Opportunities and Limitations of Building Energy Performance Simulation Tools in the Early Stages of Building Design in the UK

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Received: 25 September 2020; Accepted: 13 November 2020; Published: 20 November 2020

Abstract: This research investigates the use of Building Energy Performance Simulation (BEPS) tools in the early stages of building design in UK architectural practices with a particular focus on the barriers and opportunities to their effective application and further uptake. Two primary methods of investigation were undertaken; the first was a wide survey among UK architects and architectural practices, where the responses of 418 participants were electronically gathered and analysed. A deeper understanding of the issues was developed through an analysis of the process of low-energy building design using semi-structured interviews with six representatives of well-established architectural practices in the UK. The findings reveal that while there is an increasing understanding of the importance of BEPS involvement at the early design stages, there was limited evidence of actual early implementation of BEPS tools other than a few well known but specialised tools such as Passive House Planning Package (PHPP) which were used mainly for domestic energy performance evaluation. However, many practices surveyed showed interest in achieving higher standards than the “basic” regulatory backstops, which has resulted in Passive House and BREEAM seeing increasing use in domestic and non-domestic projects respectively. Although there has been a significant increase in the development and availability of tools and methodologies for assessing building energy performance our study shows that the focus for future research needs to be shifted from the “tool development” to looking at methods of implementing and using such tools in practice at the early design stages.

Keywords: building performance simulation; BEPS; early design stage; low energy design; BREEAM; Passive House; Passivhaus; UK practice

1. Introduction

Rising concerns regarding climate change have been the focus of a plethora of studies over several decades. The built environment alone accounts for around 40% of global energy consumption, leading in turn to immense rates of Greenhouse Gas (GHG) emissions [1]. In addition, according to the UK Green Building Council (UKGBC), the built environment in the UK contributes to around 40% of the total CO₂ footprint [2]. This is one of the reasons why the UK’s Inter-Governmental Panel on Climate Change (IPCC), in its recently approved 6th Synthesis Report Outline has reasserted the urgent need to reduce energy consumption and CO₂ emissions from the built environment [3–5]. Hence, plans for tightening environmental measures have been established by the UK government, to meet the targets first legislated in the 2008 Climate Change Act of cutting total GHG emissions by 80% lower than the 1990 baseline [6]. Moreover, with the increasing awareness of the challenges and a failure to meet the reduction targets set for 2016 and 2020, the UK parliament passed into law in 2019 an amendment to increase the target to “Net-Zero” (100% emissions reduction), which is required to be met by 2050 and 2045 in England and Wales [7], and Scotland [8], respectively.
In the UK, “building regulations are minimum standards for design and construction required by the UK government” [9]. For pure regulation compliance purposes, the regulations approve results calculated using the National Calculation Methodologies (NCMs) for energy rating of buildings; which include the Standard Assessment Procedure (SAP) and the Simplified Building Energy Model (SBEM) for domestic and non-domestic new built projects respectively. Both methods provide computer-based calculations for the expected operational energy consumption and CO₂ emissions resulting from space and water heating and cooling, lighting fixtures, and appliances [10]. Although regulations and laws are attempting to push towards lower emission rates through setting strict end-targets, there appears to be a discrepancy in their implementation due to a lack of methodological application in congruence with the different design stages of the building process. The early design stage specifically is one gap that holds great opportunities for the improvement of energy operation yet one that is not particularly targeted in the application of the regulations [9]. Consequently, the standards are more often seen simply as a checklist of requirements needed to gain building consent approval, as opposed to a more meaningful and impactful quest to achieve the most sustainable approach to low-energy building design within the constraints of a given context. A direct implication of this is that in the majority of cases, energy-related calculations are being held very late after major design decisions have already been taken in the absence of modelling/simulation tools [11]. A further obstacle is that the UK operates a two-stage planning and building consent system that requires permissions to be obtained prior to any building work on site. First, outline designs need to be submitted for “planning approval” followed by detailed technical drawings and specifications including energy efficiency calculations submitted for a “building warrant” [10]. This two-stage system that is managed and regulated by two independent governmental bodies encourages a linear design process where preliminary design decisions are commonly made in isolation of any sustainability considerations. At the second stage, outline designs are quite often passed on to mechanical/services engineers to develop the NCMs calculations and technical services within the previously established design which has already been granted the “planning approval”. This provides a missed opportunity for developing more integrated approaches to the outline design that inherently consider and quantifiably assess the performance of alternative design strategies and solutions before “locking-in” organisational, spatial and material decisions that are much more difficult to reverse at the later stages for both domestic and non-domestic projects. Arguably there is a discrepancy between the government’s ambitions of reducing energy demands and GHG emissions, and the way building regulations are developed and applied.

Although stakeholders are only obliged to meet the UK building regulation standards, due to the aforementioned reasons besides others, several projects seek to adopt more challenging voluntary schemes that assist in producing healthier buildings while making savings on the operational energy running costs. Two common standards in the UK are the Building Research Establishment Environmental Assessment Method (BREEAM) and Passive House. BREEAM, especially suitable for non-domestic buildings, is a score-based grading system covering several sustainability categories (including energy) [12]. Passive House, on the other hand, is specifically concerned with delivering buildings (mostly domestic) of high energy performance levels. The latter provides its own developed energy modelling software “Passive House Planning Package” (PHPP). Passive House has gained comparatively wide acceptance within UK practice where more than 1000 buildings have been accredited since its first implementation in the UK in 2009 [13]. A major significance of those schemes in comparison to the “basic regulations” is that they offer methodologies that inform stage-by-stage design decisions starting from the early design stage.

“Early design stage” has been addressed in several research studies where it usually refers to the stage at which the conceptual designs are generated [14–17]. In this research, the term refers to Stage 2 (concept design) described in the Plan of Work (PoW) provided by the Royal Institute of British Architects (RIBA), which is arguably “the definitive design and process management tool for the UK building industry” [18]. This stage is pivotal as it is where critical decisions are taken,
which shape nearly all subsequent decisions and outcomes, and the ultimate success or failure of a project [11]. Due to its fluid and iterative nature, it is always advised that decisions taken at this stage should be underpinned by robust methods that can accommodate the associated high levels of uncertainty. Moreover, the RIBA’s “Sustainable Outcomes Guide 2019” encourages stakeholders and architects, to strive for more than the “basic levels” provided by the regulations, as “sticking to only achieving the minimum requirements” could lead to failing the 2050 energy targets [19]. It encourages that sustainability and energy performance should be evaluated from Stage 2. Another problem is that due to the high degree of uncertainty across many issues, not least the viability of projects, clients generally try to minimise expenditure at early design stages. Consequently, the costs incurred in design investigation and development are considerably lower when compared to other phases such as the construction phase [14,20]. Various research studies argue that this stage should be taken more seriously, as greater investment earlier in the process can lead to decreased costs at later stages in construction and operational energy costs [21,22]. In most cases, at early design stages, the majority of decisions are based on “rules of thumb” and the intuition and experience of the architect/designer, where the level of skill varies. A number of research studies suggest that energy-related decisions should be underpinned with robust computational calculations [14,22].

Over the last 30 years or so, Building Energy Performance Simulation (BEPS) has become an increasingly important tool in both reporting predicted building energy demands and enhancing the design process to reduce operational energy consumption which accounts for more than 73% of the total energy consumed during the whole building’s lifecycle [23]. There is arguably significant potential in engaging BEPS at much earlier stages to achieve greater energy and cost-efficient designs [14,24,25]. Notwithstanding their perceived benefits, and with the existence of thousands of energy modelling tools [26], the uptake of BEPS for aiding early design decisions seems to be very limited in practice, with most being used for later-stage design validation purposes [15,16]. This problem, however, is one that has been mentioned repeatedly in previous studies as a postulate without being quantifiably updated, and especially within the UK context. This is one point that will be further explored in the current research. Numerous obstacles that hinder the early engagement of BEPSs at the early design stages were addressed in earlier studies [17,20,27]. These can be mainly classified into technical (directly tool related) and non-technical (beyond direct tool use). The fact that BEPS tools were originally developed for the use of building services engineers for late performance validation and HVAC design has hindered the migration of such methods into more mainstream architectural design practice. Alsaadani et al. [26] consider the problem to be mainly due to the different nature of the work environment/framework of architects as opposed to that of engineers, and the entrenched perceptions of duties expected from both disciplines. Typically engineers would require a “developed” model to apply and run the simulations/calculations on. This mode of working is at odds with the nature of the early design stage where there are many uncertainties and high iteration frequencies. The differences in nature between the two worlds (architecture vs engineering) have motivated the evolution of several BEPS tools to encompass the fluid dynamic nature of the architect’s framework. Developing tools have been recently considering this aspect through providing methods that would assist in merging energy simulation activities within the familiar work environment the architect is already used to. This is evidenced through the emergence of novel developed methods such as plug-in BEPS tools, Cloud Simulation, and Parametric Analysis [25]. The developed tools were expected to smoothly merge with the architect’s intuition at the early design stage when compared to imposing new disengaged parallel tools that would add to the architect’s duties, time and consultancy fees. Nevertheless, the provision of more tailored tools does not appear to adequately address the issue. The researchers hereby argue that continuing to develop more tools in isolation of the real-world needs of practice would not contribute to answering the needs of rapidly evolving targets, especially those related to cutting down GHGs. More attention is required towards considering underlying actual user requirements and reflections, barriers, and limitations to the usage of the tools in a real-world context [25]. Moreover, research needs to surpass looking solely at the micro-level of the problem i.e., tool speed and accuracy,
etc. to encompass insights into the macro-level issues including economic, regulatory and political dimensions. On many occasions, even with the willingness of the architect to involve early simulations, they are faced with resistance from clients whom in many cases will not be willing to fund early stage design when there are uncertainties in relation to the viability of projects. In other cases, depending on the adopted procurement route, the architect may have minimum authority when compared to that of the contractor who is more oriented towards reducing consultancy fees and upfront building costs rather than operational costs. While it is expected that staged improvements to the building regulations should result in better performing buildings, it does not necessarily lead to the adoption of early BEPS involvement in design and may be leading to more deficient practice. There is a growing body of research arguing that architects and designers should be aspiring to exceed minimum regulatory backstop standards by engaging BEPS tools early in the design process and some even argue that it is essential that architects are equipped with direct use of such tools [14,20,23,28–31]. Despite the significance of the issue, there is very little research that investigates the real-world practice of involvement of BEPS tools at the conceptual design stage in the UK architectural practice.

