The application and barriers of BIM in sustainable building design

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Oluwaseun Fajana
Joseph Ayo Babalola University

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Olufolahan Oduyemi Michael Iheoma Okoroh Oluwaseun Samuel Fajana

The Application and Barriers of BIM in Sustainable Building Design.

1.0 INTRODUCTION

It is a known fact that buildings contribute as much as forty percent of solid landfill waste, fifty per cent of carbon dioxide emissions, forty percent of energy requirements, seventy-one percent of electricity consumption, sixteen percent of water usage and fifty percent of raw materials (Pivo and Fisher, 2010). Hence, the implementation of an environmentally friendly method to building construction tailored towards sustainable buildings.

This has ultimately necessitated the need to embrace the Building Information Modelling (BIM) method as it syndicates architecture, information technology and construction. Therefore, its relevance among all built environment professionals as it has turned out to a dynamic research area of sustainable building design.

A lot of research work has focused on the application of BIM for cost estimation of restaurant buildings, various projects and medical research lab by Alder (2006); Kunz and Fischer (2007) and Manning and Messner (2008) respectively. In this paper, a case study of how BIM could enhance sustainability of the built environment is presented.

With the building originally modelled with Revit, other BIM interoperable software assist in performing various sustainability analyses which include building suncast shadow studies, internal sun penetration, visual impact studies, daylighting study, artificial lighting analysis, environmental cost impact analysis and energy use pattern for a proposed conference hall.

This research also intends to demonstrate opportunities and challenges available with BIM adoption as well as to provide recommendations on how to apply BIM compatible tools to sustainable building design. This would allow researchers to be more confident in demonstrating the relevance of sustainable design analysis tools in meriting sustainable design criteria.

2.0 CONTRIBUTIONS AND BARRIERS OF BIM IN SUSTAINABLE BUILDING EVALUATION

BIM's increased presence in the marketplace has fuelled a greater interest for research into new BIM technology, as well as studies regarding its level of market penetration and benefits in building construction. Some of the leading researches including Wang and Chong, (2015); Khemlani (2007) all discuss the numerous contributions of BIM to sustainable building design designs, some of which are summarised in table 1.

TABLE 1: CONTRIBUTIONS OF BIM IN SUSTAINABLE BUILDING DESIGN

CONTRIBUTIONS	RESEARCHER(S)
Integrated project delivery	Nagalingam et al., (2013)
Design optimization	Wong and Fan, (2013)
It contains rich semantic information	Wang and Chong, (2015)
Reduced waste, errors and costs	Chong et al., (2014b); Azhar, (2011)
Early collaborative decision-making	Arayici, (2011); Wang et al., (2013b)

The UK government recently developed a roadmap towards the universal implementation of BIM across the industry (Cabinet Office, 2011). Still, the application of BIM is still bridled with challenges as seen in table 2.

TABLE 2: CHALLENGES OF BIM IN SUSTAINABLE BUILDING DESIGN

CHALLENGES	RESEARCHER(S)
Non-technological challenge- Training costs and software costs	Eadie et al., (2013); Ilozor and Kelly, (2012)
Non-technological challenge- Resistance to change	Ashcraft, (2009); McAdam (2010)
Non-technological challenge- Potential legal issues	Chien et al., (2014)
Non-technological challenge- Client demand	Azhar, (2011); Abanda (2014)
Non-technological challenge- Lack of understanding about BIM	Arayici, (2011)
Technological challenges- Lack of interoperability	Kiviniemi et al., (2008); Eastman et al., (2011)
Technological challenge- The general unavailability of vendor-neutral data formats and standards, as well as issues regarding accessibility and security of data	Gray et al., (2013)
Technological challenge- BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities	Sawhney and Singhal, (2013)
Technological challenge - More work upfront and creativity	Golparvar-Fard, (2013)
Technological challenge- No standard BIM contract document	Gu et al., (2009)

3.0 RESEARCH METHODOLOGY

The study adopts a literature review to highlight the contributions and barriers of BIM in sustainable building design. Furthermore, the study adopts a quantitative research approach using a structured questionnaire amongst professionals to investigate their perceptions regarding the contributions and drivers of BIM. The sample employed in the survey was obtained from a databank of construction professionals listed in the UK Royal Institution of Chartered Surveyors (RICS), Chartered Institute of Builders (CIOB) and the British Institute of Facilities Managers (BIFM).

A total of one hundred and twenty questionnaires were distributed electronically by email with 69 responses, a response rate of 57.5% which is satisfactory and is in line with the views of Akintoye (2000) and Dulami et al (2003). Random sampling was utilised in the survey; this is where each member of a population has a known and non-zero probability of being involved in the sample. It was utilised because of the low cost involved, faster data collection and since data set is lesser, it is probable to guarantee similarity and to increase correctness and quality of data. Closed ended questionnaires were employed because they can be answered finitely by either “yes” or “no, in a few words or a specific short factual answer.

The questionnaire comprised three main sections each exploring different parts of the research question. The first section sought information on the respondents’ profile as shown in table 3. The second section ranked the benefits of the application of BIM in sustainable building design (see tables 4 to 6). The third section ranked the technological and non-technological challenges encountered in the application of BIM in sustainable building design (see tables 7 to 9). The questionnaire responses were assigned numerical codes and the data was analyzed using descriptive statistics, regression and factor analysis.

Finally, the study conducts a design tool analysis of a simulated case study. The simulated conference hall with the help of the sustainable design tools explored several what if scenarios to determine the environmental performance of a low energy and self- sustaining building.

4.0 RESULTS AND DISCUSSION OF FINDINGS

Table 3 shows that 52.2 % of the survey participants were members of the RICS, while 84.1% were members of the CIOB and 15.9% were members of the BIFM. The relevance of professional institutions cannot be over-emphasised as they promote the development of constructive initiatives in the property market. Thus, all respondents being members of relevant professional bodies further lend credence to the credibility of the research.

With regards to the respondents’ years of experience, the results indicate that most respondents (50.7%) have over 11 years’ experience working with BIM applications, 49.3% have industry experience ranging between 6 and 10 years, while 20.3% have at least 5 years or less (table 3). As the experience of the respondents is quite respectable, opinions and views obtained through the survey can be regarded as important and reliable. Majority of respondents had reasonable experience in carrying out BIM which further shows that respondents are sufficiently experienced enough to provide data which are credible.

TABLE 3: EDUCATIONAL QUALIFICATIONS AND YEARS OF EXPERIENCE OF RESPONDENTS

PROFESSIONAL QUALIFICATION	FREQUENCY	PERCENTAGE	YEARS OF EXPERIENCE	FREQUENCY	PERCENTAGE
RICS	36	52.2	0-5	14	20.3
CIOB	22	84.1	6-10	20	49.3
BIFM	11	15.9	11 and above	35	50.7
Total	69	100.0	Total	69	100.0

4.1 BENEFITS OF BIM IN SUSTAINABLE DESIGN

This was achieved using factor analysis. Bartlett's Test of Sphericity and Kaiser–Meyer–Olkin (KMO) measure were carried out to scrutinise the sampling capability confirming that factor analysis was going to be suitable for the research.

