Of collaboration or condemnation?

Exploring the promise and pitfalls of architect-consultant collaborations for building performance simulation.

Abstract

This paper examines collaborative relationships between architects and energy consultants, for the uptake and use of building performance simulation (BPS). BPS is thought to hold massive potential for the AEC industry, by allowing professionals to quantify impacts of architectural design-decisions. However, a number of technical barriers are widely-cited in the literature preventing the uptake of these tools. Instead, many architects collaborate with consultants for BPS uptake. It is hereby proposed that alongside technical barriers, additional non-technical barriers may arise when architects and consultants collaborate as a consequence of worldview differences. To enable exploration of potential barriers, the context of BPS is observed from a social lens focusing on the human dimension of interaction. Qualitative methods from the social sciences are used to extract some barriers; and a quantitative follow-up is performed to ascertain whether extracted barriers are similarly perceived amongst a larger sample of architects and consultants. Barriers identified include: negotiating control over decision-making, differences in problem-solving approaches, cliental roles and regulatory frameworks, professional trust and communication. Identification of these barriers constitutes a starting point to advance BPS research, encouraging a deeper examination of the social contexts in which BPS is used.

Keywords: Non-technical barriers, collaboration, social science methods, building performance simulation.

1. Introduction

Many 'energy' studies that are tackled from a social perspective focus directly on the energy consumer; often examining energy-problems emerging in residential settings (for examples from this journal alone, see [1-5]). The social perspective examined in this contribution has not been explored in *Energy Research and Social Science* journal to date. In this contribution, we are concerned with the social perspective of energy professionals. We focus on the collaborations and interactions with architects, for the uptake of building performance simulation (BPS) software to aid in building design decision-making.

BPS software has the potential to inform building design decision-making, by predicting the impact of design decisions on energy performance. Complex mathematical models are constructed to represent transient energy flows within the building design, as well as internal interactions between each of these energy flows [6]. Predictions of building performance are inferred based on modelling outputs; produced corresponding to the accuracy of building representation, and the extent to which boundary conditions (e.g. weather conditions, schedules of building operation,

etc.) are simplified [7].

There are a wide variety of tools available on the market falling under the BPS umbrella. At the time of writing, over 120 BPS software packages are listed on Building Energy Software Tools (BEST) Directory [8] (previously listed at [9]), some covering both whole building simulation analysis and others pinpointing a selected performative domain (thermal, solar thermal, lighting or daylighting analyses, etc.). In addition, there are tools listed in the directory (e.g. [10-11]) that focus on residential building types whereas others can be used to model a wider scope of building uses (e.g. [12-13]).

Departing from the position that *"simulations should adapt to the design process not vice versa"* [14], there are several available commercial BPS packages and third-party interfaces optimized specifically for architects (e.g. [15-18]). A large body of academic research supports the development and improvement of simplified 'architect-friendly' tools [19], aspiring for a seamless integration of BPS tools within the architectural profession (e.g. [19-22]).

However, despite developments spanning over two decades attempting to achieve synergy between BPS and architectural fields, poor uptake of BPS to inform architectural decision-making is repetitively cited as a largely unresolved problem [19;23]. A number of technical barriers, mainly tool characteristics, are cited rendering BPS hostile for architectural use [24]. These include complexities in data-input [25] and difficulties interpreting alpha-numeric outputs [19]. Many packages lack a much-needed graphical user interface to communicate effectively with architects [26] who are visually-oriented professionals.

In addition, it is widely-cited that many practicing architects do not have adequate knowledge of building physics, which is not always covered in architectural curricula in support of BPS [23; 27-29]. This is often coupled with a poor desire to learn what has not traditionally fallen under the typical architectural remit [30].

When architects do use the tools, the potential of BPS is not necessarily always taken full advantage of, i.e. comparative procedures testing the 'what-ifs' of different design-scenarios to evaluate the impacts of design-decisions in various situations are rarely exploited. Besides that, in many architectural practices, BPS is side-lined as an after-thought conducted only once all design decisions have been fixated [31-33].

Improper use of available BPS tools, coupled with inaccuracies in assumed input data have been discredited as one of several underlying causes of the 'performance gap' [34-36] discrepancies between predicted performance based on simulation outputs and actual performance during occupancy. This raises the question of whether prodigious faith in tools aiming to reach the architectural market is warranted; particularly as architects rarely conduct BPS calculations themselves [27], and often

rely on collaborations with external consultants in the field of BPS[1] [27; 37]. Only few initiatives have focused on architect-consultant interactions, e.g. [27, 38-40] However most of these initiatives adopt a performance centric approach (e.g. [41]). They suggest collaboration should be based on clear definitions of performance indicators and propose models to deal with information exchange between the parts (designers, consultants and clients) based on a systemic thinking approach (decomposing the design problems into goals, functions, systems, etc.)."

This paper examines an alternate dimension of BPS research that incorporates the human perspective, to further understandings of architect-consultant interactions in collaboration; as outlined in section 2. Recognising how professionals and stakeholders cooperate within a design team may foster greater engagement in the design, management and procurement of building projects, toward a performance-based building design process [42]. Mixed-methods used are described in detail in section 3. Results are interpreted and discussed in section 4. Results and inferences are summarized and their pertinence noted in the concluding section of this paper. Relevance of the research at the global context, from both methodology and results' perspectives, are discussed. Avenues for future research in this area are conclusively proposed.

2. A new starting point for BPS research; the human perspective

Critical review of the literature reveals that BPS traditionally focuses on 'state-of-the-art' and technological innovations in the field, meaning that little or no human intervention is assumed. This severely *"downplay*[s] *the role of choice and the human dimensions of energy use,"* contributing to the problematic of the limited *"role of social science in energy research* [toward addressing] *contemporary energy-related strategies"* [43].

This work therefore responds to calls for a broader interdisciplinary nexus argued for in this journal [e.g. 43-46], by penetrating social science methods into an area that is almost always deliberated through only technical discourses. Profound scrutiny of the *"unvisited no-man's land between the disciplines"* [47], facilitated through the use of social science methods, is what is reputed to serve as a catalyst for research progression [43].

Focusing on inter-disciplinary architect-consultant collaboration priorities the discussion *"that building physicists and building designers* […] *subscribe to different worldviews and paradigms when undertaking their everyday activities"* [48]. This is likely the result of incommensurable educational backgrounds and training; responsible for shaping worldview [49]. Furthermore, members in the collaboration are likely to speak different professional languages; which may not be mutually-

[1] The term 'consultant' is used throughout the remainder of this paper to describe building practitioners who use BPS software throughout their day-to-day working process and, in the case of this research, collaborate with architects to assist them in design decision-making. These professionals may originate from a variety of different backgrounds e.g. mechanical engineering, building services engineering, building science, etc.

understood. Since application of BPS in projects is complicated by the notion that simulation processes and outputs *"will be heavily influenced by the philosophical judgments of the person making the judgment"* [7], worldview differences may result in misunderstandings, tension and perhaps conflict between collaborating members.

Taking these considerations into account, a more holistic approach is solicited to unpack the complexity of inter-disciplinary collaborations. The starting point for this paper is therefore the following question: Do non-technical barriers that arise during architect-consultant collaborations reduce the potential for BPS to inform decision-making? The aim of this paper is to explore and start gathering insights into what non-technical barriers might be preventing BPS tools to be more efficiently used in design decision-making from a designer-consultant (architect-consultant) interaction perspective; which have insofar been disregarded in existing literature. To this end, this paper is intended predominantly, for researchers, project managers and educators who are occupied with the matter of utilizing BPS to inform design decision-making.

3. Methodology; a mixed-methods approach

The aim of this work involves researching relationships between two distinct social groups. Absence of a theory on architect-consultant interactions meant that an inductive approach was needed as a starting point to gather insights. Exploratory studies such as this tend to rely on qualitative methods, focusing the study on small, non-representative samples to acquire deep understandings of the social world. However, the inability to generalize from these small samples is often seen as a limitation of qualitative research in the eyes of quantitative proponents.

A pragmatic mixed-methods approach consisting of sequential qualitative and quantitative stages was therefore devised to answer the research question. The purpose of mixing the methods in this research was three-fold:

- **To combine the merits of qualitative and quantitative research;** while simultaneously minimizing limitations associated with both traditions.
- **For triangulation and generating complementarity;** using multiple methods allowed us to 'cross-check' results arriving from different sources. Where divergent results were produced, differences were considered to provide an additional perspective to understand the insight in question.
- **To inform the subsequent research design;** Statements constructed in the questionnaire-design were worded based on statements voiced during the interviews.

3.1 Qualitative research stage

3.1.1. Data-collection and sampling

Semi-structured interviews with architects and consultants were used initially to extract potential non-technical barriers. Few initial open-ended questions were

designed to encourage discussion, as shown in the interview guide (Appendix A). As the interview progressed, further questions were improvised by the interviewer.

Both purposive and snowball sampling were used to recruit interviewees. The sample consisted of eight architects and eight consultants based in England and Wales (table 1). Architects interviewed were purposively sampled from the RIBA Directory of UK Chartered Practices [50]. The search was limited to architects employed in practices in England and Wales which explicitly mentioned using BPS on their practice website[2]. This ensured that recruited architects had experience collaborating with consultants. All architects recruited followed a traditional design approach and out-sourced their BPS calculations to external companies specializing in energy-consultancy. The eight consultants[3] interviewed were recruited using snowball sampling; their contact details were provided by architects who had been interviewed earlier.

Sampling and recruitment occurred through a cyclical process under the rationales of theoretical sampling and theoretical saturation [52-54]. Rather than seeking to construct a sample of a pre-determined size, sampling was performed with the aim of collecting enough data to generate theoretically-saturated thematic categories, irrespective of the number of interviewees [55]. Interview participants were deemed appropriate based on their abilities to contribute to the novelty and depth of insights collected. The sample that resulted from this process is comparable to sample sizes constructed in studies of a similar nature (e.g. [56]). Furthermore, it is maintained by [57] that sample size cannot be determined irrespective of interview duration; as longer interviews will result in generation of larger amounts of data than shorter ones. In this research, each interview conducted was up to 90 minutes in length; meaning that large amounts of data were provided, and a diverse range of was insights presented therein. Recruitment of participants into the study was deemed complete once the data has become 'saturated;' insights offered by new participants started to overlap and addition of more participants did not add any novel findings.

Saturation of the data concluded this qualitative research stage and prompted the start of the subsequent quantitative one. Greater attention was placed on construction of large samples representative of architects' and consultants' populations, for purposes of generalization. Moreover, conducting a quantitative follow-up (as narrated in

[2] Although practice websites were used to recruit participants into the study, opinions mentioned by these participants were not taken to represent the views of the practice at which they were employed. Rather they were recognized to represent the view of the participants themselves.

