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Refurbishment of UK school buildings: Challenges of improving energy performance using BIM

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Abstract. UK Schools are part of the existing buildings whose operational carbon must be reduced to meet the government target of reducing carbon emissions to 80% by 2050. State funding for refurbishment is the most feasible option using two routes: Condition Improvement Fund (CIF) which is restricted to improving the physical aspects of school facilities; and Salix Energy Efficiency Fund (SEEF) aimed at energy/equipment retrofit measures. Although the use of BIM technology (underpinned by the government soft-landing (GSL) framework) together with the use of energy modelling/simulation tools have become integral to making buildings more energy efficient, they are constrained by lack of adoption. This study used primary and secondary data to investigate the effectiveness of contemporary BIM and energy simulation technologies in refurbishment of existing school buildings. Secondary data collected from 10 case studies of schools that benefitted from SEEF was supported by primary data from survey questionnaire of 126 professionals involved in refurbishment. Results showed that: (a) CIF and SEEF ought to operate in synergy due to the interaction of a building's physical envelope with heat transfer and energy used by equipment and systems; (b) refurbishment professionals are not fully adopting BIM which in turn affects managing the buildings in their operational phase; and (c) some schools are not getting technical advice on how to optimise the funds they receive from SEEF leading to non-optimal investment. Recommendations provided include: extensive training on BIM and GSL to heads of schools; upskilling of professionals on using building pathology techniques that are compatible with BIM together with COBie and NBS Toolkit; advise government agencies to reconcile the purpose of CIF and SEEF for carbon reduction solution in schools.

Keywords: BIM, refurbishment, energy performance, school buildings.

1. Introduction

The construction industry is responsible for approximately 7% of the gross domestic product (GDP) of many countries but its success and reputation is hampered by overdependence on natural resources [1]. In particular, raw materials are needed for constructing buildings as well as the energy needed to make them habitable and comfortable requires artificially adjusting the indoor environmental quality (IEQ).



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This leads to significant expenditure for the operational phase of buildings. The UK government therefore, initiated a Government Soft Landings (GSL) policy in order to link end-use requirements with financial and environmental sustainability [2]. This policy requires a follow up and aftercare services to be done by the same designers and contractors who developed a facility and it requires a mandatory three-year post occupancy evaluation (POE). It is expected that the GSL will provide feedback from end-users which can be used by owners, facility managers, utility / energy service providers for continuous improvement and learning. In addition, it is hoped that the energy performance gap (i.e. the mismatch between predicted and actual energy consumption of buildings [2], [3]) can be reduced via the GSL if stakeholders can better understand, fine tuning and debug building energy systems. Technology is expected to play an important role in this regard, including sensors and smart devices [4] leading to cyber-physical systems [5] also known as digital twinning for real-time mapping of data between virtual and physical models.

Other technologies that GSL depends on include those used for Building Information Modelling (BIM) and energy simulation, which are integrated in the design stage for assessing the performance of buildings. A review and summary of these technologies (Table 1) revealed nine popular tools/plugins [6] and also indicates there is an attempt to make them interoperable using file formats like Green Building eXtensible Mark-up Language (.gbXML) and industry foundation classes which has .IFC file extension [7]. Statistical probabilistic models are also used for large scale modelling of the energy consumption across building stocks and for studying regional and national trends without relying on 3D model-based simulations [8]. In addition to the GSL framework, another influencing factor on BIM implementation in the UK is digital twinning, as articulated by the Digital Framework Task Group (DFTG) of the Centre for Digital Built Britain (CDBB) [9]. The DFTG's publication of the "Gemini Principles" provides an overarching set of principles and framework for the national digital twin. Digital twin has been defined by the DFTG as 'a realistic digital representation of something physical' and the UK's national digital twin as "an ecosystem of digital twins connected via securely shared data". In addition, all digital twins are expected to have a distinct use, and in addition to being technologically agnostic, they should be trustworthy and function properly [9]. In light of the above policy and technological opportunities, the objective of the study was to investigate the effectiveness of contemporary BIM and energy simulation technologies in refurbishment of existing UK school buildings.

1.1 Refurbishing of existing buildings for carbon reduction – A review

For existing buildings which may not have been designed/constructed using modern simulation and modelling processes, their energy and carbon performances can still be improved using refurbishment, repair or maintenance of existing envelope / fabric or the installed energy and IEQ systems. During such upgrades, designers are able to consider options for sustainability, e.g. using materials with low embodied energy/carbon or enhanced insulation as well as equipment which consume less energy and emit zero or minimal greenhouse gases (GHG).

1.1.1 Modelling and simulation for improved performance

For better and more accurate repair/upgrades, diagnostics and fault detecting systems can be used in existing building to collect real-time data for integration with energy management systems and 3D models [10]. The age and environmental conditions of a building can also be used to assess their suitability and best options [11] e.g. using detecting faults using thermal imaging data integrated into gbXML models which are compatible with BIM [12]. Other data collected for refurbishment of existing

buildings include occupant movement data (using from sensors) that can reveal actual energy profile of spaces than what is predicted by dynamic thermal simulations [13]. Such occupant data is helpful because energy efficient retrofitting is not only a matter of improving building envelope and insulation - occupant behaviour can affect heat loss/gain [14] e.g. when doors are opened or when appliances are left on [13]. In summary, building refurbishment is an excellent opportunity to forensically examine a building's performance for the purpose of closing energy performance gaps and with respect to school buildings actual consumption is much higher than theoretical calculations and simulations [15].

Table 1. Overview of BIM tools used for energy assessment as derived from [16] and [7]

Energy Assessment Tool	Typical Application	Comments on BIM, Interoperability as well as geometry import and export
AECOSim Energy Simulator (Bentley)	Simulation and analysing of building mechanical systems, thermal and energy performance as well as environmental conditions.	Import building layouts directly from multiple file formats to easily reuse existing data without the need for third-party applications to interpret data.
Green Building Studio (Autodesk)	Used for environmental design and thermal analysis including annual electric and gas energy consumptions, natural ventilation, CO ₂ emissions, daylighting, water usage and cost, LCC.	Is interoperable through gbXML format
IES VE	It is used for thermal design and analysis of buildings including calculation of heating and cooling loads, CO ₂ emissions, solar shading, daylighting analysis, natural ventilation and mechanical airflow and whole life cycle costing (LCC).	Is interoperable through gbXML format
OpenStudio (Trimble SketchUp)	An open source standalone application that also works as a plugin for SketchUp and is a user-friendly GUI for Energy+ analysis engine.	The building envelope must be modelled in SketchUp (.skp) based on specific OpenStudio rules and simulation guidelines or requirements. Existing SketchUp models may not simulate well.
DesignBuilder	Used for thermal design and analysis including calculation of cooling and heating loads, lighting (natural and artificial), internal temperatures (air, mean radiant and operative), solar shading, solar shading, relative humidity, CO ₂ emissions and heat transfer across building fabrics.	It is interoperable with BIM models via .gbXML file format support.
EcoDesigner	Applied in energy balance evaluations, CO ₂ emissions, heating and cooling calculations, lighting, water use, LCC as well as annual electric and gas energy consumptions.	Is interoperable through gbXML format and PHPP for Passivehaus design standards.
Ecotect	Used for thermal and environmental design and analysis of buildings including calculations of heating and cooling loads, solar energy control, wind and airflow simulation, artificial and natural lighting, LCC and assessment, acoustics (sound and noise) analysis.	Can read various CAD and BIM file formats / models.
eQUEST	Used for conceptual design analysis, energy performance and energy use simulation, thermal heating and cooling load design and analysis, solar energy control, LCC and assessment.	Is interoperable through gbXML format
Energy+	Used for energy simulation including thermal design / analysis, calculation of cooling and heating loads, solar energy control, natural and artificial lighting and ventilation, LCC and assessment.	Is compatible with BIM via IFC file format.

1.1.2 Building energy and carbon management in UK Schools

With respect to school buildings, understanding their energy consumption patterns can best be achieved by data collection and analysis [17] and as a result the UK is one of few countries that have established a benchmark for energy consumption in schools. An annual target of 110kWh/m²/year is regarded as a reasonable for a typical school [18] but The “Good Practice Guide 343 (or GPG343) has stated that 191kWh/m²/year for primary schools and 196kWh/m²/year for a secondary school without a swimming pool is a good benchmark [19]. A typical UK School’s energy use reveals that space heating accounts for 58% and it is assigned approximately 45% of costs [20] (Figure 1).

