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Architects Requirements of Decision Support Tools to deliver Low Impact Housing Design in the UK: Insights and Recommendations

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Abstract
The construction industry is facing increasing pressure to address environmental performance earlier in the design process. For United Kingdom (UK) buildings, design is perceived to be the key in delivering the low carbon agenda. Hence, a fundamental change to designers' approach in designing for low impact buildings is needed.
A mixed method approach comprising of questionnaires to sustainable architectural practices were combined with interviews of architects in practice and academia. This is necessary to identify the gaps in the current use of Building Performance Energy Simulation (BPES) tools as design- decision support for architects, towards recommending the requirements of new generation architects' friendly tools for the early and detail stages of the design process to deliver the sustainable housing design in the UK.
The results indicate a limited number of architects use BPES tools; that is, until the later stage of the design process. Moreover, there is need to focus on tool development for architects decision-making process, especially at the conceptual stage, where major decision are taken. Thus, the study focuses on recommending requirements of architects' friendly tools, fit for their design-decision making at various stages of the design process. As architectural design decisions vary significantly in terms of accuracy, flexibility, and the level of detail, the study recommends that: at the early stages of the process, where relatively minimal information is available, flexibility and approximation in BPES tools is more approximate to support design decisions. Nevertheless, as the design develops, and more information becomes available, precision and higher levels of detail in BPES tools are required.
Keywords: Building Performance Energy Simulation Tools, Decision Making, Low Impact Buildings, Royal Institute of British Architects, Sustainability.

1. Introduction

Buildings account for approximately forty per cent of carbon emissions in the UK and across the European Union (Carbon Trust, 2010). They have been described as complex entities involving a wide range of stakeholders drawn from a large number of disciplines (Dibley *et al*. 2012). Despite some buildings labelled as having green credentials, Scofield (2002) observed, they were found to be responsible for as much energy consumption and pollution as comparable to conventional buildings. This is because; many environmental design decisions that are supposed to be taken with the aid of decision support tools, are taken late in the design process only to validate the design, after critical decisions have already been made (Dunsdon *et al*. 2006). This infers, architects often make decisions early in the design regarding building form, orientation, fenestrations and construction materials with little or no support (Hong *et al*. 2000). Hong *et al.* (2000) further emphasised how these issues have been observed to have important implications in achieving the low impact building agenda.
The way architectural decisions are made has a great influence on the outcome of the design. Fundamental design decisions taken early in the design process have far reaching environmental impacts later on. Thus, tools have become an important delivery to aid design and decision making for architects for the early and on-going consideration of environmental performance. Additionally, it is increasingly acknowledged that to address climate change challenges, a fundamental change to designers approach in designing for low impact buildings (LIB) is needed (Hong *et al*. 2000; Morbitzer, *et al.* 2001). As a consequence, the industry is challenged to deliver a 'new generation' of decision support tools for architects to aid the design of low impact buildings.
Thus, this study appraises Building Performance Energy Simulation (BPES) tools as decision support for architects. It explores their current use by UK architects, towards the aim of providing insights into requirements of BPES tools that fit the intrinsic way of architects' decision making to deliver the low impact housing design in the UK.

2. Decision Making in the Design Process

There is an increasing drive to achieve the sustainability agenda, as well as climate change challenges. For UK buildings, design is believed to be the key in the delivery; hence, a vital change to designers' approach in designing for low impact buildings (LIB) is required. The decision making processes for low impact buildings are complex (Dibley *et al*. 2012; Attia *et al.*2012). The responsibilities for the LIB design are mostly shared between designers and engineers. The effects of each decision depend on a large number of other decisions. For this reason, tools have become a necessity for the early and on-going consideration of environmental performance and an important delivery mechanism to aid design and decision making for architects to deliver the low impact buildings. Hence, it is widely acknowledged that tools are required in the design and decision support for such design (Papamicael, *et al*. 1997; Hong *et al*. 2000; Ellis *et al*. 2008)

However, an investigation into current design and decision tools from the Technology Strategy Board (2009) acknowledged that: decision support at the conceptual stage is particularly poor; design professionals work in different ways: through sketches, physical models, 2D and 3D computer representations, and analytically and, thus, have different requirements for representing and communicating design developments; and current tools only address the needs of one specialism or specific phase of the design process. Dunsdon *et al*. (2006) also recognised how energy and simulation tools, are inadequate to support and inform the design of low impact buildings especially at the early stage of the design process. They referred to the fact that the simulation tools currently available are only proficient in performing predictive energy assessment and there exists low-level adoption of these tools by architects. Subsequently, rather than playing a role of decision support in the design, analysis is used primarily to verify and rationalise decisions already made (Hopfe and Hensen, 2009).