[3] While associations such as the Royal Institute of British Architects (RIBA) and the Architects Registration Board (ARB) in the UK have firm criteria of who an architect is based on *"education, experience and practice"* [51], one of the limitations experienced during both this qualitative stage and the subsequent quantitative stage was an inability to find a parallel set of criteria determining the educational path and/or professional experiences needed to define who may practice as a BPS consultant. Participants recruited as BPS consultants in both research stages originated from various professional backgrounds including mechanical engineering, building physics and building services engineering, and may be performing BPS consulting services ***alongside*** their original professions. Particularly during the interview stage, rather than commenting exclusively on BPS consulting services, some of the insights voiced referred to the services provided as part of consultants' original professions, and collaboration with architects within these contexts as well. Rather than omitting these insights from the data collected, comments related to consultants' original professions were considered equally as valuable as descriptions referring exclusively to BPS consulting. Both sets of descriptions contribute toward these professionals' collective construction of experience in putting together workable building solutions, and collaborating with architects in the process.

section 3.2) was considered a way of overcoming limitations of small sample size. Combining qualitative and quantitative methods in this instance responds research questions pertaining to methodological limitations in [43]. The methodological approach followed here represents one way to gather 'in-depth' insights from a small sample size, while widening the breadth of the research findings by reaching a larger sample size, in the quantitative stage.

Table 1: Documenting details of architects and consultants recruited to participate in the interviews.

NAME[4]	PROFESSION	GENDER[5]	BASED IN	APPROX. YEARS OF EXPERIENCE
A1	Architect	Male	Wales	30+
A2	Architect	Male	England	15-20
A3	Architect	Male	England	25-30
A4	Architect	Male	England	15-20
A5	Architect	Male	Wales	10-15
A6	Architect	Male	England	15-20
A7	Architect	Male	England	5-10
A8	Architect	Male	England	5-10
C1	Consultant	Male	Wales	5-10
C2	Consultant	Male	England	5-10
C3	Consultant	Male	Wales	10-15
C4	Consultant	Male	England	10-15
C5	Consultant	Male	England	10-15
C6	Consultant	Male	Wales	15-20
C7	Consultant	Male	England	10-15
C8	Consultant	Male	England	5-10

3.1.2 Analytical procedure

Interview transcripts were analysed using qualitative thematic content analysis. This is a *"data-reduction and sense-making effort that takes a volume of qualitative material and attempts to identify core consistencies and meanings"* [58].

Qualitative analysis procedures are seldom prescriptive in nature; *"the processes through which the themes are extracted are often (if not invariably) left implicit"* [59]. Qualitative traditionalists contend that a procedural step-by-step guide to the analysis is undesirable [60]. The thematic content analysis procedure employed was therefore guided by the aim of extrapolating underlying themes that could be interpreted as non-technical barriers.

[4] Pseudonyms are used here to safeguard data confidentiality and anonymity.
[5] Male dominance of the sample was not intended. However, only male participants responded to the emails requesting participation, and were willing to be recruited into this qualitative study.

The first step was open-coding the interview transcripts to identify 'meaning units;' a *"constellation of words or statements that relate to the same central meaning,"* [61] and capture a possible non-technical barrier. Abstract labels were assigned to each meaning units. Open codes sharing a common, identifiable thread were subsequently arranged into categories; to cluster and condense the open-codes into more manageable units. Each category was also attached with a label that best described the open codes contained within. The final step in the analysis was the hierarchical structuring and arrangement of categories into themes. The analysis was deemed complete once all relevant interview excerpts had been coded, all codes had been assigned to an appropriate category and all categories fit into the hierarchical structure.

The afore-described procedure resulted in the extraction of 3 categories and 3 sub-categories:

- The new context of design teams
- Differences in approach to problem-solving.
- Practice-related barriers in collaboration.
    - The role of the client
    - Deployment of the regulatory framework (Approved Document Part L; Conservation of Fuel and Power in Buildings)[6].
    - Professional trust
    - Communication.

Practice-related barriers extracted in the third main category were re-tested in the questionnaires, as all these arise during the interaction between architects and consultants. It was considered irrelevant to quantitatively re-test and triangulate findings under 'the new context of design teams' category and 'differences in approach to problem-solving,'. These are considered background to the practice-related barriers and have been addressed in previous literature.

3.2 Quantitative research stage

Self-completion questionnaires were used to confirm the existence of practice-related barriers, to the wider England and Wales context. Questions were designed based on interview quotes from the preceding stage. Statements voiced by interviewees were developed into 5-point Likert-scale questions.

Two questionnaires were designed. Questionnaire 1 was designed to re-test barriers mentioned by architects interviewed and to ascertain whether these were recognized amongst the wider population of architects. Similarly, questionnaire 2 was based on barriers voiced by consultants. Barriers voiced by both architects and consultants were included in both questionnaires.

[6] Approved Document Part L; Conservation of Fuel and Power addresses energy-efficiency standards that need to be met to comply with building regulations in the UK [62]. This document is referred to as 'Part L' throughout the remainder of this manuscript.

3.2.1. Sampling and distribution

To construct samples of architects and consultants, it was first necessary to determine architects' and consultants' population sizes in England and Wales. The RIBA Chartered Members Directory [63] was assumed to be a comprehensive compilation of UK architects. The Register of Low Carbon Consultants, (CIBSE) was considered the closest possible listing of consultants in the UK [64]. Equal probability systematic sampling was used to generate the two samples, calculated using equation 1 with the correction factor for finite populations (equation 2) [65]. Based on these calculations, the sample of architects was 329 (nA = 329) for a confidence level of 95%, and the consultants' sample was 280 (nC = 280).

$$\boldsymbol{Sample\ size} = \frac{\boldsymbol{Z^2 \times p \times (1-p)}}{\boldsymbol{m^2}}$$

Such that:

Z = the confidence level. 95% confidence level means Z = 1.96.

p = worst case percentage, expressed as a decimal. Conservative value = 0.5.

m = margin of error, expressed as a decimal. 95% confidence level means m = .05.

Equation 1. Used to calculate the sample sizes of architects and consultants from their respective populations.

$$\boldsymbol{New\ sample\ size} = \frac{\boldsymbol{sample\ size}}{\left[\frac{(\boldsymbol{sample\ size - 1})}{\boldsymbol{population}}\right] + \boldsymbol{1}}$$

Equation 2. Correction factor for finite populations.

Both questionnaires were launched online using SurveyMonkey (www.surveymonkey.com) on the same day; and both were available for 166 days[7]. Emails were sent to sampled architects and consultants requesting their participation, including a link to the questionnaire. This procedure yielded a total of 323 complete responses that were deemed suitable for analysis; 175 from architects and 148 from

[7] One of the known limitations of online questionnaires is low-response rate [67]. The threat of low response rate was heightened in the case of this research as both samples consisted of busy professionals with heavy workloads and responsibilities. To overcome this, reminder emails were sent out to sampled participants. Another measure taken was to refrain from collecting personal information from the respondents; including name, age or years of experience, as recommended in [68]. While refraining from collecting personal information was initially considered an opportune trade-off to increase participation, it was later recognized that this meant that basic sample demographics were unavailable. This further meant that basic sample characteristics were unknown, and the sample could not be described as representative of wider populations of architects and consultants across England and Wales. This further meant that generalizations could not be made beyond the sample being tested. The analysis was also limited considerably as a consequence. Comparisons could only be conducted based on profession; whereas collecting knowledge of sample demographics may have allowed further trends to be uncovered, based on years of experience or gender, for example. This has been recognized as a limitation of the research.

consultants. This equates to a response rate of 53.2% from architects and 52.8% from consultants, which fall within the same range of response rates quoted in previous questionnaire-based studies in the same field (e.g. [66]).

3.2.2 Questionnaire data analysis

Likert-scale data was treated as interval data; assuming that distances between each point on the Likert-scale are equidistant and could be measured. A compound variable was generated for each of the four practice-related barriers addressed in the questionnaires. These compound variables were entitled:

- 'Clients encourage BPS uptake in architectural decision-making through early collaborations with consultants'
- 'Positive attitudes toward Part L'
- 'Positive trust dynamics between architects and consultants' and
- 'Consultants feel their communication with architects is effective.'

To create the compound variables, each of the original set of variables addressing each of the above factors were first coded on an interval scale, such that 'SA = 1, A = 2, etc.' Each of the coded variables were summed and divided by five to generate a new score for each respondent to the compound variable. By generating compound variables, the sample's central tendency, and average extents of agreement or disagreement to each of the investigated barriers could be determined. All arithmetic operations could then be performed on this data, including measurements of central tendency. Generating composite scores also meant that further inferential statistical analyses, such as independent samples t-tests, could be performed for purposes of comparison, and correlation analyses to examine the inter-relationships between variables[8]. Inferential statistical analyses were performed using IBM SPSS.

4. Results and Discussion

Three main thematic categories, and four sub-categories were extracted using the qualitative thematic content analysis described;

- The new context of design teams *(section 4.1).*
- Differences in approach to problem-solving and praxis *(section 4.2).*
- Practice-related barriers in collaboration *(section 4.3).*
    - The role of the client *(section 4.3.1).*
    - The deployment of the regulatory framework *(section 4.3.2).*
    - Professional trust *(section 4.3.3).*
    - Communication *(section 4.3.4).*

These three main categories are all further discussed qualitatively throughout this

[8] A more detailed analysis of questionnaire results, including inferential statistics examining inter-relationships, including an exploratory factor analysis and deeper inferential statistics are reserved for a future publication.

results and discussion section. It is important to note that thematic categories and sub-categories extracted from architects and consultants are **not** presented in isolation; as two opposing 'sides.' Rather, insights from members of both professions often overlapped; architects and consultants provided two different sides of a story. The reader will find that the discussion of qualitative insights are interwoven with original interview quotes from **both** sets of professionals, together with frequent references to relevant literature to satisfy either one or both the following objectives;

- To support a category or highlight contrasts between a category and opposing literature findings.
- Theories from fields such as sociology and educational psychology are used as reference to substantiate certain categories, and to explain how these could hinder BPS integration.

Questionnaire results related to the third main thematic category 'practice-related barriers in collaboration,' are also shown. Under these sections (4.3.1-4.3.4) data from the original Likert-scale variables addressing each practice-related barrier are presented from architects and/or consultants. Results of the statistical analyses, along with qualitative insights are used to arrive at inferences made throughout this section to predict the potential impacts of each barrier, and how it may reduce the potential for BPS to inform design decision-making.

4.1 The new context of design teams

In the late 1990s and early 2000s, a number of international directives encouraging energy conscious-design placed considerable restraints on previously unrestricted energy use, such as the Energy Performance Buildings Directive in Europe [69-70]. Rather than using BPS to design mechanical systems, it was instead proposed that BPS could be used to design spaces and internal components therein, and to therefore reduce energy consumption from the onset. Architects were further encouraged to envisage BPS outputs not only as indicators of energy consumption, but as quantitative measures of design quality.

However, interviewed architects who were trained prior to this era, believed that architecture concepts or kernel was *"the holy grail that was dangled out there as something to aspire to"* as voiced by A2. The notion of using numerical indicators of performance to inform design conception and development was *"so different from what they had been used to."* Insofar, these architects had envisioned such technologies to serve a secondary role; subjugated as a necessity to make the design-idea 'work.' Thus, using BPS technologies to inform decision-making was, and still is often met with reactions of, *"well, that's not architecture, is it?"* as observed by consultant C3.