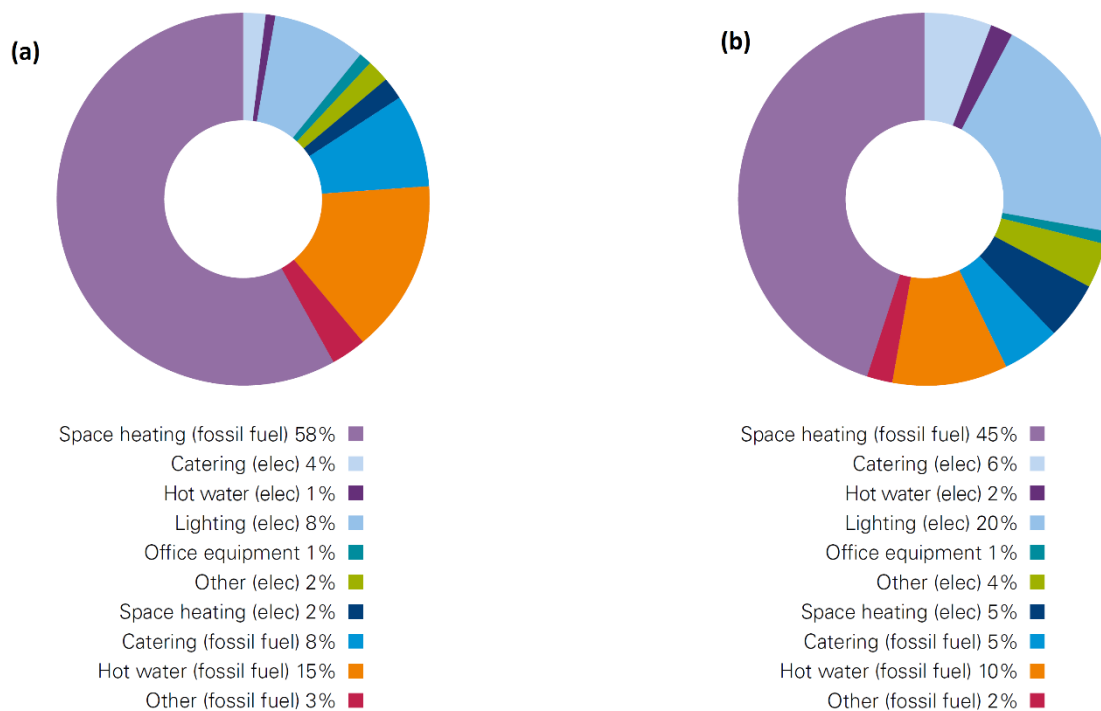


Figure 1. An average school’s breakdown of (a) energy use and (b) energy cost [20].

Schools are important for the UK’s carbon reduction strategy and a consultation done by the Department for Children, Schools and Families in 2009 [21] showed that they accounted for 2% of the total GHG emitted in the UK. However, this is equal to the GHG produced from energy and transport by the cities of Manchester and Birmingham combined [21]. The consultation produced a summary of carbon footprints of schools (Figure 2) with predictive modelling indicating that without intervention the carbon emitted from such schools will remain at their levels up to the year 2050.

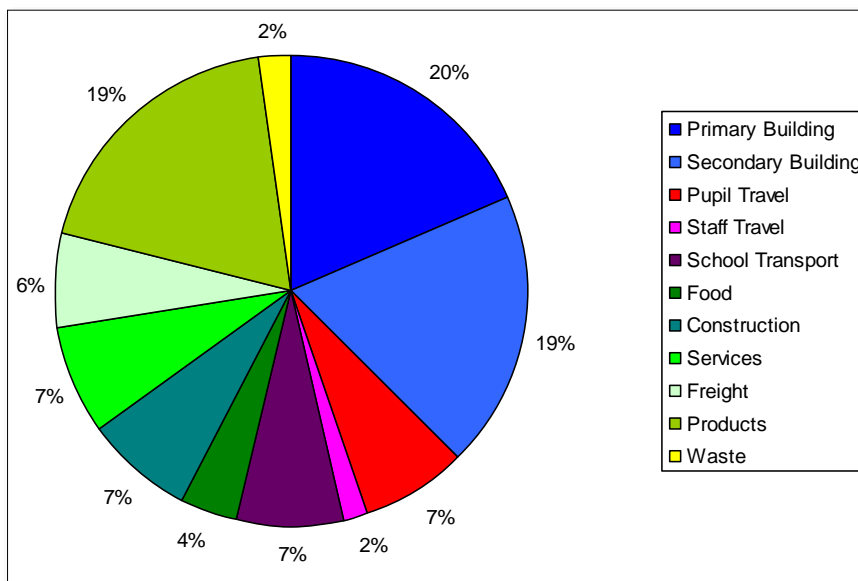


Figure 2. A sector breakdown of schools' carbon footprint in England [21].

The DCSF consultation work data suggests that if business as usual (BAU) is allowed to continue, i.e. without active intervention to reduce carbon emissions, the UK will not meet its 80% reduction of carbon emissions to the 1990 levels by the year 2050 [21]. Using 2004 carbon reference levels, UK schools had three choices: “Leadership” which would lead to a 42% reduction in total carbon emissions by 2020; “Compliance” with minimum requirements which would deliver 34% reduction in carbon emissions by 2020; or “Business-As-Usual (BAU)” which will see lead to a 6% reduction of carbon emissions.

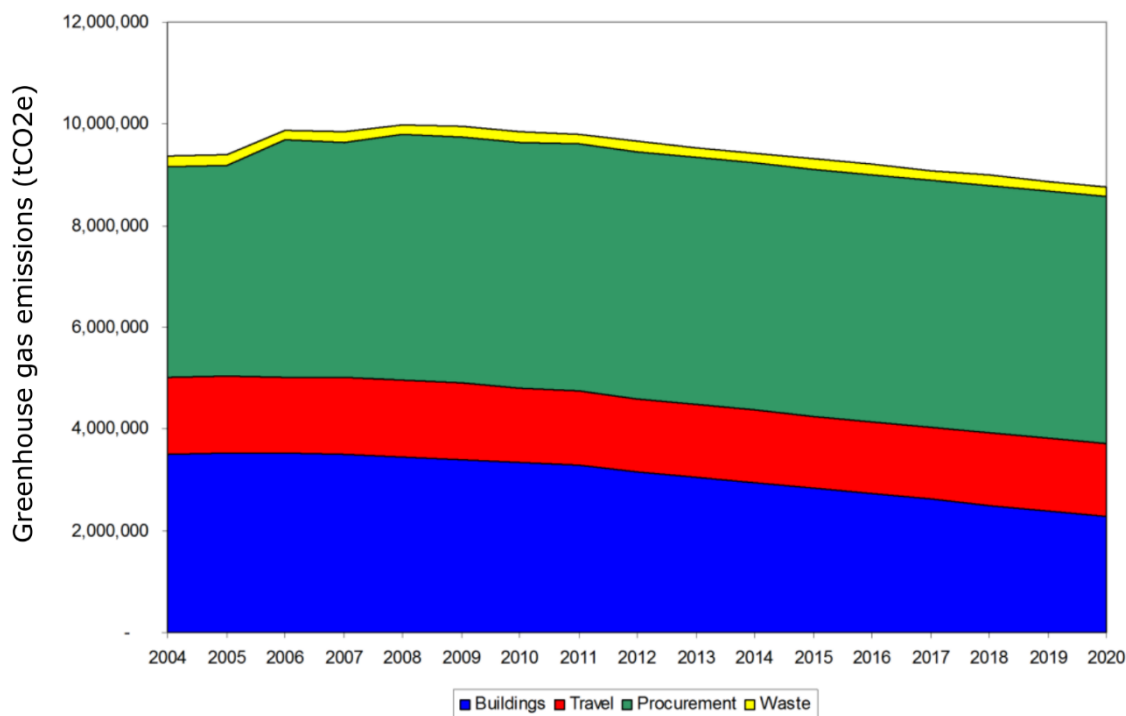


Figure 3. Projected carbon emission trends in English Schools [21].

Since compliance and BAU are not the best options, the importance of demonstrating leadership and pro-activeness by schools cannot be over-emphasised. Hence, the thoughts and opinions of designers will be critical to the success of a school's carbon management program. This is one of the objectives this research intends to achieve from the perspective of AEC professionals. Preceding studies ([22], [23]) on this subject had focused at the role of school management (head teachers, principals, etc) in providing the kind of leadership expected from the administrative and operational (building use) perspective.

