighted the application of BIM in the design processes from four viewpoints: (1) conceptual design, (2) design and analysis, (3) developing construction-level information, and (4) design and construction integration. In the conceptual design phase, they believe that BIM will have a huge impact in strengthening the decision made relating to building plan, its massing, appearance, placement and orientation. With respect to other aspects of building performance analysis, [27] claimed that that the application of BIM has beneficial inputs in the functional aspects of building performance such as structural integrity, temperature control, ventilation, lighting, circulation, acoustic, energy distribution and consumption, water supply and disposal. They further argued that success here "demands intense collaboration among a team of specialist, requiring a mix of configurable tools that, when combined, form a design workbench [27].

2.5 Benefits of BIM Integrated Energy Performance Analysis

[22] analysed the current state and benefits of BIM-based sustainability by administering questionnaire to professionals within the subject area. Their findings revealed that:

- Practitioners use BIM for: (i) energy analysis, (ii) day lighting/solar analysis, (iii) building orientation analysis, (iv) massing analysis and (v) site analysis
- Practitioners using BIM based sustainability analyses realised some significant time savings
- Practitioners using BIM based sustainability analyses realized significant cost savings
- Prevalent software used was: (i) AUTODESK Ecotect^{TM}, (ii) Autodesk Green Building Studio (GBS)^{TM} , and (iii) Integrated Environmental Solutions (IES) Virtual Environment^{TM}.

3. METHODOLOGY

A case study approach was exploited in order to provide an in-depth analysis of BIM-based energy analysis and the energy performance of buildings. This approach is supported by [32] who stated that "case studies are used when a researcher intends to support his/her argument by an in-depth analysis of a person, group of persons, a group, an organisation or a particular project".

[32] further provided three types of case study designs: (1) descriptive, (2) the analytic, and (3) the exploratory case study. Whist descriptive case study focuses on answering such questions posed with: how, what, who, where and when; the analytic case study is concerned with the association and relationship between attributes. In addition, an exploratory case study explains and tries to show the connection amongst objects of a research [32]. This research employs the three types of case study because the researcher anticipates that the research findings will reinforce the relationship and connection between BIM-based energy analysis and the energy performance of buildings.

For the purpose of this investigation, three completed BIM integrated construction projects were selected:

- The Masdar Headquarters Project ,Abu Dhabi
- The Arboleda Open BIM Project, Dominican Republic
- The Robert Gordon University Garthdee Campus Development

These projects were chosen because building information modeling (BIM) was used in their design/construction. In addition, building information modeling was used in the sustainability and energy analysis (partially in the Robert Gordon University Garthdee Campus Development) of these projects. This choice is in line with the argument of [33] who posited that: case studies may be selected on the basis of their being representative to those used in statistical sampling to demonstrate particular facets of the topic.

3.1 The Case Study Approach

According to [33], case studies employ interviews of key ‘actors’ in the subject of study. [33] further provided that such interview data may be coupled with the scrutiny of documentation. With the above in mind, the following processes were used in the analysis of the above case study projects:

- Identification of suitable case study projects
- Review of project’s method of design and construction (from literature)
- Interview with project professional responsible for the building energy analysis(where necessary)
- Discussion of the benefits and/or constraints of linking an energy analysis software with a BIM model
- Presentation of findings

3.2 Case Study Reports

The Masdar Headquarters project was designed by Adrian Smith + Gordon Gill (AS+GG), to be the world’s first positive-energy building, a building that produces more energy than it consumes and surpassing the highest standards set by global building energy rating systems–the LEED. The project is part of the Masdar City project, a zero-waste, zero-carbon-emission development and will include numerous systems that generate energy, eliminate carbon emissions and reduces waste.
The design of the Masdar Headquarters building adopted a combination of passive design strategies, active systems strategies and renewable energy to achieve its sustainability goals. However, unlike other projects where sustainable strategies appear to be an afterthought, the building’s basic forms appear to have been derived from these strategies. In order to reduce its solar heat gain, the building form was designed to shade the entire building structure. This consists of a seven-acre large canopy with a large over hang that dominates the building’s roof. In addition, the building comes with operable windows that give occupants the option of naturally ventilating interior space. In addition, the roof canopy incorporates one of the world’s largest photovoltaic and solar thermal arrays which simultaneously produce electricity and thermal energy for solar cooling [34]
The project was designed using building information modeling (BIM) and this enabled the team members to integrate architectural, structural, and building systems from the project inception, thereby increasing the efficiency and constructability of the entire system. According to Robert Forest (a managing partner with AS+GG), “the BIM process helped us evaluate different strategies and capitalize on the true value of sustainable opportunities at the beginning of the design process-long before systems and design decisions are locked in place”. In order to collaborate and integrate the client and the project team, a variety of Autodesk Building Information Modelling solutions were employed. These BIM solution include: (1) Autodesk® Revit® Architecture software, (2) Autodesk® Revit® Structure software, (3) Autodesk® Revit® MEP software,(4) Autodesk® Ecotect® Analysis software, and (5)Autodesk® Navis works® Manage software. Building Information Modelling was used on the project for primarily for documentation, discovery, coordination, and conflict resolution.