Besides portraying a current overview of uptake and attitudes towards the BEPS tools in practice with special focus on the early design stage, this research endeavours to tackle these issues from several essential angles. It aims to formulate a comprehensive understanding of the opportunities and limitations to the problem and addresses a number of specific research questions:

- What is the current awareness level of the impact of early energy simulations and the perceived role of the architect in relation to energy modelling tasks?
- Is there a significant movement towards the uptake of BEPS tools in architectural practice and if so, which tools are prevailing and how is that related to the architect’s intuition in the design process, and what are the factors that affect the choice of usage of such tools?
- To what extent is the earlier discussed discrepancy in the UK building regulations reflected in practice when it comes to energy modelling activities and meeting requirements?

A field study using a mixed-methods approach was conducted in which a quantitative-based wide-scale survey targeted individual architects and architectural practices across the UK. In addition a qualitative-based study, where six in-depth semi-structured interviews were conducted with professionals from well-established practices to further examine on a case-by-case basis, potentials and obstacles experienced in project designs. An earlier conducted research review (by the same authors) provided an overview of the range of BEPS tools currently available in practice and offered a classification system summarising their essential attributes and differences [25]. The paper also reviewed key academic research into novel BEPS trends and methods. The key outcomes from that research informed the development of the field study work conducted within the current research.

The study focuses on the architecture profession, because in the UK, architects are usually considered key players and the main designers in the building design process [32]. In many cases, architects are the first to be approached when there is a need to undertake a building feasibility study and as a result, they are, in many cases, responsible for the major design decisions from the very start of the project and are responsible for shaping and developing the building concept, programme organisation, spatial integration and material decisions which have a direct impact on the energy performance of the building. On many occasions, other disciplines such as environmental, mechanical, services and structural engineers will be employed to provide additional professional advice usually serving the architect’s vision for the project [32]. Seldom are other professional services engaged at the start of the project and in the early design stages, which raises the question of how and to what extent can more specialised energy performance parameters be assessed and determined at early design stages where these decisions are likely to have the greatest impact [33].

The cumulative goals of this exploratory study are to first establish an in-depth understanding of the current status in the use of and attitudes towards BEPS in the UK practice. Secondly, the study examines how BEPS tools are actually being implemented in practice in the design of buildings and
what obstacles and opportunities exist to improve their application. Finally, it discusses some of the opportunities and challenges that the industry faces when it comes to further implementation and increasing the uptake and integration of such tools at the early design stage. The study is expected to be mainly benefiting BEPS tool developers, researchers and policymakers concerned with that field.

2. Previous Research into the Use of BEPS Tools

A number of previous studies have been carried out into BEPS tools which informed the focus of the current research. Attia et al. [20] compared 10 tools in terms of user-friendliness. Among those, Integrated Environmental Solutions Virtual Environment (IES-VE) was found to be the most user-friendly for architects at the time. Crawley et al. [25] focused on comparing the technical capabilities of 20 BEPS tools. The outcome of the research was extensive tables describing the capabilities of each; the comparison was user-agnostic in that sense. Similarly, Hopfe et al. [17] compared six random BEPS software based on the developers’ claim they are suitable for usage at the conceptual stage. The comparison focused mainly on the ability of engagement at the early design stage. Based on that software review and some interviews, the research introduced a comparison that included things like geometric building representation, user interface, calculation engine, and others. It also went beyond the tools themselves and suggested that there are other obstacles in the process when it comes to the early design stage, namely that the architects and engineers face miscommunication issues on many occasions.

Few studies attempted to understand real-world BEPS use through surveying architectural practice. One study conducted by Erbas et al. [34] in the Netherlands, surveyed a group of 149 (mostly architects) to ascertain the types of barriers that hinder using design informing tools to facilitate “green building design”. They recommended that tools should be developed to facilitate flexibility of use which is appropriate to the design stage, such as the ability of those tools used at early stages to give fast outcomes, even if they are not very accurate. They also found that architects preferred using software plug-ins supported by existing Design Authoring Software (DAS) such as Revit and SketchUp. Alsaadani et al. [27] chose to focus on the non-technical barriers related to BEPS use in UK practice, collecting the responses from 175 architects and BEPS users. They highlighted that the issues are not just technical, but there are social aspects related to communication barriers, in addition to the widespread notion that the energy analysis tasks are not part of the architect’s domain. Other survey-based studies were conducted earlier in other countries such as Singapore [35], Austria [36] and Belgium [31]. Although a number of these were conducted to capture the use of BEPS tools in practice, there was no evidence of more recent research investigating this issue in the UK practice.

3. Methods of Investigation

In order to develop a more in-depth, cumulative understanding of the earlier discussed interrelated issues, a desk-based research preceded the application of the mixed-methods applied within the current research. This earlier study was carried out by the same authors and was published in the CIB World Conference in 2019 [26]. The study attempted to establish the essential information that would assist in the formulation of the basis of the current research methodology and aimed at providing an understanding of the trending methods and novel developments in BEPS tools in both practice and research contexts through systematic reviews, besides providing a classification system based on differentiating criteria. A summary of the research is provided in the following section (Section 3.1) as it contextualises the current study. Two methods then concurrently followed the desk-based research; wide-scale survey and semi-structured interviews (to be discussed in Sections 3.2 and 3.3 respectively). The latter two were seen to be complementary for developing “insights from statistical and narrative methods to help create a fuller understanding” of the problem [37] (p. 666).
3.1. Preliminary Desk-Based Research into BEPS Tool Development

The Building Energy Software Tools (BEST) directory, which is the primary up-to-date source for BEPS tools according to the US Department of Energy, was used to compile a comprehensive list of tools [38]. Besides the BEST list, the authors also depended on many review papers that included a comparison between different BEPS software [20,29,39]. Moreover, 66 published research papers were systematically reviewed, those included the application of one or more tools and/or novel methods of BEPS. Finally, 55 of the most prevalent BEPS software were classified according to user groups; design stage implementation; and plug-in availability, in addition to other criteria. This preliminary overview served as the basis upon which the subsequent primary questionnaire and interview questions were designed. The preliminary study showed that there are currently thousands of energy-related tools in the industry. However, it excluded those tools which are highly technically-specific, such as those used purely for building services in relation to HVAC design, pipe sizing, etc. It was perceived by the authors that any attempt to build upon the inclusion of all those types of tools would give misleading percentages and results, for instance, tools that were shown to be targeting architects within their user groups would have not exceeded 3%, which is, although being based on empirical evidence, yet an unfair claim to make. The authors chose however to focus on those BEPS tools that are used to impact architectural design decisions throughout all the different design stages.

BEPS tools were originally developed for engineers in the design of HVAC systems and other mechanical services. Relatively recently there has been a trend in developing BEPS tools for use in the design process for more diversified user groups including architects. This includes existing software that have been upgraded to accommodate such needs such as IES-VE and DesignBuilder, or those which were specifically developed for the assistance of architects at early design stages such as Sefaira. The research concluded that, after excluding the technically-specific tools, around 40% of the available BEPS tools are directed only for services engineers while around 60% of them “were anticipated to be used” by both engineers and architects. Another figure that is related to the timing of implementation showed that almost 46% of the identified tools are suitable for the early design engagement, and not only for verification purposes. It should be clear that we are here talking from the side of the tool developers and not the real uptake in the market, as those figures have been derived mainly from the tool developers’ official websites. A positive point to comment on, however, is that the change in marketing frames stating that a tool is designed for the engagement at the conceptual stage shows the general trending direction of the market which may be perceiving the importance of such early engagement. However, the actual uptake of such tools in practice is yet to be investigated as shown throughout the methods that follow in the current research.