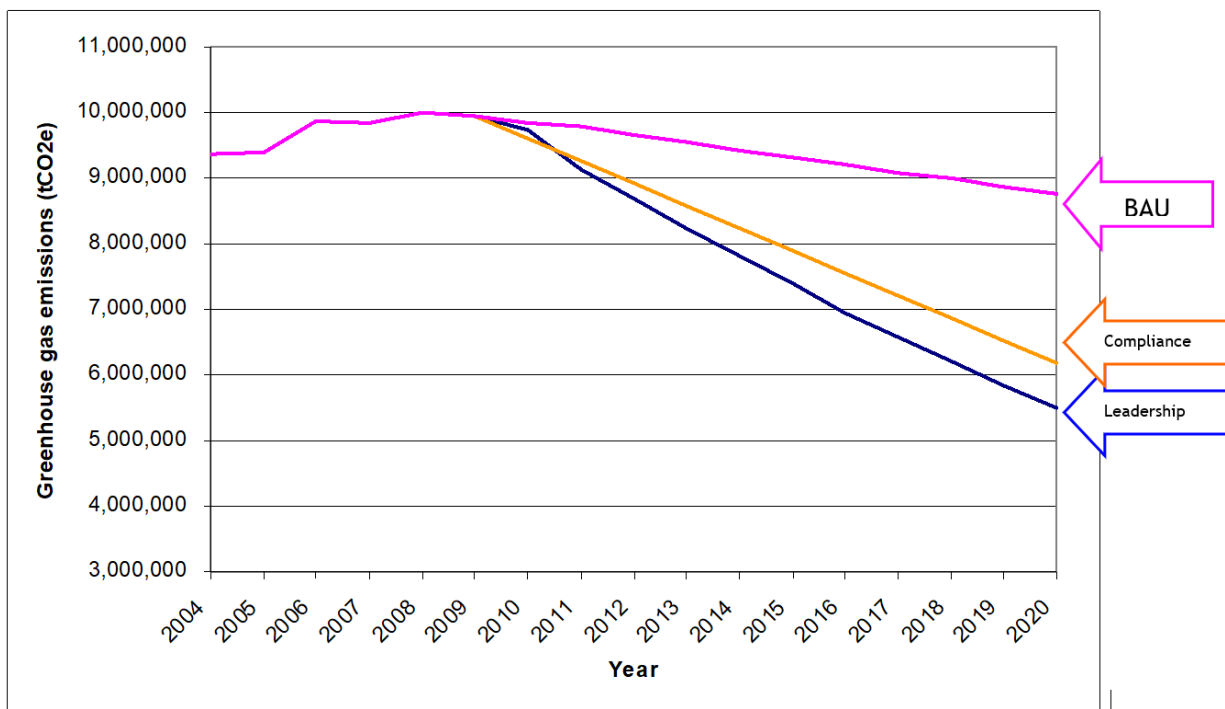


Figure 4. Three carbon management scenarios for schools in England: Leadership, Compliance or Business-As-Usual [21].

1.1.3 Measuring energy consumption with Display Energy Certificates

In their study which explored the use of Display Energy Certificates (DECs) Godoy-Shimizu, et al. [24] found that consideration for number of pupils in DECs provides insights such as an incremental rise in CO₂ emissions per student from primary schools to secondary schools (up to 47%) and a further increase with academies. These increments were mostly attributed to the use of electric energy, but other correlating or contributory factors include location of school, its density and use of heating, ventilation and air-conditioning (HVAC) systems. Such increments linked to electric energy were found to have negated the significant reductions in the consumption of fossil-thermal energy over the last decade. A similar study [25] also found vast differences between the energy consumption of primary and secondary schools. Their study also showed that DECs are beneficial as a yardstick when comparing schools' energy consumption based on occupancy and weather conditions. However, using artificial neural networks (ANNs) to analyse 465 out of 7,770 schools in the UK, they also found that energy use patterns have changed in the four years leading up to the time of investigation, and highlights the challenges of

using static DECAs as benchmarks. They suggested that DECAs need to be kept up to date and using the most recent trends as a baseline for assessing and categorising energy use schools.

1.2 Interventions for energy efficient school buildings

There are two major intervention programmes that are applicable to schools in England who wish to refurbish their facilities towards improved energy and lower carbon footprints. These programmes are the Condition Improvement Fund (CIF) and the Salix Energy Efficiency Fund (SEEF). An overview of both schemes with respect to this research is provided in the following sub-sections.

1.2.1 The Condition Improvement Fund (CIF)

The condition Improvement Fund (CIF) is a scheme that provides capital funding for academies and sixth form colleges and is sponsored by the Education Funding Agency (EFA) [26]. The focus of the funding is to support ‘condition projects’ i.e. those interventions that will help maintain the eligible schools in a safe, good working or fit-for-purpose state. The issues that would typically be addressed by CIF include: health and safety; energy efficiency; building compliance and poor building condition; continuous heating and water supply as well as weather tight buildings [26]. Specifically, the eligible priority work packages that can directly impact energy efficiency include: Block replacement or refurbishment; Boiler and heating systems; Expansion of the gross internal floor area (GIFA); building fabric (weather tightness); mechanical and electrical systems (heating and water supply). Eligibility requirements for CIF restricts it to establishments that are not part of a chain of academy trusts (which have up to 5 academies or a population of pupils exceeding 3000). Schools that are part of an opt-in chain or those that receive ‘formulaic funding’ are also ineligible to apply for CIF. Projects can be approved under one of three categories as explained below [26].

1. **Condition projects:** Projects under this CIF category are aimed at improving the general condition of a school building without any expansion to the buildings GIFA.
2. **Condition with expansion projects:** These projects are also aimed at improving of the general condition of a school building where up to 10% GIFA expansion of the old building is to be done.
3. **Expansion projects:** Projects funded under this category are aimed at solving overcrowding problems or creating additional places in sixth-form colleges or academies that demonstrate high performance [26].

The assessment of all applications made by establishments for CIF financing is based on three main criteria and their weightings: Project need (70%); Project planning (15%) and Value for money (15%)

1.2.2 Energy efficiency aspects not covered by CIF: The emergence of Salix loan fund

Interestingly, some categories of work that are aimed solely at energy efficiency, including lighting, and which do not seek to improve the overall condition of a school are not favoured under the CIF eligibility. Rather, such projects are now supported by an energy efficiency loan scheme through a partnership between EFA and Salix Finance [27]. This scheme known as the Salix Energy Efficiency Fund.

The Salix Energy Efficiency Fund (SEEF) provides 100% interest-free loans for Schools to obtain and use for improving the energy performances of their buildings. This funding is available for all schools whether they are traditional academies or large Multi-Academy Trusts (MATs). Therefore, this scheme is more accessible to schools of various kinds and sizes than the CIF scheme. By providing full funding, it is expected that the annual energy savings from such projects will enable them pay back the loans with a period of 8 years [26], [27]. This is an ambitious target that reveals the confidence which the

partners (EFA and Salix Finance) have in the cost savings achievable from energy efficiency measures in schools. The experiences of these schools are documented in several case studies, and it would be helpful to appraise these schools based on the core aim of this research. A case study based archival analysis of selected schools was carried out [22, 23] as part of the data collection and research process.

2. Methods

The research was approached using a mixed-methods strategy that combined case study data (available from archives) with primary data collected from questionnaire survey as explained in the following sub-sections. The primary function of case study data was to provide a factual basis for savings achieved by various schools that had undergone refurbishments through the SEEF funding process. The objective of collecting primary data was to get first hand views of AEC professionals who were involved in school projects and refurbishment in general, in terms of their engagement with the tools, technologies and processes designed to support low carbon refurbishment of schools.

2.1 Case study

Case study data was collected from a selection of 10 schools that had benefited from interventions funded by SEEF. These schools (Table 2) were selected based on four types of interventions including:

- The installation of Building management system (Penair School and Scottish Agricultural College);
- The installation of Efficient gas condensing boilers (Whitstone Academy, Harrogate Grammar School, Bedford Hall Methodist School and Meon Junior School);
- The installation of LED lighting systems (St Brides Major Church Primary School and Foundry Lane Primary School);
- General lighting upgrades project (Woodridge Primary School and Our Lady and St George's school).

2.2 Questionnaire survey

Primary data was collected using a survey questionnaire aimed at Architecture, Engineering and Construction (AEC) professionals. The questionnaire that was distributed electronically and invited participants were required to access the survey via a hyperlink. The sample frame consisted of an initial database of 615 AEC professionals which was sorted into those who worked in the UK (217) who were then contacted via email. A further 168 UK-based professionals were contacted privately through a professional social media platform (LinkedIn). This gave a total of 385 potential respondents out of which 126 participated fully leading to a 32% response rate, which was deemed acceptable for the purpose of this research.

