Teaching BPS to architects: *A closer look at the building performance simulation 'consumer' and 'performer' training paradigms*

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Abstract: This contribution builds upon a previous study, in which three university-level BPS training paradigms were identified. Using a critical literature review, we focus on two of these; training the 'consumer' and 'performer' architect, exploring similarities and differences between teaching approaches of these two paradigms. Divergences are found in the location of BPS teaching content within the wider scope of architectural program delivery. The 'consumer' paradigm is generally followed in undergraduate architectural education, tends to be taught as an elective module and is almost always linked to a design studio component. The 'performer' paradigm is linked to both undergraduate and postgraduate architectural education, is mostly affixed to stand-alone core technical modules and is sometimes attached to the design studio. Similar BPS performance domains are taught across both paradigms, but the rationale underlying BPS tool selection differs. Visualization capabilities and ease-of-learning tend to be the criteria used to justify selection of BPS tools used in articles describing the 'performer' paradigm. On the other hand, assignment of BPS tasks to an 'expert' under the 'consumer' paradigm allows for software with more complex analytical functions to be selected. To conclude, the findings demonstrate how moving beyond descriptions of individualized teaching experimentations in BPS research, toward cross-paradigmatic studies of BPS education, may contribute to the construction of a much-needed foundation to support BPS teaching in the future.

Keywords: *BPS training paradigms; Critical literature review; Architectural education; Performer; Consumer.*

1. Introduction

There has recently been growing research interest in BPS[1] education; focusing particularly on how BPS is taught to architects. Including BPS within university-level architectural training may serve as a long-term solution for integration of BPS in architects' design decision-making processes [1]. It has further been suggested that reducing the knowledge gap between graduates' extents of BPS literacy and industry requirements may help reduce the 'performance gap' [2], i.e. misalignment between predicted and actual building performance [2]. While it is believed that, *"the teaching of BPS … deserves as much attention as the development and validation of models and simulation tools"* [3], most articles discussing teaching BPS present individualized teaching trials (e.g. [4-6]). Meanwhile, a comprehensive, theoretical foundation of how to teach BPS to architects remains a work-in-progress.

In this work, the investigation undertaken in [7] is continued. Through a comprehensive review of academic literature discussing how BPS is taught, three BPS training paradigms were identified; training the simulation 'expert,' and training the architecture student to become either a 'consumer' or 'performer' of simulations (figure 1). In training the simulation expert, BPS is consolidated as a stand-alone area of expertise within building physics and engineering domains. Attention is placed on acquisition of fundamental knowledge that allows the expert to conduct simulations as a series of experimental procedures. This allows the expert to be positioned as an independent consultant to the design team. Fundamentals taught within this paradigm include in-depth building physics, building representation and abstraction, choosing a

[1] Building performance simulation.

suitable zoning strategy, appropriate BPS tool selection and scrutiny of outputs.

While the 'expert' paradigm tends to attract students from a range of disciplinary backgrounds (e.g. mechanical engineers, building services engineers and architectural technologists), the 'consumer' and 'performer' paradigms tend to be more attractive to architects. When training the 'consumer' architect, emphasis is placed on collaboration and communication between the architect and the simulation expert, as the latter undertakes simulation tasks and translates results into meaningful outputs for the architect. Alternatively, the rationale underlying the 'performer' paradigm is that performing simulations allows architecture students to develop a deeper understanding of how individual design decisions impact on building performance. The 'performer' paradigm therefore follows an experiential 'learning-by-doing' approach that aligns with constructivist learning theories.

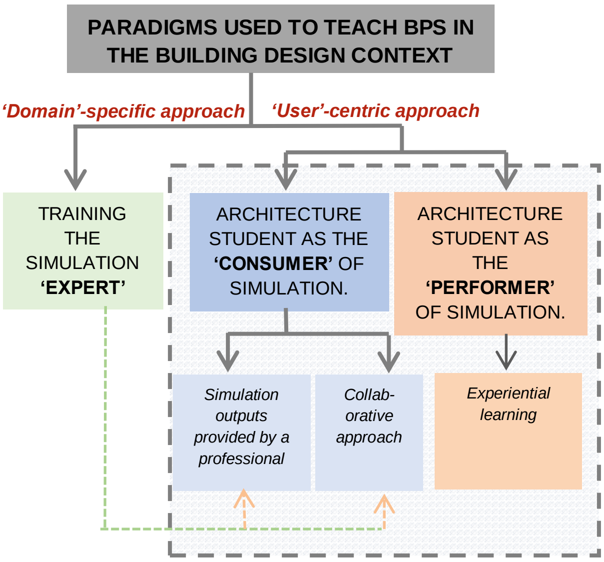

Figure 1: Paradigms used to teach BPS in the building design context.

