PERFORMER, CONSUMER OR EXPERT?
A critical review of BPS training paradigms for building design decision-making.

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ABSTRACT

In response to swift changes in the building industry, and the need to evaluate impacts of design decisions for energy-efficiency and legislation, universities are introducing training initiatives in BPS for building design decision-making. This work aims to identify and discuss prevalent paradigms used to teach BPS. Through a comprehensive and critical literature review, three paradigms are found: training the simulation 'expert' and training the architecture student to become either a 'consumer' or 'performer' of simulations. Examples from the literature are presented to illustrate each paradigm, followed by a discussion of where trainees of each paradigm would be situated in practical project environments. Recognizing these paradigms serves as a foundation to set up future teaching initiatives and research in this area. However, there is a need for members of both architecture and BPS communities to work together towards harmonizing distinguishing features of each paradigm, to fully-exploit the potentials offered by them.

Keywords: BPS training; critical literature review, paradigms.

1. INTRODUCTION

This paper aims to identify and discuss different paradigms of teaching building performance simulation (BPS) to be used in building design decision-making. The analysis is based on a comprehensive and critical review of English language publications discussing university-level BPS teaching initiatives directed primarily towards architectural students, enrolled in both undergraduate and postgraduate programs worldwide.

From a market perspective, the need to train architects in BPS predicates urgent reformation in current paradigms of architectural education, as the demand for new generations of architects who can independently understand, embrace and quantify design decisions for sustainability and energy-efficiency is underlined. In 2012, the American Institute of Architects (AIA) released the architects' guide to integrating energy modeling in the design process; encouraging architects' uptake of BPS to inform design decision-making (AIA, 2012; Reinhart et al., 2015). Right before that, in 2011, the Royal Institute of British Architects (RIBA) proposed a guide with suggestions for sustainability elements to be integrated throughout the different design stages (Gething, 2011). Besides suggesting which parameters and targets should be taken into account, the document also points out where energy modeling could be undertaken and for what specific purposes.

From an education perspective, it has recently been recognized that *"the teaching of BPS is a topic that deserves as much attention as the development and validation of models and simulation tools"* (Beausoleil-Morrison and Hopfe, 2015). Similarly, one of the key findings from a recent international survey is that a sizeable portion of professional architects believes that building performance should become a core component of architectural curricula at the university level, and that BPS should become a demonstrable skill prior to registration and licensing within professional architectural bodies (Soebarto et al., 2015). Correspondingly, more and more architecture schools are adapting their curricula and degree programmes to acclimatize to changes in the AEC industry (Reinhart et al., 2011; Kumaraswamy and de Wilde, 2015). Investigating the role of architectural education and focusing research interest, effort and funding on pedagogical affairs, toward improved uptake and use of BPS by the architectural community is further recommended by Hetherington et al., (2011), Doelling and Nasrollahi (2013); Alsaadani and Bleil De Souza (2016); Nault et al. (2017) and Attia et al., (2012) to name a few.

Research interest in this area is noticeably new founded; the above-cited quotation highlighting that some research attention must be directed along the avenue of *"the teaching of BPS"* (Beausoleil-Morrison and Hopfe, 2015) was composed only three years ago. It is therefore understandable that, at the time of writing, the teaching of BPS in the building design context is not grounded in theoretical literature. To date, a solidified and comprehensive theoretical foundation of how to teach BPS to architects and building designers does not exist. As a consequence, most research output concerned with the teaching of BPS for architects and building designers tend to present case studies documenting individualized teaching approaches attempted (e.g. Strand, 2001; Soebarto, 2005; Norford, 2006; Schmid, 2008; Sabry et al., 2010; Palme, 2011; Doelling and Nasrollahi, 2012; Reinhart et al. 2014 and 2015, etc., all of which are included in the review performed in this article in table 1). While these are often described as successful efforts by the authors of these works, and while approaches described in the articles may be considered recyclable; to be duplicated by others teaching the same subject matter at other universities, such individualized case studies cannot be considered representative as approaches to teaching adopted in the wider scope.

To date, the only work attempting to understand how BPS is taught around the world, beyond a distinct series of individualized case studies, is the recent survey research undertaken by Hopfe et al. (2017). Findings of this work indicate that, a normalized, one-size-fits-all model of teaching BPS to architecture students does not exist; and that teaching strategies and approaches differ from country to country and from school to school. Furthermore, findings indicate that only a nominal percentage of survey respondents incorporate the teaching of BPS in architectural design. Most of the time, architectural design studio and lectures in BPS are taught as two parallel streams; one does not inform the other. Moreover, only a limited number of instructors, who conduct BPS-integrated designs studios, recognize that a direct relationship exists between the two knowledge domains. The authors conclude that *"there is room for improvement,"* and that *"a shift in thinking in the architecture academia* [is] *necessary"* (Hopfe et al., 2017).

These findings echo descriptions of current teaching initiatives as *"scant"* and *"disparate"* in the 2015 position paper published on behalf of the IBPSA board (Clarke, 2015). Clarke (2015) highlights that *"there is an urgent need to harmonize the disparate educational information being used within degree programmes worldwide."*

However, we contend that, as a fundamental precondition to harmonizing educational information, it is first important to understand how BPS is taught for the purpose of building design in the wider milieu. This work therefore originates from the recognition that a theoretical body of knowledge about how BPS is taught in the building design context does not exist. Based on a comprehensive review of the literature, the purpose of this work is to unfold BPS teaching paradigms used in the building design context. The scope of this work is limited by formal training initiatives undertaken in universities; at both the undergraduate and postgraduate levels, and therefore does not include informal training initiatives such as student self-learning using help files, online tutorials and wizards[1]. The scope is also limited to initiatives training users in BPS for the purpose of optimizing architectural design decisions. While these are mostly undertaken at schools of architecture, as this review will unfold, the use of BPS for building design is also taught in a wider array of energy and built-environment related domains[2]. Works included in this review are therefore limited by the teaching of BPS for building design decision-making; regardless of whether or not they are undertaken at schools of architecture, engineering or any other built-environment discipline. However, the scope of this review does not include works discussing the training of engineering students in the design of HVAC systems and sizing, systems control and demand management, etc.

It is aspired that this work may contribute toward the construction of a theoretical foundation of knowledge in the discourses of BPS and building design in the long term.

2. METHODOLOGY

A comprehensive and systematic review of the literature, discussing how BPS is taught to support design decision-making, was performed. Identified scholarly and academic sources specializing in the broad scopes of energy and the built environment, and building design education, were queried (Appendix A, table A1). Keywords (Appendix A, table A2) were used to refine the research approach and identify the most relevant

[1] There are no formal studies discussing the use of these kinds of resources in the academic literature, meaning that it is not possible to report on them.

[2] Examples of these include the engineering postgraduate course undertaken at Carleton University in Canada and the Master of Science module delivered at Loughborough University in the UK described by (Beausoleil-Morrison and Hopfe, 2015, 2016a and 2016b). The Master of Energy Efficient and Sustainable Buildings programme at the School of Property, Construction and Project Management at RMIT university in Australia, described by Rajagpolan et al. (2016) is another example. These kinds of programmes are not always exclusive to architects, and tend to attract multi-disciplinary student cohorts from mechanical engineering, building services and architectural technology backgrounds (Bernier et al., 2016). Nevertheless, growing numbers of architecture students and/or graduates are enrolling in such programmes in response to market requirements. While these degree-programmes remain optional to architectural graduates with an interest in sustainability, energy efficiency, LEED accreditation, etc. these types of programmes constitute an important form of continuing education and training for architects willing to specialize in these areas.

scientific articles on this topic.