4. BIM AND SUSTAINABILITY/ENERGY ANALYSIS

In order to achieve the sustainability vision captured above, the design team used BIM to create several design scenarios and saw their implications. For example, in order to lower the project’s overall carbon footprint, the design team proposed two alternative construction methods. The first followed the conventional construction sequence whilst the second approach proposed building the cones and rooftop frame first. This second approach will enable the project produce electricity during construction and provide shade to the workers on all subsequent phases of the construction.
In carrying out the energy performance analysis for the project, the design team exported the BIM model to the Autodesk® Ecotect® Analysis software via the industry foundation classes (IFC). The IFC is an open, neutral and standard specification of Building Information Modelling that makes it possible to hold and exchange data between different proprietary software applications (building SMART, 2013). These allowed the team to successfully study and perform different type of energy analysis on the BIM model. Energy analysis performed include: solar analysis, building orientation, wind cone flow, daylighting analysis and photovoltaic study (for optimizing panel layout) in the early stages of design. Subsequently, the result of these analyses was used to optimize the properties of the building form in order to reduce energy consumption. For the purpose of this case study, the following energy analyses on the Masdar Headquarters project are discussed:

4.1 Solar and Day lighting analysis

In order to control the admission of natural light (direct sunlight and diffused skylight) into the building and also to the amount of energy the building used, the project team came up with the ‘saw-tooth’ façade idea. This façade will allow access to daylight and views while shading itself from direct sunlight, mitigating glare and solar heat gain. The building’s walls were further designed to face the highest transparency vision glazing towards cardinal north or south, where daylight is at its highest angles. The design team used Autodesk® Revit® to build the model and review the geometries while Autodesk® Ecotect® Analysis software was used to analyse and review the direct solar gain condition on the façade, shadow conditions and daylight admission.

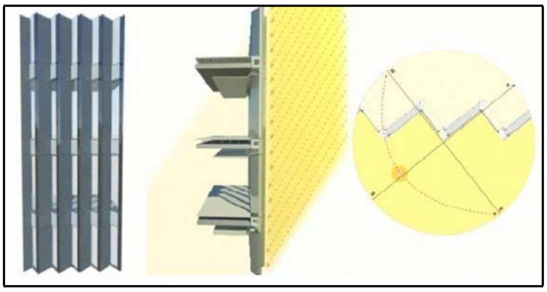


Fig. 5.1. Masdar Headquarters BIM-based energy analysis showing saw-tooth façade allowing access to daylight whilst shading itself from direct sunlight

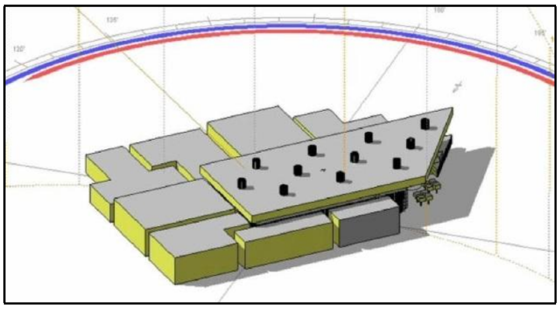


Fig. 5.2. Masdar Headquarters BIM-based energy analysis showing shadow conditions and the direct solar gain condition on the façade

4.2 Ventilation and Airflow analysis

One imposing feature of the Masdar headquarters project is the 11 steel windcones which sit on top of a concrete foundation. Autodesk® Revit® software (Architecture, Structure and MEP) were used to design a model which helped in rationalizing and coordinating the building's complex geometries faster, as well as figuring out how the 11 windcones and concrete foundation will work. Using Autodesk® Ecotect®, the team were able to successfully study, simulate and visualize ventilation and air flow on the BIM model. One of such analysis was visualizing how the building's 11 windcones provided natural ventilation and cooling (drawing warm air up to roof level, where wind moves it away) and forming oasis-like interior courtyards at ground level.

