

With regards to energy modelling: how does students' knowledge compare with industry expectations?

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Abstract

The global attention toward reducing energy consumption has resulted in the development of specialized disciplines and standards to address and assess the performance of buildings during design and operation. Nevertheless, the mismatch between the buildings' predicted and measured energy performance, typically known as 'the performance gap', remains worrying. The literature identifies tool limitation, user-influence and lack of incentives amongst the factors influencing this market's development and the successful implementation within the industry. However, the relationship between academia and work environment has rarely been investigated. This study explores this aspect of the UK energy modelling market with the aim of comparing the industries' expectations of junior employees with the knowledge and skills with which students with engineering, architectural or environmental-related backgrounds, assumed to represent the future workforce, enter the professional environment. A mixed method including surveys is pursued and complemented with qualitative data gathered through informal interviews. The results suggest a general correspondence between the knowledge provided by academia and required professionally, however students are not trained to be "work-ready" with a varied understanding of the modelling exercise in terms of building physics, practical implications, assumptions, simplifications and variability.

Introduction

The energy context and the built environment

With the intent of promoting a more sustainable future and limit the "very high risk of severe, widespread and irreversible impacts globally" (Pachauri et al. 2014) the experts invoke for adaptation and mitigation strategies. The E.U. aims to maintain global warming below 2°C by reducing overall greenhouse gas (GHG) emissions by at least 20% below 1990 levels, by 2020, and by 30% in the event of an international agreement being reached (European Union 2010). The UK government has set an 80% total carbon reduction target by 2050 (UK Government 2008).

The built environment plays a dominant role as, not only it globally contributes to more than 40% of energy use and one third of GHG emissions, but it is also among the sectors with proven and commercially available technologies capable of cutting emissions by between 30-

80% with potential net profit during the building life-span.(UNEP 2007)

In this scenario, interested member of the architecture, engineering and construction (AEC) industry and academia have specialized in delivering environmental design solutions, while contributing to the development of numerous compulsory or elective building performance regulations and rating systems. Despite the field's increasing development since the 1970s energy crisis, the mismatch between the predicted energy performance of buildings, obtained through computer-based simulations, and the actual measured performance, typically addressed as 'the performance gap', remains increasingly worrying (De Wilde 2014; CIBSE 2015).

The energy modelling industry

The energy modelling segment generally involves the following main components: the human factor, the modelling objectives and tasks, and the simulation tool.

There are many actors involved in the energy/sustainability design market ranging from architects to mechanical engineers and modellers. Nevertheless, as advertised in job position descriptions, two main professional categories can be identified: senior and junior employees, who are generally newly graduates or students completing their degrees. Different studies have therefore explored this transition period, concluding how Higher Education Institutions (HEI) and employers should collaborate to allow academics to teach in a manner that promotes employability skills and attributes without diminishing the academic content (Lowden et al. 2011;Archer et al. 2008, p.8). This is particularly relevant in terms of modelling, as it is a relatively new field that involves both practical skills and abstraction capacity.

Among the modelling objectives, regulations are crucial in the AEC industry. In England and Wales, Part L treats the conservation of fuel and power (HM Government 2016) for the entire building stock: new, existing, domestic and non-domestic. This is standardized form of assessment that is intended to provide minimum standards and therefore does not reflect the building's actual energy performance. The National Calculation Methodology (NCM) provides technical guidance for the compliance assessment of buildings other than dwellings. The method is based on the comparison of the building assessed, referred to as the 'actual building', against an equivalent 'notional building generated by the software.

Computer-based energy modelling tools have become increasingly widespread; however, the confidence and applicability of this methodology is still extensively explored. The following realms are recurrently explored:

1. Industry-related implementation difficulties depending on: tool availability, costs, lack of appropriate degree of expertise, inappropriate incentives, lack of feedback and of confidence in the results (Raslan & Davies 2012; Hensen & Radosevic 2004; De Wilde 2014).
2. Intrinsic variability of the results caused by software and information reliability. This introduces scepticism on the validity of the simulation results both for compliance (Raslan & Davies 2012) and real-life modelling (Type et al. 2011), while also contributing to the discrepancy between simulated and measured energy consumption.

Disregarding the economic and social issues, a growing body of literature is exploring the reasons for variability of predicted results to increase the processes' reliability. The following are considered the main factors contributing to this phenomenon:

1. Tool limitations due to the calculation engines, appropriate representation of the physical reality and thus inter-tool variability of results (Raslan & Davies 2010; Schwartz & Raslan 2013; Brun et al. 2009; Neymark & Judkoff 2004; Type et al. 2011);
2. Uncertainty of data inputs and assumptions, including occupancy profiles, material characteristics and weather data (Costola et al. 2009; MacDonald & Strachan 2001; Hopfe & Hensen 2011); the unreliability of quality assurance procedures that hamper efficient and correct communication within the design team (Hensen & Radosevic 2004; Parand & Wilson 2010; Tian et al. 2009);
3. User-influence, in terms of: literacy, modelling skills, assumptions, educational background and human-error.