BPS teaching initiatives described in the academic literature, regardless of where the teaching initiative was undertaken, were included in our review. However, the literature search process was limited to English-language works; for practical purposes of understandability and legibility. This search process resulted in the identification of 37 papers suitable for analysis and review (Table 1)[3].

A qualitative thematic content analysis was performed to analyze the content of the articles. This is a *"qualitative data-reduction and sense-making effort that takes a volume of qualitative material and attempts to identify core consistencies and meanings"* (Patton, 2002). The thematic analysis was conducted with the purpose of identifying the paradigms of thinking behind each different report on BPS teaching. Each paper was analyzed by open-coding the article's content, to identify how each of the open-codes fit into the identified thematic categories. The authors preferred to resort to a manual 'pen-and-paper' approach to analyze and code the textual data. This is because computerized approaches to qualitative analysis are known to distance the researcher from the deep, rich qualitative data (Bassett, 2004). On the other hand, in qualitative tradition, it is important that the researcher gains a thorough and profound familiarity with the texts.

3. THE DIFFERENT TEACHING PARADIGMS

From the thematic analysis two main approaches of teaching BPS were identified: a 'domain'-specific approach and a 'user'-centric approach. 'Domain'- specific approach teaching focuses on understanding BPS and exploring the analytical potential it can offer. In the 'user centric' approach teaching focuses on exploring the use of BPS within the design process to support design decisions.

These two approaches result in fundamentally different teaching goals and courses of action. When the goal is to understand the BPS tool and explore the analytical potential it can offer, a rather classic approach to teaching seems to be preferred, i.e. lectures with fundamentals followed by specific exercises to explore their application in solving different types of generic problems. The training results in preparing BPS 'experts'.

When the underpinning goal of transferring BPS content is to explore the use of the tool within the design context, teaching initiatives tend to feature a design component as a common denominator and are heavily based on understanding the use of BPS results. They therefore assume designers are the ultimate BPS users either directly, when conducting BPS themselves, or indirectly, when 'consuming' BPS results prepared by consultants. This distinction also results in different teaching goals and courses of action. When considered the 'performers' of BPS, students are trained to run BPS themselves and integrate it throughout their design process. When considered the 'consumers' of BPS, students are trained to interpret results and interact with a BPS consultant while designing.

From the aforementioned thematic analysis, three different paradigms of teaching can be identified: training the BPS 'expert' and training the architecture student to become either a BPS 'consumer' or BPS 'performer' (Table 1; Figure 1). Examples from the literature of each of these three paradigms are presented, followed by a discussion of where trainees of each paradigm would be situated within practical project environments and scenarios.

[3] While the intention is for this paper to serve as a comprehensive review, and to therefore cover worldwide BPS teaching initiatives, as stated in the introductory section, the majority of works covered in this review originate from English-speaking countries. Out of the 37 articles included in the review (shown in table 1) nine of these originate from the UK, nineteen originate from universities in the USA and Canada and two come from Australia. Only nine publications found originate from non-English speaking countries (Germany, Brazil, Chile, Turkey and Egypt) and were published in the English language. Therefore, while this review is intended to be comprehensive in that it covers all works found, the authors do not claim that the teaching of BPS in all parts of the world occurs in the same way, as not all world regions are equally represented in this paper.

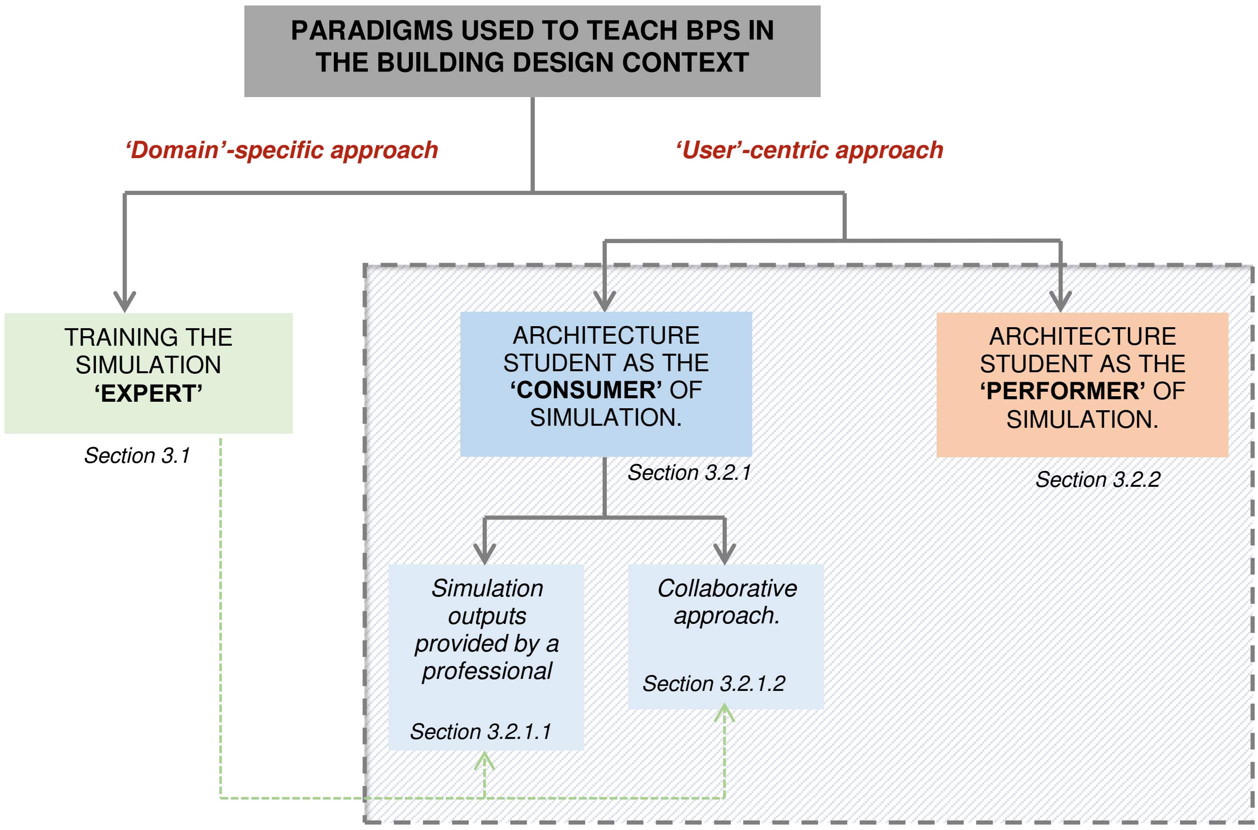

Figure 1: Prevalent paradigms used to teach BPS in the building design decision-making context.

Table 1: Publications extracted from the systematic literature review and analysed.