The systematic research review of 66 publications revealed several trending methods that are adopted in both research and professional fields such as sensitivity and uncertainty analysis to overcome the early design decision uncertainties. Cloud-simulation was found to be a growing method which enables instant simulation results as the simulations are carried out on the Cloud. Artificial Intelligence (AI) related methods such as Genetic Algorithms and Artificial Neural Networks were found to assist the optimisation and energy prediction process with higher accuracy and speed. In addition, parametric analysis based methods were found to have applications on both research and commercial fields; examples of BEPS software adopting these methods are Ladybug and Honeybee which are used as plug-ins within Rhino software. Again, the presence of such variety into the development of methods focusing on assisting the attributes associated with the early design stage i.e., uncertainty, iterative nature, speed, etc. shows the grand ambition towards the involvement of the tools in the earliest design stages. However, it also shows, together with the previously reviewed publications in Section 2 that there is a major tendency towards developing new/enhanced tools without necessarily paying much attention to issues beyond the tools themselves. Moreover, the majority of the research seems to be working in isolation of specific work environments that could vary significantly from one place to another. UK practice, for example, has its own set of opportunities and limitations which wouldn’t necessarily be shared with other regions. Besides giving a fundamental understanding of the
context, the study findings were used to inform the surveys' and interviews' development in terms of overall design and detailed questions formulation.

3.2. Wide-Scale Survey

With the aim of acquiring a comprehensive snapshot of BEPS tool awareness, frequencies of application and attitudes of practitioners across different levels of architectural practice, performing a wide-scale survey with a broad geographic spread capturing the primary regulatory variations of the UK regions was found to be the best strategy to achieve this goal. One questionnaire (S-Arc) was aimed at “individual architects” registered with the Architects Registration Board (ARB), the body empowered to “regulate the architects’ profession in the UK” [40]. A second questionnaire (S-Prac) targeted “architectural practices” chartered from one of the three main professional bodies in the UK:

- The Royal Institute of British Architects (RIBA); representing England and Wales; the Royal Society of Architects in Wales (RSAW), which covers Wales is a subsidiary of the RIBA [41].
- The Royal Incorporation of Architects in Scotland (RIAS); representing Scotland.
- The Royal Society of Ulster Architects (RSUA); representing Northern Ireland.

The surveys (S-Arc and S-Prac) were seen to be complementary, as targeting only one population could inexpediently lead to the amplification of unbalanced results leading to inaccurate interpretations. Several architects in the UK work as freelancers or within small colleague-based teams and not under the umbrella of chartered practices, so it was important to capture these views. In addition, targeting different levels of the practice would allow for exploring the opportunities and limitations within the field at the micro and macro levels. Individual architects could give more sound insights when it comes to the challenges experienced with the direct handling of such tools, whereas when it comes to broader matters such as regulatory, expenditure and client-related issues, more vigorous information could be elicited from practice representatives. Moreover, targeting practices captured additional feedback from other non-architect users, particularly those practices that depend on in-house specialists to perform their energy modelling activities i.e., environmental specialists, technologists, and services engineers. The range within the target groups reflected a wide spectrum of practice scales that would inherently capture a range in scale and complexity of projects from public to private sector, domestic to non-domestic adding to the richness of the collected data.

Both questionnaires shared fundamentally similar structures, however, there were some variations to accommodate the differences of the surveyed populations (practitioners vs practices). The questionnaires were divided into four main sections; the first captured the general background of participants mainly to validate the results and to make sure it is representative and covering a satisfactory spectrum. The second investigated the level of awareness and general use of BEPS within the target groups. It also included questions about the DAS used by participants, as this piece of information was thought to be of significance especially to BEPS tool developers aiming at providing software plug-ins and interoperable packages. Being performed on an online platform using SurveyMonkey [42], the survey allowed for directing different sets of questions to different groups, where some questions/sections were dependent on the answers given to the preceding ones. This option allowed for the third section to appear as different sets of questions for two distinct groups. For one group (BEPS-users), the section dug into details around the types, methods, timing and users of BEPS tools, while for the other group (BEPS non-users), the questions investigated the reasons that hindered the usage of those tools, and attempted to grasp an insight of the future practice through investigating the willingness of learning BEPS. A final section was then directed to the whole sample to inspect general opinions regarding issues around the level of agreement on the advantages of early BEPS engagement and the need to equip architects with such tools. In addition, perceptions towards economic, client and regulatory influences on that matter were investigated.

The developed questionnaires were tested in a limited pilot study that was sent out for review and critique to 60 direct contacts; 40 individual architects, and 20 practice representatives of which 25% of the
sample responded. Specific feedback was taken into account in the revised questionnaires, those included applying minimal alterations and formatting to some questions. In addition, the questionnaire was streamlined to make sure it would take around 15–20 min to complete.

The ARB register [40] was used to determine the “individual architects” population, while for the “architectural practices”, the registers of the three institutes were used (RIBA, RIAS and RSUA). The ARB register included a total of 42,914 architects. However, the population was further filtered to include only the 38,594 (S-Arc population) architects with UK-based addresses. The list was then compiled into 47 Excel sheets titled according to different postcode UK regions. As for the chartered architectural practices, a total number of 4636 practices (S-Prac population) were distributed as follows: 3664, 843 and 129 for the RIBA, RIAS and the RSUA respectively [43–45]; those were then listed into three distinct Excel sheets.

To figure out representative sample sizes, two approaches were merged. One applied a statistical calculation defined by Equation (1) which was derived from Blair et al. [46]. The result of the equation determined a target group of 384 responses. This figure was considered for both populations alike despite their different sizes, as the Equation is designed for calculating the sample of populations exceeding several thousand without considering the exact population count as a parameter.

\[
\text{Sample Size} = \frac{Z^2 \times p \times (1 - p)}{m^2}, \quad (1)
\]

where:

- \(Z\) = confidence level, where a 95% confidence level would make \(Z = 1.96\)
- \(p\) = worst-case percentage, in decimals. Conservative value = 0.5
- \(m\) = margin of error, in decimals. Would be equal to 0.05 when the confidence level is 95%

The second approach was based on reviewing previous studies in different regions that adopted similar survey methods; this information is listed in Table 1.

| Authors       | Location | Year | Sample Size | Reference |
|---------------|----------|------|-------------|-----------|
| Fernandez et al. | Spain    | 2020 | 171         | [47]      |
| Erbas et al.   | Netherlands | 2012 | 149         | [34]      |
| Weytjens et al. | Belgium  | 2010 | 399 + 223   | [31]      |
| Mahdavi et al. | Austria  | 2003 | 198         | [36]      |

By combining those two outlined approaches, the final target sample was calculated to be within a range of around 150 to 400 anticipated respondents; an initial average figure of 300 to be reached was accordingly selected. However, bearing in mind the 25% response rate acquired from the piloting phase (when direct contacts were approached), the authors decided to lower the response expectancy to 15% instead to give enough safety margin. Accordingly, a final figure of around 2000 correspondents was expected to be sufficient for gathering a response from around 300 (15% of 2000) participants. The following step was to choose two sample groups of 2000 participants from both populations for S-Arc and S-Prac. The latter figure represented around 5.5% of the S-Arc population (38,594), and around 43.5% of the S-Prac population (4636). To give similar selection chances to all population members, same-probability systematic sampling steps were followed, where those percentages were chosen from all the geographic-based formulated lists mentioned earlier. Members were chosen based on a Random Number Tables method, which depends on randomly selecting the participants after associating each with a distinctive randomly-generated number. Finally, a listed target of around 4000 members with their associated contact information, namely email addresses, was established: 3364 from England and Wales, 552 from Scotland and 114 from Northern Ireland.
The questionnaires were electronically distributed via email invitations to all 4000 participants. Over the course of 3 months, in the period between the 20th of October 2019 and the 20th of January 2020, a total of 511 responses were collected representing a response rate of around 13%.

3.3. Semi-Structured Interviews

With the aim of obtaining a more nuanced understanding of the context, an even more focused method was adopted. Semi-structured interviews were conducted with practice representatives especially involved in the design of five selected projects that have shown to achieve substantial merit in terms of energy efficiency. The interviews covered several aspects around the practice in which the interviewees represented, in addition to having a closer look at the circumstances of which the BEPS tools, if any, were implemented in the design of the case-by-case real-world projects.

The authors conducted “key informant interviews” (KIIIs) for the purpose of gathering qualitative-based evidence to assist in informing the research. The KIIIs are based on selecting targeted participants who are highly experienced and can contribute with valued information and insights in relation to a specific subject [48]; energy-efficient design in our case. This level of deep insight was not possible to be grasped if the researchers were only to depend on the wide-spread surveys. The KIIIs were preceded with a web-based contextual mapping that included around 50+ potential buildings around the UK that have achieved low-energy credentials e.g., Passive House and BREEAM. It was taken into consideration, that besides the energy aspect, BREEAM includes nine other sustainability aspects that need to be achieved through a points-based system [49], meaning that in some cases, even relatively not the best performing buildings could acquire total acceptable credentials. Hence, only those known to be achieving high levels of energy efficiency were considered. As the interviews were semi-structured, the sequence of the discussion flow was not identical in all of the KIIIs, however, the structure in almost all KIIIs included the following key themes:

- A background of the interviewee’s experience in the field, incentives of adopting low-energy design methods, role in the practice and the specific case study.
- A discussion around the general approach of the practice and types of project it is involved in and the different available expertise.
- The DAS and BEPS tools used within the practice and methods and timing of engagement in case the tools are used in-house. Or the methods of engagement and communication in case of relying on external expertise.
- A discussion around the delivery of the chosen case study that was delivered by the practice; project details, special context, client requirements, the process of delivery, tools used, etc.
- Finally, general perceptions and opinions towards the use of BEPS in the practice, where general and specific barriers and potentials in relation to current and future practice were discussed.