The increasing requirement of BPS uptake in architectural design has since had an effect on the composition of many design teams. A3 observes that architects who *"didn't do that much at university in respect of sustainability"* are often unable to

fully embrace concepts of building physics and apply them to their designs. Correspondingly, consultants are nowadays brought onto design teams for assistance. However collaboration with consultants is not a straight-forward game of splitting tasks. Energy consumption is intimately associated with architectural decisions such as building form, orientation, envelope and internal spatial layout. Varying yet inter-related and concurrent demands of different performance fields such as solar, lighting and thermal increase the complexity of environmental control, having strong implications on consumption and performance results. Consultants' expertise and their abilities to use BPS software gives them the opportunity – and sometimes the authority – to interfere with what used to be exclusively architectural decisions, meaning that boundaries of architects' and consultants' roles and responsibilities sometimes overlap, as suggested in the following quote:

> C2: *"I use DSM* [dynamic simulation modelling] *software; so I sometimes recommend the reflectance of surfaces. So the modeller is basically suggesting to the architect what type of colour to choose.* ***Previously the architect was deciding!"***

Based on the interview data, we may infer that the architect of today no longer holds the same level of control over design decision-making. Knowledge and technological prowess are progressively shifting decision-making to consultants. This aligns with the finding in [71] where the authors describe architects' previous leadership position as *"slightly eroded."*

This erosion might mean control over design decision-making, originally residing in the hands of the architect, needs now to be negotiated. This may give way to difficult collaborative relationships if professionals compete for control over the design decision-making process, which is visible in the following interview quotes;

> C1: *"Sometimes the modeller is just* ***a slave*** *doing stupid work.* I *feel my work is just* ***required,*** *but not necessary for* [architects]."

> C3: *"The architects like to think that they're the ones that create the buildings, but they're only there to cover over our services. We design our services and the architects are just there to put a rainproof cover over it."*

The issue of negotiating control over design decision-making opens a debate at the level of project management and potentially liability. Who should have the final word in decision-making? Is it the architect, who has traditionally been responsible for building design; yet whose judgment is often idealistically based on abstract concepts, intuition and rules of thumb? Or is it the consultant, who is empowered with an ability to objectively quantify the impact of each decision?

4.2 Different approaches to problem –solving and praxis

It was insinuated that architects tend to view project constraints and design creativity as two conflicting yet inherent features of design decision-making. Interviewed

architects further argued that increasing constraints on a project may pervade over the designer's creativity; curtailing the likelihood of creative design solutions transpiring. This perceived ideological conflict is visible in the following exemplar quotes:

> A5: *"I think* **[technical observations]** *probably hinder* **[creativity]** *a bit...you probably wouldn't want to stretch the boundaries of your imagination and make something bigger."*
>
> A7: *"You always get the odd individual who hasn't ever been on site very much ...* ***they're not constrained by getting bogged down on all the technical thoughts."***

Interviewed architects further suggested two alternatives by which constraints are traditionally addressed in design decision-making; either by challenging them (A2), or working within their boundaries (A6);

> A2: *"Architects are trained to challenge constraints because that's what allows them to be creative. They will challenge ten constraints on a project, nine of them will remain and need to be exactly how they need to be, but there may be one that actually isn't that important after all, and suddenly it opens up a whole new opportunity and that's what your design hangs on."*
>
> A6; *"To a certain degree having some constraints helps, because* ***they can give you something to work to; a starting point, which can be helpful."***

Conversely, the interviewed architects contended that consultants demonstrate a preference against challenging constraint boundaries; Similarly, Participant C7 stated that the consultant's responsibility as a member of the design team is to be *"there on the outset to constrain the parameters of design."* Furthermore, C5 explicitly stated a need for further constraints to be enforced. This is visible in the following quote;

> C5; *"Building orientation and shape should be determined by building regulations as well. Once there is a guideline, it directs everybody. But if there are no guidelines, then I have the freedom to do whatever I want to do.* ***If there's a guideline, it makes sure I don't deviate from that guideline. They have the freedom, but the guidelines would not make them deviate so much."***

It can be inferred from the interview data, that both professionals view and deal with constraints in different ways. Architects will try to challenge them toward achieving creative outcomes whereas consultants will try to enforce them to guarantee specific types of performance results. This means that one of the reasons potentially inhibiting architects' reliance on BPS for design decision-making could be their perception that use of the tools and meeting benchmark values for performance provides additional constraints, curtailing their design freedoms. This is particularly pertinent during early design stages, where BPS calculations have most impact on building performance as incongruously, these are also the stages at which multiple design options are most freely explored and where the most creative solutions are conceived.

4.3 Practice-related barriers in collaboration

This third and final theme is concerned with practice-related barriers emerging when architects and consultants interact. It is possible that disagreements arise as a consequence of changes in the landscape of design teams (section 4.1), coupled with differences in approaches to problem-solving and praxis (section 4.2), are partially liable for some of the arising barriers; such as negative trust dynamics. However, some of the forthcoming presented barriers are largely practice based; concerned with cliental and financial requirements and how BPS is used solely to satisfy regulatory requirements. The impacts of such practice-based barriers have seldom been investigated in previous BPS literature.

4.3.1 The role of the client

It is proclaimed in the literature that BPS is most advantageous when used during the earliest stages of the design process [19]. However, architects interviewed felt that project clients tend to discourage early-stage collaborations with consultants. Being the financial driver behind a project, the client is regarded at the top of the social hierarchy as testified in the following quote;

A4: *"We're all appointed by clients. You could probably view those as your employer rather than your client. You're very reliant on the client, unfortunately, in a lot of ways. The client drives so much"* of how the project is procured and delivered.

A2 remarked that, *"it is rare that we get the opportunity to work with a simulationist before we make a planning application,"* i.e. Stage D of the RIBA Work Stages [72] [9]. This is because for the client, early collaborations mean that *"the client has to pay suddenly for two consultants right at the beginning rather than one that's managing"* the project. Architect A2 indicated that cost tends to factor higher on the client's list of priorities than the design's energy-efficiency; that *"trying to convince a client to think sustainably…some* [clients] *are* [even] *quite resistant to it, as it's perceived as having a cost implication."* Participant A5 indicated that one of the reasons for such resistance is a lack of knowledge; *"there's a certain amount of education about sustainability that needs to happen with clients."*

The idea that clients may hinder uptake of BPS in design decision-making has not been widely explored in previous research. However, in the survey conducted in [73], lack of cliental demand was identified as a barrier.

4.3.1.1 The role of the client; quantitative follow-up

As the role of the client influencing BPS integration was discussed by interviewed architects, five Likert-scale questions addressing the role of the client were incorporated in the questionnaire distributed to architects. Results are shown in figure 1. Variables were combined to generate a compound variable entitled **'Clients**

[9] RIBA work stages from 2008 are cited here rather than the 2013 version as this was the reference interviewees were referring to.

encourage BPS uptake in architectural decision-making through early collaborations with consultants' (M = 3.636, SD = 0.660). The mean of the composite variable falls between the third point on the Likert-scale denoting neutrality, and the fourth point denoting disagreement.

It can therefore be concluded that architects in this sample feel that clients tend to discourage early collaborations with consultants with consultants, reducing the potential for BPS to inform design decision-making. Architects in this sample agree with the opinion voiced by architects interviewed in the preceding research stage. From the interviews and quantitative survey results, it is possible to say that clients' reluctance to employ consultants in the early design stages is likely to have an impact on collaborative efforts.

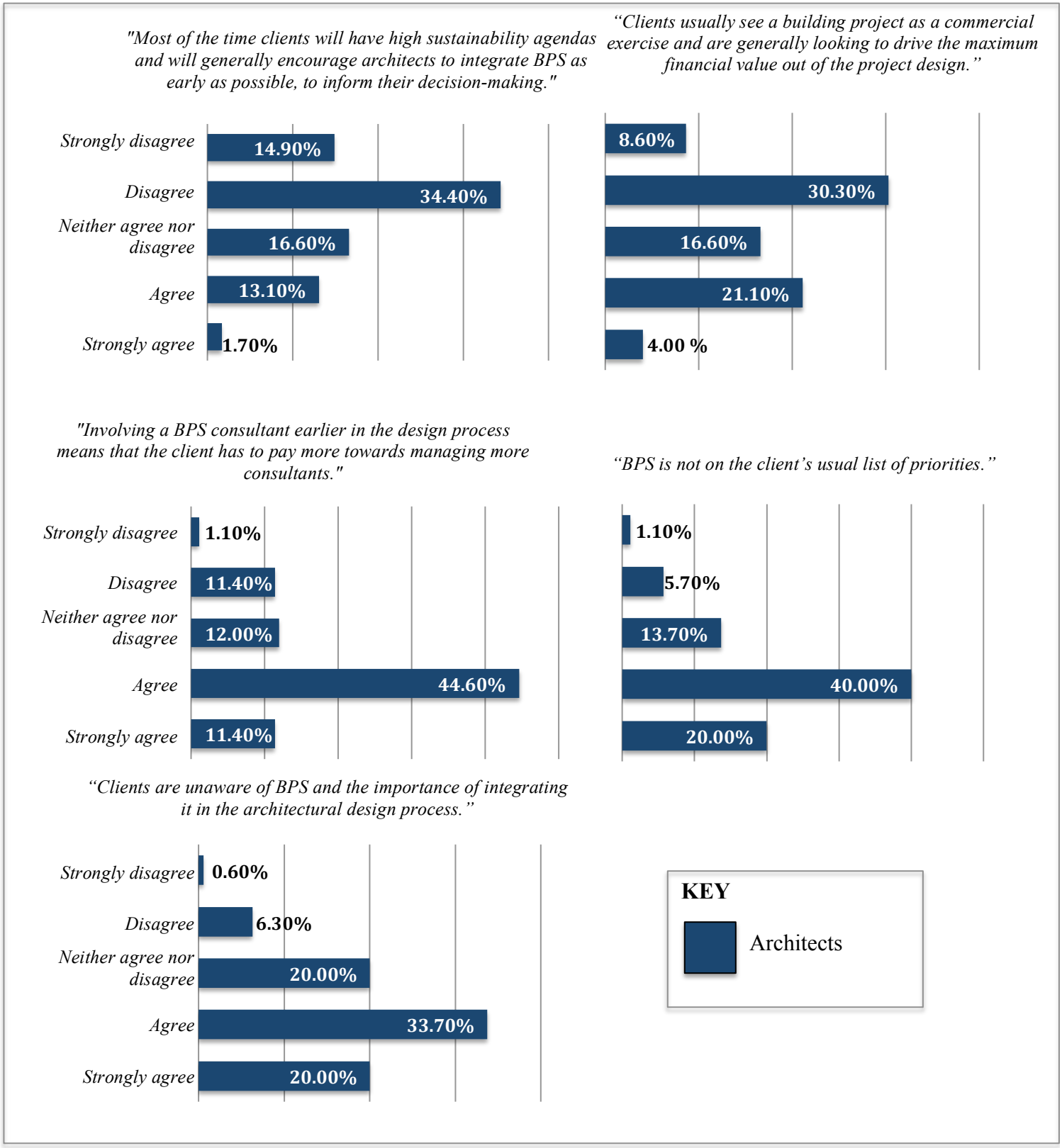

Figure 1: Likert-scale variables investigating whether clients encourage or discourage early collaborations between architects and consultants; for BPS to inform design decision-making.