Most of the abovementioned papers recognize user-influence as a cause of energy prediction variability however, this realm is often kept as a control variable and seldom assessed. The majority of the researches focusing on user-influence have been carried out during the 1990s, during the initial stages of the implementation of simulation tool, and therefore mainly address manual development, learning supports, interface optimization and introduction to the building industry (Hand 1991; Hand & Hensen 1994; Bartholomew et al. 1997; Hand & McElroy 2002). However, in 1997 Guyon et al. concludes that "user [influence] is non-negligible in the results obtained from thermal simulation programs" resulting in an absolute variation of 1:2 and indicates how the "good homogeneity [of results obtained] category by category, explained by the fact that the same culture gives similar interpretation problems" (Guyon 1997).

Since then software have improved, industries have become familiar with simulation tools, and a large variety of training tools and courses have been developed.

However, the 'performance gap' has not been bridged yet. A recent study approached the existing mismatch between predicted and actual energy performance by investigating the literacy of the design teams (Imam et al. 2016). The research identified a three-part definition of literacy and concluded that the 108 participants randomly chosen among professionals of the AEC industry that fully completed the exercise could not be considered literate. This suggests how result variability is also related to user competence and therefore "clearly emphasizes a potential gap that can be bridged" (Imam et al. 2016, p.13).

In this context, this study aims to explore the energy modelling segment of the UK environmental design market, from academia to work environment, driven by the belief that the human factor is amongst the most important elements of any process. The 'performance gap' is thus addressed from the human perspective to understand the knowledge and skills with which students with engineering, architectural or environmental-related backgrounds, assumed to represent this market's future workforce, enter the professional environment, and how their preparation compares with the industries' expectations and standards. The objectives are to:

- Achieve a general understanding of the energy modelling market in terms of: qualifications required or pursued; software use and type of simulations performed; professional roles; level of confidence, satisfaction and expectations towards courses and junior employees;
- Compare the knowledge of the two groups in terms of energy modelling at a practical level to identify potential common trends;
- Combine the results obtained to holistically explore the transition between academia and work environment, possible collaboration measures that could potentially benefit both parties and improve the market's status.

Methodology

Computer-based modelling has been chosen to explore the interaction between academia and professional realisms as it represents the most recent application of knowledge, as well as, an increasingly important specialism to promote sustainability in the built environment.

The study is divided into a social and a practical analysis, that run parallel and contribute to obtaining a more holistic understanding of the industry. A mixed-mode approach is pursued leading from a quantitative and qualitative analysis of the market, to a more specific investigation of thermal modelling skills.

This approach allows to understand: the composition of the market; the actor's mutual feelings and perceptions; their level of awareness, by comparing the information obtained from the participants to their results. Furthermore, it allows to validate the assumption that students represent the market's future workforce and to identify appropriate candidates for the practical analysis.

The analysis focuses on modelling for Part L Compliance, as it is the only compulsory document in the UK and hence should be the most widespread, and it presents a more controllable standardized approach.

Table 1: Means of online Questionnaire distribution

Mean	Communities, Institutions and Firms*
Website & Letters	International Building Performance Simulation Association (IBPSA), CIBSE
Social Networks	Facebook: WSP Graduates, UCL MSc EDE.
	LinkedIn: Environmental Consulting Professionals, IES-VE Users, IBPSA, CIBSE, CIBSE YEN, CIBSE EPG, UCL IEDE
Direct email	Higher Education Institutions: AA, University of Loughborough, UCL, University of Bath, University of Cardiff, Heriot Watt University.
	Practices and Companies: ARUP, WSP PB, Max Fordham, XCO ₂ , Syntegra.
*The table only includes those who have accepted to participate.	

The Social Analysis

Online surveys and informal interviews have been used to explore the students' knowledge, confidence and aspiration and the industry's expectations and perception of "junior modellers", intended as employees with less than one year of working experience in this area. The study initially uses a non-probabilistic convenience sampling technique by inviting professionals and students of the environmental design realm to participate at the social questionnaire.

Two different questionnaires, respectively directed to students and professionals, have been distributed between June 6th and August 25th 2016. The questionnaires included multiple choice, list and short answer questions and are available at: https://eSurv.org?u=A_Professionals_Survey_; https://eSurv.org?u=A_Student_Survey_.

The surveys gathered information on: qualifications possessed; experience; role/aspired roles; modelling skills and software used; level of confidence and preparation of employees, respectively for students and professionals. Both concluded asking for participation at the interviews or practical questionnaire.

Table 2: Online Survey Participation Data

Participants ¹		Participant Response Rate	Average Question Response Rate ²
Group	N.		
Students	90	61%	85%
Professionals	134	94%	80%
1 Members of energy/sustainability market who participated. 2 Refers to the number of complete questionnaires.			