Six KIIIs were conducted during the period between 18 July 2019 and 13th of February 2020 with five project architects and one services engineer; most of the interviews took place in-person, and only a few were conducted through phone calls. The interview was designed to last for 60 min, however, due to the complexity of the issues, a couple lasted nearly 120 min. All conducted interviews were recorded after acquiring the interviewees’ consents. For confidentiality reasons, the interviewee names have been replaced by symbols I-x where x resembles an associated number to each interviewee; the same applies to the discussed projects: P-x.

“Case studies” in this context is not meant to be referring to the discussed projects as such. Those projects, however, were used as vehicles to grasp more focused on-ground responses rather than holistic impressions. “Case studies” is thus used in a more generic sense to refer to the whole “case” which included the specific interview together with the discussed project. Table 2 summarises key information about the five case studies together with the associated projects and interviewees.
Table 2. Case studies; key information about the associated interviewees and the discussed projects.

| Case Study | Project | Project Location | Area m² | Value | Type | BEPS | Credential | Interviewee/s | Practice Size (Employees) |
|------------|---------|-----------------|---------|-------|------|------|-----------|---------------|--------------------------|
| 1          | P-1     | Newcastle upon Tyne | 2600    | £5 mill. | Old factory to office building | IES-VE | BREEAM V Good | I-1 (Architect) | 11–50 |
| 2          | P-2     | Ports-mouth      | 11,000  | £53 mill. | University Sports Center | IES-VE | BREEAM Outstanding | I-2 (Engineer) | 201–500 |
| 3          | P-3     | London           | 2000    | £4.6 mill. | High School | IES-VE | BREEAM Excellent | I-3 (Architect) | 51–200 |
| 4          | P-4     | Whickham, Tyneside | 213     | £450 k | Private house | PHPP | Passive House | I-4 (Architect) | 2–10 |
| 5          | P-5     | Northumberland   | 151     | £275 k | Private house | PHPP | Passive House | I-5 (Architect) | 11–50 |

3.4. Methods of Data Analysis

IBM SPSS Statistics 26 [50] was used for the analysis of the data acquired from the surveys. As the research is of an inductive exploratory nature, the quantitative data analysis mainly relied on descriptive statistical methods, namely, univariate and bivariate analysis were implemented for the purpose of investigating significant frequencies and to examine the correlations between different variables [51]. Regarding the qualitative section, the recordings of the six KIIs were first transcribed, where each transcript was divided according to key specific and general coded themes. This thematic classification approach allowed for a systematic method of synthesising the different views [52].

4. Findings from the Wide-Scale Survey

The results of both surveys, S-Arc and S-Prac, were merged and analysed side-by-side to give a holistic perspective of the current UK practice status. To acquire a higher level of reliability, responses from practices outside the UK together with responses of less than 80% completion rate were excluded. Accordingly, the total number of responses considered were 217 and 201 for the S-Arc and S-Prac respectively; the “actual sample” counting 418 was considered to be relatively good representative value when compared to the Equation (1) outcome and to the previous survey-based research represented Table 1 in Section 3.2. The results of the survey were summarised under the following sections: sample description and validation; BEPS tool users and methods of implementation; BEPS tool non-users; attitudes and perceptions towards BEPS. Italicised excerpts will be used throughout all the results sections (Sections 4 and 5) to highlight the respondents’ and interviewees’ responses.

4.1. Sample Description and Validation

The sample of 418 participants showed quite satisfactory results in terms of cumulative distribution around the UK’s regions where there are regulatory variances; 74% (309 participants) of the responses were received from England, 5% (30) from Wales, 17% (71) from Scotland and 4% (18) from Northern Ireland. As shown in Figure 1, when comparing the regional distribution of the collected response rates with those of the population of architects in those areas, both figures were found to be highly in line with each other. The figures also showed a satisfying level of variations that covers the whole population spectrum in terms of participated practice sizes (from 1 to 100+) and the project types (domestic and non-domestic) and sizes they are involved in.

Moreover, for gaining a higher level of confidence towards the sample representativeness, the percentages of participated practice sizes (number of employees) were compared to those figures presented by the RIBA in their annual “RIBA BusinessBenchmarking” published report; the 2019 version was the reference in that case [53]. Figure 2 shows a high level of congruence.
4.2. BEPS Tools Awareness

Before diving into details about the actual uptake of BEPS tools in practice, this section attempted to acquire a general sense of the “level of awareness” among architects towards BEPS tools. Based on the data gathered in the earlier desk-based research [26] discussed in Section 3.1, eleven of the presumably well-known tools were listed to test if the participants were able to recognise any of them (or others in the “Other” section). The list also included the NCM-based tools SAP and SBEM despite not being technically simulation tools as it was expected that for several architects, the knowledge about energy modelling is exclusively limited to NCMs, where the results have even verified this assumption. SAP and then SBEM were found to be highly recognised; by 83% and 61% respectively, with 36% of respondents indicating that their knowledge regarding BEPS is strictly related to NCMs.

In relation to BEPS tools, Figure 3 illustrates that PHPP topped the list with 29% of respondents recognising the tool’s name. This may support the notion that Passive House and its associated tool are growing in popularity since their initial use in the UK [11]. Despite the fact that Autodesk ceased to provide new licences for the software since March 2015, Ecotect came second on the list (24%). This could be due to the software being one of the earliest tools that were specifically designed to encompass architects’ needs for early design engagement [54]. This relatively high rate of recognition does not necessarily mean that the software is still widely used although previously acquired licences before 2015 are still active. The cloud-based tool Autodesk Green Building Studio (GBS) followed...
at 15%, and then IES-VE and Sefaira, each at equal 13%. From the demonstrated results, it could be concluded that there is a link between the highly recognised tools and the fact that those tools were designed, or developed, to accommodate the early involvement in the design process.

![Figure 3. Most recognised Building Energy Performance Simulation (BEPS) tools in practice.](image)

Finally, excluding the NCM tools, nearly 40% of the participants showed unfamiliarity with any (or another) of the listed BEPS tool names. This may signify that although there is a clear movement towards the enlightenment of architectural practice with BEPS, there is still a large number of practices that may be missing essential knowledge upon which they could make an informed decision to choose/or not to adopt BEPS tools.

4.3. BEPS Tool Users and Methods of Implementation

The previous section established an overview of the level of awareness towards BEPS tools in the UK practice. This section will attempt to dig deeper into issues around the actual uptake of BEPS in terms of which, who, when and the methods of implementation of these tools.

As several previous research has asserted, BEPS tools should be integrated with the current workflow and merged seamlessly with the intuitive tools [14,16]. The most common DAS were investigated to inform future research into BEPS tool development. Figure 4 illustrates that AutoCAD was the most significantly used DAS by 51% of respondents. However, no evidence in research nor practice was found to support any BEPS associated with AutoCAD use. This may go back to, the wide use of AutoCAD mainly for drafting. In addition, with high significance, SketchUp followed with a 42% usage rate; this would make it the first ranked pure design tool on the list. SketchUp is known for its user-friendliness and intuitive support, moreover, it is perceived as a decent environment allowing easy integration of plug-ins [55]. Revit, a resonating name in practice and considered to be the most popular in the Building Information Modelling (BIM) world, was found to be used by 28% of respondents. Despite not being listed as a choice in the questionnaire, Vectorworks was added by 19% of the participants, making it an important software, especially the fact that it is BIM-based. However, it doesn’t seem to be gaining enough attention from BEPS developers with Energos being the only compatible plug-in found [56]. While there was no significance found to the remaining DAS, Rhino (used by 8%) could be of specific interest being known to support Parametric Analysis methods through the embedded software Grasshopper [26].
To get more distilled results, the NCM tools were first investigated in separation of the rest of the BEPS tools. For S-Arc, only seven (4%) were shown to be using, either or both of SAP and SBEM. Both were found to be used as stand-alone tools except for two responses that showed using them on the cloud-based platform, “energydesigntools.co.uk”. For S-Prac, 11% and 3% used SAP and SBEM respectively. Nearly all the NCMs users (95%) declared they were used for compliance at late stages.

Regarding the remaining BEPS tools, only 29 (14%) of S-Arc were found to be involved in direct use of BEPS tools. Additionally, 37 (17%) of the S-Prac showed they were using the BEPS tools in-house; 19% outsourced, while the rest (64%) were not involved at all. Moreover, around 70% (24 participants) (11% of total S-Prac) of those in-house practice users were found to have one or more architects that perform the BEPSs. A correlation was found between the BEPS tool usage and practice sizes; the direct proportion shown in Figure 5 would suggest that the reason may be referred to the higher capabilities of larger practices to accommodate such expertise with the required “costly” tools given the amount and frequency of jobs those practices carry out in comparison to smaller practices.