4.3.2 The deployment of the regulatory framework

Interviewed architects explicitly demonstrated negative attitudes toward Approved Document Part L of the building regulations (Conservation of Fuel and Power). This is evident in expressions like, *"I'm 80% negative about Part L, but I'm sure every architect has the same opinion,"* and *"I'm not sure building regulations are as good as they are written."* Architects' attitudes toward building regulations have been widely explored in [74-75]. Regulations are explored within the scope of energy-efficiency are also addressed in [71]. It is recognized in these publications that architects consider regulations as bureaucratic restrictions, which are seldom regarded in a positive light.

It further became evident during the interviews that several architects were not aware that software used to grant compliance with Part L of the building regulations in England and Wales (compliance software)[10] is not necessarily the only type of software to simulate building behavior to inform design decision making. Amongst the majority of architects interviewed, initial introduction of the concept of BPS would invariably spark a thread of conversation about compliance-modelling and fulfillment of Part L criteria.

Architects' restricted apprehension of the purposes of available software was confirmed by the consultants interviewed; as is apparent in the following extracted quotes;

> C2: *"Still it's very difficult to explain to the architect what the difference is between SBEM"* and modelling for 'design' purposes.
>
> C3: *"I don't think an architect realises that you don't even model a building in SBEM."*

These quotations may substantiate the notion that many architects may be unaware that BPS exists outside a regulatory framework, meaning that calculations are often only conducted to demonstrate compliance. This finding has been previously noted in [76]. As a consequence, BPS calculations might need to be undertaken twice: to aid/inform design decision-making and to comply with building regulations[11]. This is discussed in the following quotes;

C4: "*On occasions we've used compliance software to demonstrate compliance; and*

[10] In concurrence with the Directive on Energy Performance of Buildings driver [69], a number of predictive tools were introduced in the UK to apply the National Calculation Methodology (NCM) and verify non-domestic building compliance with criteria specified in Approved Document Part L (Conservation of Fuel and Power). The tool originally developed for NCM execution is the Simple Building Energy Model (SBEM), which is a quasi-state default calculation tool. A non-graphical user interface is incorporated for data-input. However, in steady-state calculators, building parameters are fixed and variables are averaged out over long periods of time [76]. Complex interactions and heat transfer phenomena occurring over short-time steps are not accounted for. Thus emerges an argument that tools relying on steady-state calculations cannot be considered 'design-assistive,' for their inherent inability to capture the intricate, dynamic *"myriad of physical interactions"* [6] and heat exchanges occurring constantly over time [6. 76]. They are instead restricted to a category of 'compliance' tools.

[11] The only circumstance in which this repetition can be avoided is in the case that the consultant is fully licensed to use certain 'design'-tools, such as Integrated Environmental Solutions (IES) software or Thermal Analysis Simulation (TAS) software [76] for compliance purposes.

then [we] *remodel*[ed] *the building with IES to show the client some of their specific needs."*

C5: *"We just had to 'bite the bullet' and not make that much money on it. And hence we had to model it twice.*

C1: *"It's completely stupid to analyse something several times;* [spending] *hours modelling something to make sure it works perfectly. And then you have to make sure it complies. 'Yes, but I just did it! Same steps! Same things! Why am I doing it again but in a really easier way?' You do it first in a really complicated way but it doesn't show the compliance. And then you have to do it again easily using a software that is not as accurate as you used before, but it tells you 'yes, you are complying with the regulation.'"*

Building regulations are highly influential in the undertaking and procurement of building design projects [42]. As clients are the financial drivers behind building projects, it becomes imperative that they can distinguish between minimum standards promised through compliance [42], and what can be achieved beyond minimum standards, recognizing how BPS can help to achieve this. But based on the following insights voiced by C3, this distinction is not clear to clients.

C3 recounts an example where the consultants *"suggested we model the building* [using a dynamic simulation tool] *to find out if one* [strategy] *is more appropriate than the other* […] *in terms of CO_2 reduction."* This comparison was not possible using SBEM. However, the client's response was, "*no we just want to get the cheapest way possible please; just modeling for legislative reasons. And just leave it at that, nothing else."* In this case, modelling to achieve compliance is *"a tick in the box,"* that does not *"influence the design in any way. It just provides benchmark requirements."*

It was further suggested in consultants' interviews that reliance on compliance software, with little recourse to design tools, might be reducing design quality rather than enhancing it:

C3: *"We had an extension to a large warehouse, one zone, one large room; no heating demand and no domestic hot water demand. It was being used by a pharmaceutical company as a buffer zone* [for] *flu vaccinations to be stored in bulk for times when it was needed. So there was no minimum or maximum temperatures that machines could be stored at. I think the building itself, unheated, was in the comfort zone, and the occupancy was going to be very low. However, with* [SBEM] *you can't pick and choose these types of things. So automatically there's a demand for hot water allocated when there wasn't going to be. And there had to be a demand for heating. But the suggested energy consumption of this new building was ten, twenty, thirty times what its' actual consumption was going to be, which swathes the client's decision-making possible to become compliant. Now I'd suggest that, because the building was going to remain unheated, the fabric was maybe not as important*

than maybe looking at something that would happen when the building was used because lighting would go on. However, because the way [SBEM] *was working, the software was improving fabric first, and a lot of budget was being spent improving the fabric, by which point when it came to spending money on a good lighting strategy, it wasn't there. So they went for a fairly standard approach for that, and I thought it was kind of working counter-productively."*

C3 concluded his account by stating *"that's what happens regularly with compliance software,"* because with *"the other type of modelling* [dynamic simulation; design tools] *we have more of a license to look at different things and change parameters. Whereas with compliance software, we don't."*

4.3.2.1 Regulatory framework; quantitative follow-up

Five Likert-scale variables elucidating attitudes toward Part L were included in both architects' and consultants' questionnaires. A new compound variable was computed combining the five original Likert-scale variables originally addressing attitudes toward Part L. This was entitled 'positive attitudes toward Part L.' An independent samples t-test was conducted on this composite variable to determine whether architects' attitudes toward Part L differed from those of consultants. No significant difference was found in the means of the two groups; $t(271) = -.860$, $p = .391$, M(architects) = 3.094, SD (architects) = 0.534, M(consultants) = 3.037, SD (consultants) = 0.558. The means of the two groups are located close to the third point on the Likert-scale, indicating that, on average members of both groups have neutral attitudes toward Part L of the building regulations.

In this case therefore, quantitative results do not wholly agree with insights derived qualitatively, as opinions of Part L described by architects interviewed were negative, whereas on average architects' responses to the questionnaire demonstrated neutral attitudes. In addition, statistical analyses indicated that consultants' attitudes are similar to architects' attitudes. It is likely that architects' attitudes toward Part L may be associated with misperceptions about differences in purpose and potential of available design and compliance tools. Conversely, the neutrality in consultants' results may be related to the recognition that having separate platforms for different purposes causes repetition of modelling services sometimes at no extra cost. The irony that design quality may sometimes be compromised for the sake of ensuring compliance may also contribute toward the construction of consultants' neutral attitudes toward Part L of the building regulations.

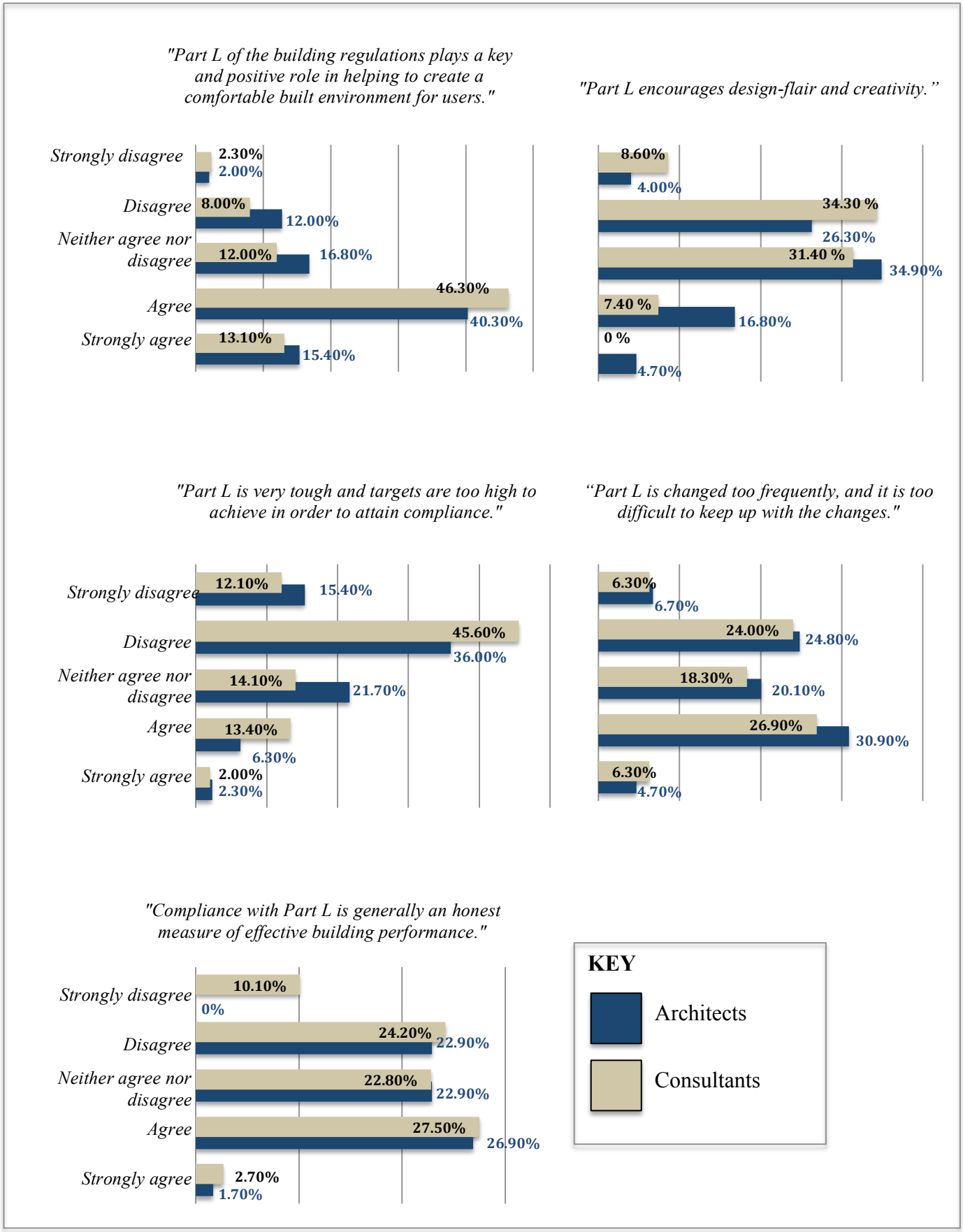

Figure 2: Likert-scale variables investigating architects' and consultants' attitudes toward Part L of the building regulations.