Current studies (Ellis and Mathews, 2001; Augenbroe *et al*. 2004; Mora *et al*, 2006; Nicholas and Burry, 2007) show that limitations in both tools and the design process pose challenges to the integration of simulation in the process. The conversion of 3D models between design and analysis representations is not well supported by existing data transformation mappings, and typically requires expert translation and interpretation (Augenbroe *et al*. 2004). Most simulation tools necessitate detailed information about a building's construction and services before even an indicative analysis can be performed; information that may not be available at the conceptual design stage (Ellis and Mathews, 2001). These incompatibilities has been observed to inhibit the development of an interactive information exchange network where design and simulation analysis processes are active simultaneously, and serve as barrier, rather than reinforcement to conventional practice (Nicholas and Burry, 2007). Mora *et al*.(2006) also laid emphasis on how computer support for conceptual design of building structures is still ineffective, mainly because existing structural engineering applications fail to recognise that structural and architectural design are highly interdependent processes. Hence, to deliver low impact buildings, the loop between building design, operation and performance must be closed (Technology Strategy Board, 2009).

2.1. Building Performance Simulation Tools

According to Mirani and Mahdjoubi (2012), the design for energy conscious building which is environmentally friendly requires a careful analysis and evaluation of all proposed design alternatives throughout the different stages of the building design. Traditionally, these were performed manually by architects, to produce sketches and drawings of plans, sections, elevations and perspectives. With increasing need for more accurate performance prediction, detailed assessment and evaluation of design parameters influencing the building's energy performance, computer based tools have been developed and are increasingly used.

Thus, application of computer based tools in building design can be broadly categorised as computer based drafting and design tools, such as AutoCad, and computer based Building Performance Energy Simulation (BPES) tools, such as Autodesk Green Building Studio, Design Builder, Open Studio, Design Advisor, Energy plus, eQUEST, and IES VE. BPES tools, according to Hong *et al.* (2000), are used to simulate: Energy performance analysis for design and retrofitting; Compliance with building regulations, codes, and standards; Passive energy saving options; Building Energy Management and Control System (BEMCS) design; Cost analysis; and Computational Fluid Dynamics (CFD).

A brief summary of eight different simulation tools for thermal building simulation was described and developed as part of a critical software review in Hopfe *et al*. (2006). A more extended report on different energy performance simulation programs can also be found in Crawley *et al*. (2005). Another overview is further accessible on the building energy software tools directory from the U.S. Department of Energy (2012). Building Performance Simulation (BPS) tools, in general, should be used to calculate a variety of outcomes of the proposed design, such as energy consumption, performance of heating and cooling systems, visual and acoustic comfort, dynamic control scenarios for smart building technologies, smoke and fire safety, distribution of air borne contaminants, and others (Augenbroe *et al*. 2004). Nevertheless, the best established use of simulation by architects is after finalising the design, i.e. for performance verification and commissioning (Morbitzer, 2003).

Tianzhen and. Jinqian (1997) state, *'From the perspective of many architects, most BPS tools are judged as too complex and cumbersome'*. In fact, it is repeatedly reported that a growing gap exists between architects as users of BPS Tools (Attia, 2010). Dunsdon, *et al*. (2006) state, existing simulation tools address the needs of one specialism or specific (usually the later) phase of the design process. Subsequently, only a small minority of architects use the existing simulation portfolio to perform the evaluation of energy efficient strategies and technology options, at the crucial formative stages of the design process and the project at large. Furthermore, most of the BPS tools cater more for engineers. This, according to Attia. *et al*. (2009) and Attia (2010; 2012), is because most tool developers use engineers' feedback to develop architect friendly tools. Thus, most of the BPS tools are not suitable for the architectural design. Building simulation design is not fully integrated into the design process; hence, the limited use of simulation tools by the architects, especially at the early design stage, where it is most necessary. Thus, Mendler *et al*. (2006) and De-Wilde and Prickett, (2009) argued that tools should be centric to the design process. With the growing importance in bridging this gap and integrating simulation tools for the whole building design process for architects to achieve low impact housing design in the UK, it should also be used as an integrated element (Augenbroe, 1992; Mahdavi,1998).