Having earlier identified the prevalent paradigms, this work explores how BPS is taught to 'consumer' and 'performer' architects to answer the following research questions:

-RQ1: Undergraduate or postgraduate? Is BPS mostly taught at the undergraduate or postgraduate level of architectural education, and what are the aims of BPS teaching at each level?

-RQ2: Integration in architectural curricula: Is BPS taught as either a stand-alone core or elective module, or integrated in the design studio?

-RQ3: Module delivery: What BPS domains are commonly taught? What BPS tools are used in teaching and what are the selection criteria for these tools?

By addressing the issue of how BPS is taught to architects, this study intends to contribute to the overarching question of how we may bridge between architectural and BPS worlds. A full discussion of the overall training needed behind teaching BPS to architects is presented in [7]. Together with [7], these two articles may also serve as a 'one-stop-shop' for educators intending to set up BPS teaching modules and seeking precedent studies to inform course development.

2. Methodology

A critical review[2] of English-language academic literature describing how BPS is taught at the university-level was performed. A survey of scholarly journals and academic conference proceedings both specializing in the broad scopes of energy in the built environment and architectural education were undertaken, with keywords related to BPS and architectural education used to refine the search[3]. The scope of this study was limited by the following inclusion criteria:

- Formal training initiatives undertaken at universities worldwide. Studies discussing informal training through student self-

[2] Based on the definition of critical literature reviews provided in [8].

[3] For a full list of sources reviewed to extract relevant articles, as well as all keywords used to refine the search approach, please see Appendices A and B in [7].

learning, using help files, online tutorials and wizards were not included.

- Studies reporting on teaching BPS to inform architectural design decision-making. Therefore, studies discussing teaching BPS to train engineering students in the design of heating, ventilation and air-conditioning (HVAC) systems and sizing, systems control and demand management, were excluded.
- English-language publications only, for understandability and legibility reasons. As a result of this criterion, the majority of works reported on originate from English-speaking countries (14 from North America, 4 from the UK, and 2 from Australia). Only 10 articles from non-English speaking countries were found, meaning that Asian, Middle Eastern and Continental European contexts are under-represented. Due to this limitation, we do not assert that results of this work, together with findings of [7], describe how BPS is taught in all parts of the world equally.

This search strategy and inclusion criteria resulted in the identification of 28 publications, sub-divided into[4]:

- 12 articles discussing the 'consumer' paradigm.
- 16 articles discussing the 'performer' paradigm.

In addition, four more articles [9-12], were incorporated in the analysis that had not been included in [7], bringing the total number of articles analyzed to 32 reporting 27 teaching initiatives. Thematic content analysis, a process of extracting commonly occurring themes in a dataset to identify *"core consistencies and meanings"* [13] was used to answers the three aforementioned research questions.

3. Results and discussion

3.1. Undergraduate or postgraduate?

It is stated in [14-15] that BPS teaching is more common in postgraduate architecture programs than undergraduate ones. However, out of 27 teaching initiatives included in our review, 18 report teaching BPS at the undergraduate level and only 9 report teaching BPS to postgraduates, and 2 [16-17] report teaching BPS to both undergraduates and postgraduates together. Our analysis further reveals that:

- The 'consumer' paradigm is widely undertaken in undergraduate architecture programs.
- There appears to be some disagreement regarding whether the 'performer' paradigm is best suited to undergraduate or postgraduate architectural education. Out of 20 'performer' initiatives, 12 are for undergraduates, 6 are for postgraduates and 2 are for both.