4.3.3 Professional trust

Discussion of negative trust dynamics between architects and consultants emerged during the interviews. Interpersonal trust is a *"psychological state comprising the intention to accept vulnerability, based upon positive expectations of the intentions or the behaviour of the other"* [77]. Having trustworthy intentions in collaboration entails assuming that other project team-members are trustworthy, and withholding from the expectation that they may engage in opportunistic actions [78].

Dimensions of poor interpersonal trust occurring in the interview data align with the three dimensions of trust described in Hartman's trust model [79]; competence trust, integrity trust and intuitive trust. These are defined in table 2.

Table 2: Definitions of each dimension of trust according to Hartman's trust model [79].

Integrity trust	The trustor's belief in the morality of the other party (the trustee); and that the trustee will inherently look after the trustor's interests.
Competence trust	The trustor's belief that the trustee is capable to carry out allocated tasks.
Intuitive trust	An instinctive 'gut feeling' that the trustee's intentions and actions are trustworthy.

Both architects and consultants interviewed signalled poor trust in members of the other party. Interviewed consultants openly questioned architects' **integrity** in conducting BPS tasks themselves; based on motivations to demonstrate their building design is compliant with Part L of the building regulations. This is evident in the following dialogue;

> Interviewer: *"If an architect was to use a modelling software, would you trust the work that they do?"*
>
> C3: *"Possibly not. A very sceptical side of me would be saying,* 'someone else will have done this calculation to demonstrate compliance, and gone for the easiest option and maybe manipulated some software to demonstrate compliance.' *So I'd be very sceptical of someone else's work in that respect."*

Participants C6 and C7 also expressed poor trust in architects' **competence** to conduct BPS tasks; as is evident in the following quotes;

> C6: *"I don't think an engineer would trust results from an architect" because I have to believe in the technical competence of the person who's modeling. The*

person has to carry the same credentials and experience [as I do]*."*

C7: *"If* [an architect] *comes to me to say,* 'we've oriented the building better because of some modelling we'd done...' *I'd find that very interesting and I'd be thinking,* 'wow, this is good! Someone wanted to engage about this!' *But my next question would be,* 'what package did you use?' *And if they say* 'Ecotect,' *there'll be bells going off the back of my head going* 'Oh my God! *I've got to now explain why this isn't the best result.'*

The aforementioned forms of trust were further confounded with an element of what is labelled in [80] as poor **intuitive** trust in architects; in other words an instinctive 'gut feeling' that architects' work and actions are untrustworthy, based on prior experiences, judgments or biases. This is visible in C5's remark that architects *"perhaps got another level to prove* [simply because] *the work is coming from an architect."*

Besides that, consultants interviewed frequently reported experiencing difficulties in receiving correct and accurate input data from architects. C3 felt that *"many architects* [fail to realize] *the importance of getting accurate information, or why you even need to provide it at all."* He also pronounced *"the most difficult thing to get from the architect is the u-value calculation."* He recognizes that *"maybe* [u-values have] *nothing to do with building simulation, but it doesn't help if you're not given the right information to start with, or the information you're given isn't correct."* Incorrect or inaccurate input data *"puts another complication in what we're trying to create."* Furthermore, omitting information might breed poor trust dynamics in collaborative efforts.

Architects interviewed were less overt in their discussion of trust in consultants. However, references to poor trust in consultants' professional integrity can be inferred from the following quotes;

A1: ***"If***[12] *the services engineer does his job."*

A3: *"I expect* [the services engineer] *to work with me. But there's got to be a trust there.* ***I've got to have an expectation that he will do his best."***

Another issue of trust also appeared in relation to information-sharing among professionals.

C2: *"I have seen in the industry, some of the architects...some of the consultants, they don't want to share* [information] *with you....they want to keep* [it] *to themselves...because they think* [if] *they have got the knowledge, they are superior to you."*

Similarly, participant C4 admitted to favouring financial goals over the overarching

[12] Note that the word 'if' in this quote can imply this professional might not be doing their job.

goals of the collaboration;

C4: *"I don't think an architect realises you don't even model a building in SBEM...so I never tell them because the process would reduce our fee slightly."*"

4.3.3.1 Professional trust; quantitative follow-up

To ascertain whether architects and consultants in the sample of questionnaire respondents feel that they trust each other, a compound 'trust' variable entitled 'positive trust dynamics between architects and consultants' was computed by combining the five Likert-scale variables shown in figure 3.

An independent samples t-test was performed on this compound variable to compare architects' and consultants' levels of trust toward each other. A non-significant difference was found in the means of the two groups $t(271) = .157$, $p = .876$, M(architects) = 2.79, SD(architects) = .51, M(consultants) = 2.85, SD (0.58). The means for both groups indicate that on average, members of both groups have similar levels of trust toward each other; both are positive but skewed slightly toward the third point on the Likert-scale denoting neutrality.

The questionnaire result therefore does not confirm qualitatively derived insights that trust dynamics between architects and consultants may be poor. While architects and consultants demonstrate similar levels of trust, the skewedness of the quantitative result toward neutrality may be inferred as possible indications of the following:

- That respondents may have not questioned the concept of professional trust in much detail before; indicating uncertainty in response.
- That there may be additional unexplored territory in the domain of BPS research leading toward the construction of trust that need to be addressed further.

In any case, positive trust dynamics are crucial to a harmonious and fluid collaboration between architects and consultants. No matter how advanced BPS technologies being used are, neutral or negative trust may contribute toward a breakdown in the collaborative effort, and consequently the integration of BPS within design decision-making. Therefore, while the concept of trust may appear distantly-related to BPS, the effects remain hugely pertinent.

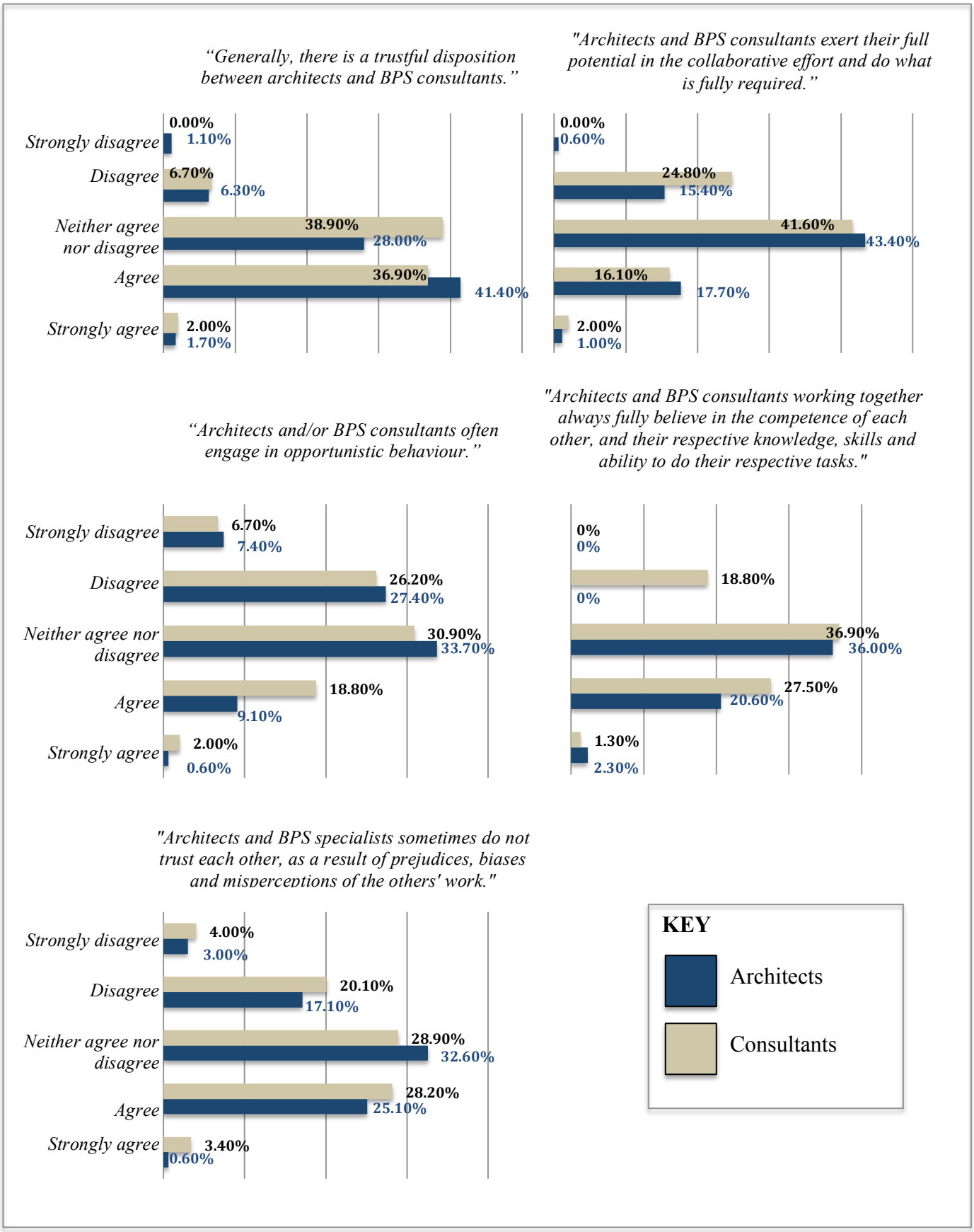

Figure 3: Likert-scale variables investigating whether architects and consultants trust each other.

4.3.4 Poor communication

There is a link between positive trust dynamics and effective interpersonal communication in professional relationships [80]. Frequent, open and effective interpersonal communication is recognized in the literature as an antecedent of trust, and is found to breed positive trust dynamics [80-81]. Conversely, negative trust may indicate that communication is inefficient.

Consultants interviewed further conveyed impressions that architects are generally unknowledgeable of the work conducted in the BPS field and of the benefits of BPS, e.g.