However, some advancement has been reported towards developing architect-friendly tools (Toth *et al.* 2011; Integrated Environment Solutions, 2012; Energy Plus-Energy Simulation, 2013). This includes: interoperability, by which data can be transferred from architectural model to the simulation environment such as in Open Studio which is a free plugin for the Google Sketch Up in 3D drawing program and plug-in of IES, such as IES VE-Ware or the Revit Architecture plug-in IES (Integrated Environment Solutions,2012). There is also Autodesk AutoCAD plug-in to create and edit Energy Plus input files (Energy Plus-Energy Simulation, 2013). The IES VE Sketch-Up plugin allows the user to assign important sustainable design information like location, building type, room type, construction types and HVAC systems to a Sketch-Up model and then import it directly into an IES tool for analysis (Integrated Environment Solutions,2012).

Mirani and Mahdjoubi, (2012) further argued that despite the proliferation of energy simulation tools described by Integrated Environment Solution (2012) and Energy Plus-Energy Simulation (2013), they do not connect to the actual analysis needs of the architects, especially at the early design stage. Those that attempt integration, such as IES Virtual Environment typically implement model exchange or model sharing strategies to achieve information transfer in a manner that is not customisable, and are more suited to the later stages of the design process (Toth *et al.* 2011). Open Studio plug-in for Google's Sketch Up, use validated simulation tools, but are incomplete in a collaboration sense as the coupling link deals only with the translation of geometry between programs, and not material properties, building systems, or occupation (Toth *et al.* 2011). Additionally, none of the tools implements parametric modelling capabilities to explore design constraint.

As for the Autodesk AutoCAD, problems had been reported in the process of transferring or importation of data from the architectural models to the energy analysis software (Schlueter and Thesseling, 2009). Importing and exporting of building geometry is error-prone and tedious, especially as geometry models established in CAD-software are often not suitable as simulation models. The simulation results and possible conclusions remain in the simulation software; a feedback into the design software is not possible. Changes in design due to performance criteria have to be done manually in the design software, the model has to be exported and simulated again. These steps have to be repeated after every change in the design (Schlueter and Thesseling, 2009). This is because; different methods of modelling are used in the different types of software; thus, efficient exchange of geometric data is difficult and sometimes there is inconsistency in the geometry transfer between software packages. Hence, data may be lost or overwritten in the process of transfer between models or has to be re-entered. Holistic performance assessment is not considered in any kind of computer-aided architectural design (CAAD) environment that architects use. The whole building's geometry must come from the architects' model, including: the number of rooms; the connections between rooms; their relationship to the exterior; exposure and aspect to the sun along with the shape and total area of built surfaces or openings.

Thus, in these newer software, which is attempting to address the well know failing of older software, sometimes by allowing AutoCAD to create and edit input files, the design process needs to be well advanced before any of the BPES tools can be applicable, as they are not suited at the creativity stage of the process. Hopfe *et al*. (2006) and Hopfe (2009) further stated that there is no independent evaluation and classification of tool usability and functionality in practice versus users' type and needs. Also, tools developers had not been stating the capabilities and limitations of the tools (Toth *et al.* 2011), therefore, potential user is faced with difficulty of choosing a suitable program among the growing BPS tools pool. In essence, current BPS serve as an accepted tool for design confirmation but not mainstream for true design-decision support for architects. There is replication of many tools with striking similarities and no attempt to develop architect-friendly, effective and efficient design and decision support applications (Attia, 2009). Hence, this paper is a contribution to many on-going efforts to ameliorate this situation. The focus is to recommend the characteristics of BPES tools that fit the intrinsic way of architects design and decision making at the early and later stages of the design process.

3. Methods

The approach adopted to fulfill the purpose of this paper is the mixed method approach. It consists of both quantitative and qualitative methods of research to generate and analyse data in the same study (Blaikie, 2010). It is adopted in the form of a quantitative online questionnaire survey and qualitative in-depth, semi structured interviews. This is similar to previous researchers (Adeyeye *et al*. (2007) and Osmani and O'Reilly (2009), who emphasised the usefulness in combination of the two methods in a way that the strengths of one method offset the weakness in the other.