The Interviews

Semi-structured interviews were carried out on a smaller sample of population who demonstrated particular interest in the research. The interviews were conducted individually and have been carried out either physically, via skype or phone.

The interviews were carried out informally, without using a strictly prepared set of questions, and aimed at discussing the results obtained from the social questionnaire at the moment of the interview, the specific answers given by the interviewee, the status of the environmental design market and possible ideal collaboration scenarios between the academic and professional realms. Feedback on the clarity and design of the practical questionnaire was also collected from those who participated.

Table 3: Interview Participation Data, Professionals

Studies	N	Experience	Company Size
Engineering	4	5≤years≤15	10 ≤ employees ≥250
Arch. Eng.	1	0≤years ≤2	50 ≤ employees ≤ 249
Architecture	2	0≤years ≤5	50 ≤ employees ≤ 250

Table 4: Interview Participation Data, Students

Studies	N	Course	Work Experience
Engineering	1	MSc	Outside UK, other sector
Arch. Eng./ Architecture	1/3	MSc	Outside UK, other sector or None
Environ. Science	1	MSc	Outside UK, other sector

The Practical Analysis

The practical questionnaire has been created using the same platform as the previous surveys (available https://eSurv.org?u=1_practical_exercise_questionnaire) and has been distributed between the 7th and the 27th of August 2016. The modelling task consists in a Part L Compliance Check using IES-VE (DSM) for a mixed-commercial and office building in Central London, and it includes: geometrical modelling and thermal zoning, building service, auditing and result analysis.

The questionnaire directly refers to the modelling of design features specifically selected by reviewing manuals, reports and online available tutorials (IES 2014; NCM 2014), and auditing reports kindly made available by Arup. The questions have been purposely designed to include commonly encountered challenges. Each question addresses a specific competence or knowledge and the answers provided are designed to offer the most common approaches to each task, including what will be referred to as the *best approach* (BA). This is not intended as a series of correct answers but rather at the approach suggested by the manuals and training materials reviewed. As Table 5 summarizes, a subsample including only IES-VE users has been selected for strictly IES-related questions while considerations regarding the knowledge of Part L will be included where relevant.

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Table 5: Practical Modelling Survey Participation Data

Participants Group	N.	Participation Response Rate ¹	Average Question Response Rate ²
Students	24	67%	94%
Profess.	29	53%	97%
Subsample of IES-VE Users			
Students	22	76%	95%
Profess.	24	59%	98%

¹ No. of people who accessed the questionnaire.
² No. of Participants.

Results

The Social Analysis

The results indicate how the composition of the workforce seems to have changed with respect to background education (Figure 1). This could depend on the sample; however, it possibly could determine a more design-oriented mind-set than earlier generations.

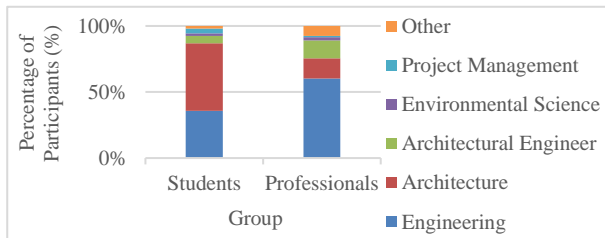


Figure 1: Educational Background

Bachelor and master degrees are the qualifications mostly sought for in 'junior modellers' (JM) and these are also the qualifications that most applicants possess since the majority are currently taking a master course. However, the results also suggest that, as the size of the company increases, the qualifications required of JM are less homogenous. In addition, the comments left by professionals stress the importance of the knowledge of building physics and built environment suggesting the preference for a general technical background.

In terms of career, while 61% of professionals have covered the role of energy modellers, only 24% students seem interested in the position. Most students aim to apply for roles of environmental designers and environmental/energy and sustainability consultants (i.e. between 48% and 62%). Excluding sample biases, this indicates that students are either unaware of what the career progression is or will not have to replicate it since the field is now more widespread. Most professionals' interviews, have explained that when they started working the only way of accessing the environmental field was through mechanical or building service engineering.

The results highlighted good correspondence between software taught in academia and used in the work environment, with IES ranking at the top of the list and EnergyPlus indicated amongst the most popular "other" software by both groups. Similarly, as Figure 2 illustrates students are taught the most commonly performed real building simulation analysis, but they are rarely exposed to modelling for specific standards which are instead

common in the industry.

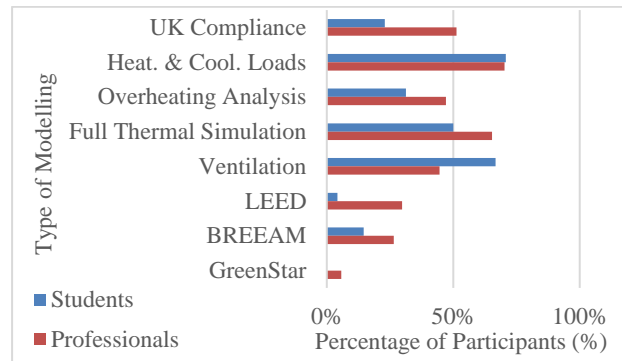


Figure 2: Type of Modelling Analysis performed/taught

Professionals

The participants are homogenously spread among the industry in terms of size of the company (Figure 3) and years of experience (Figure 4). Based on the years of experience it is likely that junior, senior and probably associate level employees have participated. The sample is hence considered a good market approximation.