> C7: *"There are often* [architects] *who don't understand what it is that we are trying to do."*
>
> C3: *"I'm generalizing very much now...but the lack of understanding maybe even to a slight ignorance in the importance of building simulation, and what role the simulation can play in helping their designs."*

Interviewed architects did not contradict this; instead blaming their lack of knowledge on their **paradigms of architectural education** such as in the following quote;

> A5: Architects *"are not trained as building scientists. So architects, if they were to do simulations themselves, they would almost need to retrain."*

However, research in educational psychology reports a positive correlation between interest and knowledge of a particular domain [82]. Personal interest fuels people's motivations for knowledge-acquisition and directs their engagement toward learning activities [83]. Based on this explanation, architects' poor BPS uptake may largely be a matter of personal interest; or lack of it thereof. To draw from the interview-data, consultants realised that some architects are simply *"not bothered"* about all matters related to energy-efficiency. Participant C8 maintained that, if an architect is *"intellectually interested"* in BPS they *"will go and find the knowledge,"* whereas *"if you're not interested in it you will not go and find the knowledge."*

However, explicitly describing difficulties they experience in their professional relationships with architects as a consequence of the latter's lack of knowledge and interest, consultants equally demonstrated anxiety at the deliberation that architects could enter 'their' domain and conduct BPS calculations themselves. It is in the architects' ignorance that consultants' positions currently thrives, as stated in the following quotes;

> C8: *"If* [architects] *had the knowledge then we wouldn't have the need for a job ... we are working because the rest of the team don't have the knowledge."*
>
> A6: If architects were able to conduct BPS themselves, *"it would take away the work of service engineers."*

However, while communication plays an intrinsic role in nurturing trustworthy professional relationships, it is also important for communication to be efficient for successful information-transfer [84]. Consultants demonstrated a concern that *"the understanding and interpretation* [of information] *is difficult...it doesn't seem to have the impact or the required result"* on the designed end-product.

4.3.4.1 Poor communication; quantitative follow-up

Likert-scale variables shown in figure 4 were combined to form a composite communication variable entitled 'consultants feel their communication with architects is effective' (M = 3.184, SD = .533). The mean of this variable, which lies just past the third point on the Likert-scale indicates that consultants do not feel that their communication with architects is effective. On average, their opinion about communication is neutral.

Additional statistical confirmation was sought to ascertain the relationship between trust and communication variables; as described in [82-83]. A Pearson's correlation was conducted to explore this relationship; as perceived by consultants. A strong positive correlation was found between the two variables ($r = .535$, $p = .000$, $nC = 148$), with trustworthy relationships associated with perceptions of effective interpersonal communication.

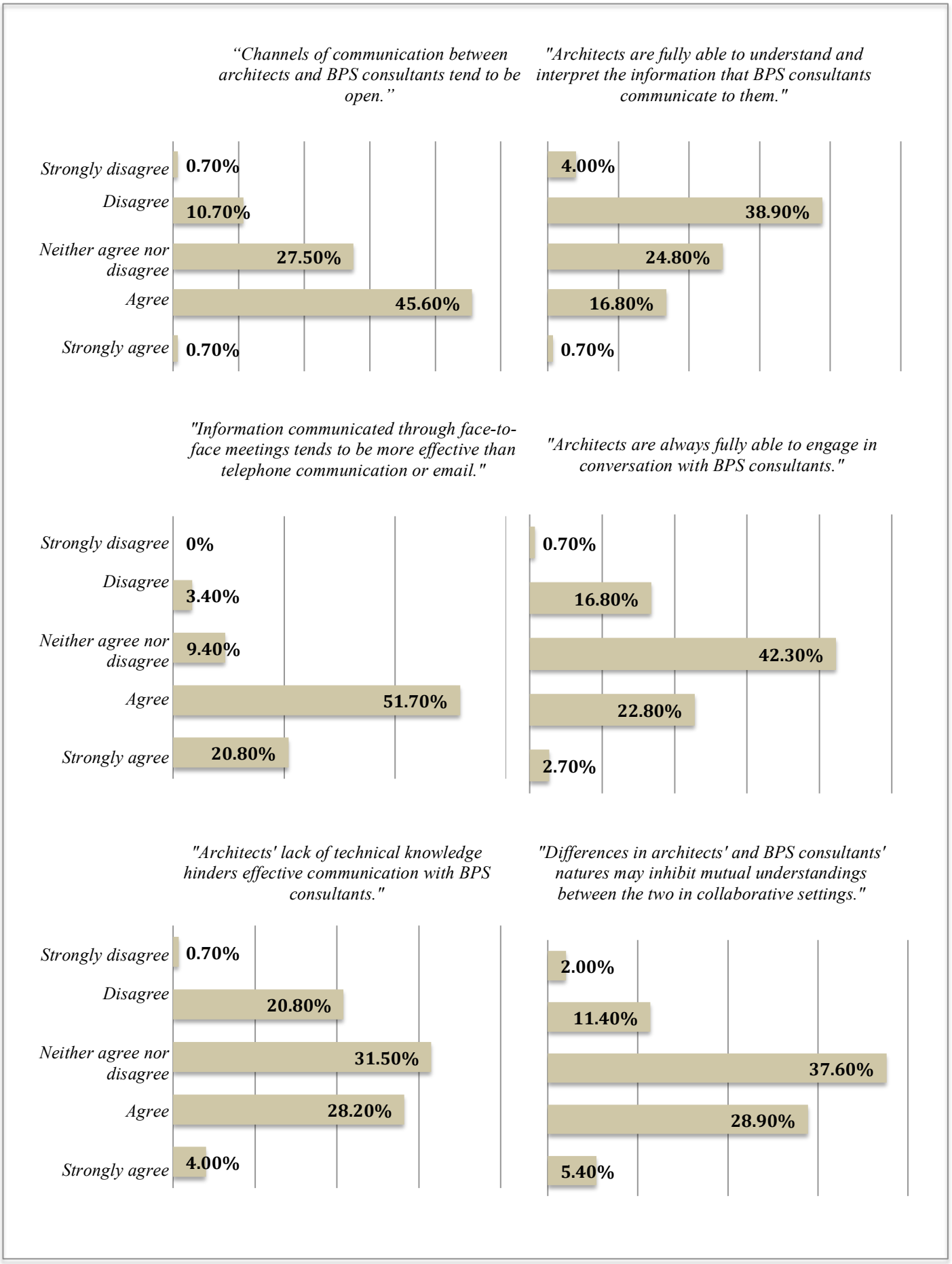

Figure 4: Likert-scale variables investigating whether consultants perceive their communication with architects to be efficient.

5. Conclusions

Interdisciplinary collaborations are meant to overcome limitations in knowledge or physical capability, and to facilitate the execution of design ideas that may be impossible if the work is undertaken unilaterally. However, the data suggests that non-technical barriers may arise when architects and consultants enter into a collaborative initiative. These challenge the design decision-making process that the collaborative relationship is originally intended to facilitate. These barriers can be summarized as the following:

- **The new context of design teams:** Building performance requirements are now requested to be explicit and quantifiable, and tools exist to enable this to happen. This becomes a specialist subject that requires expertise and brings new players, the consultants, as design team stakeholders. However, as performance related decisions and design decisions many times overlap, architects are forced to 'negotiate' their original control on design decision-making with specialists, which can cause tensions in what is supposed to be a collaborative relationship.
- **Differences in approach to problem-solving and praxis:** The way architects deal with constraints is different to the ways consultants deal with constraints. Differences in problem-solving approaches cause communication misunderstandings as well as tensions in the design decision-making process.
- **Practice related barriers,** further subdivided into:
    - **The role of the client:** Data derived both qualitatively and quantitatively indicate that, in most cases, building design budget tends to be set up in such a way that consultants are only brought to the team at a later stage. Reasons behind that can be various: lack of interest from clients in using BPS to aid design decision making, clients being unaware of BPS importance, and business-related decisions including financial interests and budgetary constraints. This limits their participation and input in the design decision-making process as most of the important decisions tend to happen in the early design stages.

      The deployment of the regulatory framework: Qualitative data suggests that architects seem to perceive simulation as mainly a compliance checking exercise. This limits their use and the participation and input of consultants in informing the design decision-making process. This may be associated with architects' poor attitudes toward Part L. Quantitative data investigating attitudes confirmed that architects' attitudes toward Part L veer toward negativity. However, architects' results were comparable to consultants'. While consultants' attitudes were comparable to architects' in the questionnaire; this is unlikely to be because of misperceptions about the tools. Rather, consultants' neutral attitudes possibly mirror inherent complexities experienced as a consequence of the divide between available 'design'

and 'compliance' tools (e.g. repetition of the work in different software platforms or even an inability to accurately re-assess performance in a design tools because of clients' financial restrictions).

- **Professional trust:** Interview data suggests that lack of professional trust may be disrupting the collaborative effort between architects and consultants; from at least **three dimensions.** Lack of trust in professional **competence** and commitment are reported; consultants claim to be dissatisfied with the information provided by architects and architects seem to be dissatisfied with the level of commitment provided by consultants. Lack of trust in professional **integrity** is also reported, when information sharing is favoring individual financial goals rather collaborative efforts. Poor trust as a result of personal **'gut feelings'** is also implied. However, responses to questionnaire data addressing these dimensions of trust indicate that, on average members of both communities feel that trust dynamics are generally positive, although results are skewed toward neutrality.
- **Communication:** Lack of knowledge displayed by architects and the way BPS results are communicated to them seems to disrupt the information flow that should be happening in collaborative design teams, making collaborative efforts less efficient. Quantitative results confirmed that communication between architects and consultants is not perceived to be efficient; consultants' opinions on communication was neutral, on average.

To summarise, the findings show that improvements in BPS tools, legislation and regulations are not enough to widespread the uptake of BPS tools to inform design decision-making. Results presented in this work were tailored to the UK (England and Wales) context due to methodological boundaries related to sampling and data-collection described in section 3. Inherent contextual influences, namely professional education and regulatory frameworks, undeniably play a decisive role in how BPS is integrated in architectural decision-making in practice. Nevertheless, the problem of poor BPS integration in the architectural world has been pronounced and investigated by researchers based in all corners of the world (e.g. European continent in [19, 20, 22 and 25]; North America in [26, 29 and 85]; Australia in [21, 28] Latin America in [21, 22 and 30] and Asia and China in [32 and 86]).

The problem of poor BPS integration in building design decision-making is particularly pertinent in nations where legislative efforts similar to those existing in the UK are often influential drivers toward incorporating sustainability and energy considerations within building design. While details and nuances of BPS application within building design departing from legislation and/or energy policy may vary from one country to another, the overarching notion that further strategies beyond technical and/or regulatory frameworks and policy are needed to advance BPS uptake in practice, is equally consistent and relevant across the world.

The significance of this research is wide-scale from a methodological perspective as well as the results standpoint; as a similar methodological approach can be applied to energy research across various disciplines. As a starting point to this research, the design process was primarily regarded as a platform for social interaction between multi-disciplinary practitioners of averse epistemological traditions, and application of BPS in architecture was envisioned as an amalgamation of different knowledge-domains. Corresponding to this social view, methods, approaches and techniques from the social sciences not used before in this area were employed. Findings were formed by taking into account results of both qualitative and quantitative traditions. From a methodological standpoint, this research illustrates:

- The applicability of social science methods to a subject-area traditionally regarded deterministically, and its effectiveness in pointing out additional further investigative directions that have gone unexplored in the past, yet whose effects may be notably contributing to the research problem.
- How mixing the methods can serve the purpose of generating complementarity in the data; revealing alternate facets of a single 'energy' phenomenon, and simultaneously offset biases associated with mono-method research designs.
- How marrying between qualitative and quantitative approaches paints a convergent picture; capturing 'what' potential barriers are, while explaining the essence of human dimensionality in BPS applications; namely facets such as professional worldviews and enculturation, attitudes, perceptions, biases and sensitivities; amongst others.