Publication	University at which the teaching experience undertaken is described	BPS domain(s) studied	Teaching paradigm		
			'Expert'	'Consumer'	'Performer'
Hand (1993), Hand and Hensen (1995), Hand and Crawley (1997).	Energy Systems Research Unit (ESRU), University of Strathclyde, Glasgow, Scotland, UK.	N/A	●		
Hanna (1996).	The Mackintosh School of Architecture, Glasgow School of Art Glasgow, Scotland, UK.	Daylighting			●
Batty and Swann (1997).	Cranfield University, Cranfield, UK.	Thermal.		●	
Tsou et al. (2000).	Department of Architecture, The Chinese University of Hong Kong.	Daylighting		●	
Strand (2001).	University of Illinois at Urbana, Champaign, Illinois, USA.	Thermal.			●
Roberts and Marsh (2001).	Cardiff University, Cardiff, Wales, UK.	Daylighting, acoustics and energy use			●
Strand et al. (2004).*	University of Illinois at Urbana, Champaign, Illinois, USA.	Not stated.			●
Soebarto (2005).	The University of Adelaide, Adelaide, South Australia.	Solar/shadow/ shading analysis Thermal			●
Norford (2006).	Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts, USA.	Daylighting Airflow Thermal			●
Delbin et al. (2006 and 2007).	University of Campinas (UNICAMP), São Paulo, Brazil.	Light, thermal and sound.		●	
Schmid (2008).	Universidade Federal do Paraná (UFPR), Curitiba, Brazil.	Light, thermal and sound.		●	
Augenbroe et al. (2008).	Georgia Institute of Technology, Atlanta, Georgia, USA.	N/A – *students create their own BPS platform.*	●		
Ibarra and Reinhart (2009).	McGill University, Montréal, Quebec, Canada.	Daylighting.			●
Charles and Thomas (2009a, 2009b, 2010a, 2010b).	Roger Williams University, Bristol, Rhode Island, USA.	Thermal, ventilation, acoustics.		●	
Sabry et al. (2010).	American University in Cairo, Cairo, Egypt.	Daylighting.			●
Palme (2011).	Catholic University of the North, Chile.	Acoustics, lighting, solar and thermal.			●
Doelling and Nasrollahi (2012) and Doelling and Jastram (2013).	Technische Universtät Berlin, Germany.	Thermal Daylighting.			●
Reinhart et al. (2011 and 2012).	Harvard University, Cambridge, Massachusetts, USA.	Thermal Lighting.		●	
Kim et al., (2013).	University of Pennsylvania, Philadelphia, USA.	Thermal Solar / daylighting Lighting Airflow			●

Publication	University at which the teaching experience undertaken is described	BPS domain(s) studied	Teaching paradigm		
			'Expert'	'Consumer'	'Performer'
Reinhart et al. (2014).	-Ain Shams University, Cairo, Egypt. -Concordia University, Montréal, Quebec, Canada. -Federal University of Paraíba, João, Paraíba Brazil. -Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil - Harvard University, Cambridge, Massachusetts, USA. - Iowa State University, Ames, Iowa, USA. - Miami University, Oxford, Ohio, USA. - Massachusetts Institute of Technology, Cambridge, USA. - Parsons the New School for Design, New York City, New York, USA. - University of Idaho at Boise, Boise, Idaho, USA. University of Southern California, Los Angeles, California, USA.	Daylighting		●	
Reinhart et al. (2015).	Harvard University, Cambridge, Massachusetts, USA.	Thermal Lighting Daylighting			●
Goçer and Dervishi (2015)	Ozyegin University, Istanbul, Turkey.	Thermal Lighting Daylighting			
Kumaraswamy and de Wilde (2015).	Plymouth University, Plymouth, UK.	Thermal Lighting Daylighting			●
He and Passe (2015).	Iowa State University, Ames, Iowa, USA.	Energy Daylighting.			●
Beasoleil-Morrison and Hopfe (2015, 2016a and 2016b).	Carleton University, Ottawa, Canada and Lougborough University, Lougborough, UK.	Thermal	●		
Rajagopalan et al. (2016).**	Deakin University, Victoria, Australia and Royal Melbourne Institute of Technology (RMIT) University, Melbourne, Victoria, Australia.	Energy Use Intensity (EUI) Daylighting Thermal	●		●
Bernier et al. (2016).	Polytechnique Montréal, Montréal, Québec, Canada.	Thermal Lighting Daylighting Airflow	●		

**Four different training courses are described in this publication; three for professionals and one for university students. Only the final one is taken into account in this review.*

*** Two different BPS initiatives are reviewed in this publication. The first initiative within the Master of Architecture (MA) programme follows the 'performer' teaching paradigm for architects. The second initiative, as part of the Master of Energy Efficient and Sustainable Buildings (MEESB) programme is concerned with training the simulation 'expert.'*

3.1 The 'domain'- specific approach - Training the simulation 'expert'

During the 1990s, Hand (1993), Hand and Hensen (1995) and Hand and Crawley (1997) offered an initial series of recommendations regarding training options that would be well suited to teaching *"the next generation of simulationists"* (Hand, 1993). They also discussed challenges to training simulation 'experts' and topics to be addressed during training. The aim was to consolidate simulation as an area of expertise within a scientific domain of building physics/engineering rather than an expertise in software operation. Therefore the advice given in these studies was mainly 'domain'-specific – i.e. focused on learning simulation as an experimental procedure to be used for multiple purposes (e.g. design decision making, HVAC systems design etc.) so the expert could position him/herself as an independent stakeholder – a consultant – in the building industry.

Proposals to train BPS experts, mainly outlined by Hand (1993) and Hand and Hensen (1995) were based on a training ladder which included: lectures with fundamentals of physics and simulation, structured exercises with progressive levels of complexity, software interaction normally self-taught through user manuals, workshops with experts for results' clarifications and error diagnosis and a final exercise with a real problem to be solved with the supervision of a trained expert. Through this formal training, Hand (1993), Hand and Hensen (1995) and Hand and Crawley (1997) shed light upon a critical challenge to prospective BPS instructors. Much of the pre-existing training courses offered by tool vendors, which often claim to produce users of 'expert' status within a limited time frame, are counterproductive to the learning process necessary to achieve this 'expert' status. These tool-centric teaching experiences tend to focus primarily on how users interact with the tools and produce models, using a single software suite alone.

In conveying a message that the software in-training is easy to use, tool vendors may over-simplify or even overlook the instruction of underlying fundamentals and important simulation aspects, such as how to abstract the building model while maintaining the most accurate representation of the building. Hand and Crawley (1997) claimed that user-friendly BPS tools do *"not alter the difficulty of understanding the complex thermophysical processes and interactions within building and environmental control systems."* Yet these often remain excluded in the training offered by tool vendors, user manuals or tutorials. They proposed training to comprehend how the building design can be best represented, how heat transfer processes are dealt with, which facilities provided by the software to use and whether, how and when to interrogate predictions produced by initial models. This shifts the focus away from the computer workstation and towards acquisition of fundamentals, how to re-read design issues as simulation tasks, understanding how different tools may be suited to different types of simulation problems as well as the limitations of each tool available.

In training the user to become a simulation 'expert,' Hand (1993), Hand and Hensen (1995) and Hand and Crawley (1997) emphasize the importance of investing sufficient time planning how to model a problem using manual aids, such as paper and pencil, before rushing to the keyboard. This planning may include an initial blueprint of the model geometry and zoning, identifying the zones in which systems may be installed and/or distinguishing the areas of the model where additional detailing may be required. It also includes how to best represent the building and the appropriate level of abstraction as, either oversimplification and/or inclusion of excessive detailing will produce divergent results. Emphasis is also given to the critical scrutiny of simulation outputs as it falls upon the user to ascertain whether predictions produced by the software are within a probable and acceptable range. Rather than accepting initial outcomes at face value, without further model calibration, a skeptical attitude on the user's part is necessary. This often means producing multiple variants of the initial model, to either confirm or deny initially proposed hypotheses and/or conjecture. Hand and Hensen (1995) maintain that *"it is hard to imagine an evolution in interface sufficient to release the user of* [these] *burdens;"* as responsibility falls upon the user, regardless of the computational platform employed.