![Commonly used Design Authoring Software (DAS) in practice.](image)

In an attempt to verify and quantify one of the commonly repeated statements in research, “BEPS are used most commonly for late design stage validation purposes” [14,16,17,20,25], multi-layered questions were directed to those who are involved in BEPS either in a direct way or through outsourcing the tasks. The direct answer received (from 36% of the sample) showed that in general 66% strictly apply the energy-related tasks at late stages, while only 34% involve them at the conceptual stage. This apparently

![Relation between BEPS usage and practice sizes (number of employees).](image)
confirms that the earlier statement is true and still current. However, when only focusing on those architects (14%) and architectural practices (17%) that are directly using the BEPS tools, we found that around 87% of the BEPS direct architect users commence using them at the conceptual stage, meaning that in most cases, when architects or architectural practices decide to apply BEPS in-house, they would tend to use them at RIBA Stage 2.

When inspecting the prevalent used BEPS tools (Figure 6), PHPP showed significant popularity among the users (close to 70%). This would support the impressions towards PHPP in terms of ease of use and direct clear targets set within the package [11]. IES-VE followed with a good 50% difference (19%). In an earlier study [20], the tool was chosen by architects as the most user-friendly at the time. Sefaira, Ladybug and Honeybee followed by 16%; those are mainly targeted for architects at the early design stages. Moreover, Honeybee and Ladybug are Parametric Analysis based software, and would seem to confirm that this novel method is emerging in both practice and research. Autodesk GBS and Insight had fairly low uptake rates; 10% and 6%. This point will be further discussed in Section 4.4.

Finally, as the earlier desk-based research revealed, there are emerging ways in which the BEPS tools are being used [26]. Besides the stand-alone conventional way, plug-ins and cloud-based simulations are novel methods that assist more the natural needs of the early design stage, and integrate more easily with the intuitive DAS used by architects. Figure 7 demonstrates the methods of uptake of the most commonly used BEPS tools in relation to the most popular DAS in practice. The figure shows that although PHPP is widely used among architects, its stand-alone format appears to be the most common (76%), while the remainder used its plug-in format (DesignPH) within Revit and SketchUp. This may be due to the fact that this specific tool not being strictly technically simulation-based, but rather depends on inputs within spreadsheets making it comparatively simple and fast to use. IES-VE showed variations in terms of usage format, but the stand-alone version was most prominent (60%). Honeybee and Ladybug were shown to be only used as plug-ins within Rhino, while Autodesk GBS as a 100% cloud-based tool. Sefaira was shown to be mainly used as a plug-in within SketchUp, the main reason for that is that both pieces of software are owned by the same company, Trimble inc. [57]. These results in general would tend to show that there are progressive movements towards developing the tools to cope with the intuitive tools already being used by architects to facilitate smoother uptake.
4.4. BEPS Non-Users

Although the study was about the actual use and uptake of BEPS, due to the fact that the non-users already represent the majority of the total sample (355 participants = 85%), the authors wanted to capture the perceptions and barriers to use from this important group. Moreover, investigating this sector could further reveal the underpinning reasons for disengagement with the tools, and if there is something we could learn regarding the current limitations and opportunities.

First, a direct question was addressed to those non-users to investigate the reasons for not considering them. According to Figure 8, the main reason chosen by 56% of the non-users was the lack of sufficient knowledge about BEPS. This supports the idea that there is a gap in terms of awareness and architects’ education about the subject. In addition, if this is the level of awareness from architects, how are clients expected to be aware of BEPS benefits and be encouraged to invest in early integration? The “clients not encouraging” reason was “added” by 5% of the respondents in the “Other reasons” section and some commented, “small business can’t afford expensive software when clients do not require the service”, “Lack of client requirement to do anything beyond Building Regulations?”.

Cost limitations seemed to be a major challenge as it came second on the list (34%). This reason specifically received numerous comments in the free opinion text box associated: “cost, we are a small practice, we do not have that much work to keep paying for the software licence”, “cost compared with the size of projects i.e., domestic scale projects generally have a much lower profit margin”. Those results, in connection to those illustrated earlier in Figure 5 would suggest that cost is a very significant barrier for BEPS uptake, especially for smaller-scale practices that may not necessarily be having the continuous amount
of job flow required to sustain the use of those tools. One participant even suggested, “can pay for it monthly or per project”, with other comments that had a similar meaning.

The selection “lack of time” was meant to be presented as a general sentence for the participants to reflect upon in the free text box. The criteria accumulated 27% where the comments included a variety of reasons that are related to time limitations; some commented on the lack of time within the professional life for learning BEPS, “I am not able to just pause everything and head for a course in a totally new subject”, while several commented that the conceptual stage is already very time-restricted, “clients usually give us tight time-frames, especially at the Conceptual Stage”.

In the “other reasons” section, besides the “clients not encouraging” reason mentioned earlier, “better to outsource” and “not seen in the architect’s domain” were added by 11% and 6% respectively. Although these figures may not appear to be significant, they are considered by the participants to be of special importance. Regarding the first reason, some participates commented, “we outsource this work now”, “it is easier to outsource when required than keep up with the accreditation for each different system”, this may mean that each of the accreditation systems would require a whole set of different expertise, which could hardly be maintained by a single practice. Finally, 6% were found to adopt the conventional perception that the BEPS tasks are out of the architect’s responsibility domain.

When asked about the willingness of the current non-users to adopt BEPS tools in the future, 46% showed a positive response, 17% were negative, and 37% were not sure. The 46% (163 participants) positive responses from the non-users would suggest that increasing numbers of architects seem to be considering BEPS tasks as a part of their design responsibilities. Those were further asked about the specific tools they would consider using. Again, Figure 9 shows PHPP had the highest demand (15%). The specific advantages of the tool have been mentioned in several areas in the paper. Despite not showing actual significant uptake values in practice (see Figure 6), both Autodesk owned pieces of software, Insight (11%) and GBS (10%), received the second and third highest rates of prospect usage. The reason for this was clearly stated by those who chose them. Most of the comments were related to the confidence in Autodesk’s products, “Autodesk is a brand I trust and am familiar with”. The choice being based on the brand name would suggest a lack of awareness of the tools’ capabilities in comparison to others. Others commented that they will only consider tools which can integrate with the intuitive tools they are already using, “will only consider using related software to programmes already being used”, “I use Revit and would choose easier options to input my models”, “would be compatible with Autocad and Revit?”. This point again supports that those tools offering methods of seamless integration are more likely to be used. However, the responses do not seem to show those architects are aware of which tools possess those capabilities. Ladybug, Honeybee (4%) and Sefaira (3%) followed and were shown to be receiving increasing actual uptake values in the architectural practice (see Figure 6).

![Figure 9. BEPS tools willing to be learnt and used in the future.](image-url)
Finally, close to half (42%) of those who expressed their willingness to learn and use BEPS stated they did not know which they wish to learn, “I have no knowledge of the systems”, “I don’t know which would be best”. Those 42% shown to be aware of the benefits behind the uptake of such tools did not seem to be having enough knowledge about BEPS and the different options available.

4.5. Attitudes and Perceptions towards BEPS

To generate a better understanding of the limitations and opportunities concerning BEPS involvement, this section will discuss the opinions of the whole sample regarding: architect’s role; criteria of BEPS tool choice; clients and expenditure; and regulations and NCMs.

In general, 63% of the participants agreed that energy considerations were not prioritised and taken as seriously as they should be, while the remainder of responses remained generally neutral. Opinions regarding four statements targeted attitudes towards whether architects should be skilled/proficient in BEPS at the early design stages without necessarily the need to rely on other specialists (engineers or technologists). Figure 10 shows that there was a significant acceptance (80%) towards equipping architects with skills in BEPS technologies to be able to run energy simulations on their own, “to provide preliminary quick and dirty results”, “I use it on every project however, generally architects are not aware of its potential”. Furthermore, around 70% viewed that this would help in cutting down the time consumed for the communication and exchange of information between the designer and the energy modelling specialist, especially at the early highly iterative stage of design.

Moreover, around 40% disagreed that BEPS were complicated for architects to learn and use, whereas only 15% of respondents agreed. Finally, nearly half of the sample (52%) disagreed with the statement that using BEPS to reach energy efficiency was the responsibility of the engineer alone rather than the architect. All four results showed positive perceptions about architects being equipped with the BEPS tools. Moreover, it shows confidence from the side of architects towards the ability to learn them, nevertheless, when comparing those results with the actual uptake of the tools in practice, a discrepancy may seem to occur. This may support earlier suggestions that architects are willing to uptake the tools (see Section 4.3), however, they seem to be lacking guidance, education and encouragement in relation to BEPS tool integration.