In terms of perception of new employees, the results suggest how over 80% of professionals believe that JM require extra training. However, academic experience is slightly preferred to work experience, whereas full dynamic thermal modelling is more significantly preferred to experience with standards. In addition, the comments left at the end of the questionnaire, suggest that professionals do not expect specific skills from graduates but the mind-set to understand the underlying

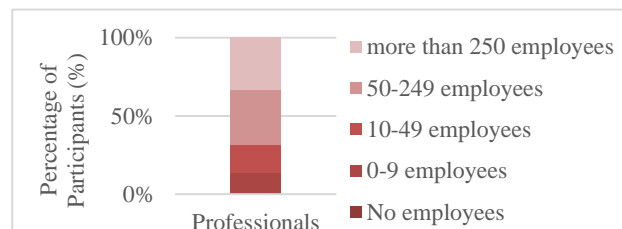


Figure 3: Company Size

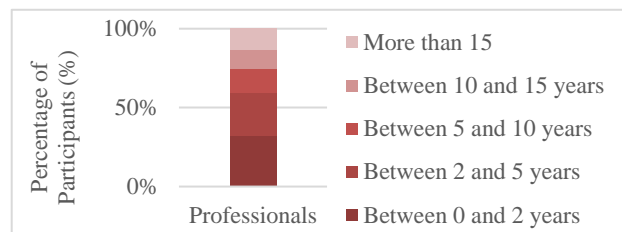


Figure 4: Years of Experience

mechanisms behind the design. Competencies instead seem to be anticipated from those with work experience and, overall, a combination of work experience and schooling is perceived as the best option. Areas identified as most challenging for JM are: modelling and understanding of building and HVAC systems and the knowledge of building physics; followed by the capacity to make assumptions, relate the model to reality and understand the varying design stage details required. Moreover, knowledge of compliance, calculation of

heating and cooling loads and the model auditing and interpret results, are also indicated as areas that could be improved. Hence, generally a JM *“is not expected to have any significant qualifications other than a degree. What’s required keen interest and a systematic approach”* since *“most schools are not training students to hit the ground running. Most would get this from internships.”*

Students

Among the student participants: 87% study full-time, 78% of which have no job and the rest have jobs in their field of study while the remainder 13%, is almost equally divided amongst part-time students and researches. The majority have previous work experience outside the UK in non-environmental sectors of the AEC (Figure 5) and approached their higher education courses to improve their career in the industry (Figure 6). This underscores the importance of providing feedback between the two realms.

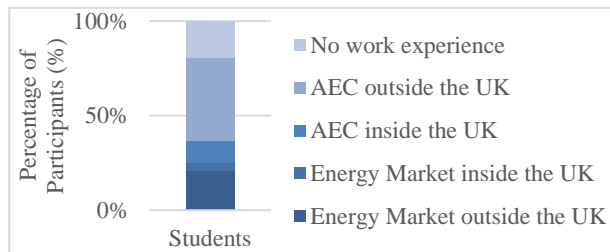
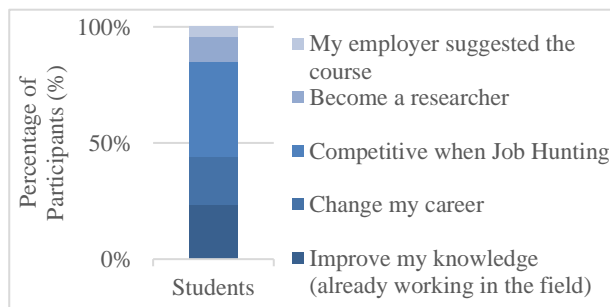


Figure 5: Students' work Experience



The third section of the questionnaire aimed at appraising

Figure 6: Reasons to Continue Studying

the students' confidence in terms of energy modelling. The results suggest how students are confident of their modelling skills but more uncertain regarding knowledge of Part L and NCM. The results have also been analysed by isolating students with architectural and engineering backgrounds. Similar trends emerge within both groups, with architects presenting slightly stronger tendencies towards “agreeing” and “disagreeing” respectively for questions related to general modelling and understanding of NCM and Part L, compared to engineers. This minor difference suggest how architect, used to modelling, encounter less difficulties when interacting with the software while engineers, more used to regulations and numbers, tend to naturally feel more confident when exposed to figures and thresholds. The difference however is not significant, indicating how both groups generally face the same difficulties when studying similar material.