This paradigm is still in use today, over two decades from originally proposed, as authors who address training experts such as Bernier et al. (2016) and Beausoleil-Morrison and Hopfe (2015) adopt a similar training structure. Both studies emphasize the understanding of fundamentals and modelling outside a specific software environment so that experts are forced to think critically throughout the entire experimental process. Bernier et al.'s (2016) teaching delivery is less practice based – i.e. delivered mainly through formal lectures and guided exercises. On the other hand, Beausoleil-Morrison and Hopfe (2016a) propose a *"complete and continuous learning cycle"* to transfer theoretical knowledge regarding BPS while simultaneously exposing students to practical exercises to apply the theoretical knowledge gained. To achieve this cycle, they map the teaching of BPS onto David Kolb's Experiential Learning Theory (ELT) in terms of BPS theory and/or application (table 2). This approach is less linear in terms of growing complexity as proposed by Hand (1993). During the 'reflective observation' phase the student is invited to reflect upon and re-visit fundamental theories from the 'abstract conceptualization' stage; making the learning cycle continuous and closing the loop of the student's learning. It also proposes students should interact with the software from the beginning of their learning as BPS is used from the onset in the 'active experimentation' stage.

Table 2: The BPS continuous learning cycle mapped against Kolb's experiential learning theory (ELT). Adapted from Beausoleil-Morrison and Hopfe (2015).

Kolb's Experiential Learning Theory (ELT).		**Beausoleil-Morrison and Hopfe's (2015) continuous learning cycle** - *mapping against Kolb's learning theory.*	
Learning stage *(according to Kolb's ELT).*	**Definition of learning stage** *(according to Kolb's ELT).*	**Relevance of learning stage in the context of BPS.**	**Example of teaching application in the context of BPS.**
Abstract Conceptualization (AC).	Studying theoretical foundations on a given topic.	Studying theories underpinning BPS knowledge (e.g. heat transfer fundamentals, mathematical construction of models, etc.)	Traditional delivery of lectures and topical lectures.
Active Experimentation (AE).	Transforming theoretical knowledge into practical experience.	Application of theoretical knowledge by using BPS tools, making decisions regarding modeling and simulation methodologies (e.g. abstraction and representation, selection of time-steps, etc.)	Offering guidance and support to students via tutorials, exercises and assignments, analysis of exemplars, reading user manuals and engaging with online tutorials (i.e. methods of self-learning).
Concrete Experience (CE)	Critique of accumulated knowledge gained via AC and AE modes, toward solidification of knowledge.	Critical engagement with outputs; skeptical reading and interpretation of BPS outputs, verifying results against expectations, inputs and any other variables that may impact upon outputs generated.	The 'simulation autopsy' (Beausoleil-Morrison and Hopfe, 2016b); a *"working session"* in which both students and instructors critically reflect on the simulation outputs to determine whether results align with expectations, and if not, what the likely sources of error may be.
Reflective observation (RO).	Reflection upon theoretical knowledge, practical experiences and critique, leading toward the constructive cementing of knowledge.	Reflection upon critical results' scrutiny, diagnosis of errors and correction. Relating this process of reflection to theoretical foundations studied during AE mode of learning.	Continuation of the 'simulation autopsy;' (Beausoleil-Morrison and Hopfe, 2016b).

It is interesting to note that the literature on training experts rarely focuses on how simulation data is transferred or communicated to the party outsourcing this expertise, i.e. how does it fit the different types of design workflows (building design, systems design, control design, etc.). Specific patterns and types of information communicated to these professionals and the design stages at which different pieces of information are best communicated to architects to inform their decision-making, are also seldom discussed. There are only a few exceptions that indirectly address this topic (e.g. Hand, 1993) when claiming experts should also be trained on selecting the most appropriate *"flows of information, decision points, and relationships between simulation facilities, generation of patterns and their interpretation"* (Hand 1993). However, these patterns, workflows and decisions points are not exactly recorded as contributions to the body of knowledge but supposed to be conveyed by immersing students in real world problems with expert supervision from those running these projects, i.e. based on 'learning by doing'.

Another approach found in the literature to address this topic is provided by Augenbroe et al., (2008). They propose that students should be immersed in a scenario in which they, apart from the training in fundamentals, also become tool creators. By becoming tool creators, students are expected to become more sympathetic to the end-user's perspective, more understanding of underlying principles, governing equations and assumptions embedded within BPS software and therefore better-equipped to use these software at an expert level to produce information for designers. However, the training of these students is still highly 'domain' oriented as to create their own platforms, students scrutinize modeling assumptions embedded within existing commercially-available tools, examined in heat and mass transfer principles and equations to be derived, discretized and included within their coding and finally test their programs in solving research assignments. The training is focused on creating a tool rather than on creating an interface between this tool and its users, perhaps because the user is always assumed to be an 'expert'.

These authors assert that graduates who have undertaken this experience become *"better dialogue partners in design teams"* (Augenbroe et al., 2008). How this contention was arrived at remains unclear from this contribution alone, given that this work is primarily focused on solidifying the students' technical knowledge; with little or no exploration of when and how, in a collaborative workflow this knowledge should be used and/or communicated.

3.2 The 'user' centric approach

When the intent of the teaching initiative is to produce architectural graduates who are capable of performing simulations themselves, teaching approaches differ considerably to when there is a desire to produce architectural graduates who do not necessarily perform BPS tasks themselves (i.e. in terms of creating the model, running the BPS software and interpreting the outputs), but can work with simulations (i.e. become the 'consumers' of simulation who are able to use simulation results they receive to make or alter design decisions).

This dichotomy mirrors, and perhaps stems from a similar, and currently unresolved polarization of the two views in the wider BPS community. On the one hand, Attia et al. (2009), Attia et al. (2012); Bombardekar and Poerschke (2009); Pedrini and Szokolay (2005), Hetherington et al., (2011); Grahovac et al. (2013); Marsault (2013); Doelling and Nasrollahi (2013) to name a few, all support the aspiration that the architectural designer should also be the 'performer' of BPS. Placing the inherent power of BPS in architectural hands is thought to both facilitate and streamline the design decision-making process; whereby design decisions are supported by quantitative measures of performance instead of qualitative rules of thumb, or subjective opinions of aesthetics[4]. Realizing this aspiration is regarded to be part of the evolutionary role of architectural education (Doelling and Nasrollahi, 2013). The counter-argument, that BPS should be left to simulation experts who work with, or collaborate with architects is supported by MacDonald et al. (2005); Bleiberg and Shaviv (2007); Hitchcock and Wong (2011); Grinberg and Rendek (2013); Viola and Roudsari (2013); Alsaadani and Bleil De Souza (2012; 2016 and 2017) to name a few. This view originates from the position that, in reality within the building industry, architects seldom perform simulation themselves, and instead tend to collaborate with specialists in the BPS field, becoming 'consumers' of simulation, to overcome limitations in knowledge, time and praxis, amongst other practical constraints.

3.2.1 Architecture student as the 'consumer' of simulation

This paradigm follows the idea that simulation should be undertaken by experts, because learning the software and constructing BPS models does not fall within the architect's traditional scope of work (Delbin et al., 2006; Charles and Thomas, 2009a and 2009b; Schmid, 2008). Studies that focus on defining the architecture student as the 'consumer' of simulations tend to shift the emphasis toward exploring interactions between designers and 'consultants'. They emphasize that the architect should still be able to work 'with' BPS, i.e. that *"the decision-making members of the design team should learn how to read basic energy simulation outcomes and how to adapt their design accordingly"* (Reinhart et al., 2011).