Respondents were asked to choose and rank seven criteria upon which they may choose a BEPS tool. The radar chart (Figure 11) revealed that “ease of use” was chosen by the majority to be most important (scoring 5.2), this resonates with previous researchers pointing out that architects tend to prefer user-friendly tools [14,20]. In addition, “ease of result interpretation” showed to be an important...
criterion (3.4), as the same studies commented that architects prefer less complicated data input/output. One participant commented, “graphically pleasing data that is easily reproduced as imagery or charts to provide to clients . . .”. Again, “cost” showed to be a critical criterion (4.4), several respondents saw cost as a prime factor, they suggested that purchasing a software would mean by necessity keeping it unused on several occasions leading to a waste of money. They suggested there should be different ways of payment/subscription methods, such as monthly or per-project; “cost, I am a small business and we invest heavily in IES-VE licences, but unless a project requires BREEAM or the local council states key environmental targets, it is not being used to its best potential”. “Ease of learning” scored (4.3); “assistance with learning to incorporate at early design stages”, “good training availability and product support”, “access to training and online help availability”. “Link to other design tools” ranked high as well (4.1), which confirms the idea that architects are willing to use tools within their familiar intuitive environments. “Accuracy of results” (3.2) and “compliance with regulations” (3.0) did not seem to be as important as the other criteria. This may go back to architects tending to use the tools for informing early design decisions rather than trying to acquire accurate predictions of energy consumption, and also, that architects are heavily involved in the production of initial project concepts and would need more informing tools at this stage, rather than the phase of regulatory compliance, “suitability for early-stage conceptual design work rather than full compliance modelling”.

![Figure 11. Criteria upon which architects would choose BEPS software.](image)

The degree of acceptance of three statements related to expenditure and client’s influence was examined. According to Figure 12, 84% of the sample perceived that clients were in most cases unaware of the benefits behind the implementation of BEPS at early stages of design, and would not be easily convinced to invest more at that stage, “clients would rather save expenses for the ‘timber and bricks’ bit rather than on the ‘drawings’ bit”. However, the participants showed nearly neutral replies concerning clients’ requirements being the main driver for BEPS implementation. While (54%) agreed that expenditure was a major driver (and barrier) in the decision to use BEPS early in a design. From these results, it could be understood that architects could have the ability to convince the clients with the BEPS involvement if the cost was to be increased within a reasonable range. However, architects should be in the first place convinced and in command of the subject themselves.

A final set of statements concerning building regulations and NCMs was directed for participants’ opinions. Figure 13 shows that there is a general understanding that the NCMs are compliance tools that are used at late design stages (60%). However, although 37% agreed that the NCMs are not suitable for early design integration, 29% seemed to be convinced that SAP and SBEM could influence the design at the conceptual stage. In terms of BEPS tools, there was quite a balance in opinions with some weight towards agreement (46%) that BEPS tools are more often used for compliance purposes rather than for design. Although the majority (70%) agreed that energy efficiency standards should
be considered at the conceptual stage, many (40%) were convinced that the early integration of BEPS should remain voluntary and not be regulated for in legislations. In addition, there appears to be a clear split between the number of architects that see the importance of early BEPS involvement and the actual uptake of those tools in real-world practice (see Section 4.3).

Figure 12. Opinions regarding the relation between BEPS implementation and clients and cost. (1) Most of the clients are not aware of the importance of the early design stage energy analysis; (2) client’s requirements are the primary factor when it comes to BEPS involvement in a project; (3) cost limitations are the primary factor when it comes to BEPS involvement in a project.

Figure 13. Opinions regarding energy modelling tools and regulations. (1) Standard Assessment Procedure (SAP) and the Simplified Building Energy Model (SBEM) are only commonly used as assessment tools at the end of the design stage; (2) SAP and SBEM can be used to influencing design at the conceptual design stage; (3) the prime reason BEPS tools are currently used is to comply with building regulations rather than enhancing the design; (4) meeting energy regulatory standards should be considered while initiating the design at the conceptual stage; (5) building regulations should oblige that BEPS should be used at the conceptual design stage.

There seemed to be a general understanding of the specific role of the NCMs. However, there also seemed to be a general mixing up between those NCMs and BEPS tools as many respondents appeared to be dealing with both as if they were one. This may support the idea that there is broadly a lack of understanding and essential knowledge on the layers of details into the BEPS world.

5. Findings from the Case Study Interviews

This section will summarise a total of around 700 min of semi-structured KIIs conducted throughout six distinct meetings. All interviews were transcribed and analysed, and then the most significant ideas were summarised under the titles (themes) set out below.
5.1. BEPS for Informing Early Design Decisions

Without exception, all the interviewees perceived the importance of early integration of BEPS/energy-modelling with design. Two base case projects (P-1 and P-4) especially amplified the importance of early engagement and the consequence of the uptake delay. P-1 was a retrofit project that converted a 120-year-old factory to a contemporary office building. In that project, the BEPS preceded nearly all architectural work except for general planning outlines. The BEPSs in that case were performed by an outsourced services engineer as the practice did not have in-house expertise:

“So, we were quite keen that the 120 years old brickwork structure would remain evident on the outside and the inside… So the question that we posed to […] engineers was that we have to insulate this inside or outside, which would be a disaster! So how do we do it? And they […] used the BEPS modelling to help and think about that… So they used the software (IES-VE) to see alternatives… So when they put all of that into their model what they realized was that we could meet the criteria by sometimes insulating the inside and sometimes insulating the outside… And so that’s why [P-1] looks the way it does! So, in that case, it was definitely the modelling worked in parallel with the architecture… in other occasions, it’s the other way around where we draw something and then the software would prove that that scheme can work, which supports your theory!” (I-1)

In the other example, the project architect (I-5) discussed a clear example of a missed opportunity he experienced with P-4 which was Passive House accredited. In that case, the practice commenced the work on P-4 after another practice has already made the initial planning and massing, and after the “planning approval” had been granted. At this stage, many architectural design aspects were locked-in and were very costly to revisit and amend. In that case rules of thumb alone were not efficient due to the special situation of the building context:

“Before the client came to us, he made the design, but the earlier architect wasn’t experienced… So, it turned out that through investigation there was a close protected tree… also, there is quite a big area, most loads and loads of trees, steep slope… So what we had to do was try and keep with the Planning Permission but make it into through analysis of the PHPP and some of the thermal modelling, then get it into what could be a Passive House… and we had to make the building work quite hard with the u-values, and because of the high ceilings as well. So he has not used typical Passive House compact 2.5 ceilings, he used 3.6 m ceiling instead!… So the general orientation, the size and orientation of windows shouldn’t have been like that… if we were designing from scratch we would have probably designed it differently…” (I-5)

5.2. Where and Who Should Carry Out the BEPSs?

While all the interviewees promoted the importance of the early integration of BEPS, different viewpoints were discussed in regards to how and who should be doing the analysis, “There is no one way of performing the simulations, many factors come into the picture, it all depends on the scale, type, time and budget of a project” (I-2). The interviewees here asserted that there is a common confusion among architects when it comes to energy modelling tasks. Many would talk about all related activities as one, that are carried out for validation purposes by the services engineers; “many architects do not differentiate between early design modelling and those which are carried out after the design has been already developed” (I-3). I-5 and I-4 agreed to that due to the highly iterative nature and time limitations at the early stages of design, and confirmed that ideally the BEPS expert should be available in-house for faster feedback, “in many cases, when we receive the feedback from the M and E engineers, they are obsolete and the project has already developed beyond that point…” However, I-1 and I-6 commented that the option of possessing the expertise in-house is not always feasible, I-1 commented, “in my practice, working on projects that require simulation are very occasional, once I have the annual suitable amount of work, I will definitely consider having the expertise in-house”. Nevertheless, I-2 and I-3 added that the in-house expertise could be very much substituted with an external engineering practice that is highly engaged and aware of the
requirements and nature of the stage. This pretty much is subject to the nature of the procurement route followed, as in some routes the contractor is the one who appoints the project team which limits the architect from choosing a familiar M and E practice to work with; “this project was a success [P-1], we worked side by side with the M and E, and had 2-3 meetings on weekly basis” (I-1), “we are a relatively big practice, however, we are usually able to choose the M and E we are working with . . . so we did not consider having the expertise in-house” (I-3).

In terms of equipping architects with the energy modelling tools, all the interviewees asserted that architects must at least have the fundamental basics of BEPS, if not for the aim of using the tools directly, then for the purpose of understanding the feedback received from the services engineers; “a common language between the architect and the engineer is substantial; in many cases, the architects are only focusing on the aesthetics, while on the other side, the engineers don’t care much about how the building looks like” (I-3). Moreover, there was quite a clear link between a project’s type and size and the use of such tools. Architects involved in smaller-scale residential projects (I-5 and I-6; using PHPP) asserted that in that case, architects should directly use the tool themselves, and that would help in cutting down time and expenditure when compared to inviting an engineer on-board. Other interviewees who engage with larger-scale non-domestic projects (I-3 and I-4) felt that architects should be using iterative tools such as Sefaira. They affirmed that these should only be used for informing detailed design decisions at the early stage, and that larger-scale projects would definitely need the intervention of experts early in the process to carry out more “accurate” and “in-depth” simulations. The interviewees were very aware that simulations carried out at the late stage of design had a different purpose and would better be carried out by services engineers; “it would be even better to outsource the job to specialists, especially when the projects requiring these are occasional” (I-1).