Principal component analysis was then employed to extricate group factors with eigenvalues greater than 1, overwhelming all other factors with eigenvalues less than 1 based on Kaiser's criterion (Field, 2000).

Before the factor analysis, validity test for factors was conducted according to the method by Kaiser (1974). By Kaiser Method, a value called eigenvalue under 1 is perceived as being inadequate and therefore unacceptable for factor analysis. Based on Kaiser's eigenvalue rule, factor analysis is performed and the retained factor requires the eigenvalue to be larger than 1.

After the primarily factor analysis, oblique rotation method was used to look for a linear combination of the original factors, such that the variance of the loadings is maximized. The final factor analysis results are shown in table 4.

TABLE 4: FACTOR ANALYSIS

Correlation Matrix							
		(1)	(2)	(3)	(4)	(5)	(6)
Correlation	BIM can be used to determine environmental performance for sustainable building design (1)	1.000	.114	-.019	-.348	.131	.156
	Design optimization (2)	.114	1.000	-.017	-.218	-.013	-.113
	Reduced waste, errors and costs (3)	-.019	-.017	1.000	.133	-.114	-.249
	Integrated project delivery (4)	-.348	-.218	.133	1.000	-.098	-.010
	It contains rich semantic information (5)	.131	-.013	-.114	-.098	1.000	.139
	Early collaborative decision-making (6)	.156	-.113	-.249	-.010	.139	1.000
Sig. (1-tailed)	BIM can be used to determine environmental performance for sustainable building design (1)		.176	.439	.002	.142	.100
	Design optimization (2)	.176		.444	.036	.459	.177
	Reduced waste, errors and costs (3)	.439	.444		.137	.175	.020
	Integrated project delivery (4)	.002	.036	.137		.212	.467
	It contains rich semantic information (5)	.142	.459	.175	.212		.128
	Early collaborative decision-making (6)	.100	.177	.020	.467	.128	

From the correlation above, it was deduced that all the benefit factors were insignificant except for 'integrated project delivery. This particular factor has a standardize significant value of (.05). However, it was observed that two factors (design optimization and reduced waste, errors and costs) resulted with eigenvalues greater than 1, capturing 48.043% of total variance (see table 5).

TABLE 5: TOTAL VARIANCE

Extraction Method: Principal Component Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.596	26.600	26.600	1.596	26.600	26.600
2	1.287	21.443	48.043	1.287	21.443	48.043
3	.943	15.722	63.765			
4	.874	14.573	78.337			
5	.738	12.302	90.639			
6	.562	9.361	100.000			

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The value of KMO is 0.533, which is above Kaiser's (1974) specification of 0.5. The factor scores were generated by using the Bartlett method, which calculated for each response, the 'weighted sum' of their standardized value for every variable multiplied by the corresponding factor loading of the variable in table 6.

TABLE 6: KMO AND BARTLETT'S TEST

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.533
Bartlett's Test of Sphericity	Approx. Chi-Square	23.049
	Df	15
	Sig.	.083

4.2 BARRIERS OF BIM IN SUSTAINABLE DESIGN

The summary statistics of the barriers of BIM in sustainable design are presented in the table seven below. The t-value column provided the individual significance of each independent variable in the regression equation and showed whether the variable was making statistically significant contribution. A variable must have a significant value of alpha less than 0.05 to make significantly unique contribution.

TABLE 7: REGRESSION ANALYSIS

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.270	1.393		3.065	.003
	Technological challenge: Lack of interoperability	.379	.210	.363	1.805	.076
	Technological challenge: BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities	.051	.154	.058	.331	.742
	Technological challenge: The general unavailability of vendor-neutral data formats and standards, as well as issues regarding accessibility and security of data	-.068	.095	-.117	-.717	.476
	Technological challenge: More work upfront and creativity	-.107	.193	-.095	-.556	.581
	Technological challenge: No standard BIM contract document	-.033	.105	-.060	-.314	.755
	Non-technological challenge: Training and software costs	-.260	.128	-.359	-2.028	.047
	Non-technological challenge: Client	-.249	.096	-.376	-2.589	.012

	demand					
	Non-technological challenge-Resistance to change	.013	.109	.019	.115	.909
	Non-technological challenge: Lack of understanding about BIM	-.116	.097	-.191	-1.199	.235
	Non-technological challenge: Potential legal issues	-.296	.125	-.389	-2.376	.021
a. Dependent Variable: BIM can be used to determine environmental performance for sustainable building design						

Table seven above presents the summary for the challenges of BIM in sustainable building design. Only three of the attributes of non-technological barriers made statistically unique contributions at 95% confidence level namely: training costs and software costs, client demand and potential legal issues.

In analysing the technological challenges of BIM in sustainable building design, the standardized beta coefficients which provide the order of importance or relative contribution of BIM attribute show that lack of interoperability makes the largest contribution, followed by BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities. The multiple regression equation that shows the challenges of BIM (Cobim) to the sustainable building design is given by the constant and the coefficients of the unstandardized beta as:

$Cobim = 4.270 + 0.37LO_{i} + 0.05BI_{msraytbe} - 0.068GA_{vndfas} - 0.107MW_{uac} - 0.033NO_{sbimcd} - 0.260TS_{c} - 0.249CD + 0.013RT_{c} - 0.116SLO_{uabim} – 0.296PL_{i}$------ (1)

The equation shows that the lack of interoperability makes the largest contribution, followed by BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities are positively correlated.

The box labelled ‘model summary’ (table 8) gives the measure of how well the overall model fits, and how well the predictor (lack of interoperability, BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities, more work upfront and creativity, no standard BIM contract document, training and software costs, client demand, resistance to change, the general unavailability of vendor-neutral data formats and standards, as well as issues regarding accessibility and security of data, lack of understanding about BIM and potential legal issues). The first measure in the table is called R. This is a measure of how well the predictors predict the outcome, but the square of R provides a more accurate measure.

In this case it is 0.224, so 22.4% of the variance in BIM challenges can be explained by (lack of interoperability, BIM specific requirements are yet to be adequately embedded within current state of procurement thus creating disruptive possibilities, more work upfront and creativity, no standard BIM contract document, training and software costs, client demand, resistance to change, the general unavailability of vendor-neutral data formats and standards, as well as issues regarding accessibility and security of data, lack of understanding about BIM and potential legal issue. The final column gives the standard error of the estimate. This is a measure of how much R is predicted to vary from one sample to the next.