The Interviews

Professionals

The more experienced professionals agreed that student knowledge is generally good and has been improving over the years. However, while some participants implied in their answers that they would be look for relevant engineering, architectural or similar backgrounds, two of the participants with between 10 and 15 years of experience, spontaneously pointed out how a specific educational background is not crucial if the candidate demonstrate a technical mindset.

On job training differs in the two above cases. The first types of firms will have more specialized employees and training procedures. Differently, the second approach is that of considering *“college [as a place where] you develop the structure of your thinking, [after which] you can work with some basic engineering principals like fluid dynamics, math”* (P1). These firms are ready and keen to support and train the employees from the basics. In all cases, however, interviewees generally agreed that, *“there is a transition [period] between academia and professional life that needs time to happen and is also very dependent on the culture of the office itself”* (P1).

Consistently with the results from the questionnaire: the knowledge of building services and building physics, is considered weak in inexperienced employees, while the capacity to simplify, make assumptions and to relate modelling features to real-life performance is seen as the most challenging capacity. Practical experience with design outcomes and workflow therefore, are the main areas that professionals would tackle through collaboration between academia and industry. Among the most interesting scenarios suggested: building monitoring carried out by students and supervised by the design team; assigning students a completed project to develop during the year under the supervision of original design team to be faced with actual “real-life” constraints.

Nevertheless, professionals agreed that the training process occurs “organically” within the firms and it is not perceived as a burden. Consequently, it seems generally hard to quantify in terms of resources targeted at training employees and all professionals agreed that recovering those resources would not alter a company’s “economic” capacity of investigating more sustainable solutions as this almost exclusively depends on the clients’ agenda.

Students

The students interviewed were overall satisfied with their courses in terms of knowledge, however most seem to agree that these were too generic and could have gone more into practical and technical detail or offered more optional courses to allow students to follow their inclination. In addition, energy ratings standards, building systems and industry-oriented modelling with different software have been indicated as areas of interest but of low confidence.

Consistently with the results found so far, all students demonstrated an interest in practical experiences, such as, site trips and placements. Furthermore, excluding the difficulties with building services that has been agreed upon numerous times, the student's comment on the areas perceived as weak for JM by professionals were very interesting. In terms of ability to appraise the relevance of a details and make assumptions, most interviewees understood where the comment originated, but either did not identify with the issue or strongly related the differences between employer and company standards. In terms of design stages and comprehension of professional roles instead, most students agreed that the first should be introduced by the companies while it would be useful to receive a brief explanation of work positions towards the end of the academic courses. Lastly, when those who already started working were asked to comment on the role of sustainability in the market most were together dismayed and hopeful indicating how currently it is marginal, but they can see it being developed.

The Practical Analysis

The participants at the questionnaires are varied in terms of experience, with approximately 10% of each group having no experience with IES-VE but with similar software, and respectively 54% of the students and 14% of professionals, having no experience with Part L assessments. Therefore, specific considerations have been made to distinguish the questions strictly related to either Part L and IES-VE, including appropriate sample selection.

Geometry and Model Construction

The results gathered suggest a general correspondence between the answers given by students and professionals, however different prevailing trends are recognizable in terms of understanding of the software calculation methods and of Part L, and the capacity to simplify the design and adopt standard modelling procedures. The results will refer to the IES-VE users sub-sample except when specified differently.

Professionals demonstrate a better understanding of Part L and calculation methods adopted by the software in terms of compliance. This is in terms of the mechanisms according to which elements are assigned between 'notional' and 'actual' buildings. For example, 68% of students against 88% of professionals, correctly assign the louvres to the 'local shade' category, so they will only benefit the 'actual building'. Likewise, 58% of professionals and 45% of students, would create multiple zones with the same template and connect them through holes in the floor to create a multi-storey atrium. This approach facilitates achieving compliance as the 'notional building' would only present one window with height of 1.5m if the area is modelled as one. The approach to ceiling void modelling is heterogeneous within both groups: respectively 33% and 45% of professionals and students would not model false ceilings, while 65% and 38%, respectively, would use the "internal void or warm roof" template. Despite, professionals are less consistent

in the modelling approach in this case, the majority select the appropriate thermal template. In this case, modelling ceiling voids will result in a smaller glazing area on the notional building's façade, making achieving compliance harder. It is therefore possible that some professionals might choose the less accurate but more favourable solution in terms of compliance. Lastly, as Figure 7 shows, most students do not consider lighting profiles when defining thermal zones. Professionals demonstrate a better approach as it is preferable to differentiate areas with different lighting systems and proximity to windows due to parasitic loads and control of electric consumption. It is surprising that almost half of the professionals are unaware of this practice given the experience with Part L. Therefore, though overall the results are not significantly different, professionals present sharper trends towards what is considered the BA.