The following section highlights the results obtained from the case study and questionnaire data.

3. Results

3.1 Results from case study

From the case study data also presented earlier [23], it is apparent that the loan value was not a direct indicator (or directly proportional) to the annual or lifetime savings. For instance, the loans taken by Foundry Lane primary school (£27,019) and Meon Junior school (£18,000) are significantly different in amount. However, the lower amount spent by Meon Junior school led to 211% lifetime savings because it was spent on gas boiler refurbishment whereas the higher loan taken by Foundry Lane primary school that was spent on LED lighting delivered a 182% lifetime saving. Nevertheless, even though the annual

savings of CO₂ from the costlier loan (15 tonnes) was only slightly more than the annual savings of the cheaper loan (12 tonnes), the lifetime savings of CO₂ is more favourable to the costlier LED lighting project.

Table 2. The case study data for 10 schools which took Salix-finance loans.

Case ID	Project	Description	Documented year	Loan value	Annual Savings	Lifetime savings	Lifetime savings as % of loan	Annual savings of CO ₂	Lifetime savings of CO ₂	Calculated years of CO ₂ savings	Project payback
1	St Brides Major Church Primary School	LED lighting project.	Dec-13	10,125	2,218	28,840	285%	11	150	13.6	4.5
2	Foundry Lane Primary School	LED lighting project.	Dec-13	27,019	3,784	49,191	182%	15	196	13.1	7.1
3	Scottish Agricultural College	Building management system.	Nov-12	120,341	49,229	172,301	143%	322	1126	3.5	2.4
4	Penair School	Building management system.	Nov-12	5,358	2,524	21,256	397%	12	98	8.2	2.1
5	Whitstone Academy	Efficient gas condensing boilers.	Sep-16	220,000	27,500	275,000	125%	NA	NA	NA	7
6	Harrogate Grammar School	Efficient boilers and new zone controls.	Oct-16	223,323	34,343	343,430	154%	NA	NA	NA	6.5
7	Bedford Hall Methodist School	Efficient boilers and heating system.	Nov-16	49,278	11,266	124,280	252%	NA	NA	NA	4.4
8	Meon Junior School	Oil to Gas boiler fuel switching project.	Dec-13	18,000	4,802	38,032	211%	12	92	7.7	3.8
9	Woodridge Primary School	Lighting upgrades project.	Dec-13	4,438	1,379	13,790	311%	5	5.8	1.2	3.2
10	Our Lady and St George's	Lighting upgrade and installation of PIR controls	Nov-16	47,401	6,304	152,497	322%	NA	NA	NA	8

Note: In this case study table, the data found in Column 8 (Lifetime savings as % of loan) and Column 11 (Calculated years of CO₂ savings) were computed and not part of original data.

Similarly, it could be deduced that whereas Penair School took a loan of £5,358 to spend on Building Management System, leading to lifetime savings of £21,256 and lifetime CO₂ savings of 98 tonnes, the £4,438 loaned to Woodbridge primary school that was spent on lighting upgrades produced a lifetime saving of £13,790 and lifetime CO₂ savings of just 5.8 tonnes.

In summary, the case study data suggests that schools have probably not been strategic in the amount the take as loan or in the types of projects they spent it on (for instance, spending similar amounts of money on lighting upgrades rather than on BMS which would save more carbon as explained). Although it is expected that a school embarking on a costlier type of refurbishment is responding to a need, it is pertinent for the school administrators and designers to study the long-term impacts and make informed decisions accordingly. This is clear from the Penair vs. Woodbridge school projects where the loan amounts are not too dissimilar (£5,358 and £4,438 respectively), but the lifetime savings are drastically different (£21,256 and £13,790 respectively) or 98 tonnes of CO₂ against a meagre 5.8 tonnes of CO₂ respectively. This weight of this finding is considerable reflecting that all the surveyed professionals indicated that their organisation had someone who was a certified energy assessor (see Figure 12c) and that BREEAM standards were popularly followed (see Figure 14). In other words, if energy assessors are predominantly found in such AEC firms and sustainability standards are followed, it could only mean that the specific experts were not involved in the decision making process of refurbishing schools for energy efficiency, which is what SEEF funding is aimed at.

3.2 Results from questionnaire survey

3.2.1 The survey respondents

From the data collected, the respondents were categorised according to their location (Figure 5a) where: London had a slight majority of respondents (26.2%); followed closely by West Midlands (23.8%); then East Midlands (14.3%); and East of England (9.5%). The professionals who responded were

overwhelmingly comprised of architects (40.5%), then contractors (11.9%) and building services engineers (7.1%); while BIM consultant, architectural assistant and architectural technologist all had a 4.8% representation (Figure 5c). In terms of on the job experience (Figure 5b), the majority of respondents (52.4%) had more than 10 years' experience; followed by those with 3 to 5 years' experience (23.8%); while those with 0 to 2 and 6 to 10 years' experience all had 11.9% representation. Finally, in terms of specialisation, respondents were asked to select the type of work they 'mostly' engaged in, for which: 45.2% stated they were largely involved in design and construction of new buildings; 33.3% said they were equally involved in both new and refurbishment work; while 9.5% were mostly doing refurbishment work.

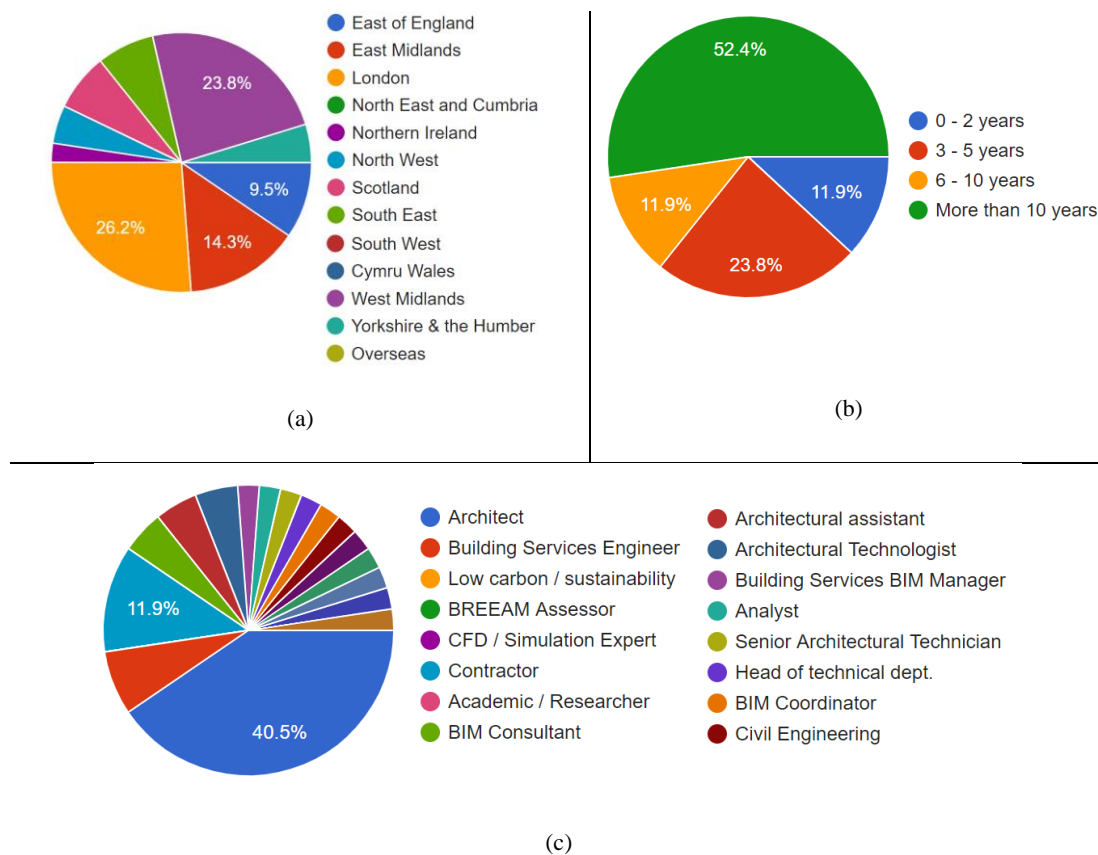


Figure 5. Overview of the professionals who took part in questionnaire survey (n=126).

3.2.2 Respondents' involvement in school buildings

When respondents were asked to select all kinds of buildings they were involved in (multiple choice question) 54.8% were involved in private developments that included schools; 47.6% were involved in primary school buildings specifically; 45.2% were involved in secondary school buildings; 28.6% work on high school or college buildings; and 19% were involved in special needs schools. In fact, only 2.4% were not involved in school buildings of any sort (Figure 6). The data summarising the respondents' background, location and experience (Figure 5a – Figure 5c) as well as the data about their involvement in school buildings (Figure 6) are evidence that support the appropriateness and quality of respondents in providing useful information necessary for this research.