5.3. Limitations and Opportunities of BEPS Tool Implementation

The KIIs revealed pretty much similar challenges to those resulting from the survey. However, they added that while there are challenges related to the technicalities of different software, much more influential barriers are faced within the actual practice. Generally, the interviewees mentioned that there was still a common misconception that energy simulation activities are totally out of the architect’s domain; “from my experience, architects in general are not motivated enough to learn and use BEPS for several reasons, I believe the time has come for these ideas to change” (I-3). Another reason described by I-3, I-4 and I-6 is that architects tend to rely on visual graphics more than numerical-based information that is commonly the output of various BEPS tools. I-3 mentioned that some software were starting to provide different user interfaces designed specifically for architects such as Sefaira; “I really like the grades and colours of diagrams provided by Sefaira . . . “. (I-3) however considered that, even with the “good” user interfaces, architects still lacked the ability to interpret the outcomes and reflect them on their designs; I-3 continued; “. . . but I am always not very confident if the provided numbers are good or bad! More supporting information is needed”. Although PHPP users (I-5 and I-6) were found to be using it as a stand-alone format, they commented that it is a matter of habit, but they may consider using DesignPH plug-in, they suggested that tools merging with intuitive DAS would be more popular.

5.4. Current Regulations and Associated NCMs

All the Interviewees agreed that the aspiration of architects and stakeholders should always exceed the regulatory standards and that keeping the ambition to “just meet” the regulations will hardly lead to any “actual” improvements in energy performance. Building regulations were heavily criticised due to an approach that tightened up the thresholds while not paying any attention to the process itself. The task described as “ticking some boxes” has been repeated in several interviews. None of the interviewees saw the NCMs as design tools, “No, absolutely not, we use SAP and SBEM purely to get through the regulations, but we knew that the PHPP will cover it, it is miles better” (I-5), “SAP and SBEM are not design tools. PHPP is a design and a certification tool” (I-6). So, they did not give the NCMs any consideration during the design stage; “I design everything in the PHPP, I then go to my assessor and
say can you do the SAP calculation, and they do it, because it’s just ticking boxes, that the projects that I’m working on will walk through the building regulations without any problems. So, I leave that to the last possible minute” (I-6). Moreover, NCMs were even accused to be benefiting poor designs:

“Regulation or verification point is done through a metric which doesn’t make a particular sense . . . the way this methodology works is through either SAP or SBEM which is based on comparing to creating a national building which has the same characteristics . . . so it inherently benefits poor buildings to an extent because your form could be whatever it is, and they’re not encouraging you to build it more efficiently”. (I-4)

Some interviewees even proposed that Passive House accredited buildings should not need to run the NCMs; “Building regulations do not pay any attention to PHPP calculations, they are not recognised as being valid or acceptable. So, I think that there are bids to try and get PHPP to be recognized as an acceptable alternative, which I support” (I-6), “Certainly, SAP is purely a compliance too. So, you wouldn’t use that. No, I think PHPP should be embedded as a way of assessing housing schemes, as the best tool, really” (I-5).

6. Discussion

In this section, the previously described findings from the desk-based research [26], survey and case study interviews are synthesised in order to obtain a clearer picture of the status quo of BEPS in UK architectural practice. The discussion will focus on key issues, namely, the current level of awareness and tool uptake, perceptions, key challenges and potentials.

With regard to the overall current awareness level of the importance of early design stage BEPS implementation, there seem to be some apparently contradicting results. On the one hand, there appears to be a consensus from the architectural community that the energy efficiency input should be considered as early as possible in the Conceptual Design stage (see Figure 10 in Section 4.5), and that the issue is not gaining the required level of attention in Practice and at Governmental levels (see Section 4.5). On the other hand, despite their perceived importance, the actual uptake of BEPS tools at the early design stage seems to be still very limited. Although the majority of practices stated that they are involved in BEPS tasks (around 70%), however, this figure was shown to include all sorts of energy modelling tasks which are performed in-house or outsourced throughout all design stages. In unpacking that figure, we find out that 66% stated they strictly involve the energy modelling tasks at late design stages, leaving only 34% who use BEPS at the early stages. Moreover, only around 15% of the architectural community showed they are directly engaged with the tools; in-person or in-house (see Section 4.3). Based on those results, we could argue that the majority of BEPS activities are still carried out at later stages for validation purposes rather than informing design decisions and this finding supports previous research presuppositions [14,17,20,25,27]. Those figures would also contradict the initial results acquired from the BEPS tool developers’ websites (from the desk-based research [26]) that around 60% of the tools are designed for early design integration.

Furthermore, based on the aforementioned results, the desk-based research, research reviews (see Section 2), and on those results elicited from the qualitative study (especially Section 5.3), there seems to be a general misconception in both research and practice which leads to putting all energy-related tasks in one box. Some questions underpinning some previous research in the same filed are usually around “who should run the simulations, architects or engineers?” or “at which stage should the simulations be applied?”, etc. However, although those appear to be legitimate research questions, nevertheless, asking those kinds of questions may reveal a misleading conception. Based on the findings of this study, it has been concluded that a distinction between the different types of energy modelling exercises is mandatory for gaining a deeper understanding, and that the mixing-up of those exercises, or even talking about BEPS usage as a holistic activity without making this differentiation would lead to several misconceptions. The authors hereby suggest that for more efficient tackling of the related problems, energy modelling exercises carried out at different stages should be clearly distinguished and addressed separately, where each simulation exercises should
have a definitive purpose, timing, and key potential users. This distinction arguably, is believed to allow for clearer dialogue in future research. The authors hereby suggest that there are mainly three types of energy modelling exercises; “Early Design Simulations” (EDSs); “Late Design Simulations” (LDSs); and “Compliance Calculations” (CCs). EDSs are those carried out at the very early stage when the conceptual design is still in the generation phase. The main purpose of the EDSs is clearly to inform the decisions taken by the architects during the generation of a design, namely at the concept stage when the design is still fluid and highly iterative. LDSs usually occur in an intermediate stage between EDSs and CCs, and would often include detailed simulations on more developed design alternatives. CCs are those calculations that are run using the NCMs. Based on the research, the latter cannot be considered as design informing tools especially in the early stages of design and are exclusively used as assessment tools for regulatory compliance purposes. Both LDSs and CCs are mainly the responsibility of the services engineers, as opposed to EDSs which may carry a shared responsibility. It seems that the discussed confusion of the different energy-related exercises is present in practice as well with many survey respondents showing that their perception about energy modelling activities are limited to LDSs and CCs. It is no wonder then that it is usually perceived that energy modelling activities are not in the architect’s direct responsibilities where these kinds of tasks are usually assigned to either in-house or outsourced services engineers after the architects have finished their role in developing full designs, usually without using any BEPS tools.

In terms of the current and prospective BEPS tool uptake and related trending methods of implementation (discussed in Section 3.1), BEPS tools that were shown to be more easily integrated with the architects’ intuitive DAS were shown to be more prevalent. PHPP, although used mainly as a separate tool, the fact that it is designed to be used at very early design generation gives it significant popularity and a high actual level of uptake (see Figure 6 in Section 4.3). It could be expected that over the course of the next few years, the plug-in format of the software (DesignPH) will be increasing on popularity. Other tools that merge as plug-ins with the intuitive DAS such as Sefaira, Honeybee and Ladybug have also shown relatively high levels of uptake, given that the latter two depend on Parametric Analysis methods. Regarding the other trending methods, cloud-simulation was shown to be already in use in relation to software like Autodesk GBS and Sefaira for giving instant feedback. However, AI-supported methods were shown to be exclusively used in research and academic contexts rather than having a clear impact in real-world practice. Notwithstanding the capabilities of the available BEPS tools, the majority of those who have shown interest in future uptake of such tools, had little clue as to which tool they should learn to use (see Figure 9 in Section 4.4). Moreover, 10% chose Autodesk owned tools mainly because of the branding resonance and would point to a lack of awareness and sufficient knowledge of the subject.

Consequently, perhaps the major limitation with regards to the early involvement of BEPS in architectural practice is the lack of awareness possessed by architects themselves. The problem may refer to the absence of substantial knowledge that should have been acquired in earlier academic years of education. This could be comprehensible as the subject is relatively new (a matter of decades) given that arguably there is always a gap between the educational systems and actual practice. This general shortage of knowledge about the energy efficiency input in practice is directly reflected in client ambitions and requirements. This point specifically was addressed by the respondents and interviewees as a major obstacle. In addition, one of the major limitations is related to the cost of those tools which are supposed to be used at the Conceptual Design stage when the expenditure is very limited, and even more prevalent when the project progress is at the risk of being terminated or fundamentally changed for one reason or another. In addition, although the government is showing special attention regarding energy consumption and GHG emission reduction, this seems to be only reflected as backend-demands that stakeholders need to achieve without focusing much on the process or taking into consideration the early design stage sensitivity and impact on the whole project’s lifecycle.

On the other side, the authors perceive there are positive potentials in practice. The majority of the architects already sense the change in demand and appreciate the importance of early consideration
of energy efficiency. They even accept that they could have an influential role with regards to energy-efficient designs. Besides the architects who are already using those tools, many have recorded an interest in learning and using BEPS. On a grander scale, the new publications of the RIBA are focusing more and more on the necessity of early consideration of sustainability in all projects. All of these factors could be used in promoting more early integration of these informative tools. Furthermore, increasing numbers of projects that are taking energy efficiency seriously are tending to substitute the current regulatory standards with voluntary ones, which provide more appropriate methodologies throughout the whole design process i.e., Passive House and BREEAM.