3.1.1. Educational aims of the 'consumer' paradigm (undergraduate)

Modules delivering BPS to undergraduates are often considered *"introductory"* [14,17]. Introductory modules training the architecture student to become a BPS 'consumer' emerge from a belief that *"building simulation is the task of a simulation expert rather than an architect"* [5]. Nevertheless, BPS tools are regarded as *"potential allies to the teacher and learner to achieve better buildings and greater sustainability"* [15], by bridging the gap between the theoretical teaching of building physics and its practical application in design decision-making (e.g. [16, 19-20]).

3.1.2. The 'performer' paradigm: Undergraduate or postgraduate?

Unlike in the 'consumer' paradigm, training the architecture student to become a BPS 'performer' BPS cannot be singularly linked to undergraduate or postgraduate studies. Nevertheless, implicit differences can be interpreted between publications describing teaching BPS to undergraduate and postgraduate architects. For example, similar to the 'consumer' paradigm,

[4] For a full list of articles extracted, please see table 1 in [7].

undergraduate 'performers' are usually exposed to BPS at an introductory level, to enhance students' understandings of building physics and HVAC-related concepts (e.g. [14, 18, 21]).

Several postgraduate 'performer' initiatives are directly linked with a design component. Rather than using BPS to analyze performances of fully-developed designs, [4, 22-25] all describe using BPS to support an evidence-based design process, whereby BPS tools are used to support the synthesis of design ideas. While these postgraduate students are still considered *"novice users"* of BPS (e.g. [22]), there is no mention of teaching physics and/or services, implying that this foundational knowledge may have been acquired at a preceding stage.

3.2. Integration in architectural curricula

Our analysis indicates that BPS is taught to architecture students either by:

- Including BPS within the content of a stand-alone core module.
- Offering BPS as a stand-alone elective.
- Applying BPS knowledge in the architectural design studio.

3.2.1. Including BPS within the content of a stand-alone core module

In the 'performer' paradigm BPS is commonly linked with core modules of a technical nature (e.g. [6, 18, 21, 26]). However, within the 'consumer' paradigm, BPS is not as commonly considered a core subject matter. Only [5-6] report initiatives that are part of core modules teaching building physics and environmental control.

When BPS is delivered as part of a building physics module, the pedagogic aim is to provide a first-hand illustration of building physics phenomena. When BPS is delivered as part of an HVAC module [18], the aim is to enhance students' understandings of HVAC-related concepts including definition of thermal zones, understanding how input assumptions may affect hourly load profiles, and identifying how building controls may affect heating and/or cooling strategies. Finally, when BPS is linked to building technology modules (e.g. [21, 26]) the rationale is to enhance students' understandings of buildings' technical performance, and how to use BPS to make environmental predictions.

It is important to interrogate implications of teaching BPS within the contexts of divergent technical domains. How do divergent teaching practices, arising from delivery of BPS within different subject areas, affect students' understandings of BPS? We anticipate that students who have studied BPS to enhance their knowledge of building physics may interpret the topic differently to students who have studied BPS within an HVAC context, in terms of depth, potential, motivation and application. This may have implications on uptake in professional practice as well. For example, graduates who have used BPS in a building technology module may be more inclined to use BPS to inform architectural decision-making than others who have only studied BPS from a building physics perspective. Graduates who have only used BPS within an HVAC context may only be inclined to view BPS as an informant to HVAC design rather than architectural design.

3.2.2. Offering BPS content as an elective

It is asserted in [27] that modules in BPS are *"often relegated to an elective status."* However, we find this statement is true only in teaching initiatives following the 'consumer' paradigm (e.g. [15, 19-20, 28]).

Out of all the 'performer' initiatives, BPS is only offered as an elective in [17].

There are both merits and limitations associated with this elective status. Electives are often associated with greater flexibility than core modules, and a less strict interpretation of learning outcomes [30]. Students often enroll based on interest, which may create a more engaged classroom environment. However, this elective status often means that only a limited number of students will enroll; meaning that the purpose and potential of BPS for architectural design may not be transferred equally to the entire student cohort. Elective status may imply that BPS use remains an optional factor affecting design decision-making; to be chosen or ignored based on interest, priorities, time, financial or cliental constraints.

3.2.3. Applying BPS knowledge in the design studio

The 'consumer' paradigm rationale is to train architects to use BPS outputs provided by a BPS 'expert' to inform design decisions [7]. It is therefore palpable that instruction takes place within a design studio context. For example, [28-29] describe an approach for an integrated elective module (named ARCH-ENGR) and design studio occurring concurrently. ARCH-ENGR students construct a series of BPS models to develop the design concept and provide architecture students with feedback on building performance.