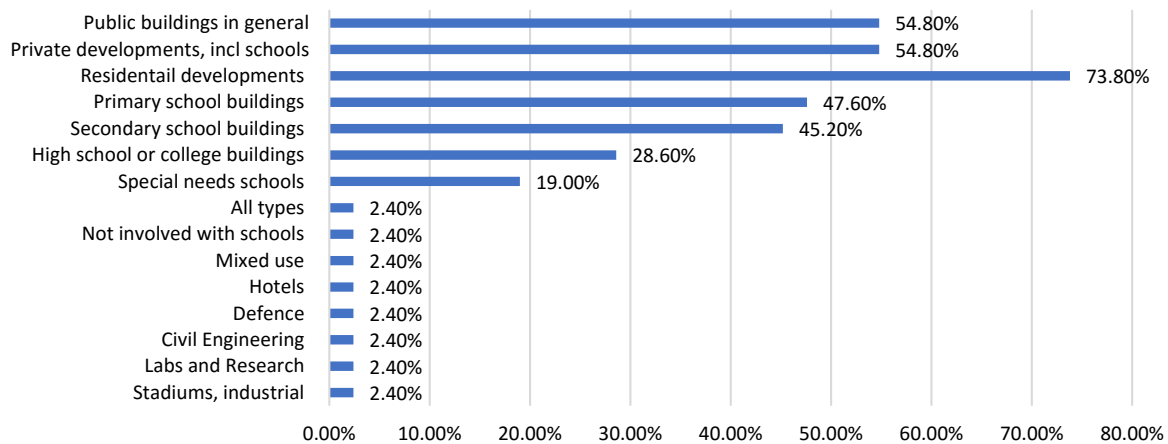


Figure 6. Respondents multiple selection of types of buildings they are involved in (n=126).

The data collected also showed that architects were more evenly distributed across locations in England and those with more than 10 years of experience were more evenly distributed across regions in England with the least distribution being those with 3 to 5 years of experience. Although location and years of experience are not key metrics of this research, they are helpful in illustrating the balance of representation across regions and on the job experience.

3.2.3 Sustainability, Energy Simulation and BIM

Based on the literature review carried out, it was necessary to investigate the BIM-compatible energy simulation tools available and used by professionals (see Table 1), in addition to the BIM standards and toolsets available for delivering BIM and the availability of certified energy assessors in the respondents' organisation. It was found that Autodesk's Green Building Studio was the most popular energy assessment tool used (23.8%) followed by IES VE (21.4%) and then Bentley's AECOSim (9.5%). Other software had between 2.4% and 7.1% but approximately 12% of respondents said they did not use any of the listed software (Figure 7).

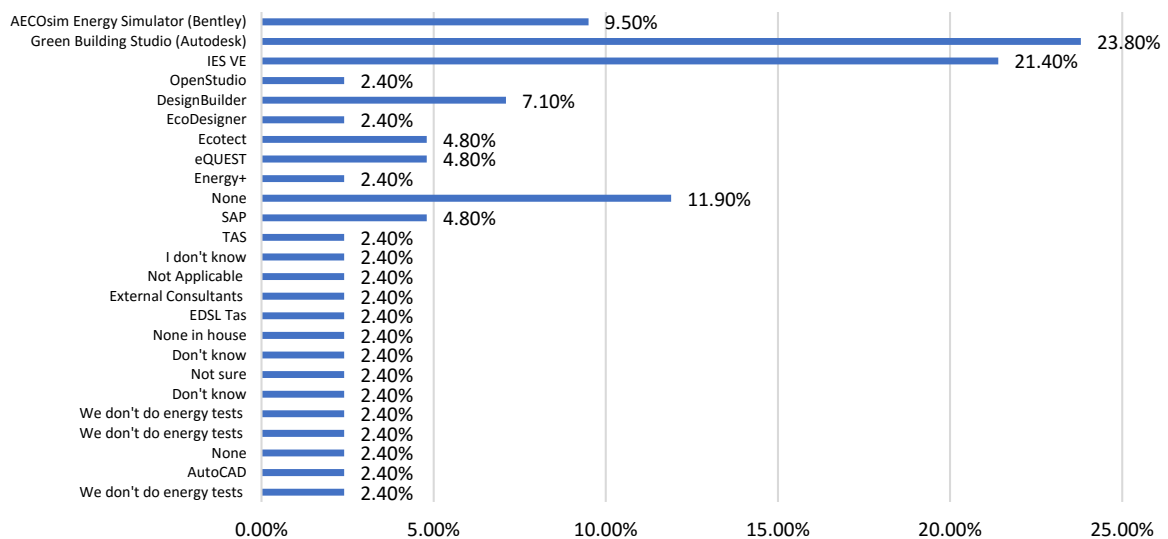


Figure 7. Respondents' use of BIM-compatible energy simulation software.

Since the UK has a government-driven BIM mandate supported by standards, guidelines and protocols, it was necessary to see if any of these standards/guidelines are being applied. The publicly available specifications (PAS) series of guidelines are common and have been used as a benchmark. In this regard, the data collected suggested that the PAS1192 series of standards were very popular among respondents as 50% of respondents were familiar with (and used) them. Other guidelines and toolsets used by respondents included COBie datasets (38.1%); NBS BIM Toolkit (33.3%); and the government soft landings (GSL) was only used by 14.3%. The low uptake of GSL guidelines is indicative of the lack of designers' preparedness to deliver buildings that conform with the sustainability expectations of the government because as shown in literature, the GSL is ingrained with the UK's BIM strategy. However, many respondents claim that they have a certified energy assessor embedded within their organisation, especially among: (i) the architects' category within which 21 respondents (16% of total) were sure of having such experts; (ii) the building services engineers' and the contractors' categories where 9 respondents (7% of total) were sure they had such in-house expertise – although in contractors' case 6 respondents (around 5% of total) did not know for sure; and (iii) in case of the building services engineers, BIM coordinator and BIM consultant, all the respondents (100% of categories) were sure that there was an in-house certified energy assessor within their organisation.

Given that energy assessment is crucial to demonstrate compliance and energy performance (e.g. via EPC certification of buildings as discussed in literature), then the prevalence of energy assessors in the respondents' organisations is a welcome development. It is an indication of how seriously design professionals took energy assessment. This issue will be even more relevant when the case study data is investigated for evidence that expert advice has been sought when using SEEF funding to make the school buildings energy efficient. This is particularly important because most of the responding professionals claim their organisations were not involved in post-occupancy evaluation (POE) monitoring of buildings (see red bars in Figure 8).

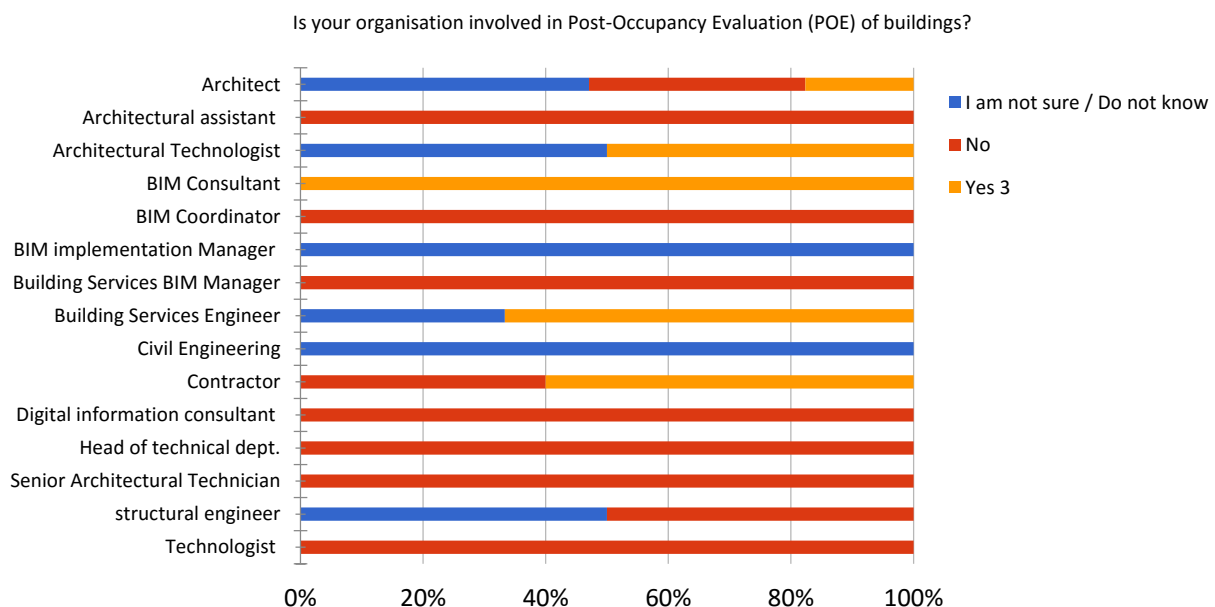


Figure 8. Involvement of respondents' organisation in post-occupancy evaluation (n=126).