From the desk study literature review, questions were developed to determine the content of the questionnaire survey. The quantitative online survey was administered to sustainable architectural practices identified from the RIBA directories of architects. The use of questionnaire survey corresponds with researchers such as Adeyeye *et al*. (2009) and Thomas-Alvarez and Mahdjoubi (2012). Other researchers that influenced the use of surveys and especially the online method of administration includes Lovell (2005), who used '*survey'* to confirm the increase in the interest of sustainable homes in the UK. Isiadinso *et al.* (2011) also explored the complexity of the contexts, philosophies and demonstrations involved in best practice for low carbon buildings, using a mixed research approach that also included online survey and administration. The draft questionnaire was rigorously tested for validate, significance, easiness, flexibility and conformity with the ethnical confidentiality required and five online surveys also conducted as a pilot. A total of 425 sustainable practices were selected randomly from the RIBA directory of architects to cover the entire geographical UK. Thus, each architectural practice within the targeted population had an equal probability of being selected. This is because, with randomisation, a representative sample from a population provides the ability to generalize (Babbie,1990). The method used for selecting the samples is from Creative Research Systems (2012), similar to Soetanto *et al*. (2001); Xiao (2002) and Ankrah (2007), to determine a suitable size for the sample.

Architects were targeted in the questionnaire as the main respondent because they are the key players in the construction industry, whose services are needed from the conception stage of a project, to its final handing over (Oyedele and Tham, 2007). They also have the major responsibility to get the message across in the participatory decision making processes and thereby educate other stakeholders into more genuinely collaborative roles (Chen *etal*. 2008). They were thus, most likely to offer more reliable and informed responses to the theme of the Questions posed in the study. This presumption converges with the contention of Borman (1978)**,** who states that people who are suitably experienced in what they do should be in a better position to provide relatively accurate responses. The use of a questionnaire survey in this research corresponds with researchers (Adeyeye *et al.,*2007; Osmani and O'Reilly, 2009; Thomas-Alvarez and Mahdjoubi, 2012) who used it to enable large amounts of information to be gathered and then compared (Yudelson, 2008) cheaply, effectively and in a structured and manageable form (Adeyeye *et al*., 2007).

Other researchers who influenced the use of survey, especially the online method of administration used in this study, include Lovell (2005). She conducted an internet-based survey of low energy housing to reveal over 150 low energy housing developments that have been built or planned in the UK, from 1990 to 2004, comprising over 24 000 dwellings. Isiadinso *et al*., (2011) also explored the complexity of the contexts, philosophies, and demonstrations involved in best practice for low carbon buildings. They used a mixed research approach that also included survey and interviews. The themes of the questions include:

Section A: Personal Information: This focuses on year of experience and geographical location of respondents.

Section B: Design and decision support tools: This focuses on the use and implementation of design and decision support tools by architects at various stages of the design process.

Section C: Statutory and Non Statutory regulations and standards.

Section D: Other Support: This focuses on the stage(s) of the design process, that architects take decision.

After the data collection, analyses were made using SPSS 19 to explore the characteristics, summarised in sections 4.1.1 and 4.1.2. The questionnaire survey analysis was combined with the extant study of the literature review to form the basis for pilot interviews and, consequently, the in-depth, semi structured interviews. The pilot interview was used to assess whether questions were clear, understandable and whether the structure and flow were acceptable. A sample of ten architects was finally interviewed. The interviewees were with diverse qualifications, years of experiences, and past sustainable housing projects in UK. Details of their profiles and years of experience are shown in Table 1.

Table 1: The Interviewee Profile

Interviewee	Academia	Practitioners
A		A practicing architect in the UK. He has 20 years of experience and a wide knowledge of different areas of sustainability issues especially as related to low carbon housing design in the UK.
B	An architect in academia with 18 years of experience	
C	An architect in academia with 10 years of experience and vast knowledge of sustainable practices.	
D	A practicing architect but is now in academia. He has 16 years of experience and participated in design of a notable low carbon energy village.	
E		An international architect in practice. He has thirty (30) years of experience and a world record of sustainable past projects using sustainable materials.
F		A practising architect with 25 years of experience in design of sustainable housing.
G		A young, dynamic, and enthusiastic architect with strong ideas and innovation on sustainability. He has three (3) years of experience.
H		An international architect with a dynamic record of past sustainable projects and publications. He has thirty-(30) years of experience.
I		A practicing architects of 10 years' experience.
J		A practicing architect of 15 years' experience. He is also working on the same project with interviewee 'I'