[4] For a detailed discussion of how placing BPS in architectural hands may improve the design process, please read Augenbroe (2001), Clarke (2001) and Attia et al. (2009 and 2012).

Creating a BPS-rich environment in which architecture students can become accustomed to working 'with' BPS predicates the inclusion of a BPS professional or expert as a core component of the teaching set-up. Interacting and communicating with an expert in BPS would draw architecture students' attention to the benefits and limitations of BPS, some modelling assumptions and simplifications and, most importantly for architects, how to understand and work with the results. Most significantly, *"as* [architects] *learn more about the subject,* [they] *become better at understanding* [their] *own limitations,"* (Reinhart et al., 2011) and what the BPS 'expert' may add to the design decision-making process. This is likely to lead to a more fruitful intellectual engagement between the architect and the BPS consultant or expert.

Inherently, the teaching of BPS is intertwined with the teaching of underlying building physics fundamentals. Proponents of the 'consumer' paradigm claim that *"building simulation tools"* can serve as *"potential allies to the teacher and learner to achieve better buildings and greater sustainability"* (Charles and Thomas, 2009a).

It is widely contended that teaching building physics is most often restricted to theoretical lectures and only simple calculation exercises (Delbin et al., 2006 and 2007; Palme, 2011; Schmid, 2008). In most cases there is limited application to design problem solving, meaning that students' understanding and practical application of energy-related and comfort issues remain underdeveloped. It is therefore difficult for them to directly apply the theoretically accumulated building physics knowledge in design studio. Students' building physics knowledge remains compartmentalized to the lecture hall, without properly transcending into design decision-making. Schmid (2008) and Delbin et al. (2006 and 2007) therefore advocate using BPS tools to solidify students' understandings of building physics concepts acquired during earlier theoretical modules. This includes raising students' awareness of the implications of initial design decisions (e.g. building form, orientation, layout, wall-to-window ratios) on performance, and encouraging them to use this knowledge of environmental parameters to resolve design problems. Correspondingly, the target of training 'consumer' architects in BPS ranges between optimizing the building envelope design (e.g. Charles and Thomas, 2009a, 2010a and 2010b), simulating thermal and acoustical behaviour (Schmid, 2008), improving overall thermal comfort (Delbin et al., 2006 and 2007) and reducing energy use intensity (Reinhart et al., 2011 and 2012).

Furthermore, Charles and Thomas (2009a and 2009b) maintain that endowing architecture students with a preliminary and working knowledge of building physics and BPS facilitates the architect's communication and engagement with the BPS expert, and teaches students to "*hold their own role within the consultant-designer interaction"* (Charles and Thomas, 2009b). This would allow architects to retain their position as 'design leaders' in future professional practice, who are able to *"negotiate"* with the experts *"and challenge the BPS modelling results they received from their consultant team"* (Charles and Thomas, 2009b) instead of being mere recipients of information.

3.2.1.1 Simulation outputs provided by a professional

In this teaching set up (e.g. Delbin et al., 2006; Reinhart et al., 2014), architecture students are required to provide input data for a BPS expert to construct the BPS model and conduct the simulations. The professional returns results of the simulations to students, who are then encouraged to interrogate them, interpret the results and revise the design. The professional is then invited to re-simulate the modified proposal once again. The merit of this approach is that the performance assessment method is quality assured and remains consistent across the entire student cohort. However, the stage(s) of the design workflow at which interactions between architecture students and BPS experts tend to occur are not explicitly stated in the literature.

Reinhart et al (2011; 2012) propose a similar approach to this in *"learning by playing – teaching energy simulation as a game."* In this case however, architects should not solely rely on the BPS consultant or 'expert' to translate the meaning of results produced by BPS. Thus, part of this knowledge is delivered through traditional lectures whereas the applications of it are explored through a 'constrained' design competition. Students had to modify the design of a given office building by selecting between a series of pre-set parameters and configurations, relating to building massing, orientation, building envelope, lighting and

HVAC systems. These parameters, when combined, could potentially result in up to 400,000 alternate building configurations.

In practice this translates to students completing a simulation ‘order form,’ listing the design choices (parameter combinations) they had selected. The ‘experts’ then ran simulations and emailed the results back to the students. This process followed a number of iterations; students would modify the building design configuration based on the simulation outcomes and re-submit their revised design proposals to experts, to ascertain whether the energy use had been reduced. Teams were required to describe the design strategies, what they had learned from the game and reflections on the educational benefits of the game approach.

In both cases we see a split of the design task, in which the expert is in charge of the performance assessment while the architects are in charge of making design decisions. It is essential here to distinguish between the notions of splitting the work with a BPS expert, and collaborating with a BPS expert, and to clarify why at this point, we do not use the word ‘collaboration’ to describe the working relationship between student and BPS expert in this scenario. Splitting the work does not necessarily mean that the student is collaborating with that professional; as the latter is not participating in the decision-making activity that remains the core objective of conducting the simulation. Collaboration is not a simple division of the design into a series of constituent tasks to be outsourced to different professionals, each of whom works on their part in a comfortable isolation from the other, attempting to piece the design back together into a whole at the end (Alsaadani and Bleil De Souza, 2017). Rather, effective multi-disciplinary collaborations can only occur once a unified foundation; an integrative platform for professionals to work together in harmonious synergy, is created (Alsaadani and Bleil De Souza, 2012; 2017).

3.2.1.2 Collaborative approach

Charles and Thomas (2009b; 2010a and 2010b) explore the merits of creating collaborative teaching set ups[5]. This is intended to bring together both architecture and engineering students into a single multi-disciplinary working environment to undertake a design project in which each engineering student would act as a consultant for a pair of architecture students. Architecture students and consultants were instructed to meet regularly from the conceptual design stages, and consultants were asked to employ the following prescribed workflow:

1. Creating base case energy and bulk airflow models.
2. Undertaking sensitivity tests in a series of building parameters (e.g. wall assemblies, shading configurations, natural ventilation inlet and outlets, etc.) to understand their impact on building performance.
3. Sharing, analyzing and discussing results with the architecture students they were assisting to develop and improve the design proposals, and correspondingly iterating these three steps to re-test refined proposals and ascertain whether the modified parameter resulted in improved performance.

Acknowledging that high-quality modeling can be difficult to achieve by student modelers, and within a limited time frame, the authors emphasize that greater attention of this teaching setup was placed on the afore-described iterative process, as well as the collaborative workflow, rather than the comprehensiveness of the modeling. This was particularly important for the engineering students who were unfamiliar and uncomfortable with the collaborative studio teaching setup. Due to time constraints, the simulation effort was limited to modeling a series of ‘what-if’ scenarios. The authors question whether, as a consequence of this limitation, students fully developed an understanding of how simulation could assist the whole design process, and whether they grasped the full potential of BPS software.

Another example of the collaborative approach is provided by Batty and Swann (1997). Rather than training energy practitioners to collaborate directly with architects, a building designers’ workflow is mimicked, to

[5] In these initiatives, the collaborative initiative is intended to train architecture students to become ‘consumers’ of both BPS and data acquisition (DA) information and outputs. However, as DA is outside the focused scope of this work, any discussion of DA has been discounted from this review.

demonstrate how using a BPS platform can adequately inform different stages of the building design process. At the earliest design stages (i.e. during the site analysis and research phase; before concept development), students were required to create simple exploratory models, to inform site analysis. Students would model site geometry and surrounding buildings to determine annual, monthly and daily shading patterns. As the work proceeded toward the conceptual design stage, students used BPS to make preliminary assessments of a number of conceptual design variants that affect building performance. These included orientation, glazing specifications, area, material usage, occupancy, etc. Thus, as the design process increased in complexity, the outputs provided by the simulations also increased in value for the decision-making process. As the design team proceeded, matrices were set up to assess the combination of different design variables on building performance and environmental impact; leading towards the execution of a simulation-based design process following a design-and-test approach.