TABLE 8: MODEL SUMMARY

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.473[a]	.224	.090	.696	1.562

The table 9 shows the ANOVA results. The F-value is the Mean Square Regression (0. 810) divided by the Mean Square Residual (0. 485), yielding F=1.670. The p-value associated with this F value is very small (0.0000). These values are used to answer the question "Do the independent variables reliably predict the dependent variable?" The p-value is compared to the alpha level (typically 0.05) and, if smaller, one can conclude "Yes, the independent variables reliably predict the dependent variable". It is glaring that the group of (independent) variables can be used to reliably predict ''BIM can be used to determine environmental performance for sustainable building design'' (the dependent variable). The overall significant value (0. 110) is less than the standardized significant value which reveals that the challenges are generally acceptable.

TABLE 9: ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	8.095	10	.810	1.670	.110[a]
	Residual	28.108	58	.485		
	Total	36.203	68			

4.3 DESIGN TOOL ANALYSIS

The following steps are used in this paper to develop BIM conceptual framework with emphasis on building suncast shadow studies, shading design, internal sun penetration, visual impact studies, daylighting study, artificial lighting analysis, environmental cost impact analysis and energy use analysis.

4.3.1 SITE DESCRIPTION

The proposed development site falls within Derby North riverside which is located in the northern part of the city and bounded by St. Alkmund's Way (inner ringroad), the River Derwent, Exeter Place and Darwin Place, a total area of 2.31 ha (5.7 acres). Currently the site is a surface car park (Darwin Place) and the river frontage land is occupied by a block of flats (Exeter House), the area is meant to be redeveloped and integrated back into the city centre as the redevelopment of the site area of the city centre is one of the priority projects within the Derby Cityscape Master plan.

Figures 1 and 2: Master plan proposal and site location plan

4.3.2 THE PROPOSED BUILDING

The proposed facility is a multi-use building; named 'the waterfront', the proposal consists of a self-surviving conference and multi-purpose hall.

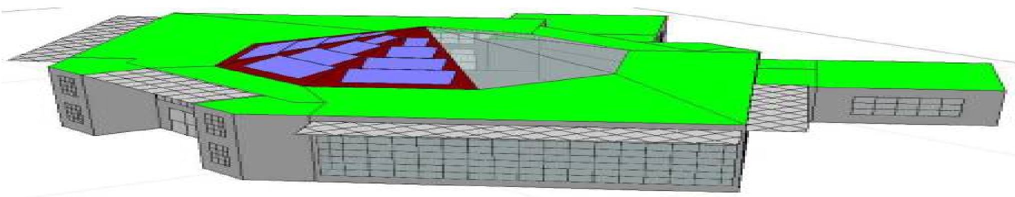


Figure 3: The Proposed Conference Hall.

4.3.3 SELECTION OF SUSTAINABLE DESIGN INDICATORS

In order to evaluate energy and resource efficiency, waste prevention, and pollution management among other indicators of sustainability at the early stage of design when cost of change is at the cheapest, various energy performance analysis tools are available. Currently, there are three commonly used BIM compatible sustainability analyses software on the market. These are Autodesk ECOTECT, Autodesk Green Building Studio (GBS) and Integrated Environmental Solutions (IES) Virtual Environment (VE).

Some authors have emphasized on the integration of BIM with GBS or VE (Stumpf et al., 2009; Rundell, 2007). In this paper, the Autodesk ECOTECT and Autodesk Green Building Studio (GBS) were utilised for appraising environmental performance as they are appropriate tools for this task.

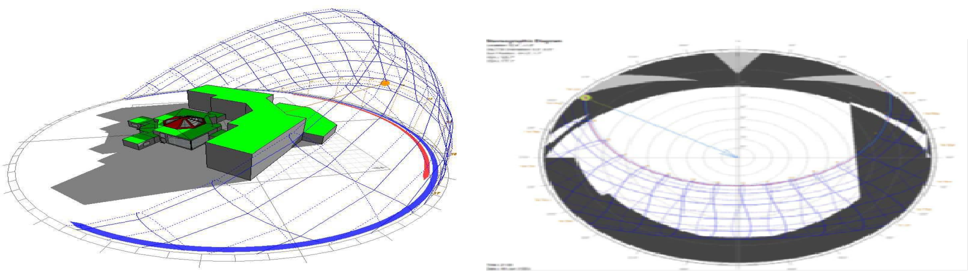
4.3.4 ANALYSIS AND DISCUSSION OF RESULTS

i) BUILDING SUN CAST SHADOW ANALYSIS AND OVERSHADOW

The overshadowing and sun path analysis is carried out to determine the extent to which the conference room would be overshadowed especially during the two solstices (December 21st and June 21st) when there is high tendency of overshadowing.

Baseline Design

The figures below are the initial design made before exploration of various what if scenarios as well as the sun path diagram that evaluated the extent to which a point on solar panels on the conference hall would be overshadowed by the hotel tower.



Figures 4 and 5: Baseline overshadowing pattern for winter solstice and Baseline sun path diagram for a point on solar collectors

The initial analysis shows that the building would be overshadowed throughout December and January while it will not be overshadowed only between 10am and 3pm in November and February. This means that there would be no access to daylighting and solar heat during the period. As such, the design is passed through various sensitivity analyses.

Sensitivity Analyses

Various what is scenario explored include tilting of the two wings of the hotel part, increasing the depth of the courtyard and relocating the solar panel. The option of increasing the depth of the courtyard is adopted as:

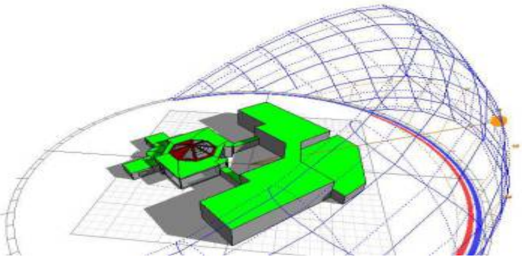
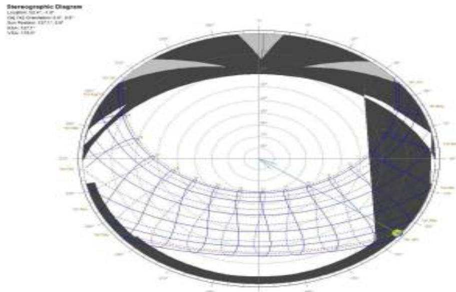
• It adds the least alteration to the design in general

• It enhances solar gain to the hotel facilities

• It did not alter the desired shape; hence, it also enhances the possibility of increasing glazing to south facing part of the hall.