The approach was informed by three major publications (Mackinder and Marvin, 1982; Imrie 2007; Isiadinso *et al*. 2011). Mackinder and Marvin (1982) used interviews with architects to understand the role of information, experience and other influences on the design process. Open-ended questions were used at intervals in the interview process and architects were encouraged to lead the discussion. Imrie (2007) involved a sample of practicing architects from the Royal Institute of British Architects (RIBA) database and combined the analysis from the interview with other web-based information of a sample of architectural practices primarily based in London. Finally, Isiadinso *et al*. (2011) conducted an online survey and interviewed experts who were construction professionals with substantial records of accomplishment or linking expertise in sustainable design in both industry and academia.

4. Results and Discussion

4.1. Questionnaire Survey Results and Analysis

Responses were received from sixty-two architectural practices, representing a 17.4% response rate. The response rate is low but similar to Ankrah (2007), who states that the UK construction industry is notorious for poor response to questionnaire surveys. Takim *et al*.(2004) also alleged, a response rate of 20-30% is normal, especially within the construction industry.

4.1.1. Current use of BPES Tools as Design- Decision Support for UK Architects

Limited architectural practices (32.8 per cent) use simulation tools such as Autodesk Green Building Studio (AGBS) and Massachusetts Institute of Technology (MIT-DA) Design Advisor at the technical design stage; 31.3 per cent use such tools at the design development stage D of the RIBA Outline plan of work; 13.1 per cent use them at the concept stage C and 8.2 per cent at the preparation stages A and B. However, 11.7 per cent specified that they use such tools at all stages of their design, while 3.3 per cent responded that, they have not used such tools at all in their design (Figure 1).

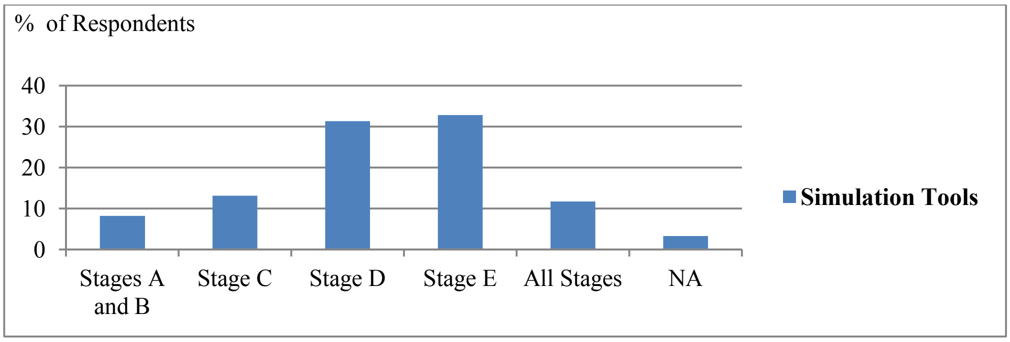


Figure 1: Use of BPES Tools in the Design Process

On energy simulation tools (such as IES, eQUEST, Energy plus software), more than half (64.9 per cent) of the architectural practices acknowledged they have not used such tools in their design. However, 15.8 per cent of the practices used the tools at the technical design stage, while 7.0 per cent responded that they had used energy simulation tools at all stages of the design process (Figure 2).