When asked about the energy assessment standards that they used, BREEAM featured prominently among most professionals but this is not surprising since this BRE standard is developed and marketed from the UK. However, other standards such as LEED, Green Star, SAP/SBEM were also recognised and used by some professionals including architects and architectural technologists. In fact, the representation of respondents who did not know about these standards (or who thought they were inapplicable to them) were: architects (15); architectural technologists (3); contractors (3) digital information consultants (3) structural engineers (6) and a group calling themselves 'technologists' (3); making a total of 33 respondents or 26% of total respondents not familiar with such standards. This suggests that (to different extents) there is general awareness of energy assessment standards among professionals that responded.

Some questions were asked in form of Likert-style statements intended to gauge the sentiments of respondents through the levels of agreement or disagreement. For example, respondents were asked about how useful the government soft landings were for monitoring the energy performance of buildings. The data collected (Figure 9) was cross-referenced according to disciplines and it revealed that agreement tends to be slight to moderate among many professionals, however strong disagreement was found among to be significant among architectural assistants/technologists (up to 50%) while the only categories of professionals where there was strong disagreement were architects (6%) and building services BIM manager (33%).

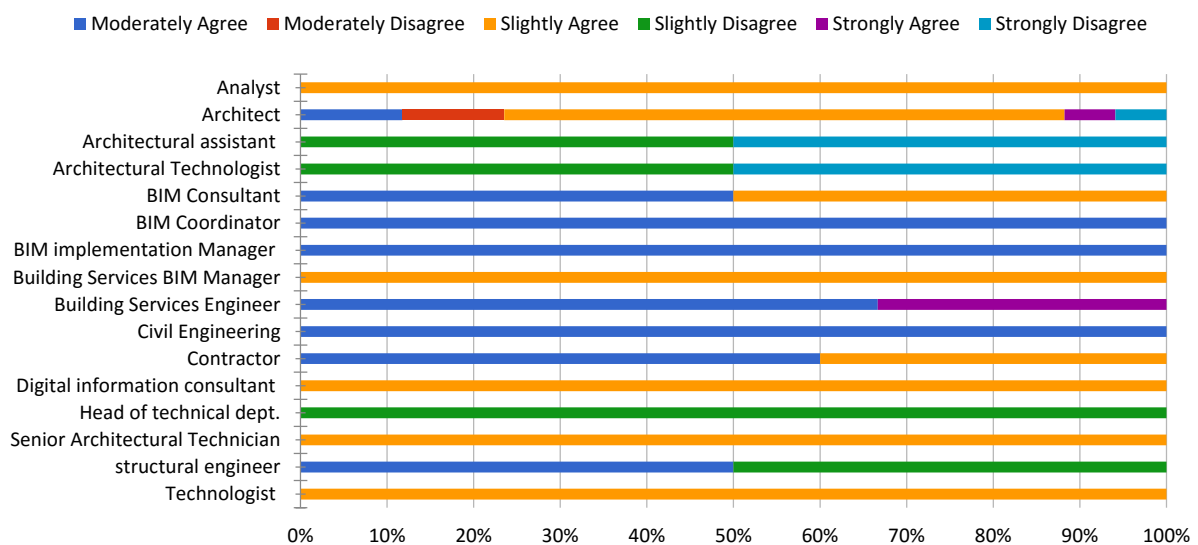


Figure 9. Perceived usefulness of GSL for monitoring energy performance of buildings (n=126).

The next question of interest was aimed at seeking responses about the extent to which respondents used BIM (processes and technologies) throughout the lifecycle of buildings there were involved with. In this regard, there was substantial level of strong agreement among the following represented professions: architects (24%) architectural assistants (50%), BIM consultants (50%), building services engineers (67%) and civil engineers (100%) as shown in Figure 10.

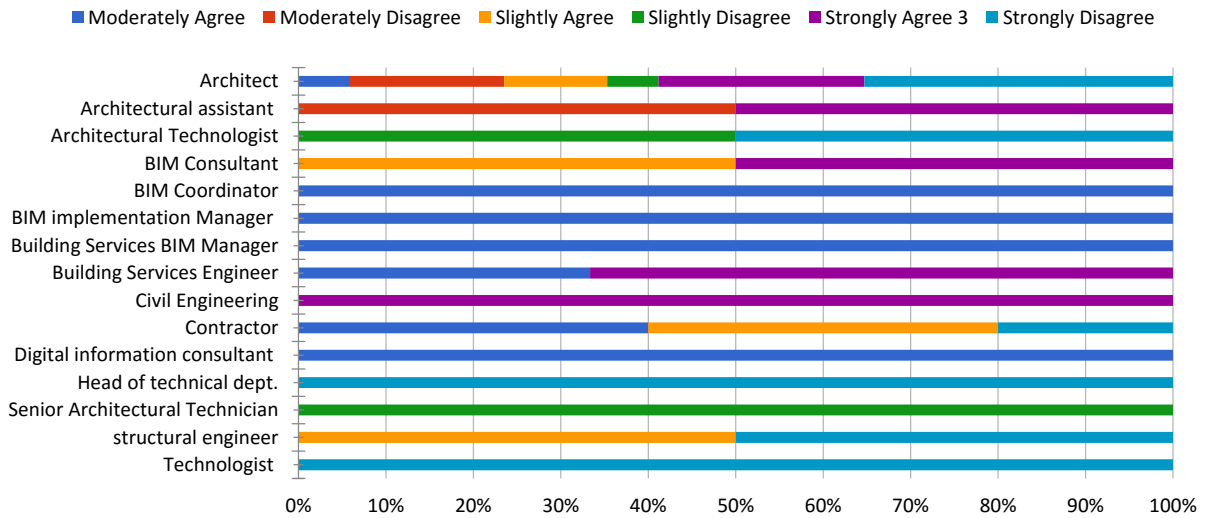


Figure 10. Use of BIM processes and technologies across lifecycle of buildings (n=126).

Strong disagreements with lifecycle use of BIM were significant among architects (35%), architectural technologist (50%), contractor (20%), head of technical department (100%), structural engineer (50%) and technologists (100%). In addition to the other levels of agreement/disagreement, the data (Figure 16 above) suggests an approximate split between those who used BIM consistently throughout the project lifecycle and those who did not. Further insight into this issue can be obtained from the next statement, where it was put to respondents that they would not be implementing BIM if it were not due to client requirements (Figure 11). In this regard, only BIM coordinators, building services BIM manager and head of technical department fully disagreed with the notion, with a relatively small representation among architects (18%). There was also a moderate level of disagreement among architectural technologist (50%), building services engineers (33%), contractors (20%) and structural engineers (100%). This is an indication that accepting to use BIM persistently in all project phases is not as entrenched as would be expected.

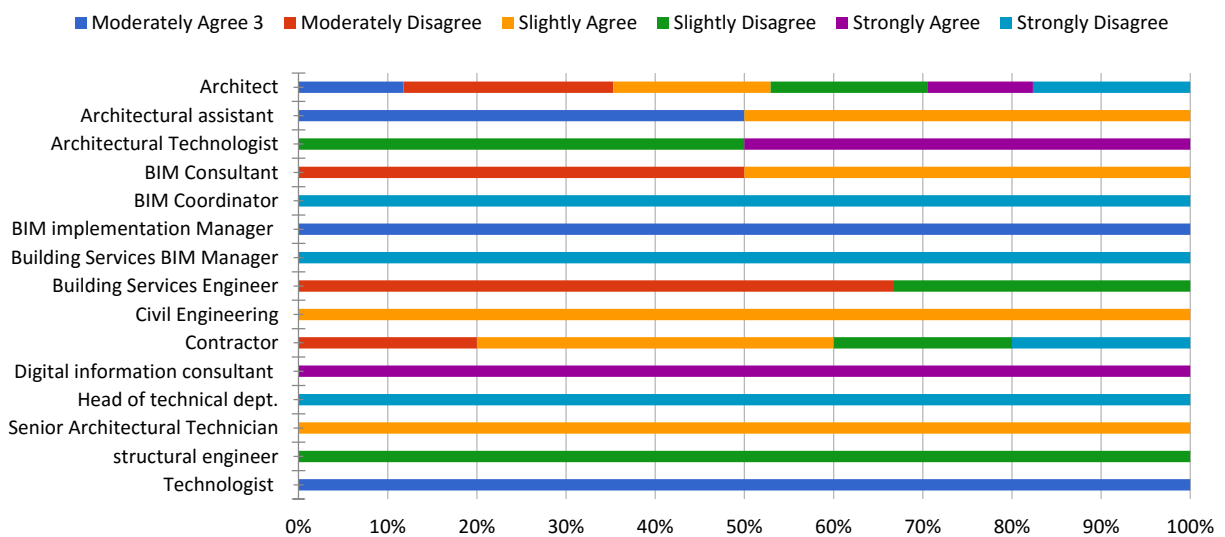


Figure 11. Sentiments about not implementing BIM if not for client requirements (n=126).