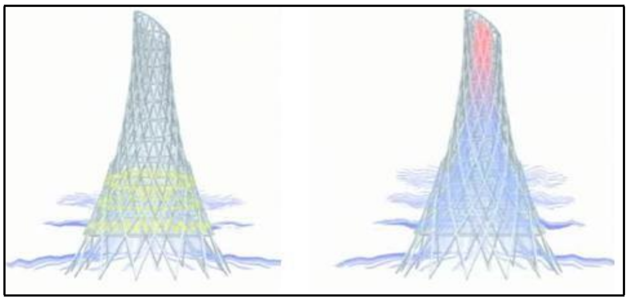


Fig. 5.3. Masdar Headquarters BIM-based energy analysis showing ventilation and airflow analysis on a wind cone

Source: the material for the above case study was sourced from the following online articles and videos:

- Carboun: Middle East Sustainable city by Karim Elgendy,
- Autodesk: Masdar Headquarters project

4.3 Case Study Discussions

The above case studies have demonstrated some of the sustainability benefits of linking energy analysis software to a BIM model. This integration has proven to produce fast and accurate analysis of model data during the conceptualization and design phases of projects. Design team members are able to create and simulate several design scenarios, visualize their implications as well as making very informed decision

On the Arboleda and Masdar Headquarters project, the design team exploited on the numerous benefits of Building Information Modelling to analyse and optimize the properties of the building form for reduced energy consumption. For example, close integration of the BIM model with the energy analysis tools on the Masdar Headquarters project enhanced the design team's ability to evaluate its design assumption as well as making well informed decisions. In addition, the design team were able to capitalized on the take-offs generated from the BIM model in order to quantify consumption of natural resources and aid in forecasting the use of sustainable materials. With the BIM and energy analysis integration, the project team was also able to: (1) prepare a more accurate cost and budget model, (2) keep track of items such as total recycled content and embodied carbon dioxide level, (3) set carbon targets for specific project elements, (4) compare design options as well as validating design decisions, (5) see real-time updates on the project's carbon content, and (6) generate fewer RFIs during construction. The result of the BIM and energy analysis integration was the delivery of the world's first positive energy building.

In addition, the case study on the Robert Gordon University Garthdee Campus Development confirmed that:(1) the use of building information modeling is an efficient way to design and construct buildings, (2) the use of building information modeling increases project coordination and reduces risks, and (3) the use of BIM maximizes project resources and increase productivity and profitability.

5. CONCLUSION

The objective of this investigation was to identify the extent to which the application of Building Information Modelling to building energy performance assessment contributes/enhances the energy performance of building during operation. Findings from the questionnaire data analysed confirm that on a 5-point scale, a vast majority of the respondents (78%) thought that linking a BIM model to an energy analysis software enhances the energy performance of a building. In addition, the case study on the Masdar Headquarters project demonstrated that integrating BIM in the sustainability/energy analysis process helped the team to deliver a building that is 103% positive energy.

Whilst there are many established benefits of using Building Information Modelling in design and construction, findings from this research show that its adoption by stakeholders for sustainability/energy analysis is still low. This was further confirmed on the case study on the Robert Gordon University Garthdee Campus Development where the M+E and sustainability consultant did not feed into the BIM model.

6. RECOMMENDATIONS

The following recommendations are hereby made:

- That BIM-based sustainability/energy analysis should be made mandatory for all projects irrespective of the size. By so doing, more energy efficient buildings will be produced.
- That research and development into cost-effective BIM-based energy analysis software/tool be carried out. By so doing, more stakeholders and industry personnel will have the wherewithal to adopt Building Information Modelling not just for design and construction, but also integrating BIM in the energy performance analysis of buildings.

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