Finally, findings captured associated with human dimensionality of BPS presented here can be considered starting points; prelude to illuminate further investigation in at least two future research domains.

1. Further studies about collaboration: The study unfolded that part of the problem of BPS deployment in practice relates to overcoming barriers in the domain of project management and economics (negotiating control, interferences from clients, budgets and regulatory frameworks and lack of trust among professionals). However, these were unfolded from data collected from two groups of professionals in separation and complete isolation from one another. The study did not include an examination of architects and consultants working together.

   It would be realistic, and probably more effective, to develop ethnographic studies observing architects and consultants working together; possibly from the lens of practice management and economics in more detail. A participatory ethnographic and first-hand approach may allow us to answer the following research questions:

   - How do barriers unfolded in this research, and any new barriers extracted, arise in practical project scenarios and design meetings? What impact do these barriers (and others) affect project design,

procurement and delivery? How do architects, consultants and other stakeholders on the design team address these barriers?

- From a methodological perspective, do participatory and ethnographic research methods identify more non-technical barriers than interviews and surveys? Do the findings from an ethnographic study compare to the use of interviews and questionnaires? Do the two methodologies divulge alternative dimensions of the problem; or do they reveal similar results?

2. Further studies about the role of architectural education; as the study also revealed that part of the problem of BPS uptake in practice may be related to overcoming barriers in architectural education. Understanding the role of architectural education may help to answer some of the forthcoming questions:
    - At what points in architectural education is BPS introduced to architecture students, if at all? Are these initial introductions followed-through in design studio projects, and are students encouraged to use BPS to demonstrate predicted performances of these buildings in design studio projects? How are students taught to deal with BPS in light of the discussion about constraints?
    - Are approaches related to problem-solving and praxis discussed in this paper particular to paradigms of architectural education in the UK? Or are these approaches common amongst architects following different training systems in other geographical regions (e.g. European Continent or the Americas?) Do different approaches lead to improved examples of BPS uptake, and what lessons can be learnt and applied in the UK context?

Exploring different paradigms of dealing with problem-solving constraints in architecture and engineering schools and /or fostering collaborative projects throughout undergraduate education could help improving barriers related to different approaches to problem-solving, communication and trust.

In conclusion, this research serves as a gateway to illustrate how adopting inter-disciplinary approaches may provide lattice for architectural and 'energy' domains to converge. It also emphasizes that consideration of different research philosophies, methodologies and apparatus is instrumental, enlightening and expansive to the BPS domain.

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References

[1] Marechal, K. and Holzemar, L., 2015. Getting a (sustainable) grip on energy consumption: The importance of household dynamics and 'habitual practices.' *Energy Research and Social Science* 10 (2015), pp. 228-239.

[2] Kastner, I. and Stern, P. C. 2015. Examining the decision-making processes behind household energy investments: A review. *Energy Research and Social Science* 10 (2015), pp. 72-89.

[3] Sunnika-Blank, M. and Galvin, R., 2016. Irrational homeowners? How aesthetics and heritage values influence thermal retrofit decisions in the United Kingdom. *Energy Research and Social Science* 11 (2016), pp. 53-66.

[4] D'Oca, S., Crgnati, S. P. and Buso, T. 2014. Smart meters and energy savings in Italy: Determining the effectiveness of persuasive communication in dwellings. *Energy Research and Social Science* 3 (2014), pp. 131-142.

[5] Walker, S. L., Lowery, D. and Theobald, K. 2014. Low-carbon retrofits in social housing: Interaction with occupant behaviour. *Energy Research and Social Science* 2 (2014), pp. 102-114.

[6] Clarke, J., 2001. *Energy simulation in building design.* 2nd ed. Oxford: Butterworth Heinemann.

[7] Williamson, T. J. 2010. Predicting building performance: the ethics of computer simulation. *Building Research and Information* 38 (4), pp. 401-410.

[8] IBPSA-USA 2016. *Building Energy Software Tools (BEST) Directory.* Available online at: http://www.buildingenergysoftwaretools.com/ [Accessed March 26th 2016].

[9] U.S. Department of Energy 2016. *Commercial Buildings Resource Database.* Available online at: https://buildingdata.energy.gov/cbrd/resource/705 [Accessed March 26th 2016].

[10] NRCan 2016. *HOT2000 Software Suite.* Available online at: http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/17725 [Accessed March 26th 2016].

[11] ORNL 2016. *The Weatherization Assistant (NEAT/MHEA).* Available online at: http://weatherization.ornl.gov/assistant.shtml [Accessed March 26th 2016].

[12] Enerwin 2016. *Ener-Win Energy Simulation Software for Buildings.* Available online at: http://enerwin.com/ [Accessed March 26th 2016].

[13] IES 2016. *Integrated Environmental Solutions.* Available online at: https://www.iesve.com/software [Accessed March 26th 2016].

[14] Morbitzer, C. A. 2003. *Towards the integration of simulation into the design process.* Thesis (PhD). University of Strathclyde, Energy Systems Research Unit ESRU, Scotland, UK.

[15] Autodesk 2014. *Autodesk Ecotect Analysis; Sustainable Building Design Software.* Available online at: http://www.autodesk.co.uk/adsk/servlet/pc/index?id=15055760&siteID=452932 [Accessed: 3rd November 2014].

[16] Autodesk 2016. *Green Building Studio.* Available online at: http://www.autodesk.com/products/green-building-studio/overview [Accessed: March 26th 2016].

[17] DesignBuilder 2016. *DesignBuilder-Simulation Made Easy.* Available online at: http://www.designbuilder.co.uk/ [Accessed: March 26th 2016].

[18] OpenStudio 2016. *OpenStudio®.* Available online at: https://www.openstudio.net/ [Accessed: March 26th 2016].

[19] Attia, S. Beltran, L. De Herde, A. and Hensen, J. 2009. "Architect Friendly": A comparison of ten different building performance simulation tools. *11th International IBPSA Conference,* Glasgow, Scotland, July 2009.

[20] Attia, S., Hensen, J. L. and De Herde, A. 2012. Selection criteria for building performance simulation tools: Contrasting architects' and engineers' needs. *Journal of Building Performance Simulation* 5 (3), pp. 155-169.

[21] Pedrini, A. and Szokolay, S. 2005. The architects approach to the project of energy efficient office buildings in warm climates and the importance of design methods. *9th International IBPSA Conference,* Montreal, Canada, August 15-18, 2005.

[22] Venancio, R., Pedrini, A., van der Linden, A., van der Ham, E. and Stouffs, E. 2011. Understanding envelope design: Survey about architectural practice and building performance. *12th International IBPSA Conference,* Sydney, Australia, November 2011.

[23] Bleil De Souza, C. 2009. A critical and theoretical analysis of current proposals for integrating building thermal simulation tools in the design process. *Journal of Building Performance Simulation* 2 (4), pp283-297.

[24] Attia, S. and De Herde, A. 2011. Early design simulation tools for net zero energy buildings: A comparison of ten tools. *12th International IBPSA Conference,* Sydney, Australia, November 2011.

[25] Zimmerman, G. 2005. From floor plan drafting to building simulation – an efficient software supported process. *9th International IBPSA Conference,* Montreal, Canada, August 2005.

[26] Guglielmetti, R., Macumber, D. and Long, N. 2011. OpenStudio: An open source integrated analysis platform. *12th International IBPSA Conference,* Sydney, Australia, November 2011.

[27] MacDonald, A., McElroy, L., Hand, J. and Clarke, J. 2005. Transferring simulation from specialists into design practice. *9th International IBPSA Conference,* Montreal, Canada, August 2005.

[28] Soebarto, V. A. 2005. Teaching an energy simulation program in an architectural school: lessons learned. *9th International IBPSA Conference,* Montreal, Canada, August 2005.

[29] Reinhart, C., Dogun, T., Ibarra, D. and Wasilowski Samuelson, H. 2012. Learning by playing – teaching energy simulation as a game. *Journal of Building Performance Simulation* 5 (6), pp. 359-386.

[30] Palme, M. 2011. What architects want? Between BIM and simulation tools: an experience teaching Ecotect. *12th International IBPSA Conference,* Sydney, Australia, November 2011.

[31] Bleil De Souza, C. and Knight, I. 2007. Thermal performance from an Architectural Design Viewpoint. *10th International IBPSA Conference,* Beijing, China, September 2007.

[32] Yezioro, A., Shapir, O. and Capeluto, G. 2011. A simple user interface for energy rating of buildings. *12th International IBPSA Conference,* Sydney, Australia, November 2011.

[33] Hensen, J. L. M. and Lamberts, R. 2011. Introduction to building performance simulation. *In: Hensen, J. L. M. and Lamberts,* R. eds. Building performance simulation for design and operation. Oxon: Spon Press, pp. 1-14.

[34] Menzes, A. C., Cripps, A., Bouchlaghem, D. and Buswell, R. 2012. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy* 97 (2012), pp. 355-364.

[35] ZeroCarbonHub 2014. *Closing the gap between design and as-built performance; Evidence Review Report.* Available online at: http://www.zerocarbonhub.org/sites/default/files/resources/reports/Closing_the_Gap_Between_Design_and_As-Built_Performance-Evidence_Review_Report_0.pdf [Accessed: March 27th 2016].

[36] Guerra-Santin, O., Tweed, A. C. and Zapata-Lancaster, M. G. 2014. Learning from design reviews in low energy buildings. *Structural Survey* 32 (2), pp. 246-264.

[37] Bleiberg, T. and Shaviv, E. 2007. Optimisation for enhancing collaborative design. *10th International IBPSA Conference,* Beijing, China, September 2007.

[38] Prazeres, L. and Clarke, J. A. 2003. Communicating building simulation outputs to users. *8th International IBPSA Conference,* Eindhoven, Netherlands, September 2003.

[39] Prazeres, L., Clarke, J. A., Hand, J. and Kim, J., 2007. Delivering building simulation information via new communication media. *10th International IBPSA Conference,* Beijing, China, September 2007.

[40] Prazeres, L., Kim, J. and Hand, J. 2009. Improving communication in building simulation supported projects. *11th International IBPSA Conference,* Glasgow, Scotland 2009.

[41] Augenbroe, G. The role of simulation in performance based building. *In: Hensen, J. L. M. and Lamberts, R.,* Building performance simulation for design and operation. Wiltshire, UK: Spon Press, Taylor and Francis.

[42] Bakens, W., Foliente, G. and Jasuja, M. 2005. Engaging stakeholders in performance-based building: lessons from the Performance-Based Building (PeBBu) Network. *Building Research and Information* 33 (2), pp. 149-158.

[43] Sovacool B. K. 2014. What are we doing here? Analyzing fifteen years of energy scholarship and producing a social science research agenda. *Energy Research and Social Science,* 1 (2014), pp.1-29.

[44] Sovacool, B. K., Ryan, S. E., Stern, P. C., Janda, K., Rochlin, G., Spreng, D., Pasqualetti, M. J., Wilhite, H. and Lutzenhiser, L., 2015. Integrating social science in energy research. *Energy Research and Social Science,* 6 (2015), pp. 95-99.