Batty and Swann (1997) contend that working through this simulation-based design process fosters a deeper understanding of a building's thermal performance and how BPS can enhance design decision-making. While there is no doubt that a sound technical knowledge is of paramount importance for the BPS 'expert,' the ability to communicate that knowledge to a non-technical audience in order to benefit the architectural design process is no less essential. However, it is unclear whether Batty and Swann's (1997) contribution is based on assumptions of building designers' workflow, or is grounded in evidence about the design process. Nevertheless, for the architectural design process to reap the maximum benefits from the contribution of simulation experts, training in collaboration and communication, as well as constructing a reciprocal understanding of the architectural design process, like in the experience described by Batty and Swann (1997), needs to become a prominent feature in the education and training of BPS professionals and 'experts.'

3.2.2 Architecture student as the 'performer' of simulation

Under this educational paradigm, delivering BPS content to students of architectural design follows the rationale that, by being the primary performers of BPS, students will better understand elements of building performance and the impacts of design decisions on performance (Kumaraswamy and de Wilde, 2015; Charles and Thomas, 2009a; Soebarto, 2005). When students use BPS tools themselves, *"the design values of comfort, adequacy and energy efficiency of the built environment become clearer than when only theoretically considered"* (Soebarto, 2005). This teaching approach is also believed to help students think about performative aspects earlier during the design process, and consider how to create integrated and tailored solutions that fully utilize the information provided by BPS. In addition, it is further contended that training students to follow an experiential, simulation-based design process improves students' creativity in problem solving, which *"maintains the core of architectural education"* (Goçer and Dervishi, 2015).

The focus in training the architectural designer to become a 'performer' of BPS is not to teach students how to use one or more BPS platforms (Soebarto, 2005) or to become expert simulationists (He and Passe, 2015). Rather, the software plays an assistive role toward demonstrating how BPS may be used to guide the design process. Placing students in formative situations, and fostering hands-on learning allows students to better notice how buildings perform, *"than using the conclusive language of a handbook"* (Soebarto, 2005).

Training architecture students to become 'performers' of BPS appears to follow the underpinning notion that learning from one's personal experience offers the best in knowledge acquisition. This further aligns with Jean Piaget's constructivist theory of learning, which underlines the importance of students' active involvement in the learning process. According to this theory, the student is not a mere, objective recipient of knowledge. Rather, a student's own background, understanding and experience play a dominant role in how this knowledge is molded, mediated and gradually constructed. Grounding BPS teaching delivery within the student's own design realm therefore creates a personalized platform in which the experience of learning to use BPS is tailored within the student's own design experiences and tacit interpretations of the design process.

3.2.2.1 Teaching the 'performer' architect

Our review finds the 'performer' paradigm to be the most commonly employed trajectory of teaching BPS to architects described in the literature. The summary conducted in table 1 shows 15 records of teaching architects to become BPS 'performers.' A semester-long teaching set up is often described (e.g. Strand, 2001; Soebarto, 2005; Sabry et al., 2010), allowing for an incremental construction of knowledge following a design-and-test approach.

The beginning of the setup usually involves traditional lecture delivery in BPS (including building physics); with explanations of how BPS can assist in design development. The objective at this initial stage is to enhance students' understandings of building physics and HVAC-related concepts, including mass and energy balances, building envelope, internal gains and resulting heating and cooling loads (e.g. Strand, 2001; Kumaraswamy and de Wilde, 2015; Norford, 2006). The necessity of this fundamental understanding is emphasized by Soebarto (2005) who notices that, when *"students lack … knowledge in the issues related to thermal performances of buildings,"* including the *"basic principles of load calculations and some of the technical terms associated with them"* this makes any attempt of introducing BPS fundamentals, and discussing different BPS software platforms *"problematic"* (Soebarto, 2005).

As the objective of this approach is not only for students to become proficient in one or more BPS tools, but also to adopt a more direct, 'hands-on' approach to grasping building physics fundamentals, theoretical lectures are followed by training in one or more BPS software platforms, sometimes connected to building design software (e.g. Autodesk Ecotect in Soebarto (2005) and Sefaira in the MA teaching program described by Rajagopalan et al., (2016)). This paves the way to the use of BPS platforms in a building design project, and/or the modeling of one or more building components.

In this context, BPS tools are regarded as design tools; helping architects to visualize and ascertain the impact of design decisions in parametric format. Rather than using BPS to analyze performances of fully-developed proposals, Ibarra and Reinhart (2009), Kim et al. (2013), Doelling and Nasrollahi (2012), Doelling and Jastram (2013), Soebarto (2005) and Rajagopalan et al. (2016) all describe using BPS to support an evidence-based design process, whereby BPS tools are used to support the synthesis of design ideas, and are thus incorporated from the earliest stages of design ideation and progression. This design trajectory means that the training target of 'performer' architects is purposively broader than that of 'consumer' architects discussed in section 3.2.1. In addition to optimizing thermal behavior, improving internal comfort, energy efficiency and achieving improvements in building envelope design (e.g. Rajagopalan et al., 2016), targets of the 'performer' paradigm include using BPS to incorporate passive strategies to yield improvements in space conditioning (e.g. Norford, 2006) as well as making thermal load predictions to design and/or select appropriate HVAC systems (e.g. Strand, 2001; Reinhart et al., 2015). 'Performer' architects are also taught to recognize the interactions that occur between inter-related performative domains including thermal, daylighting and airflow, and learn how effects of one of these domains may impact on the others. Thus, unlike the 'consumer' paradigm training targets, which appear to focus predominantly on a building's thermal behavior, 'performer' students are trained in a range of performative areas including thermal, daylighting and airflow simulations. For example, students enrolled in the initiative described by Ibarra and Reinhart (2009) used Autodesk Ecotect to prepare models followed by RADIANCE software to simulate daylight distributions in internal spaces. Kim et al. (2013) use EnergyPlus, RADIANCE and ANSYS Fluent to design, test and modify a proposal for a retractable shading device considering performance in terms of energy usage, daylighting, natural ventilation and passive cooling.

This breadth of training targets appears to convey an important delineation between the roles of 'consumer' and 'performer' architects. The former's training is restricted to using BPS outputs to inform design decision-making, meaning that the 'consumer's' design role is confined to making building design decisions. However, the broader and seemingly more open-ended nature of training targets for the 'performer' architect expands this design role beyond that of building design, to involve designing the problem solving approach using BPS. Fully-exploiting the design-assistive potential of BPS includes being in a position to recognize what the targets for BPS testing are and, correspondingly what the performative domain(s) that needs to be tested will be. This explains why, within the 'performer' paradigm, BPS is regarded as a welcome complementary addition to the iterative and cyclical design development process. Noting that architectural design is inherently an activity of discovery, and maintaining that adding environmental performance factors, via BPS testing, ultimately makes this process of discovery more profound, Kim et al. (2013) name this process 'discovery-performance-design.'