Final Outcome

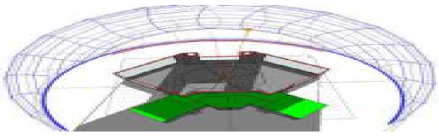
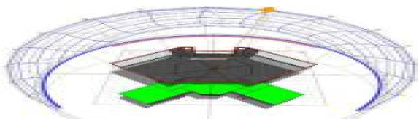
The analysis assisted in selecting an adequate spacing between the hotel tower and the conference hall so that the hall will not be overshadowed almost throughout the year and without putting unnecessary spacing between the buildings. The final outcome shows that the building would not be overshadowed even during the solstices

Figures 6 and 7: Final overshadowing pattern for winter solstice and final sun path diagram for the point on solar collectors

ii) INTERNAL SUN PENETRATION AND SHADING DESIGN

The solar penetration patterns differ from month to month throughout the year. While it may be desirable during the winter, excessive solar penetration may not be desirable in summer. As such, the solar design in this study is purposely meant for summer while internal blinding would serve as a means of preventing solar penetration (at the wish of occupants) during other months of the year.

Figures 8 and 9: Baseline sun penetration pattern at winter solstice (December 21st) and sun penetration pattern at summer solstice (June 21st)

Result Analysis

The images show that there is high depth of solar penetration throughout the year. Although the penetration pattern is minimal during the summer as shown in June and September, there would be a need for solar shading device to prevent solar penetration during the warm season in order to prevent excessive need for cooling that would result from unwanted heat gain.

Figure 10: Sun penetration pattern on September 21st

Shading design

The way by which the building has been positioned against the southern part of the site will make it benefit greatly from the sun throughout the year, especially in the winter. However, there would be need for some sort of sun shading devices purposely optimised to prevent excessive solar gain in summer.

Automatic Shading Design

The automatic shading device created for the window adequately shaded/prevented the indoor environment from solar penetration as shown below:

Figure 11: Effective summer solar shading through automatic device

However, it is noted that the projection is over designed and with less aesthetic quality to the whole design, therefore, the actual depth is calculated and the required shading device projection for summer period is achieved by optimization.

Optimized Shading Device

The shading effect of the shading device proved to be adequate for summer period. Internal blinding or use of such shading devices as BRIE SOLAIRE would be adequate for winter shading. This is because of preference of solar gain during the cold season. Therefore, occupant or self- controlled device would be adequate.

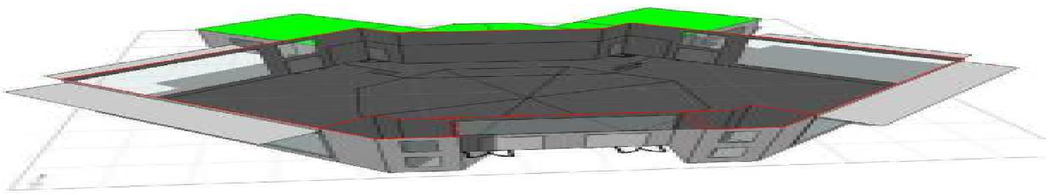


Figure 12: Through optimized device

iii) DAYLIGHTING STUDY

Desired daylighting level for a conference hall is at the range of 500 to 300lux. In the case of conference hall which might be used for more intense reading and writing such as the like of this design which is referred to as multipurpose hall, a minimum lux of about 500 is recommended. In order to benefit from adequate daylighting so as to reduce energy use for daylighting purpose, it is desirable that the lux level is not less than 500 especially at the podium.

Baseline daylighting study

The lighting study shows some areas towards the podium having as low lux level as 32lux. Clerestory windows are introduced at the upper part of the adjoining spaces to throw light into the hall and the door type is changed from wooden to glazing; this increased the lux level but still remained inadequate as shown in figure 13.

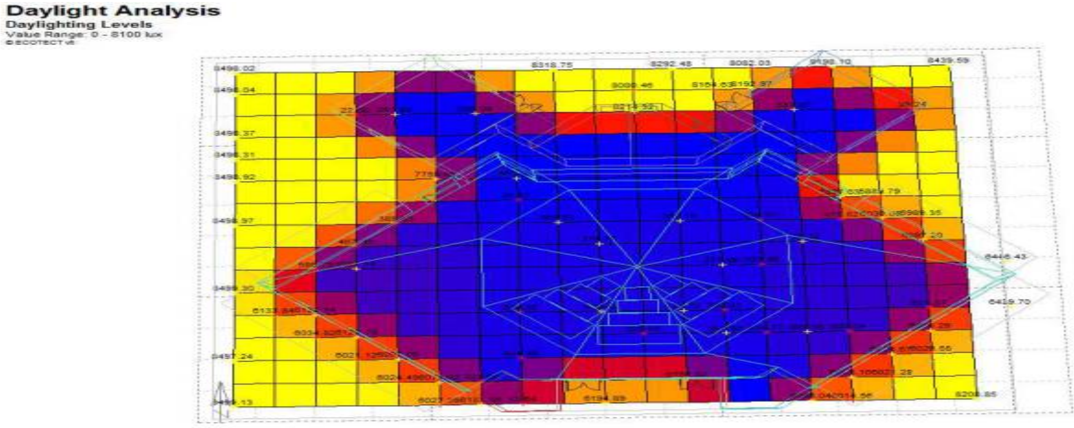


Figure 13: Through optimised device

Skylight option

In order to achieve the target lux level, an option of using skylight is explored with the resulting result shown in figure 14.

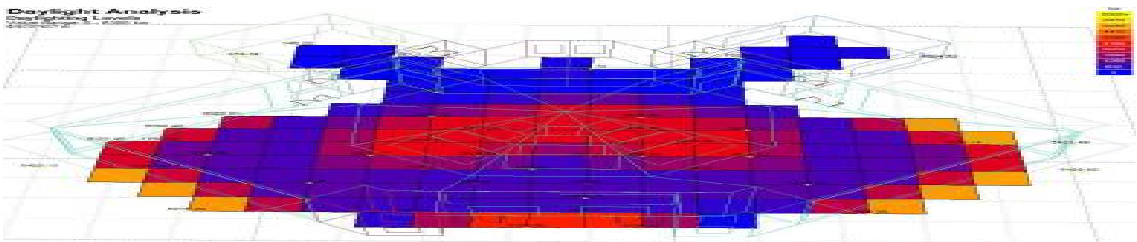


Figure 14: Skylight option

With the introduction of the skylight, the minimum daylighting level comes above 500 lux, this provides the building with the opportunity of using daylighting thereby reducing energy need for lighting during the day. Effort must therefore be taken to choose proper glazing/translucent materials for the skylight so that energy gained through artificial lighting would not be lost to heating as a result of heat loss through the skylight.

iv) ARTIFICIAL LIGHTING ANALYSIS

For places like multipurpose halls, their night use is indispensable especially during periods when it gets dark as early as 4pm; therefore, artificial lighting is also evaluated to ensure that there would be adequate lighting level during the night. This is actually meant to be for night period as the daylighting has been satisfactorily achieved for energy saving in day time.