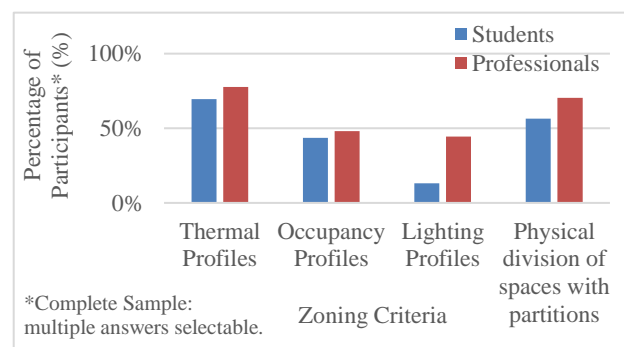


Figure 7: Thermal Zoning

In terms of simplification and capacity to abstract from the actual design, the two groups present similar modelling approaches with a slightly higher tendency of professionals to simplify and interpret the design. Consistently with the results presented in Figure 7, students divide the floor area less and tend to follow the physical partitions more than professional. Similarly, students and professionals agree that urban furniture, streets and sidewalks may be ignored, however 91% of students would model the trees in the design while 46% of professionals would not. As Figure 8 illustrate, students would simplify the perimeter of a zone rather than the window geometry while professionals would do the opposite though overall simplifying more. Simplifying the windows of an entire façade is probably perceived as a larger approximation compared to a single floor plan corner whereas, actually, that might not be the case. However, this could be attributed to the fact that students are less used to work within the industry time-frame: drawing many windows following the geometry is more time-intensive than one perimeter. Finally, students are relatively aware of standard modelling approaches but again have the tendency of being more faithful to the design, as demonstrated by the fact that they tend to trace the dxf, because probably unaware of the actual impact of the approximation (Figure 9).

Therefore, the results suggest a common approach between the two groups that is overall the *best approach*.

Students tend to be more precise in terms of geometric construction, while professional are more keen on simplifications and are more aware of standard modelling approaches and tool calculation methods. Knowledge of Part L does not significantly influence the model's construction but facilitates compliance.

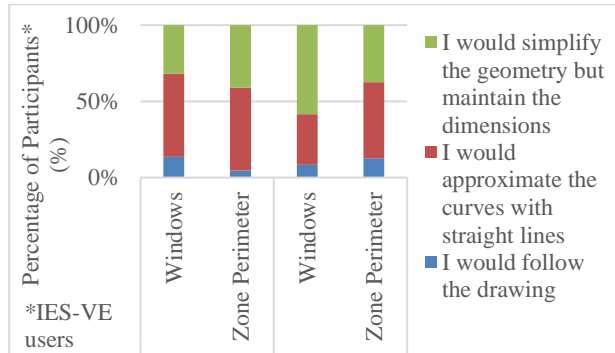


Figure 8: Modelling and Simplification

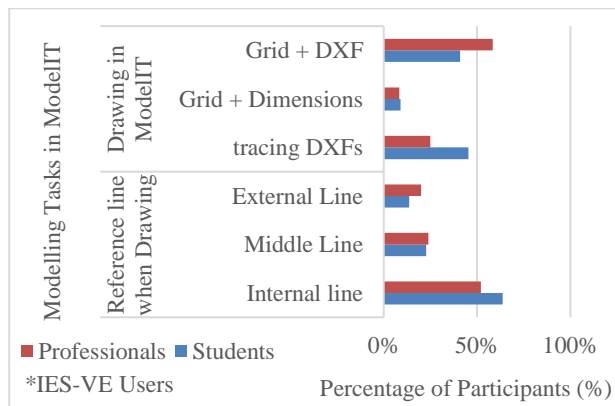


Figure 9: Standard Modelling Approaches

Building Services: HVAC, light, DHW

The second section of the practical survey explores the competence in terms of system modelling on IES-VE and the knowledge of building services.

In terms of procedures, the modelling of ventilation and lighting systems has been assessed for the IES-VE user

subsample. The results do not suggest any significant trend, however, what can be deduced is that students are slightly less familiar than professionals with standard compliance modelling procedures such as NCM lighting controls and the “free-cooling option” for natural ventilation. The latter is the recommended methodology for compliance modelling; however, is not particularly widespread among professionals either, with only 21% selecting it over Macroflo. Given the trends emerged so far, the popularity of Macroflo probably depends on the fact that ventilation modelling is more widespread in the industry and modellers are therefore more concerned to achieve a realistic ventilation model. On the other hand, participants appear less knowledgeable in terms of modelling of lighting systems and therefore tend to use less detailed methods. Only 19% of students, out of all participants, select Radiance; this probably depends from their greater familiarity with full thermal modelling than with compliance modelling.

The knowledge of building services is independent of the software used, therefore the complete sample has been considered. The results indicate that overall professionals are more knowledgeable and confident than students; however, some difficulties are noticeable across the board. For example, when asked to rank building systems according to their impact on the building emission rate (BER) for a mixed-commercial building in the UK, it is difficult to identify clear trends. The most obvious difference between the two groups is the impact attributed to lighting systems that are ranked among the last by students but first by professionals as these are often a major issue for Part L. The same confusion is noticeable when asked to rank the modelling inputs in order of BER impact, with professionals again being slightly more consistent. However, as Figure 10 illustrates, professionals demonstrate a better knowledge of building services than students. The variety of results registered among students when asked to model the identical VRF and VRV systems is indicative. Professionals instead, generally seem more competent with an almost constant proportion that is less knowledgeable.