[45] Wong, C. M. 2016. Assembling interdisciplinary energy research through an actor network theory (ANT) frame. *Energy Research and Social Science,* 12 (2016), pp. 106-110.

[46] Schmidt, S. and Weight, H., 2015. Interdisciplinary energy research and energy consumption: What, why, and how? *Energy Research and Social Science* 10 (2015), pp. 206-219.

[47] Pamela, B. and Jack, S. 2008. Qualitative case study methodology: Study design and implementation for novice researchers. *Qualitative Report* 13 (4), pp. 544-559.

[48] Bleil De Souza, C. 2012. Contrasting paradigms of design thinking: The building thermal simulation tool user vs. the building designer. *Automation in Construction* 22 (2012), pp. 112-122.

[49] Kalay, Y. E. 2001. Enhancing multi-disciplinary collaboration through semantically rich representation. *Automation in Construction* 10 (6), pp. 741-755.

[50] Royal Institute of British Architects (RIBA) 2011. *RIBA Directory of UK Chartered Practices.* Available online at: http://members.architecture.com/directory/default.asp?dir=1 [Accessed January 4th, 2016].

[51] Architects Registration Board (ARB) 2016. *Regulating the use of the title "architect;" The Architects Act 1997.* Available online at: http://www.arb.org.uk/regulating-use-of-the-title-architect-the-architects-act-1997 [Accessed March 26th, 2016].

[52] Strauss, A. and Corbin, J. M. 1990. Grounded theory method: Procedures, canons and evaluative criteria. *Qualitative Sociology* 13 (1), pp. 3-21.

[53] Strauss, A. and Corbin, J. M. 1998. *Basics of qualitative research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, California: Sage Publications.

[54] Lincoln, Y. S. and Guba, E. G. 1985. *Naturalistic Inquiry.* Newbury Park, CA: Sage.

[55] Bowen, G. A. 2008. Naturalistic enquiry and the saturation concept: A research note. *Qualitative Research* 8 (1), pp. 137-152.

[56] Hopfe, C. J., Struck, C., Hensen, J. L. K and de Wilde, P. J. C.J. 2006. Considerations regarding decision support tools for conceptual building design. *Proceedings of the Joint 11th International Conference on Computing in Civil and Building Engineering (ICCCBE-XI),* Montreal, Canada, June 2006.

[57] Wilmot, A. 2005. Designing sampling strategies for social qualitative research: with particular reference to the Office for National Statistics' Qualitative Respondent Register. Office for National Statistics published paper. Available online at http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/guide-method/method-quality/general-methodology/data-collection-methodology/reports-and-publications/index.html [Accessed: March 30th 2016].

[58] Patton, M. Q. 2002. *Qualitative Research and Evaluation Methods.* Thousand Oaks, CA: Sage.

[59] Bryman, A. 2001. *Social Research Methods.* Oxford: Oxford University Press.

[60] Bryman, A. and Burgess, R. G. 1994. Reflections on qualitative data analysis. *In:* Bryman, A. and Burgess, R. G. eds. *Analyzing qualitative data.* London: Routledge.

[61] Graneheim, U. H. and Lundmann, B. 2004. Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse education today* 24 (2004), pp. 105-112.

[62] Planning Portal 2016. *Part L (Conservation of Fuel and Power).* Available online at: www.planningportal.gov.uk/buildingregulations/approveddocuments/partl [Accessed March 24th, 2016].

[63] Royal Institute of British Architects (RIBA) 2011b. *RIBA Directory of Chartered Members.* Available online at: https://members.architecture.com/directory.default.asp?dir=3 [Accessed January 4th, 2016].

[64] Chartered Institute of Building Services Engineers (CIBSE) 2012. *Low Carbon Consultants and Energy Assessors.* Available online at: http://www.cibse.org/index.cfm?go=page.view&item=649, [Accessed: January 14th 2012].

[65] Czaja, R. and Blair, J. 1996. *Designing surveys; a guide to decisions and procedures.* London: Sage.

[66] Raslan, R. and Davies, M. 2010. An analysis of industry capability for the implementation of a software-based compliance approach for the UK Building Regulations 2006. *Building Services Engineering Research and Technology* 31 (2), pp. 141-162.

[67] Kaplowitz, M. D., Hadlock, T. D. and Levine, R. 2004. A comparison of web and mail survey response rates. *Public Opinion Quarterly* 68 (1), pp. 94-101.

[68] Fowler, F. J. Jr. 2002. *Survey Research Methods Third Edition.* London: Sage Publications.

[69] *Energy Performance of Buildings Directive (EPBD) 2003.* Available online at: http://www.epbd-ca.eu [Accessed: 17th December 2012].

[70] *Energy Performance of Buildings Directive (EPBD) recast 2010.* Available online at: http://www.buildup.eu/publications/9631 [Accessed 4th September 2014].

[71] Hamza, N. and Greenwood, D. 2009. Energy conservation regulations: Impacts on design and procurement of low energy buildings. *Building and environment* 44 (5), pp. 929-936.

[72] Royal Institute of British Architects (RIBA) 2008. Outline Plan of Work 2007; Amended November 2008. Available online at: http://www.architecture.com/Files/RIBAProfessionalServices/ClientServices/RIBAOutlinePlanOfWork2008Amend.pdf [Accessed 23rd May 2013].

[73] Pilgrim, M., Bouchlaghem, N., Loveday, D. and Holmes, M. 2003. Towards the efficient use of simulation in building performance analysis: A user survey. *Building Service Emergency Resources Technology* 24 (3), pp. 149-162.

[74] Imrie, R. 2004. The corporealisation of codes, rules and conduct of architects. *Prospecta Building Codes* 35, pp. 94-97.

[75] Imrie, R. 2007. The interrelationships between building regulations and architects' practices. *Environment and Planning B: Planning and Design* 34 (5), pp. 925-943.

[76] Raslan, R. and Davies, M. 2010. Results variability in accredited building energy performance compliance demonstration software in the UK: An inter-model comparative study. *Journal of Building Performance Simulation* 3 (1), pp. 63-85.

[77] Rousseau, D. M., Sitkin, S. B., Burt, R. S. and Camerer, C., 1998. Not so different after all: A cross discipline view of trust. *Academy of Management Review* 23 (3), pp. 393-404.

[78] Nooteboom, B. 2006. Forms, sources and processes of trust. *In:* Bachmann, R., Zaheer, A.eds. *Handbook of Trust Research.* Cheltenham: Edward Elgar, pp. 247-264.

[79] Hartman, F. T. 1999. The role of trust in project management. In: *Proceedings of Nordnet '99' International Project Management Conference,* Helsinki, Finland.

[80] Ruppel, C. and Harrington, S. J. 2000. The relationship of communication, ethical work climate and trust to commitment and innovation. *Journal of Business Ethics* 25 (4), pp. 313-328.

[81] Johnson, D. W. and Johnson, R. T. 1989. *Cooperation and Competition: Theory and Research.* Edina, MN: Interaction Book Company.

[82] Hidi, S. 1990. Interest and its contribution as a mental resource for learning. *Review of Educational Research* 60 (4), pp. 549-571.

[83] Lawless, K. A. and Kulikowich, J. M. 2006. Domain knowledge and individual interest: The effects of academic level and specialisation in statistics and psychology. *Contemporary Educational Psychology* 31 (1), pp. 30-43.

[84] Ryghaug, M. and Sorensen, K. H., 2009. How energy efficiency fails in the building industry. *Energy Policy* 37 (3), pp. 984-991.

[85] Riether, G. and Butler, T. 2008. Simulation Space: A new Design Environment for Architects, eCAADe 26 conference; *Education and research in Computer Aided Architectural Design in Europe,* Antwerp, Belgium, September 2008.

[86] Zhu, Y., Xia, C. and Lin, B. 2007. Discussion on methodology of applying building thermal simulation in conceptual design. *10th International IBPSA Conference,* Beijing, China, September 2007.

APPENDIX A: Thematic topics and questions included in the interview guide for architects and BPS specialists.

	ARCHITECTS	BPS SPECIALISTS
THEME 1: BACKGROUND EDUCATION; How background education and experience shape architects' and BPS specialists' experiences in the building industry.	1. Can we start by talking a little bit about your undergraduate architectural education? Can you tell me a little bit about that? Did you carry on with a postgraduate degree?	1. Can we start by talking a little bit about your undergraduate education? Can you tell me a little bit about that? Did you carry on with a postgraduate degree?
	2. What about your school of architecture? Was there a general trend in the architectural education? What was the focus? How were students encouraged to observe architecture in general	2. On which area(s) was most emphasis placed during your undergraduate schooling? Was there a specific aspect where most emphasis was placed?
	3. Do you think that this sort of emphasis has shaped your personal understanding of the discipline? How have you carried it forward in your work and your career?	3. Do you think that this sort of emphasis has shaped your personal understanding of the discipline? How have you carried it forward in your work and your career?
THEME 2: PRACTICES AND PROBLEM-SOLVING; Architects' and BPS specialists' descriptions of their own work, practice and problem-solving techniques.	1. Can you tell me a little bit about your working process? How do you work and what are your main considerations when you work?	1. Can you tell me a little bit about your working process? How do you work and what are your main considerations when you work?
	2. Can you tell me a little bit about how you go about solving a design problem?	2. Can you tell me a little bit about how you go about solving a simulation problem?
	3. How do you work together with the rest of your team? Does the structural organization of your practice support this?	3. How do you work together with the rest of your team? Does the structural organization of your practice support this?
	N/A	4. Is there any specific software that you use to carry out simulations? Why this software? Are you aware of any areas where this software could be improved, in your opinion?

	ARCHITECTS	BPS SPECIALISTS
THEME 3: EXPERIENCES IN COLLABORATION; Architects' and BPS specialists' experiences in collaboration with each other.	1. Why do you hire a consultant to conduct simulations?	1. Why do you do simulations? What are the main aims of the simulations?
	2. At what stage of the design process do you begin collaborating with specialists for the purpose of simulation to inform your design decision-making?	2. At what stage of the architectural design process do you receive simulation tasks from designers to analyse the performance of their designed buildings? At what stage do you think architects should start considering simulation to inform their design decision-making?
	3. Can you tell me how you think BPS specialists carry out their problem-solving exercises?	3. Can you tell me how you think architects carry out their problem-solving exercises?
	4. At what stage during the design process do you begin to discuss the project with a simulation specialist, for simulation and analysis of performance?	4. At what stage during the design process do architects begin discussing their architectural designs with you, for simulation and analysis of performance?
	5. What methods or means do you usually use when you communicate with BPS specialists? Does communication usually take place through face-to-face meetings? Do you usually use drawings and sketches, for example, rather than numbers and spreadsheets, etc.?	5. What methods or means do you usually use when you communicate with architects? Does communication usually take place through face-to-face meetings? Do you usually use numbers and spreadsheets, graphs, in written form, etc. rather than drawings and sketches, for example?