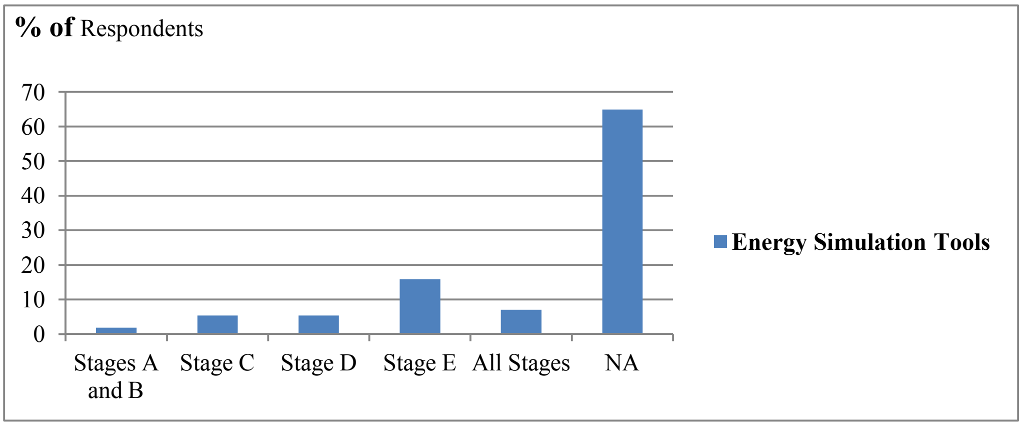


Figure 2: Use of BPES Tools in the Design Process

4.1.2. Stages of the Design Process that need Focus

To identify the stage(s) of the design process that need the most focus on BPES tools to support architects in delivery of low impact housing design in the UK, percentage distribution of the cross tabulation in SPSS 19 was used. The RIBA Outline plan of work design stages (as specified in the Questionnaire) are: preparation Stages A and B; the conceptual Stage C; the design development Stage D and technical design Stage E.

Table 2 shows the percentage of the respondents analysed from the cross tabulation. For tools such as AGBS and MIT-DA, the concept stage of the design process (37.3 per cent response rate) is the stage requiring the greatest focus. This is followed by preparation stages A and B (35.6 per cent).

Table 2: Percentage distribution of ETs and Stages of Design Process that needs focus

Stages of Design	RIBA Stages of Design Process	% Distribution of respondents in the stages of design that needs focus on Tools such as AGBS and MIT-DA	% Distribution of respondents in the stages of design that needs focus on Energy Simulation tools
Preparatory Stage	A and B	35.6	40.0
Concept Stage	C	37.3	36.0
Design Development	D	11.9	12.0
Technical Design	E	3.4	4.0
Total		88.2%	92.0%

[Notes: Differences in total value of percentage is due to removal of "*All Stages" and 'Not applicable'*, hence figures do not round up to 100%].

On energy simulation tools, preparation stages A and B (40 per cent) have a higher percentage over (36 per cent) the concept stage of the design process (Table 2). These two stages, as defined in this study, make up the early phase of the design process and indicate that these two stages need greater focus, in comparison to the later phase (stages D and E) of the design process (Table 2).

4.2 Interview Results

4.2.1. Architects' perceptions of existing BPES tools

The interviews show the diverse nature and experience of the architects who participated in the process (Table 1). All subjects acknowledged the importance of design and decision support tools in the delivery of low impact housing design in the UK. Interviewee E specified SAP, Passive House Planning Package (PHPP) and Integrated Environmental Solutions (IES) tools'. Although, he does not believe the tool will necessarily deliver the design. However, in his opinion, '*These are the best at the moment'*.

To know architects perception about existing tools and the importance of using them during design phases, calculation, simulation, energy calculator, carbon embodiment, code compliance, and checking tools software were all confirmed by more than half of the interviewees as being necessary to the design and delivery of low impact buildings in the UK. Interviewee B stated, '*The tools, at various stages of the design process, should link with ventilation strategy, air tightness, energy calculator, carbon embodiment, code compliance and checking of results'*. Interviewee D further stated, '*Tools for decision support should be easily accessible and less complex'*.

Interviewee E specifically said, '*It will be good to have a tool that starts from when the client writes a brief to the management level, and it should include health and safety issues.'* Another interviewee stated, '*Architects understand U-Value Calculator, since it is the basic thing, it is therefore definite. However, carbon embodiment is useful but there is not enough data to produce reliable prediction'*. He further said, *'Code compliance and checking tools are okay, but it will be good if confidence can be tested against post occupancy evaluation.* Hence, a degree of prediction against reality of the design and confidence in the use of tools for decision support were added to the list of requirements for recommending tools that fit into the way architects work.