7. Conclusions

This study endeavoured to make a comprehensive understanding of the current status of the use of BEPS tools in UK practice. Through mixed research methods, it sought to present a holistic picture of the current level of awareness, uptake and opinions around BEPS use at the early design stage while uncovering the limitations and opportunities concerning that matter.

The findings indicate that there is a general understanding of the significance of the early design stage and the potential benefits behind the BEPS involvement at that stage. Nevertheless, despite the availability of a range of BEPS tools, and the plethora of research on the topic, especially in relation to technical tool developments, architectural practice still does not seem to be adequately enlightened, nor motivated enough to adopt a step change to current modes of practice. Moreover, the Building Regulations standard methodologies (especially NCMs) seem to contradict the anticipated goals set by the government in relation to cutting down energy consumption rates and GHGs due to the disaggregation between Planning Approval (early-stage) and Building Warrant (late-stage). Moreover, according to the interviewees this process may be benefiting poor designs.

Consequently, those who are currently involved in BEPS integration at the early stages are mostly self-motivated and aware of the benefits of early uptake. Thus, voluntary low-energy schemes especially Passive House are gaining increasing popularity, in many instances as a substitute for the building regulations. Some interviewees even requested that Building Control would exempt Passive House accredited buildings from running SAP or SBEM calculations. The authors hereby would suggest that the regulatory bodies should amend the current regulatory frameworks by setting more holistic approaches that would include considering early design stage simulation/modelling, without necessarily imposing extra loads, but rather through setting rewarding benefits for those who consider energy demand calculations at RIBA Stage 2. This may mean changing the two stage UK consent process or facilitating the means by which Building Control and Planning can be better integrated in relation to energy efficiency decisions that considers both early stage and late stage approvals. It would also be beneficiary to consider those voices calling for PHPP calculations to be accepted instead of the standard compliance tools.

The findings revealed that there is a general lack of awareness in relation to the BEPS subject. One reason may relate to the fact that BEPS has only lately found its way into the architectural world after being mainly developed for services engineers. However, the new challenges and demands imposed in the field require a fundamental change at several levels. The subject needs to be considered as fundamental to architectural education. In addition, awareness campaigns should be initiated to support architects’ knowledge and enlighten them of the possible opportunities and benefits of BEPS adoption. These could be led by the professional bodies in the UK e.g., RIBA. Equipping architects with the appropriate knowledge and skills and getting them motivated would undoubtedly have a direct impact on clients’ awareness and acceptance of making further investments for early BEPS use. Thus, the authors would argue that architects should be primarily encouraged to undertake training that would facilitate the skills and awareness needed to tackle the problem more effectively.

The second most significant barrier of BEPS uptake after the “lack of awareness” was “cost”. Given the amount of investment involved in developing BEPS tools, they are found to be significantly costly and out of the reach of many architects/practices, especially small-scale ones which most of
the time deal with private clients for domestic projects. Options for dealing with this barrier could include, as suggested by participants, monthly or per-project subscriptions. Another could include mass funding that depends on groupings of practitioners that would pay relatively low memberships to obtain shared licences. These initiatives could be either led by the government or the professional bodies. Another incentive would be to ensure that all projects demonstrate a certain level of energy performance at planning stage, thereby effectively forcing clients to invest in early stage energy design modelling.

On the micro-level, a closer look at the technical enhancements to accelerate BEPS uptake especially by architects is needed. Ease of data handling and interpretation and links to other intuitive design software were found to be essential criteria upon which architects choose a BEPS tool. Both criteria however, are interconnected. They both suggest that architects are likely to use tools that can merge with the current frameworks they are already used to. In addition this would satisfy the architects’ apprehension in terms of providing efficient and user-friendly interfaces with clear and “colourful” diagrams that would tend to not only give textual data, but moreover, support the architect with some guidance of how to enhance the design. These criteria were found to be more important to architects than the precision of results, as architects tend to use the tools to inform their decisions through generic outputs rather than the need for accurate figures at early stages of design. Table 3 summarises the key opportunities and limitations identified from this study.

Table 3. Key opportunities and limitations of BEPS early design implementation in the UK practice.

| Key Opportunities                                                                 | Key Limitations                                                                 |
|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| • There is a general positive attitude towards the importance of BEPS implementation for informing early design stage decisions. | • There seems to be a confusion among architects when it comes to energy modelling; some architects’ knowledge about the matter is exclusively limited to NCMs, and hence, perceive them as totally the responsibility of the services engineer. |
| • Around 80% of the architects agreed that architects should be able to use BEPS tools for informing their design decisions. | • Beyond the general perceived benefits, there is a remarkable level of lack of knowledge and awareness of detailed issues regarding BEPS. Although many respondents (37%) recorded interest in learning BEPS, 42% of them failed to choose a specific tool. |
| • Around 60% of the participants were able to recognise at least one name of the listed BEPS tools, while around 15% are already directly using them (in-person or in-house), and 19% of the practices run EDSs as outsource the tasks. | • Architects seem not to be motivated enough to get engaged with BEPS neither directly nor indirectly. This is connected to the general approach of the building regulations that does not encourage energy modelling to intervene beyond the NCMs which are done at late stages for compliance purposes. |
| • Several BEPS tools are already providing methods to serve the architect’s intuition e.g., DesignPh, Sefaira, Honeybee and Ladybug work as plug-ins within several DAS e.g., SketchUp and Revit. | • Clients’ unawareness and discouragement to invest in BEPS are seen as a consequent result of the designers’ lack of knowledge and skills in the first place. |
| • There are increasing numbers of architects (and clients) that aspire to exceed the basic regulatory standards and adopt low-energy schemes such as Passive House. | • Cost of tool engagement was found to be the second largest barrier after lack of knowledge. |
|                                                                                 | • There are still technical barriers related to the use of BEPS tools; those are mainly related to poor user interfaces and difficulties connected to data input and output handling and interpretation. |

In terms of the novel trends accumulated from the desk-based research [26], their level of implication in the professional world and in connection with the previous point above, plug-ins were found to be acquiring significance from tool developers, especially with the most well-known DAS;
for example DesignPH and Sefaira which work as plug-ins within SketchUp and Revit. Sefaira and Autodesk GBS are two examples of the Cloud-Based simulation method which assists in the speed of simulation and allows instant feedback for design iterations. In addition, the plug-ins Honeybee and Ladybug are two examples of the trending parametric analysis method, which is used mainly for early design generation. Finally, AI-based energy consumption prediction which is the focus of several research studies is very limited in application and may hold significant promise in the future.

It is indeed very promising to see that there is wide understanding of the importance of the early design decisions and that BEPSs are being seen as having significant potential to assist at early design stage. This is evident through the variety of available BEPS tools, besides the general prevailing positive perceptions among architects. However, the actual uptake of these tools, although growing is still quite limited to specific self-motivated practices that chose to deal with a certain market edge. BEPSs are arguably a key potential that needs to be more invested in in terms of awareness and encouragement for further uptake. The authors perceive that architectural practice is now ready for that change to take place. However, different stakeholders need to play their roles in an efficient and integrative way to further facilitate this.

8. Limitations and Future Research

The nature of the study being basically of a holistic multi-aspect exploratory nature, specifically in the UK context, has several limitations. Making the study scope cover the use of BEPS in both domestic and non-domestic projects has maybe limited more in-depth insights into each. However, the study has sought to provide a foundation for future research, and hence a more generic route was favoured. Another limitation is that the scope focused on architectural practice without getting much insight from the services engineering domain. The rationale was that architects in the UK are the key players when it comes to the early creative design of building projects, where they are also most commonly the professionals in direct contact with the client. However, future research should certainly include the engineering views. Besides the aforementioned, the following are some recommended pointers for future research that could benefit from this study:

- Besides the ongoing research into the BEPS tool technical development, further research needs to focus on the side of the practice in terms of real-life needs and challenges that hinder the further uptake of those tools. The aim of research should arguably be not to reach the “perfect tool”, but rather, to consider different solutions that suit the different needs in practice given the different types, capabilities and natures of practices, clients and projects and different stages of project development.
- It is evident that more research should be invested in the pedagogy and introduction of proper BEPS education to architects during their early education. This will naturally reflect on professional practice and clients’ level of awareness.
- With the increasing popularity of Passive House, there may seem to be a need for more voluntary schemes that are distinctive from the regulatory standards. These should include guidelines for early BEPS integration, and ways should be sought for encouraging architects and clients to approach them.
- Finally, evidence-based research into the quantification of BEPS early engagement benefits is still required and could assist in the encouragement of stakeholders for adopting such activities. There does not still seem to be a way of accurately quantifying how much savings could be made, or how much more efficiency could be reached with the early BEPS implementation.

Author Contributions: R.M. conceived and designed the study, collected and analyzed the data and wrote the paper; J.M.K. supervised the research, co-designed, revised and edited the paper; N.B. supervised the research, co-designed, co-wrote, revised and edited the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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Acknowledgments: The authors acknowledge the participation of the interviewees and survey participants without whom the data gathering would not have been possible.

Conflicts of Interest: The authors declare no conflict of interest.

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