Within the 'performer' paradigm, several examples indicate that BPS knowledge acquired in a preceding learning stage is later applied in the design studio (e.g. [4, 12, 14, 25-26]), thus allowing students to triangulate what they have learnt throughout different stages of their training. Nevertheless, almost half of the 'performer' initiatives do not report linkage with the design studio, implying that the focus is on enhancing students' technical skills rather than regarding BPS tools as potential design aids. This further aligns with results of the international survey reported in [31], in which only 8% of instructors responded that BPS is used in the design studio.

This seeming hesitation to incorporate BPS in the design studio is alarming, as all the teaching initiatives analyzed explicitly report teaching BPS either within schools of architecture or within a building design context; where 'design' remains the central activity and in which the design studio is a platform that facilitates both formal and informal pedagogic encounters. An integrated design studio model would be an opportune venue for BPS to become interwoven into the esoteric codes of architectural knowledge; fashioning students' awareness of an evidence-based decision-making process.

3.3. Module delivery

3.3.1. BPS domain studied

Our review reveals that five performative domains are studied across all BPS teaching initiatives, and the same domains are both the subject of teaching for both 'performer' and 'consumer' architects. Most initiatives (20 out of 27) describe teaching thermal simulation. Lighting simulation, daylight analyses and sometimes both in conjunction are also commonly taught. Conversely, acoustics is only discussed in 5 publications and airflow is only discussed in 3. Most articles describe teaching multiple BPS domains simultaneously; only few teaching initiatives focus on a single BPS domain at a time (e.g. thermal simulation in [12, 25] and daylighting design in [11, 32-33]. None focus on acoustics or airflow exclusively; both are taught in conjunction with either thermal or lighting/daylighting or both. Teaching multiple domains simultaneously is understandably reflexive of the concurrent physical interactions occurring in the building, and the inherent inter-relationship between them.

All performance domains are equally taught at both undergraduate and postgraduate levels. This may be interpreted in several ways. Assuming that the undergraduate level is where basic knowledge is attained, and a postgraduate degree is undertaken to gain more advanced knowledge, it is possible that 'basic' BPS knowledge, pertaining to multiple domains, is taught at the undergraduate level and more advanced topics, also pertaining to the same domains, are taught to postgraduates. Alternatively, the notion that all BPS domains are similarly taught at both undergraduate and postgraduate levels may mirror teaching discrepancies in different countries. In countries where legislation requiring adherence to minimum building energy performance standards either does not exist or is not strictly enforced, BPS may not be taught at all to undergraduates. This means that, when students proceed to advanced degrees, basic concepts need to be covered, as described in [4]. In addition, while in some countries, a prerequisite to proceeding toward a postgraduate degree in architectural education is having completed a basic architectural degree, this is not necessarily the case in other countries where there might be a preference for a more interdisciplinary approach. Again, this means that basic concepts, pertaining to building physics, BPS and wider architectural knowledge still need to be taught at to postgraduates to leverage knowledge in the student cohort.

However, as introduced earlier, the question of how to introduce BPS in architectural education, and where the two may converge in university teaching, has received insofar limited research attention. Most publications about teaching BPS to architecture students tend to be motivated by instructors' personal interests and based on individualized teaching efforts, without being grounded in academic literature on learning theories and/or architectural education. It is possible that the question of how and where BPS fits within the overall scope of architectural education has not yet been strategically planned by the academic community.

3.3.2. BPS tool selection criteria

We observe a different set of tool selection criteria for the 'performer' and 'consumer' paradigms. In articles describing 'performer' teaching set-ups, BPS platforms are selected for having easy-to-navigate user interfaces with advanced visualization capabilities and a relatively short time-span associated with the software's learning curve. For example, Autodesk Ecotect is the platform of choice in [4, 17, 19-20, 26], while IES-VE is used in [14] and Sefaira Architecture in [25].