Reinhart et al. (2015) propose a structured constructivist approach to teach 'the performer'. Students undertake a series of interconnected simulation exercises with increased levels of complexity. These exercises are intended to draw students' attention to building physics fundamentals, and how these may affect building performance. They are therefore a combination of personal experiences with the topic with a gradual introduction of the fundamentals in a rather empirical way. There is one exercise to foster students to think about sustainability by reflecting on their day-to-day lifestyle and one exercise designed to make students understand thermal comfort parameters drawing from their own experiences of monitoring and recording temperatures and relative humidity on a psychometric chart.

As architects are trained to be primarily visually oriented professionals (Punjabi and Miranda, 2005), initial exercises demonstrate more visual aspects of energy to students. A gradual transition toward non-visual aspects of energy use is proposed as their intellectual understanding develops. BPS is introduced through daylighting and students are asked to compare results of their own 3D lighting model with a photograph taken under a clear sky. This comparative analysis allowed instructors to demonstrate how similar the results between the simulated and actual scenarios may be, provided that BPS software is used correctly.

Non-visual energy modelling is introduced through hands-on experimenting with the building envelope and how different envelope configurations (i.e. insulation thicknesses and window arrangements) directly impact on the amount of energy needed to condition a space. Multiple variants of a single conditioned, yet unoccupied space were modeled, each with different insulation and window configurations to illustrate relationships between window size and energy use inside the building. From this students are invited to experiment with renewable energy systems by undertaking solar availability analysis and shading studies to forecast monthly electricity yield from PV systems they proposed.

A set of two design exercises were then proposed for students to understand how to improve building envelope (i.e. building orientation, internal space layout, shading, insulation, etc.) to reduce energy consumed for heating and/or cooling. Two exercises in daylight modeling were also performed to train them to assess photometric measurements and calibration. All students demonstrated an ability to perform simulations, generate results and interpret them, as well as applying modifications to the design based on the results. In contrast to the teaching experiences reported in Reinhart et al. (2011 and 2012), students were given several weeks' worth of time for active experimentation in building physics, BPS and interpretation of BPS results.

4. DISCUSSION

4.1 The 'expert' and the 'consumer;' two sides of the same coin?

When training the simulation expert within a domain-specific teaching approach, the intention is to develop the expert's in-depth technical knowledge and skill-sets that not only enable the completion of complex simulation tasks, but also allows the expert to situate him/herself as an independent consultant to confer with on the design team. On the flipside, training the architecture student to 'consume' BPS entails endowing architecture students with enough technical knowledge to allow them to work with the BPS 'expert.' This would facilitate the establishment of an effective and fruitful collaborative relationship amongst both parties, so that fully informed design decisions can be made, without the loss of any important information in the process.

Juxtaposing the 'expert' and the 'consumer' paradigms within the context of this discussion brings to the fore the notion that these two parties are essentially two faces of the same coin. In other words, in a post-educational and practical project scenario, this trained 'expert' would serve as an external consultant who collaborates with the architect. The architect in turn is trained as a 'consumer' of BPS, and of the information relayed by the BPS expert. Understanding that this type of interpersonal relationship exists between these two professional parties prioritizes the need to further question whether the two parties are trained to effectively work together.

Training the 'consumer' architect to effectively collaborate with a BPS 'expert' is two-fold in nature. It first entails imparting enough technical knowledge to the architect that would enable him/her to understand and communicate with the expert. The cause also requires making sure the architect has the necessary interpersonal skills in collaboration and communication that would permit engagement in a dialogical exchange with minimal confusion or frustration. However, most 'consumer' educational initiatives reviewed in section 3.2.1 of this paper appear to focus primarily on the latter; enhancing architects' collaborative capabilities. On the other hand, there is little agreement on what elements of BPS training need to be featured as core knowledge components to be conveyed to the 'consumer' architect, to allow him/her to effectively engage with a simulation expert, and how this part of the training should be undertaken.

Conversely, training the simulation 'expert' appears to focus almost entirely on accumulating detailed technical knowledge. There appears to be little or no attention devoted to understanding how architects make design decisions, and how or where in the architects' workflow technical information derived from BPS may both fit within and inform the architectural workflow. While there is no doubt whatsoever that an accurate understanding of detailed technical knowledge should take precedence in training technical professionals, so long as technical experts are unable to effectively disseminate this knowledge to professionals from outside their own disciplinary circle, the full merits of this technical information will remain under-exploited. One route towards effective technical knowledge dissemination is therefore informing BPS 'experts' how architects work, as well as how and where BPS may inform design decision-making. The challenge behind this part of the training is that there is little formal body of knowledge about architectural design decision-making; because most of the knowledge about it is tacit and transmitted through 'learning by doing.' This means immersing 'experts' within a design environment is probably inevitable.

4.2 The 'performer' architect and the BPS 'expert;' from generalist to specialist?

The aims behind training the architecture student to become a 'performer' of BPS include raising students' awareness of implications of design decisions (e.g. building form, orientation, layout, wall-to-window ration) on building performance, while nurturing students' reflective and critical thinking skills; working toward an evidence-based design process. Interesting examples are found in the literature in terms of how this training could happen (e.g. Reinhart et al. (2015)) by aligning it with a constructivist-teaching paradigm in which, through active experimentation with a series of design problems, students construct their learning of BPS. This teaching approach involves some elements from the 'expert' teaching paradigm.

Training the 'performer' architect is inherently more technical in nature than training the 'consumer,' in the sense that the architect would need to be able to become familiar with building physics fundamentals, engage with BPS software and make appropriate decisions concerning abstraction and selection of appropriate simulation methodology. However, the amount of detailed technical knowledge gained is unlikely to equate to the simulation expert's technical knowledge. For example, the 'expert' may have greater capabilities in skeptically interrogating simulation outputs and diagnosing potential sources of error than a 'performer' architect; as this is an inevitable focus in the BPS 'expert's' training; as discussed in section 3.1. Similarly, the BPS 'expert' may have a greater awareness of the limitations of commercial tools, and may therefore be able to select and use different platforms at varying levels of depth to circumvent these limitations (e.g. using WINDOW software to simulate transient heat flow through fenestration). On the other hand, it is unlikely that the 'performer' architect will have received training in a broad scope of commercial and research-grade tools; meaning that s/he ultimately loses out on the 'expert's' adaptability by comparison.

In practical project scenarios, the 'performer' architect may play a generalist role, analogous to that of the general practitioner in the medical profession. For instance, small-to-medium sized architectural practices, which only consult with experts at later stages of the design process, may prefer to hire 'performer' architects. A 'performer' architect may similarly be favored by architectural practices situated in countries with less stringent energy legislation, or where gaining green building certifications remains optional. In both these contexts, the 'performer' architect could potentially undertake both the role of the architect and the BPS user until expert advice is needed. Therefore, so long as no formal commitment with external consultants is required to comply with accrediting bodies such as LEED or BREEAM, or to conduct more detailed calculations to enable planning permissions to be granted, the 'performer' architect could save time often wasted waiting around for consultants, ultimately speeding up the design process. The 'performer' architect could potentially save the architectural firm additional costs associated with early consulting of an exploratory nature with BPS 'experts' to perform the modeling and conduct BPS calculations. To return to the medical profession metaphor, when more detailed, complex tasks that cannot be fulfilled by a generalist are needed, the 'performer' architect would know when reference to a specialist's opinion is needed. Therefore, when the BPS 'expert's' opinion is needed, the 'performer' may act as a translator in this scenario, facilitating communication between the technical specialist and the architectural firm being represented; which would ultimately make the interaction more effective. Finally, the 'performer' architect may be regarded favorable from a professional status perspective, for reclaiming the architect's traditional role as the prime decision-maker on the design team; a position which is currently under threat (Alsaadani and Bleil De Souza, 2016; Barrow 2004; Hamza and Greenwood, 2009; Goçer and Dervishi, 2015).