Bearing in mind that the type of lighting bulb contributes not only to its intensity, it determines the extent of energy required for lighting. Therefore, an energy efficient bulb, "FluoroLampStripUnit light material" is selected; this is known to be energy efficient as differs from the incandescent types. Initial lighting design gave between 1800 and 4000lux when the electric lighting is isolated; although this is adequate, it can be termed as over-design as this would significantly impact on the cost of the project as well as energy consumption. Therefore, the amounts of lighting points were reduced, and the resulting lux values ranged from 500 to 1400lux. This means the lighting is adequate without unnecessary over-design which may impact on the cost of the project

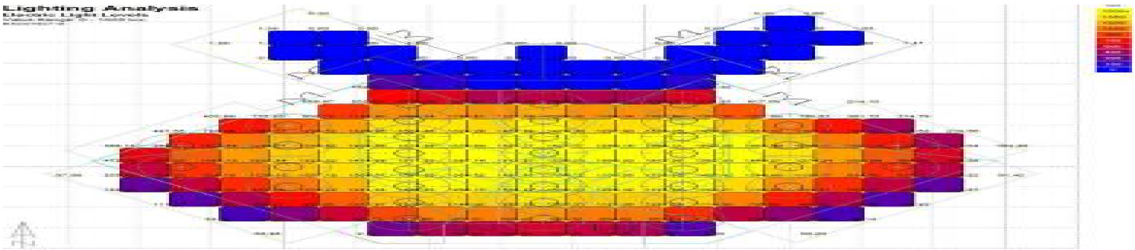


Figure 15: Artificial lightening level achieved through low energy fluorescescent bulbs

v) VISUAL IMPACTS STUDIES

The visibility study is used to simulate the extent of outdoor spaces that would be visible from inside the conference hall. The aim of the study is not only to ensure that good view is achieved from within the inner part of the space, but also to prevent bad view of the outdoor space. Figure 16 shows the obtained result from the simulation.

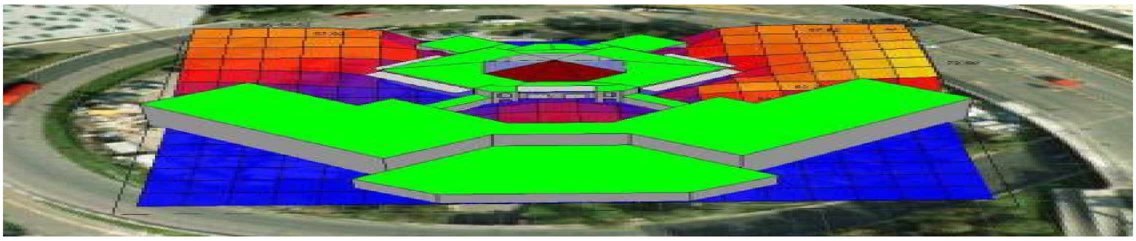


Figure 16: Extent of outside view from inside the conference multi-purpose hall

It is obvious that river view cannot be achieved as a result of the adjoining hotel tower which is also a part of the design. Meanwhile, the analysis shows that apart from a view of the courtyard which would be achieved, more than 80m2 distances can be clearly seen to the western and eastern parts of the site which is bounded by ring road. As this does not constitute what can be termed as good view; therefore, a design effort has to be made to achieve good view from the indoor space as shown in figure 17.

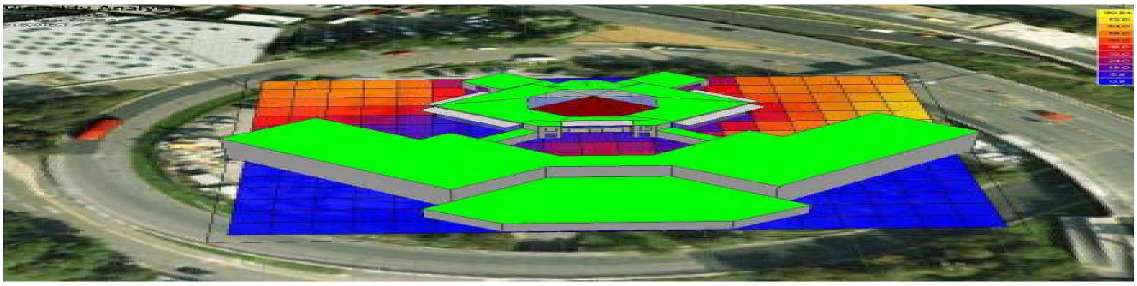


Figure 17: Extent of outside view from inside the conference multi-purpose hall

Multi-purpose solution

In order to achieve a good view, proper landscaping could be done to the courtyard, eastern and western part of the site as they are the parts that are visible through the openings. However, this does not mean that the northern part should not also be landscaped. The use of such techniques as landscaped "earthbound" in this case would not only mean a good view from the space, it would also help to prevent noise pollution from on-going vehicles, and as well serve as flood mitigation strategy.

vi) COST ANALYSIS

Cost was assigned to various materials used in the building to evaluate the baseline cost of the less thermal efficient design as a basis for comparative. The rough cost estimate was obtained from a guide available at www.homebuilding.co.uk. Initial embodied energy and CO2 footprint of the materials are also assigned using information from CES, GreenSpec guide and 'ecology of building materials'. Below is the baseline cost and environmental impacts

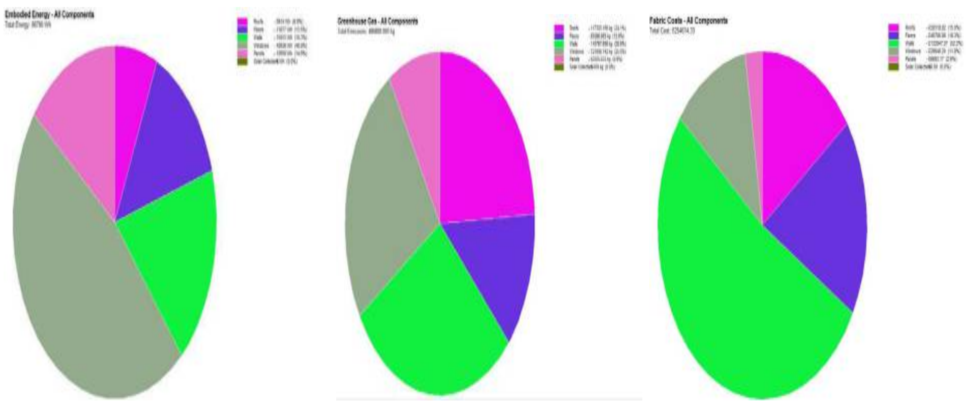


Figure 18: Baseline costs and materials

After improving insulation to wall and roof, with glazing changed from double to triple with argon gas fills, below is the cost impact result:

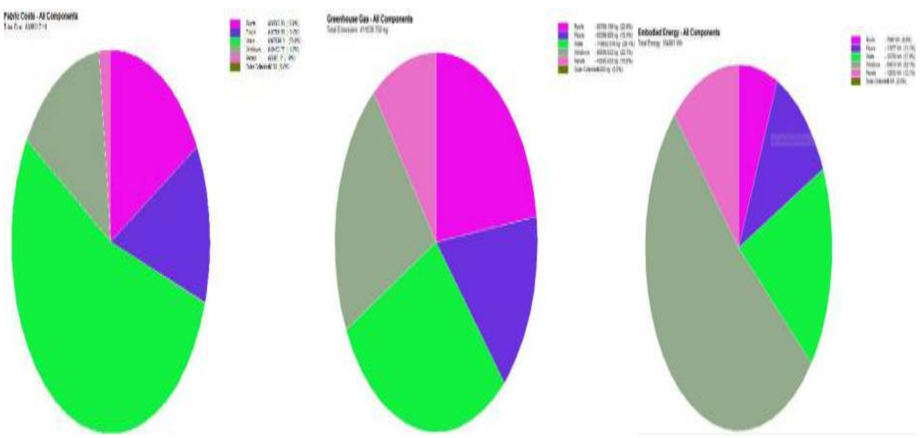
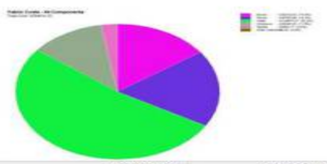


Figure 19: Comparative cost analysis

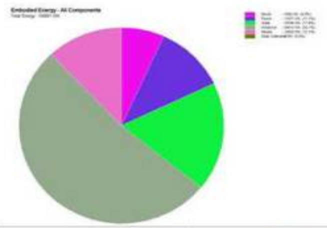
EMBODIED ENERGY - ALL COMPONENTS
Model: C:\Users\100251772\Desktop\BORIS 6TH JUNE\FINISHED SIMULATION\COST ANALYSIS initial.eco
Date: Jun 06 10:31:31 2013



ELEMENT	COST (£)	GREENHOUSE GAS(kg)	EMBODIED ENERGY(Wh)	MAINTEN. ENERGY(Wh)	MAINTEN. COST(£)
Roof	38318.82	117303.156	5914	0	0.00
Floor	46706.88	63396.805	11677	0	0.00
Wall	132947.27	140767.656	15915	0	0.00
Window	29948.20	121906.742	40636	0	0.00
Panel	6693.17	43505.633	12650	0	0.00
Solar Collector	0.00	0.000	0	0	0.00
TOTAL	**254614.33**	**486880.000**	**86790**	**0**	**0.00**

Figure 20: Initial cost, embodied energy and co2 emission potential

FABRIC COSTS - ALL COMPONENTS
Model: C:\Users\100251772\Desktop\BORIS 6TH JUNE\FINISHED SIMULATION\COST ANALYSIS.eco
Date: Jun 06 10:53:59 2013



ELEMENT	COST (£)	GREENHOUSE GAS(kg)	EMBODIED ENERGY(Wh)	MAINTEN. ENERGY(Wh)	MAINTEN. COST(£)
Roof	58503.80	93785.195	7090	0	0.00
Floor	46706.88	63396.805	11677	0	0.00
Wall	187690.31	119652.516	18769	0	0.00
Window	49453.27	90698.633	54614	0	0.00
Panel	6693.17	43505.633	12650	0	0.00
Solar Collector	0.00	0.000	0	0	0.00
TOTAL	**349047.44**	**411038.750**	**104801**	**0**	**0.00**

Figure 21: Final cost, embodied energy and CO2 emission potential

The result shows that improved glazing panes and increased insulation thickness to wall and roof resulted in cost increase as well as increase in initial embodied energy but a reduction in CO2 emission that will result from the building per annum.

If the CO2 is considered in terms of initial embodied carbon, it will still mean a substantial increase as the material is increased. This is because of the fact that the same material is still in use but with an increase in the size used. However, exploration of eco-friendly materials for wall showed a substantial decrease in both embodied energy and CO2 emission. Meanwhile, the increased initial embodied energy as a result of improved insulation thickness would be compensated by maintenance cost and maintenance energy requirement.

This is because, the later design that achieved adequate daylighting would require less energy for its maintenance. Hence, such an energy efficient design apart from being environmental friendly would also be regarded as being the cheapest as its lower running cost and energy need would compensate for the higher initial cost and embodied energy.

vii) GREEN BUILDING STUDIO ANALYSIS (ENERGY USE PATTERN)

The design was exported to GBS in order to evaluate the environmental performance and lifecycle costing of the final design made with Ecotect analysis. The result of the baseline design analysis is shown below:

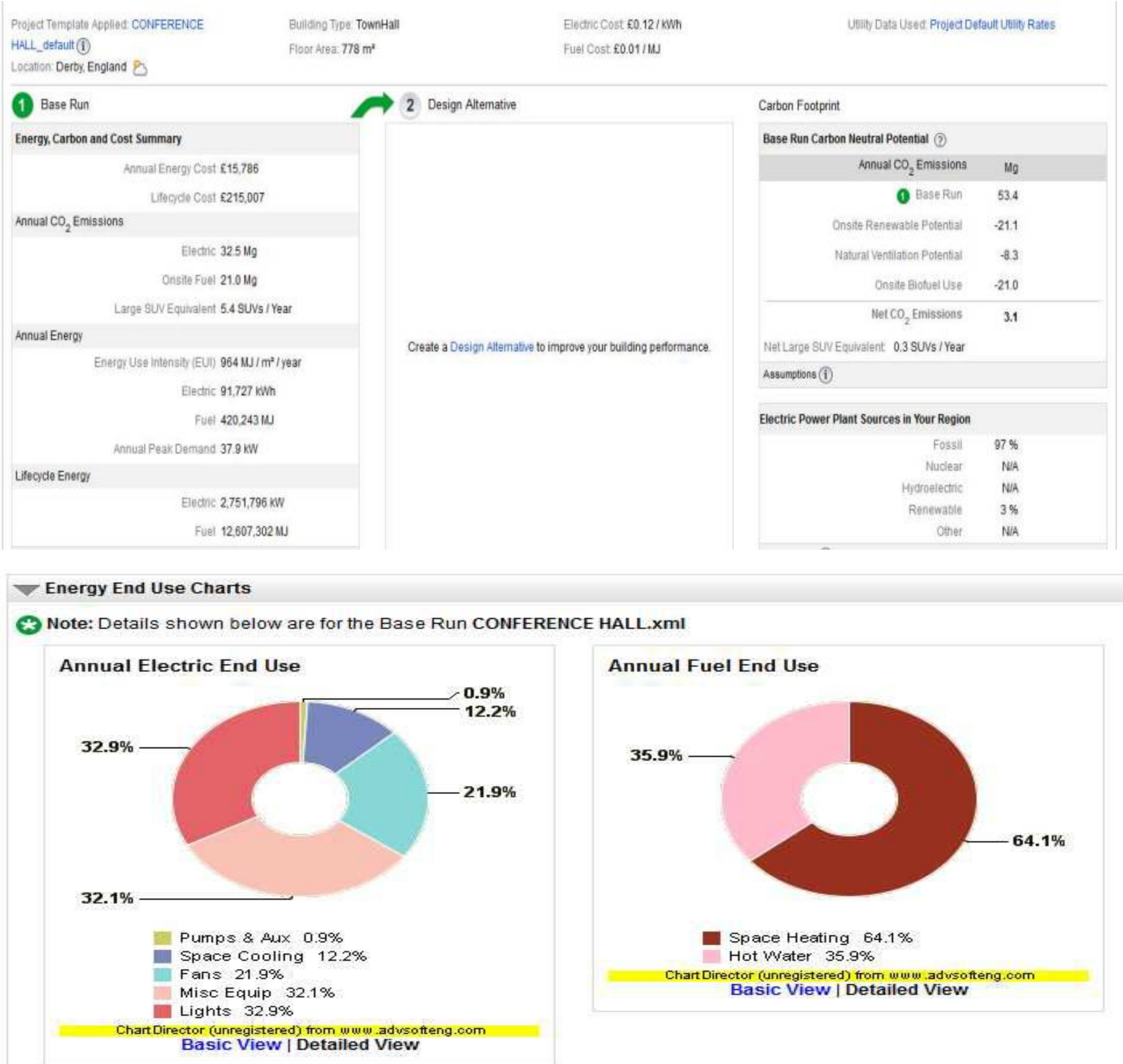


Figure 22: Baseline design analysis

The base run design recorded an annual energy cost of £15,786 at current energy cost, and a total of £215,007 over a 30years lifecycle. The CO2 emission is recorded at a total of 53.4Mg CO2 per year at the equivalent of 5.4SUVs/year with potential of reducing the emission level to an equivalent of 0.3SUV/year, which is 3.1Mg CO2 per annum. Various alternatives were explored.

Alternative Design 1

More energy efficient lighting techniques were adopted in the alternative design. Occupancy sensor and daylighting control were specified, this showed insignificant reduction in both CO2 emission and cost of energy.

Alternative Design 2

Improved insulation to roof, wall and selection of 3pane clear low E windows also resulted into less significant decrease in energy cost from £15, 786 to £15, 057 while the CO2 emission also decreased from 53.4Mg to 49.9Mg.

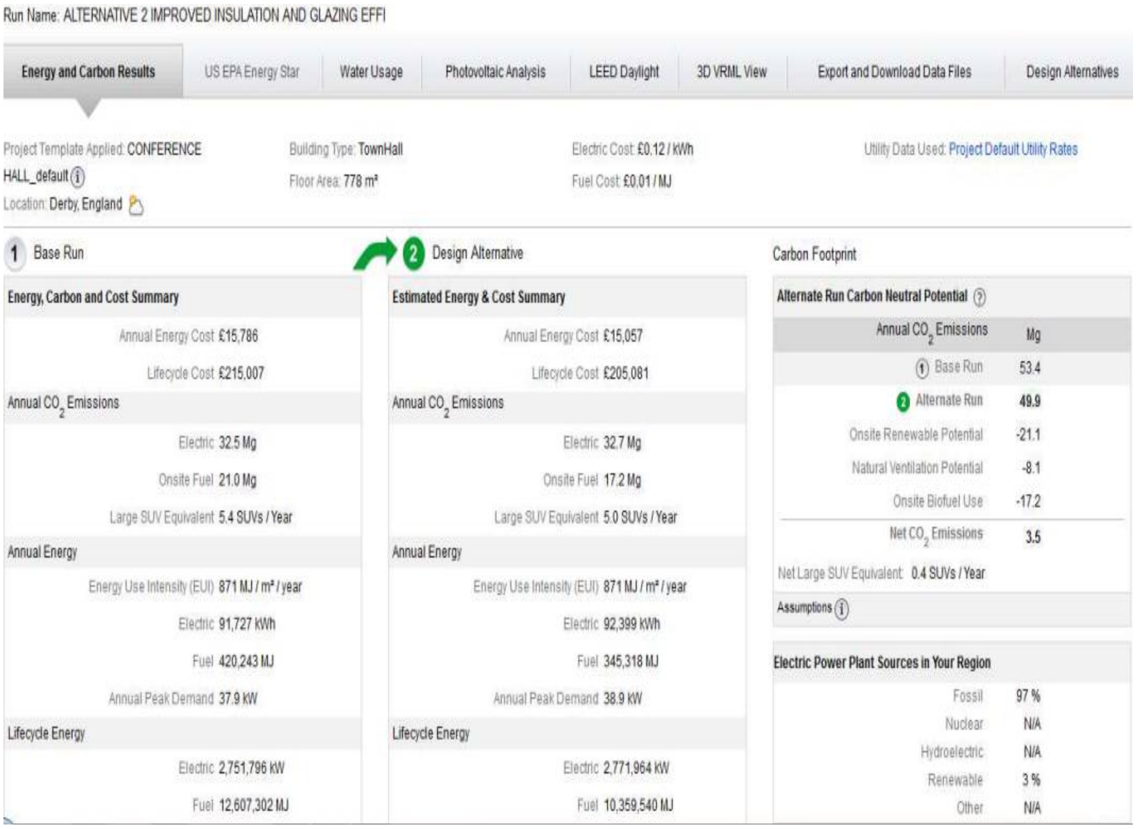


Figure 23: Alternative design 2 analysis

However, the analysis shows a likely increase in the amount of CO2 emission resulting from electricity increase from 32.5 to 32.7Mg. This is because increasing glazing thickness will reduce daylighting. Meanwhile, there is more significant decrease in the CO2 emission resulting from fossil fuel from 21.0Mg to 17.2Mg.

This is also probably due to the fact that improved glazing and loft insulation will reduce energy need for heating and cooling. Hence, in general, the alternative 2 offers a better choice than the base run design as there is decrease in the cost of annual energy need and overall reduction in CO2 emission.

Alternative Design 3

Air source heat pump was selected for HVAC, this reduced the net CO2 emission insignificantly, reduced the energy cost from the baseline design while it is less cost effective compared to alternative 2. There is an increase of annual energy cost from £15, 057 to £15, 072 when comparing alternative 2 and 3. This showed that alternative 2 is less costly compared to the baseline design and alternative 3, and it also has better potential for net CO2 reduction than the alternative 3.