Conversely, BPS tools' analytical functionality, modelling techniques embedded within the tool, tool reliability and robustness and even interoperability capabilities are cited as criteria for selection of BPS platforms used in 'consumer' paradigm teaching set-ups. For example, in [29], a preference is explicitly expressed for Dynamic Simulation Modelling (DSM) tools with transient simulation capabilities, which help develop students' *"thermal* *intuition."* Ability to access and customize the software's code to support modelling techniques is also another criterion for BPS selection (e.g. [5]). As such, BPS tools used in 'consumer' teaching set-ups include TRNSYS, Contam [27-29], TAS and Mestre [6].

As the architecture student in the 'performer' paradigm teaching set-up is responsible for conducting all modelling and simulation tasks in pursuit of an evidence-based design process, and given the inherently visually-biased nature of the architectural profession [34], considering software's graphical user interface and visualization techniques a priority for selection is understandable. It is asserted that *"professors of architecture…compete with rendering and modelling that produce very attractive rendering. Employing seductive imagery to attract the student's attention and generate his/her interest* [is therefore] *a necessary 'evil'…in this competitive context"* [35]. It is also important to note that most 'performer' teaching set-ups are undertaken within semester-long (i.e. 8-16 weeks) period [4, 19-20], also explaining why instructors do not necessarily favor tools with more complex functionality for the steep learning curve associated.

However, this need to compromise between software functionality and learning curve is somewhat overridden under the 'consumer' paradigm, in which the architecture student is no longer responsible for the entire modelling and simulation process which is primarily the work of the BPS consultant or 'expert' collaborating with the architect. This also explains why visualization-related capabilities are seldom cited as BPS tool selection criteria under the 'consumer' paradigm. We speculate that having each professional in the collaborative set-up focusing on tasks that traditionally fall under his/her traditional scope of work therefore means that greater time and effort may be invested in the quality of the modelling, more accurate results' interpretation and more successful design solutions in general, given that conditions of effective collaboration and communication are met, as discussed extensively in [7]. Nonetheless, this speculation remains hypothetical, unless proven by an analysis of performance of architectural designs produced under both 'performer' and 'consumer' teaching set-ups in a comparable framework set up for further research.

4. Conclusions

This article builds upon previous research, in which two paradigms exclusive to training architecture students in BPS were defined. The main difference between the 'consumer' and 'performer' paradigms is the question of who should conduct simulations; which inadvertently has implications on teaching approaches underlying each paradigm, as discussed at depth in [7]. In this paper, we seek to further explore common characteristics of 'performer' and 'consumer' paradigmatic teaching approaches, and to ascertain similarities and differences between them. Using a critical literature review, the following differences were found between teaching approaches of the two paradigms:

- The 'consumer' paradigm is followed in undergraduate teaching, while the 'performer' paradigm is linked to both undergraduate and postgraduate architectural education.
- In most cases, 'consumer' initiatives are taught within an elective module, whereas

'performer' initiatives are often taught within the content of a stand-alone technical core module. However, divergences appear in the subject-areas of these core modules onto which BPS content is often affixed. Such divergence may have implications on architects' understandings and uptake of BPS in professional practice later on.

- 'Consumer' architect training initiatives are almost always linked with a design studio component. However, only half of the 'performer' articles attach BPS to the design studio.
- All five BPS performance domains were similarly taught in works reporting on both teaching paradigms, but the rationale underlying BPS software selection in support of teaching differs. Motivation for selection of BPS tools used in the 'performer' paradigm include software's visualization capabilities and ease-of-learning. On the other hand, the splitting of tasks occurring under 'consumer' teaching set-ups allows selection of BPS tools with more complex analytical functionality.

However, implications of this work extend beyond the individual research findings. The findings demonstrate how moving beyond descriptions of individualized teaching experimentations in BPS research, toward wider-scaled cross-paradigmatic investigations of BPS educational approaches may unravel promising opportunities needed to set up a theoretical foundation in this area, and to *"harmonize the disparate educational information being used within degree programs worldwide"* [36], which was explicitly called for in the position paper prepared on behalf of the IBPSA board in 2015. For this reason, and to address the limitation of geographical representation posed by the English-language inclusion criterion stated in the introductory section of this paper, we seek to expand this study in further research by conducting a broader-scaled survey of schools of architecture worldwide. This would allow us to understand the prevalence of particular educational paradigms to certain world regions, and may explain whether and how each of the educational paradigms may be tailored to the specificities of such contexts, including energy legislation and professional licensing requirements.

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