Nevertheless, Interviewee A categorically made this statement in response to his own general view on low impact design and delivery of housing in the UK. He stated, '*We are the clients' servants: we can only do what we are asked. Very few clients want to have low carbon homes. Those that do, (owner-occupiers, by and large, and how many 'self-builders' are there in the UK?) frequently stop wanting them as soon as the additional costs become apparent. Developers and I include many social housing providers here, unfortunately, only want to do an elegant sufficiency to comply with statutory requirements. How many 'tools' can you be using when the total fee for designing a dwelling is frequently only a couple or three hundred pounds?*

4.2.2. Characteristics of BPES tools that fit Architects Design-Decision Making

Interviewee H stated, '*It seems PHPP is more like the tool to achieve low carbon housing because it has recipe of how to attack the problems'*. To qualitatively evaluate decision support tools in the UK, calculation, simulation, energy calculator, carbon embodiment, code compliance, and checking tools software were all confirmed by more than half of the interviewees as being necessary to the design and delivery of low carbon housing in the UK.

However, in relation to BPES tools requirements of architects' friendly tools to deliver low impact housing design in the UK, the following were acknowledged from the interview analysis, for the early and detail stages of the design process.

- **Degree of approximation /accuracy as related to design stages**;

Early Design Stages:

- Minimal details are available;
- Approximation and flexibility are paramount;
- Accuracy is less important;
- Low input to avoid hampering creativity and design thinking;
- Quick output in a language understood by architects.

Detail Design Stages:

- Much details are available;
- Precision and specification are paramount;
- Higher level of Accuracy is required;
- Higher level of detail input required;
- To produce 'Realistic' or 'as built' output.

4.3. Discussion of Results

The questionnaire survey identified the gaps in the current use of Building Performance Energy Simulation tools by UK architects. It revealed that the small numbers of architects who use BPES tools do so at the later stage of the design process. The tools that are used at the later stage by most architects are even those recognised and advertised for the early design stages, because; they are less complex. Thus, the more complex the tools, the less they are used by the architects.

Findings from the interviews further confirmed that most of these tools are complex; requires calculation understandable only to experts, such as the engineers and thus, are not compatible with architects' way of decision making. Required characteristics of architects friendly tools from the interview findings include: Providing quick analysis that supports decision making at various design stages; very quick in time of output and the need for less detail input requirements at the early (preparation and conceptual) stage of the design process when the design is not yet advanced. Thus, the findings in this study are parallel to past research findings in section 2.1 (Tianzhen and. Jinqian (1997); Attia, (2010); Attia *et al*.(2009) and Attia (2010; 2012). Hence, from the interview results in this study, approximation is required for tools at the early design stage in comparison to the degree of accuracy and detailed input required for tools at the later stage of the design process.

5. Conclusions and Recommendations

5.1. Conclusions

This paper is a contribution to many on-going efforts to ameliorate the current situation in the use of BPES tools by architects. Existing BPES tools apply roughly the same theoretical algorithms and calculation aids, thus limiting representation of certain physical phenomena. Although some models can be used for element design, they are not fit enough for architects' way of design and decision making or for exploring design constraint. Elaborate building components require separate analysis through complex simulation aids. Few tools support the early architectural design process. Input quality affects accuracy, while output needs careful expert interpretation. Thus, the paper has led to some statistical (questionnaire) and practical (from interview) results to make recommendations for software developers towards developing architect-friendly tools that fit the intrinsic way of architects' decision making. The recommendations (Section 5.2) emerge from synthesis of the findings from various stages of the research methods adopted in the study. At the early design stage of the RIBA Outline plan of works, as minimal details are available, approximation and flexibility are paramount; accuracy is less important; low input of information to avoid hampering creativity and design thinking and quick output in a language understood by architects are required. At the detail design stage, as much details become available, precision and specifications are paramount; higher level of accuracy is required; higher level of detail input are required to produce 'realistic' or 'as built' output.

5.2. Recommendations

The paper proposes a number of recommendations for software developers, particularly those targeting architect -friendly tools for various stages of the design process. For future development of 'new generation' BPES tools, that fit into architectural ways of practice to achieve low impact building in the UK, this study lists the requirements recommended for each family of Building Performance Energy Simulation tools at the early and detail stages of the design process.