Consequently, the handover of COBie datasets containing operations and maintenance (O&M) information about installed systems to end users at the end of projects was considered by respondents who were categorised according to years of experience (Figure 12). In this case, it was surprising to find that those with 0 to 2 years' experience (who would have been thought to be more aware of BIM due their recent education) were found to be the largest group with 50% disagreement. This experience group also had 25% level of moderate disagreement. Other experience brackets had strong disagreements as follows: 3 to 5 years (37%); 6 to 10 years (25%) and more than 10 years (33%). The level of strong, moderate and slight agreement tended to increase with experience brackets - suggesting that handing over of COBie datasets for O&M purposes was more favourable with experience and that younger professionals were more evenly split about the usefulness of COBie for post-occupancy management of installed systems. Specifically, the 0 to 2 years' experience bracket also had the largest ratio (25%) of those who strongly agreed that they handed over COBie datasets for O&M purposes, matched only by those within the 6 – 10 years' category.

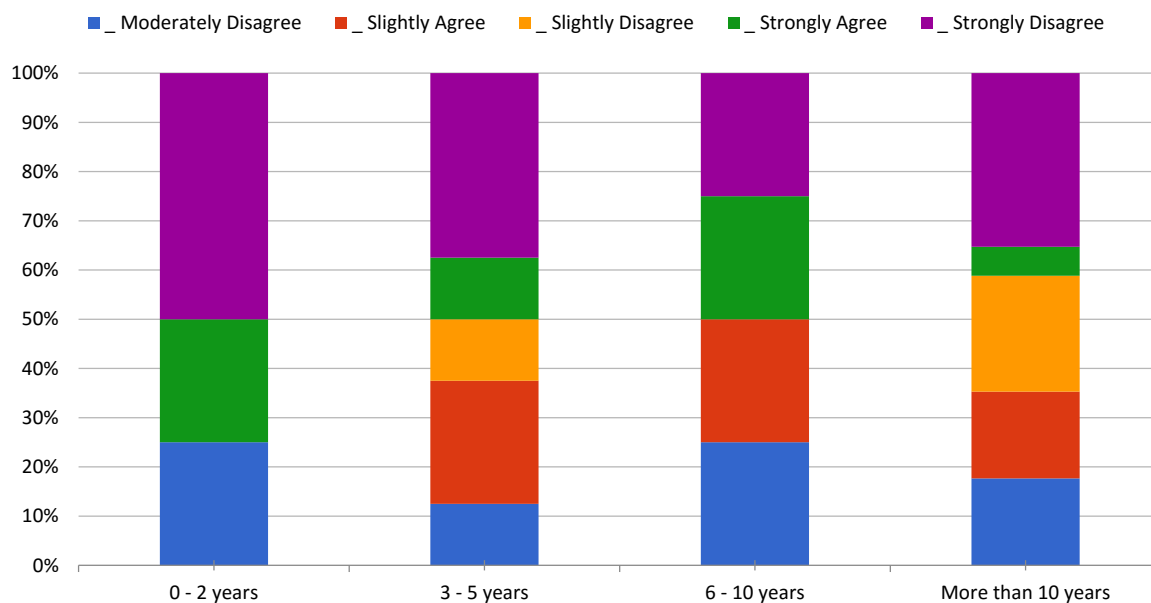


Figure 12. Perceived usefulness of COBie for handing over information about installed systems (n=126).

The use of smart metering was then pursued, to see if the professionals can shed light on whether they implemented such systems for the continuous collection of data about energy performance (Figure 13). In this case, the level of disagreement was total (100%) among BIM coordinators, digital information consultants and among heads of technical departments; and significantly high (50%) among architects, architectural technologists and contractors. The irony of not implementing smart metering among the BIM-focused professions is not lost here.

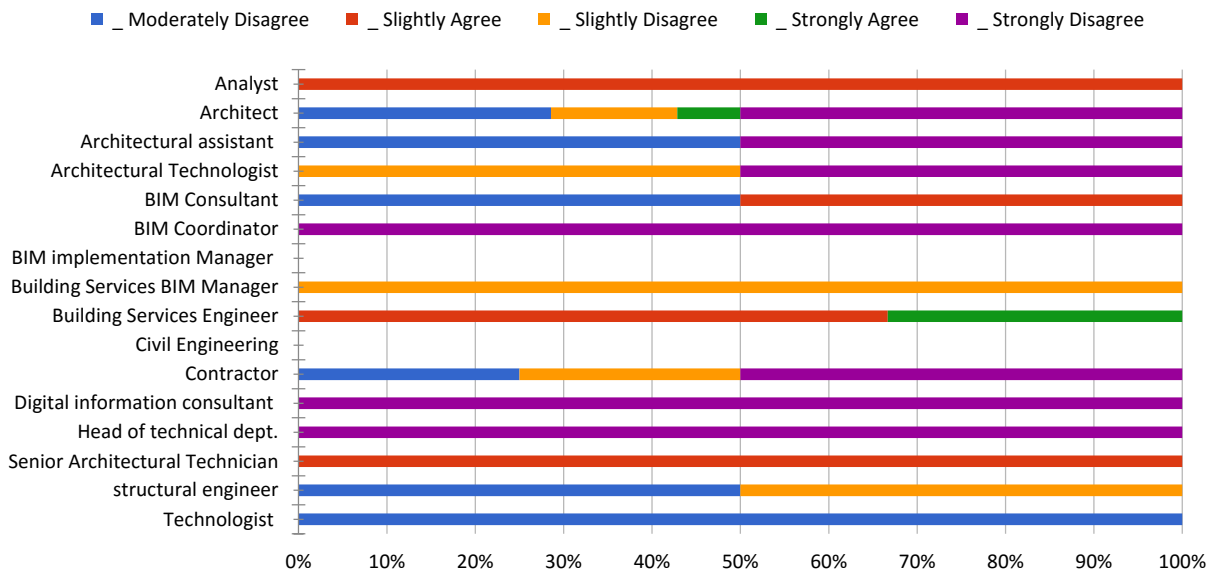


Figure 13. Implementation of smart metering for collection of energy performance data (n=126).

When confronted with the statement about whether they had “a lot of confidence in the results obtained from energy simulation carried out for their projects” the most optimistic answers (strongly agreed) came from those with 6 to 10 years’ experience (20%) and just 7% of those who had over 10 years working experience (Figure 14). There was significant level of moderate agreement within younger professionals with 0 to 2 years of experience (80%) and among those with 6 to 10 years of experience (70%). The group with largest proportion of sceptics are those with 3 to 5 years of experience (37%) and those with over 10 years of experience (27%). Overall, the 3 to 5 years’ experience bracket had the most balanced proportion of respondents across various degrees of agreement / disagreement.