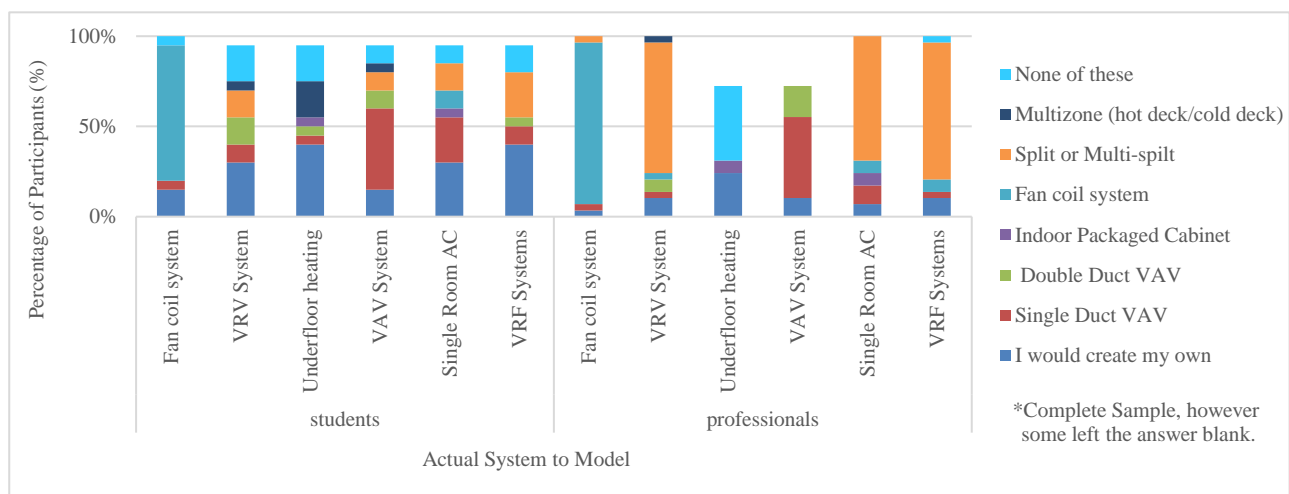


Figure 10: Modelling Building Services from Defaults

Result analysis and Auditing

Lastly, excluding non-IES-users the results indicate that that the groups largely use the similar review methods: the Tabular room data to check assignments, Vista Pro to check results. However, professionals also utilize more automated or graphical review methods such as Model Report Options and Input Visualization Data, while few students do. This demonstrates the different importance attributed to quality assurance procedures in the industry and in academic exercises. Lastly, few professionals use Design Comparison or Identify Dominant Issue Report. This could depend on the licence available but is peculiar considering the participants' Part L experience.

Discussion

The environmental design market

The study highlights various trends in terms actor involvement and market evolution that are worth considering when approaching the 'performance gap'.

Firstly, the initial assumption that students taking HE environmental design courses represent the future workforce is validated. The results suggest that professionals appreciate these qualifications, having verified that there is a good correspondence between the knowledge and competence provided by HEI and required in the industry. Exposure to regulations and rating systems is the only exception, however this is not perceived as a major limitation by most professionals. Overall, two different "recruitment" trends emerge: those interested in specific competences and those interested in the candidate's general aptitude. In the latter case, it is less significant for courses to provide specific skills, while it is more important for students to develop a critical approach to knowledge. Professionals however perceive training as an organic form of personnel growth; recovering the resources invested by hiring "industry-ready" employees would improve the strive for sustainability as this depends on the client's agenda.

Disregarding the understanding of building services and the importance attributed to on-site experiences, the knowledge provided by academic institutions is perceived differently by professionals and students. Professionals indicate the knowledge of building physics and the actual understanding of the significance of the modelling exercise as most challenging for students; commercial acumen, understanding of work flow and compliance are instead considered useful though not essential. Contrarily, students feel confident about their theoretical preparation and are more distressed about not having seen a project to its 'closure' in terms of standards, regulations and practicalities. Among different interpretations, it seems reasonable to infer that experience broadens the understanding of a topic and thus the awareness of its complexity while it is more immediate for students to perceive their practical limits when entering the work environment. Nevertheless, both groups agree that it would be more engaging for students to gain practical experience: the collaboration scenarios suggest aim to

address this gap.

In terms of evolution of the environmental design market, the study has highlighted how most of the current professionals have progressed into sustainability/energy consultancy/design roles over time. The next generation of professionals instead will probably come directly from academia which is likely to determine a different approach, less rooted in traditional design. This should guarantee a more thorough understanding of simulation tools engine's mechanisms having approached them academically. Contrarily, the excessive dependence on computational tools could jeopardize the application of first principles and hand calculations.