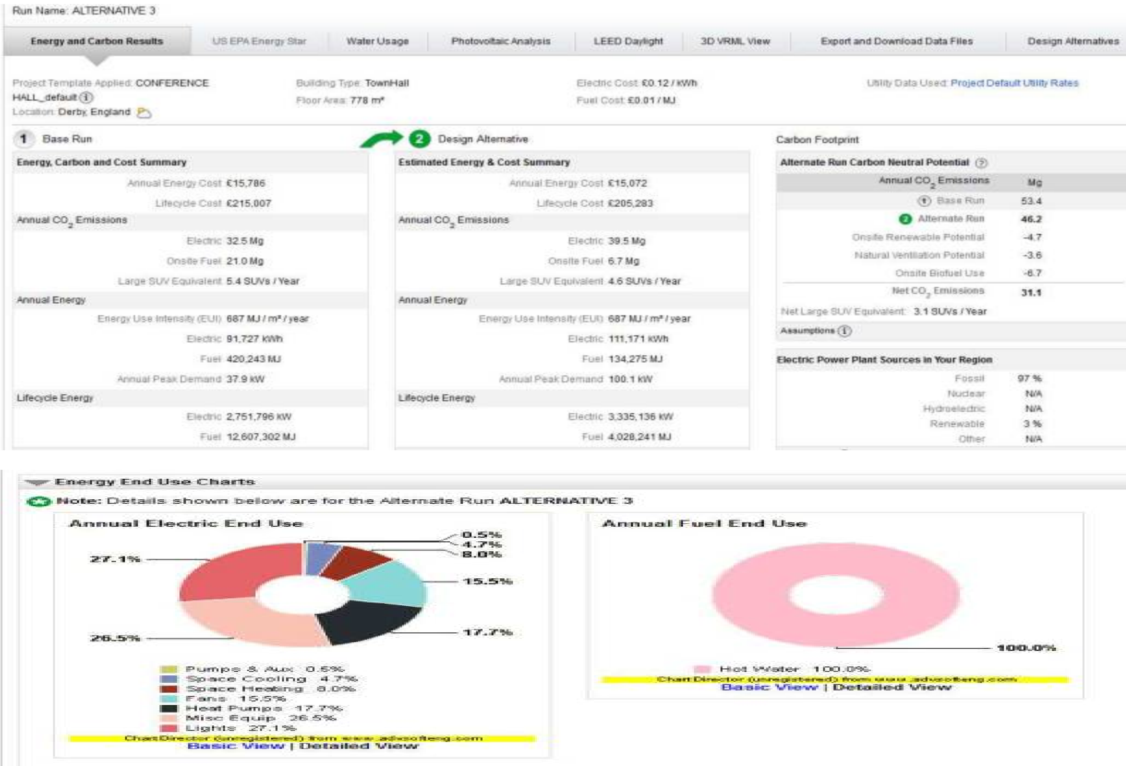


Figure 24: Alternative design 3 analysis

Alternative Design 4

The three alternative design options were combined in the last alternative; the result showed a bit higher CO2 emission than what it showed when air source heat pump was adopted. However, there is a reduction in life cycle energy cost. It is shown below:

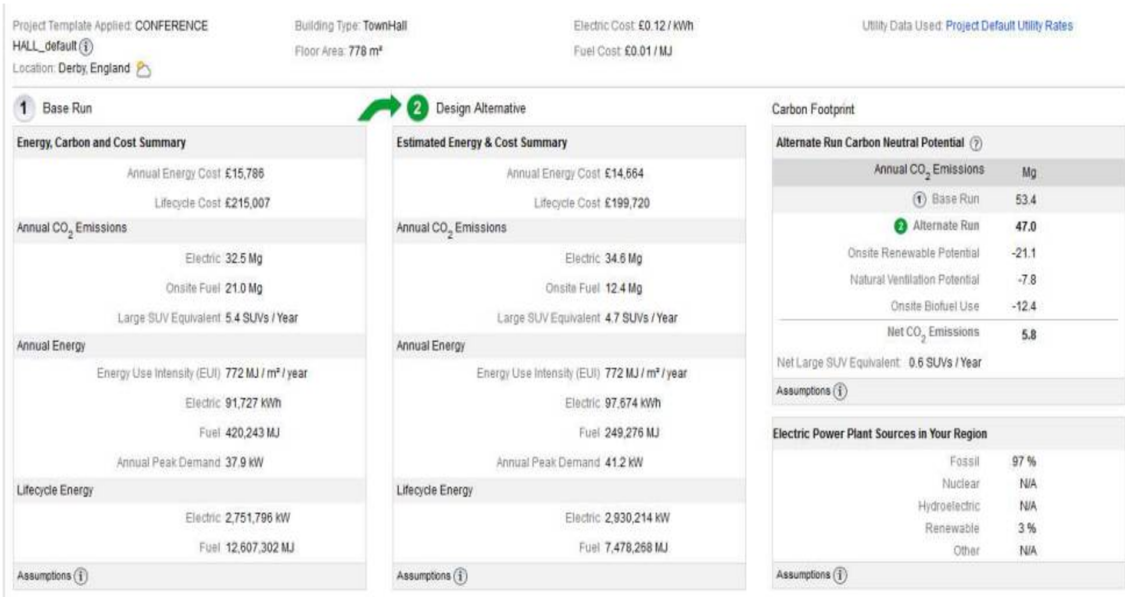


Figure 25: Alternative design 4 analysis

5.0 RECOMMENDATIONS AND CONCLUSION

In summary, the study indicated that professionals ranked the integrated project delivery as the most established benefit while the lack of interoperability was ranked the greatest technological challenge. Only three of the attributes of non-technological barriers made statistically unique contributions namely training costs and software costs, client demand and potential legal issues.

The study has been able to demonstrate that BIM compatible tools can immensely help designers to achieve good environmental rating, low running cost, low carbon house, lower life cycle cost and so on, if various what if scenarios (sensitivity analysis) are properly evaluated at the early stage of design when the cost of change is at the cheapest.

• The building was prevented from being overshadowed by the adjoining hotel tower, while the tool helped in determining adequate spacing between buildings.

• Sun penetration is prevented in summer in order to avoid excessive heat gain which may require much need for cooling.

• With the introduction of the skylight, the minimum daylighting level comes above 500 lux, this provides the building with the opportunity of using daylighting thereby reducing energy need for lighting during the day.

• Artificial lighting is also evaluated to ensure that there would be adequate lighting level during the night.

• The visibility study is used to simulate the extent of outdoor spaces that would be visible from inside the conference hall.

• Environmental cost and actual cost of the building project were evaluated to select an environmental friendly design with lesser project cost

• Using GBS, various design alternatives were analysed to determine the one with lower running cost and less CO_2 emission.

The application of Building Information Modelling (BIM) has demonstrated enormous potential to deliver consistency in the construction collaboration process. BIM can define an explicit configuration for digitized information exchange, however the technology to collaborate on models has not yet delivered the industry requirements for BIM collaboration. There is a need to speed up development and standardization of BIM sub models to provide for broader coverage of user requirements and information flows in the full lifecycle of AEC projects.

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