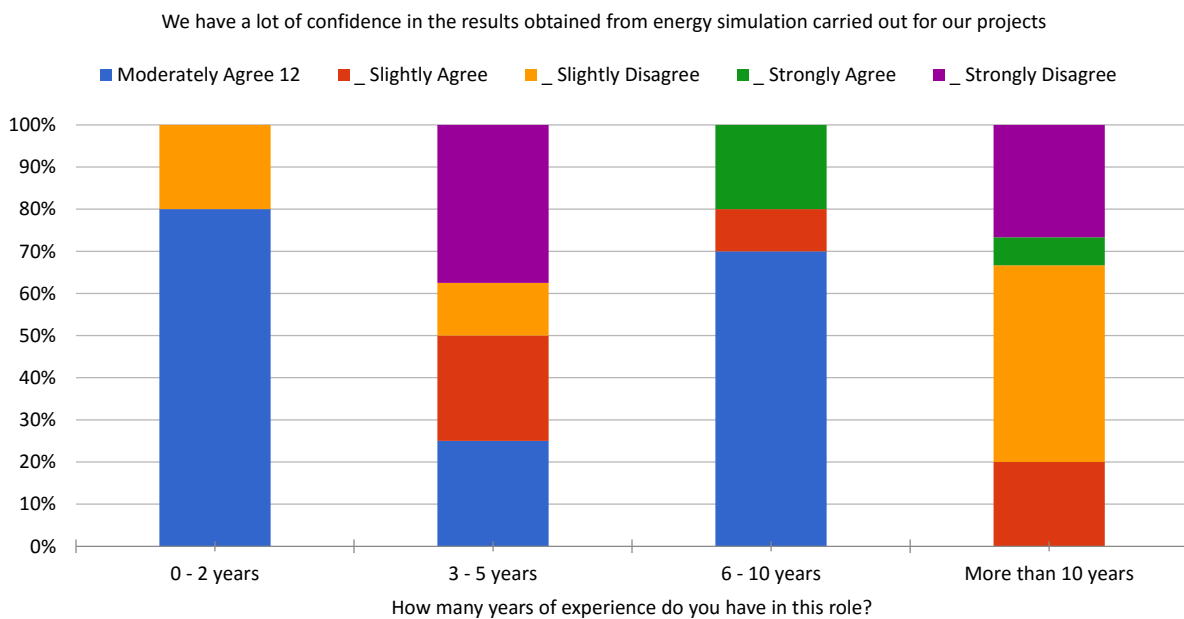


Figure 14. Level of confidence in results obtained from pre-construction simulations (n=126).

4. Discussion

The data collected from case studies suggests that there are instances where value for money was not realised or maximised by the school management, implying that they were operating at Business-As-Usual or at most compliance levels [21]. Leaders of schools (e.g. head teachers and principals) do not seem to be making informed and strategic decisions on the loan amount and what they spend it on for refurbishment and it had been suggested [23] that such heads of schools be trained on the principles (and need to integrate) GSL to the energy efficient and sustainable operation of their facilities. The case study data suggests that although a school embarking on a costlier type of refurbishment may be responding to a need, yet where the loan amounts are similar (£5,358 and £4,438 taken as loan by Penair and Woodbridge schools respectively), the lifetime savings can be considerably different (with savings £21,256 and £13,790 respectively for these schools). There was also a significant carbon saving difference between them, i.e. 98 tonnes of CO₂ (Penair) against the relatively smaller 5.8 tonnes of CO₂ saved by Woodbridge. The significance of these results is that Penair spent their £5,358 on building management systems, while Woodbridge school spent their £4,438 on lighting upgrades. The difference that the additional £920 has made to the lifetime savings and carbon emissions savings makes it a better investment and value for money. Although, the uncertainty here is that Woodbridge may already have a BMS in place, this is unlikely since many BMS systems are typically linked with sensor based lighting systems. Therefore, their decision to invest in lighting upgrades as opposed to BMS could have been better informed.

The case of Penair vs. Woodbridge school is an example of where professionals can provide guidance because although it is the administrators who apply for loans, the professionals surveyed who claim to be aware of energy assessment software highlighted in previous studies ([7] and [16]) and energy assessment standards such as DEC's (see [13], [25]) were probably not involved. Alternatively, they might have been involved but did not give the schools the best possible guidance needed to make the best of such investments as was deduced from preceding studies [23]. However, this could also be due to the limited expertise of the professionals. As implied by the survey data, the fact that energy assessors are available in organisations partaking in school projects does not imply that these specific experts are deployed or consulted in the decision making process of procuring energy efficient systems for refurbishment.

The questionnaire data indicates that professionals are not always using BIM across whole lifecycle of projects and in particular, COBie datasets which can contain a lot of helpful information about installed equipment and systems is rarely handed over for O&M purposes. This brings to question the readiness or effectiveness of implementing the GSL policies expected to help reduce energy performance gaps [2] and poses questions for the level of preparedness for UK's digital twinning ambitions [9]. It was also found from quantitative (survey) data that handing over of COBie datasets to end users for use in O&M phase was more popular among experienced professionals than among younger ones who ought to be more BIM educated. Considering that older professionals hardly had formal BIM training and did not enter the industry in an era of GSL policy or BIM mandates, this scenario could be explained by the older professionals being more aware (than younger professionals) to the long-term benefits that O&M information provides to end users.

There was a respectable level of understanding of the usefulness of GSL for post-occupancy monitoring of installed energy efficient systems from the questionnaire respondents. However, the use of BIM persistently across all project phases is not as ingrained as might be expected at this stage of the

UK's BIM journey. To start with, from the experts surveyed only BIM coordinators, building services BIM manager and head of technical department totally disagreed with the notion that they were adopting BIM due to client's insistence. Perhaps the job titles of these professionals is indicative of their position and stake in BIM so this does not suggest that other professionals agree that they are forced to use BIM. The moderate level of disagreement to this notion found among architectural technologist (50%), building services engineers (33%), contractors (20%) and structural engineers (100%) supports this deduction. The relatively modest adoption of BIM and energy efficient modelling and simulation of schools (as evident from the surveyed professionals) has consequences on their ability to exploit these technologies for refurbishment purposes. The data analysed suggests that professionals involved in school refurbishment are not using state-of-the-art methods of building pathology suggested by existing literature [11], [12] and [13]). For instance, the integrating real-time data collected by energy management systems with as-built 3D BIM models has been shown to be helpful for diagnostics and fault-detection in existing building [10]. However, the schools were probably not modelled or simulated for energy efficiency using BIM-enabled tools in the first place. The lack of professionals using such modern techniques could be traced to their general disposition to (and adoption of BIM) which was found (questionnaire data) to be relatively modest at best.

5. Conclusions

This study was aimed at investigate the effectiveness of contemporary BIM and energy simulation technologies in refurbishment of existing UK school buildings. A review of contemporary literature suggests that energy simulation tools are available for use with BIM software through plugins and data exchange formats like gbXML and IFC. However, the problems brought about by the energy performance gap remains and affects the confidence of simulation results which tend to differ from actual practice. Specifically, the following conclusions were drawn from the data collected and analysed:

- The funding model for refurbishment of state schools is primarily based on Condition Improvement Funding (CIF) loans or Salix-financed SEEF loans. At the point of application, these funding routes are mutually exclusive, whereas from the technical and engineering perspective, the envelope and general condition of a school building as covered by CIF influences the energy effectiveness of lighting and equipment covered by SEEF. Therefore, the financial model needs to be revisited from a holistic and engineering point of view.
- The schools that have benefitted from SEEF initiatives have largely benefitted from systems that enable them measure and control direct energy. For instance, the use of sensors for motion detection during lighting upgrades and smart meters that work with BMS has been widespread. These are not necessarily useful for monitoring carbon emissions and other forms of energy performance indicators or metrics like CO₂ monitors which are helpful for indoor air quality as well as airflow and water pressure and consumption monitors (helpful for sustainable use of buildings) do not appear to used in schools.
- Given the three carbon reduction scenarios established in literature, i.e. Leadership, Compliance or Business-As-Usual, schools are not showing 'leadership' in reducing carbon. The steps they are taking to refurbish their facilities, is analogous to 'compliance' at best since they are and in many respects following the processes required to get energy efficient systems. However, in many respects, it could be said that they are carrying on with BAU since for example they are not able to receive CIF funding necessary to upgrade the fabric of buildings but with respect to this objective, it can be deduced that
 - The professionals in charge of refurbishment are not fully adopting BIM and its energy simulation or handover toolsets like COBie or NBS BIM toolkit. This is affecting the

downstream or end-use capability of school management who could use these tools to assess and monitor their facilities for energy and carbon;

- The professionals are not using diagnostic tools for refurbishment like real-time data or thermal imaging for fault detection for the refurbishment and operational maintenance of school buildings;
- For the purpose of refurbishment, the integration of thermal imaging data with gbXML models is possible, but unfortunately, the data collected in this study suggests that professionals are not using this technique (thermography) for collecting building performance data refurbishment. The non-utilisation of this common but helpful method is therefore a missed opportunity.
- Other important aspects of diagnostics and fault-detecting in existing building rely on integrating real-time data collected by energy management systems with as-built 3D BIM models; and the age and environmental conditions of buildings is critical for successful modelling and simulation. However, case study and primary data collected and analysed through questionnaires and interviews suggest that these modern techniques of diagnosis and building pathology are not used in the refurbishment of school buildings.

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