The above trends suggest that while during initial stages of the implementation of the energy modelling market the main focus was aligning the knowledge and technical training provided, nowadays the focus should be that of allowing students to relate the modelling exercise to the practical outcomes. The future generations of professionals will in fact have a wider range of educational background and will lack the experience in other sectors of engineering that current professionals have had because the environmental design market will increasingly be established as a separate field itself. This is likely to have an impact on the 'performance gap'. A better understanding of simulation engines is likely to reduce tool uncertainty, however by being directly introduced to this sector junior employees will have a lesser degree of direct experience modelled elements; therefore academia should consider providing it.

Modelling skills

The study highlights different trends in terms of knowledge applied to the modelling exercise and skills necessary to complete the task.

Overall, students demonstrate modelling skills comparable to professionals but lack the knowledge of standard modelling approaches and mechanisms behind Part L simulations. In terms of geometrical construction, the groups have similar approaches however students tend to simplify less and remain more faithful to the design. Furthermore, most students were unaware of the correct thermal zoning methodology, suggesting their limited experience with Part L, and find difficulties at modelling building systems. Therefore, despite the differences are not major, while students are aware of their shortcomings in terms of NCM, compliance and industry-oriented modelling approaches, their perception regarding their capacity to simplify is not as accurate.

In terms of building systems, the practical questionnaire confirmed that students' lack of knowledge. Overall, professionals tend to have a better understanding of building services, though uncertainty is registered across the board when asked to rank modelling inputs and systems according to their impact on BER. This is reasonable considering the variability associated with different buildings types however, a stronger trend was expected since many professionals have pointed out that experience improves the capacity of making "rough

judgments”.

As suggested by Imam (Imam et al. 2016), the results therefore generally confirm gaps in the knowledge and competence of all participants. Experience however marks the difference between students and professionals, whether in terms of Part L or simply in terms of having previously encountered a similar detail. Therefore, with the objective of attempting to reduce the ‘performance gap’ it would be good to bridge the ‘knowledge gaps’ identified in terms of building services, standard modelling approaches, understanding of tool simulation methods and capacity to relate the modelling exercise to reality. Knowledge of standards and rating systems can also be useful however, the results indicate how this does not influence the quality of the model but rather facilitates achieving compliance and improves the understanding of the software’s calculation methods.

Conclusion

In conclusion, despite the sample size prevents from extending the findings to the entire population, the study represents an attempt to photograph the current state of the industry in the UK. The following may be deduced.

- HEI provide students with the theoretical knowledge that will be most beneficial when entering the work environment but do not prepare them to be “industry-ready” and remain too generalist.
- The main shortcoming of academic courses is the scarce contact with physical and industrial reality. First-hand experience, both in terms of site visits and exposure to standard modelling procedures, would contextualize the knowledge and could be achieved through collaboration scenarios.
- Professionals and students have similar modelling approaches however: students are less able to simplify and are less knowledgeable in terms of the tool’s calculation procedures, modelling of building systems, standard procedures and compliance modelling approaches; professionals are overall more knowledgeable but still present varied approaches.

Based on the above findings, having understood the marginal importance of UK regulations in terms of quality of modelling approaches, similar trends are likely to emerge in other countries’ markets. The applicability would however depend on the relevance and level of implementation that the sector achieves in the country. The UK is considered avant-garde in terms of scientific research and quality of the industry in the environmental design sector. Therefore, similar trends are likely to emerge in countries where this market has a comparable relevance, while countries with a minor implementation of this sector are likely to present different trends. The different approaches emerging within both groups are likely depend on a combination of: different background knowledge, experience and training; different modelling objectives and the time-frame available which, in the case of professionals, could depend on the size of the company or of the project. A prevailing work routine is likely to develop in a standardized approach and this could vary among different companies. Therefore, it is positive that

universities do not generally expose students to the industry framework though it would be useful to give them a sense what is currently achievable in the professional reality and what they can aim to.

Further studies could examine the potential collaboration scenarios proposed, to verify the actual usefulness in terms of knowledge and skills acquired. It would be interesting to compare the knowledge of students who have participated at “collaboration scenarios” to those who have not. Furthermore, if done in a more systematic way, over a longer time-period, and with participation incentives, it would be interesting to include an actual complete modelling and result reporting exercise. This would allow to assess conceptual and non-conceptual skills, as well as, auditing, reporting and soft skills.

Limitations

Despite the effort to select a sample as representative of the industry as possible, the studies main limitation is the reduced sample size; particularly when selecting adequate participants for the practical analysis. However, a methodology offering diverse perspectives in terms of scale and detail, has been chosen to consider the possibility of obtaining low participation. The limited scope of the study in terms of geographical application and type of modelling is the other limiting factor in terms of applicability of the results; however, the attempt has been that of analysing a renowned industry sector. Similarly, insights from members of the academia, in charge of structuring the programs, would have been interesting and might have clarified economic and social drivers.

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