5.2.1. Early Phase of the Design Process

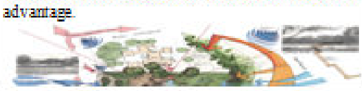
The most important decisions concerning building energy usage are carried out at the very beginning of the building design process. Appropriate building simulation tools should be used when making the design decisions, such as building lay-out alternatives and different basic building energy usage and services systems. Hence, tools for this stage, should allow the description and simulation of building in fewer minutes without extensive training on the part of architects. The results from such output should be in a form that can be understood even by non-experts and be able to give architects a quick and accurate output with minimum input. This is because, at this stage of the preliminary studies, the focus is mainly on the differences between different design alternatives, hence, calculations and all simulations should be performed quickly and effectively. Characteristics, such as degree in the flexibility, accuracy, data input, among others, should be taken into consideration when developing software tools for this stage. Hence, enough flexibility and low input information schema, amongst other requirements, are identified as being necessary in BPES tools for the early phase of the design process (Table 3).

5.2.2. Late Phase of the Design Process

When the building design process continues, simulation tools are needed again especially, for thermal function, and when selecting and sizing the systems and equipment for the building. At this phase, the input values should be much more accurate than in the previous design phase, and the results of the calculations should be rather accurate as the equipment and systems selections are based on these values. The user should be able to tailor the layout of the results according to the special needs of the project, such as energy and ventilation needs.

By the end of the building design process, the designer calculates target values for the building energy consumption, and calculations are based on the actual building data. Results should be accurate as the real energy consumption values are compared to simulation results at this very later stage of the design process. Hence, tools for this phase, from the interview analysis are categorised as detail simulation tools. At this stage, the design development stage 'D' and technical stage 'E' of the RIBA Outline plan of work, the architect had reached a point in the design process where all parameters considered in the previous stages must flow together or interact at higher level. These include: architecture; plans; the visual impact; functionality; aesthetics; the space design; working environment; principles of construction; energy solutions and targets, and indoor environment technology to form a synthesis of the design.

In general, data exchange at this stage needs to become more sophisticated, reliable and less error prone, so that practitioners can integrate these tools more smoothly into practice. Requirements of BPES tools targeted for this stage need to be more user-friendly, more capable, more robust, better documented, with minimal time for result output. The specific requirements include: *detailed and accurate input* (accurate results from detailed and accurate information input); *detailed results* (fast or give detailed results to meet detailed needs of the architects in accordance with high standard of design input); *a high level of detail* (produce high level and degree of details for the design); *photorealistic* to produce 'As built' output or close to reality as much as it can be; the output should be accurate and detailed representation of the output design, without attempt to conceal any feature whether attractive or not and *training* may or may not be required (Table 3)

Stages of design process		Some Design Decision Tasks		Characteristics of BPES Tools
Earlier Design Stages	A and B	Building orientation (appraisal); Topography (appraisal); Site usage (appraisal); Sun path (appraisal); Air change rate (appraisal); Building Shape; Insulation of building envelope; and glazing (optional)	A typical site analysis in the design process, the interplay of the building mass and natural features, such as trees, sun path, wind patterns, and the form of the land are important items to consider. It helps to ensure that the site is utilised to maximum advantage. 	Flexibility of BPES tools to accommodate rapid design changes, and to avoid hampering design creativity; **Low input to minimise disruption to design creativity;** Fast output in a language that designers understand primarily based on approximation; Interoperability to seamlessly integrate BPES tools with design tools; Interactive to enable designers to interrogate the design model performance; Intuitive and easy to use
	Stage C	Shape of building; Orientation (small adjustment); Insulation and mass; Attribution of building zone; Window size in different façade and orientation; Solar control requirements; Summer ventilation requirements; Glazing and Types (detailed analysis); Air change rate (detailed analysis);	During this early stage, designers rapidly explore and refine ideas by engaging in free-flowing, collaborative brainstorming sessions, during which a wide range of designs- in the form of sketches, 2D drawings and layouts, 3D models and renderings- are considered and evaluated until a final concept design is chosen 	
Later Design Stages	Stage D	Finalised material definition; Finalised building orientation; Finalised ventilation strategy; Finalised window properties (size, type, solar control); Lighting strategy, daylight utilisation, visual comfort and cooling		Higher level of detail and precision from detailed and accurate design information input; Detailed Output to meet detailed needs of the architects in accordance with high standard of design input; Realistic to produce 'as built' output, without attempt to conceal any feature; and Training, but not an intensive one for architects' use
	Stage E	Detailed technical analysis such as: Assessment of passive cooling system (Ground cooling); Assessment of passive heating systems (solar preheat of air); Ventilation studies; and Test and refinement of heating and cooling control strategies		

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