5. CONCLUSIONS

There is a widespread agreement amongst the scientific community that teaching BPS within the scope of building design decision-making and architectural education holds promising opportunities for the future; and may pose a long-term solution towards integrating BPS in the design process; an issue that currently remains unresolved (Pedrini and Szokolay, 2005; Attia et al., 2009; Bleil De Souza, 2009; Venancio et al., 2011; Attia et al., 2012; Alsaadani and Bleil De Souza, 2012; Soebarto et al., 2015; Hopfe et al., 2017).

This paper aimed to identify and discuss the prevalent teaching paradigms under which BPS is used to inform building design decision-making. Three different paradigms were unfolded:

- **Training the simulation 'expert':** When specialists are trained in the field of BPS to serve as independent consultants for different building design stakeholders (building services engineers, mechanical engineers, quantity surveyors and architects to name a few).
- **Training the architecture student to become a 'consumer' of the simulation:** When architects are trained to base their design decisions on BPS predictions following an evidence-based design process by working with a BPS 'expert' within the design team.
- **Training the architecture student to become a 'performer' of the simulation**: When architects are trained to have a more intimate understanding of design decisions affecting building performance and act as generalists. These architects are endowed with enough technical knowledge to perform BPS tasks and make design decisions based on the outcomes up to a certain point, after which reference to a specialist is needed.

These findings corroborate the idea that current teaching initiatives are 'disparate', as highlighted by Clarke (2015). However, the findings also open a new basis to discuss the harmonization of educational information in which recognizing these three paradigms of BPS training constitutes a possible foundation for the setup of future teaching initiatives. Once the aims behind each of these paradigms are clear, members of both the architectural and BPS academic communities can potentially reach an agreement on how to address fundamental issues embedded within each of these different paradigms.

When training the simulation 'expert', understanding how designers make decisions would allow BPS 'experts' to better fit within the architectural workflow, by knowing what information is useful, and the right time to provide this information to streamline design decision-making. Questions that remain unexplored in this paradigm are:

- What elements of architectural knowledge; pertaining to the design process and design decision-making, must be conveyed to BPS experts as a predecessor to improving collaboration and communication with architects?
- How can this knowledge be effectively conveyed to the expert, considering that it is mainly tacit and transmitted through learning-by-doing?

When training the architecture student to become a 'consumer' of simulation, issues related to the depth of knowledge in building physics and BPS to be provided to architects arise. Questions that remain unexplored in this paradigm are:

- What elements of building physics, and possibly BPS must be conveyed to the 'consumer' architect to allow an effective interaction with the BPS expert?
- How can this knowledge be conveyed to the 'consumer', considering that parts of it are also acquired by tacit means (e.g. problem simplification and abstracting a spatial scenario into a computational model), and 'consumers' will not run BPS themselves?

When training the architecture student to become a 'performer' of simulation, issues related to the depth of knowledge in building physics and BPS to be provided to architects also arise. Questions, which are starting to be answered through a constructivist-teaching paradigm in the literature, are:

- What elements of building physics and BPS must be conveyed to the 'performer' architect to ensure the BPS process is quality assured and accurate enough to be used as a basis for design decisions?
- How could this knowledge be conveyed to the 'performer' so that it complements and enhances the creative design process?

Inherently, the matter of introducing BPS technologies into the architectural domain is an issue of multi-disciplinary research and knowledge transfer. Ideally, members of both communities should work together to pragmatically agree on how teaching BPS in the building design context, via each of the three prevalent teaching paradigms, should merge knowledge from both domains. In addition, once a detailed understanding of the three teaching paradigms, and how teaching occurs under their respective umbrellas, is achieved it may also be beneficial to explore how BPS is taught in adjacent, related fields (e.g. building services engineering, mechanical engineering, civil engineering fields, etc.). Identifying prevalent paradigms used to teach BPS in these adjacent fields, and comparing these to the three paradigms commonly found in the architectural world, may yield valuable contributions.

Furthermore, this research points toward a potential link between BPS teaching paradigms and wider theories about teaching and learning in the literature. Training the architect to become a 'performer' of simulations seems to align with constructivist theories of learning, which empower designers to develop an experiential learning process that enables them to determine how much self-learning needs to occur. Since this self-learning takes place within project-based environments, it possibly cultivates creativity at the same time. However, no evident connection between the remaining two identified paradigms (the 'consumer' and the 'expert') and the theoretical body of knowledge on teaching and learning could be found, based on the analyzed publications. Therefore, to consolidate a theoretical foundation for BPS teaching, one challenge for future research is to further align each of the 'consumer' and 'expert' paradigms to relevant teaching and learning theories from the academic literature. This would help educators identify teaching goals, and experiment with different teaching methods, to determine those that are best suited for each paradigm.

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Appendix A.

Table A1: Reviewed sources for selection of relevant publications

Scope	Journals	Publisher
Energy and Built environment	Journal of Building Performance Simulation - Architectural Science Review – Architectural Engineering and Design Management – International Journal of Sustainable Energy – Advances in Building Energy Research – Science and Technology for the Built Environment – Building Research and Information.	Taylor & Francis
	Energy and Buildings – Building and Environment – Journal of building engineering – International Journal of Sustainable built Environment – Applied Energy – Energy for Sustainable Development – Renewable and Sustainable Energy Reviews. – Automation in Construction.	Science Direct
	Construction Innovation – Engineering, Construction and Architectural Management – Facilities – Journal of Engineering, Design and Technology – Smart and Sustainable Built Environment – International Journal of Building Pathology and Adaptation (Previously Structural Survey).	Emerald Insight
	Building Services Engineering Research and Technology – Indoor and Built Environment – Journal of Building Physics - SIMULATION	SAGE Journals
Design computation	International Journal of Architectural Computing	Cumulative Index in Computer-Aided Architectural Design (CUMINCAD).
Architectural design education	International Journal of Construction Education and Research – Journal of Architectural Education - The Journal of Architecture.	Taylor & Francis
	Design Studies	Science Direct
	Architectural Design – Design Management Journal – Design Management Review	WILEY
	Conferences	
Energy and Built environment	International IBPSA (International Building Performance Simulation Association) conference proceedings. SimBuild Conferences (USA IBPSA chapter). eSIM Conference Proceedings (Canada IBPSA chapter). BSO Conference Proceedings (England IBPSA chapter). BSA Conference Proceedings (Italy IBPSA chapter). ASim Conference Proceedings (China, Japan and Korea).	International Building Performance Simulation Association (IBPSA).
	Passive and Low Energy Architecture (PLEA) conference proceedings	Passive and Low Energy Architecture (PLEA)
Design computation	Association for Computer Aided Design in Architecture (ACADIA). Association for Computer-Aided Architectural Design Research in Asia (CAADRIA). Design and Decision Support Systems (DDSS) Arab Society for Computer Aided Architectural Design (ASCAAD). Education and Research in Computer Aided Design in Europe (eCAADe). CAAD Futures.	Cumulative Index in Computer-Aided Architectural Design (CUMINCAD).
	Other	
Miscellaneous	Scopus; ProQuest; Google Scholar; Official websites	---

Table A2: Keywords used in research approach

Keywords used in search
Building simulation; Building performance simulation; BPS; Building energy simulation; BES; Building energy modelling; BEM; Building performance; Building performance modelling; Building simulation software; Energy simulation; Education; Architectural Education; Teaching; Architectural Pedagogy; Architectural Design Studio; Training; Teaching initiatives.