

Integrating Sustainability in the Architectural Design Education Process

Taxonomy of Challenges and Guidelines

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The last decade have seen substantial calls and increasing pressure for developing an integrated design teaching framework, where sustainability is an imperative priority. This paper focuses on presenting a taxonomy of the main challenges encountered within the educational domain, in the attempt to reach an effective integration. The paper also presents a set guidelines to address and try to resolve the noted challenges. As the use of Building Performance Simulation (BPS) applications is a central approach in this process aiming to reach energy efficient buildings, the paper focuses on the shortcomings noted as a result of the use of these applications in the design studios, with particular emphasis on the thermal and lighting aspects of the simulation. The taxonomy presented is a summary of the findings from literature review, as well as the surveys results which were part of the author's research project discussed in the paper.

Keywords: *Environmental Design, Building Performance Simulation, Architectural Design Education*

INTRODUCTION

Introducing sustainability measures to the conventional architectural design process for the purpose of reaching energy efficient buildings, has led to a remarkable evolution, and subsequently to the introduction of a new multitude of variables that should be accommodated and resolved within the design to be approved. Architectural design students are subsequently facing mounting challenges; adding another dimension to attain conceptual building designs that can perform favourably from a sustainability perspective. The notable paradigm shift has demanded and/or imposed a rather more holistic

approach for design; one where students incorporate more performative measures, and demonstrate solid comprehension of the implications these measures brings to the design and the forces that foster or impede it (Sarhan, 2012). Schools of architecture are ultimately compelled to embrace the new paradigm, and develop an integrated design teaching approach, aiming to prepare new generations of architects with high awareness and comprehension of sustainability and the measures it inflicts on the design and decision-making process.

This paper presents an analysis of educating the design students how to integrate environmental de-

sign measures, through the use of Building Performance Simulation (BPS) tools, focusing mainly on the thermal and lighting aspects of simulation process. This leads to a taxonomy of the challenges encountered in the process and guidelines on how to overcome these challenges, and improve the students' environmental design experience. The study represented in this paper is part of a research project (Sarhan and Rutherford, 2011), aiming to introduce a new approach to overcome the noted challenges and to facilitate developing an integrated design teaching context. While the study focuses on BPS applications as a direct tool for integration, it does not fail to acknowledge the merits and values that these tools add to the architecture, engineering and construction professions.

EDUCATING THE DESIGNER

A new 'Decade of Education for Sustainable Development' has been initiated by the UN in 2005, envisaging the development of new approaches for developing structured curricula that can evidently accommodate 'learning for sustainable development'. One of these approaches was EDUCATE (2012), which embrace key directives for repositioning sustainability at a higher 'priority', and enriching the knowledge and skills needed for its integrating in architectural education. These directives seek to promote a holistic integrated approach of thinking and learning, as well as creating an 'inter-disciplinary dialogue between conventional cognitive domains'. In doing so, these directive embrace key concepts; including 'Experiential Learning', 'Reflection' in and on action, and 'Motivation' through active learning. For these directives and their derived concepts to be effective, they should adopt methods for adequately meshing these principles into the cognitive creative design context. This includes careful consideration to the architect's approach to learning, thinking, and problem solving.

Rutherford and Wilson (2006) explain that architects normally tackle the design challenge with a solution-focused rather than a problem-focus strategy. This strategy was defined by Gelernter (1988) as

'Cognitive Schemata' approach for problem solving, which is an iterative methodology where students expand their knowledge through sequence of design analysis and criticism that is mainly focused on the solution being put forward, rather than the methodology that can be applied. In other words, students will adopt an approach that most likely focused on solutions to satisfy design challenges, rather than embracing a more analytical approach for a critical analysis of this challenges' complexity leading into a resolution (Altomonte, 2009).

In essence, the aspiration of achieving an effective integrated design context is not one without notable challenges, particularly in relevance to the two contrasting aspects of the design process; the cognitive and analytical aspects. The concept of 'Conjecture Analysis' has been highlighted as a mean of accommodating these aspects (Hillier et al. within Genlernter, 1988), based firstly on 'conjecture', where students use "*extra-rational and artistic procedures of analogy, metaphor, sudden flashes of insight, and displacement of concepts to create new ideas*" addressing the cognitive schemata. The concept is also based on 'Analysis', where students adopt an approach of solid rationale and critical assessment, thus analysing technical consequences of concepts and theories adopted. Understanding the concepts and approaches to the integration can aid analysing the subsequent barriers for effective application of the integrated design methodology, which is discussed in the next section.

CHALLENGES SURROUNDING ENVIRONMENTAL DESIGN EDUCATION

Building Performance Simulation (BPS) applications offer designers the capability to generate solid assessment models for different environmental entities including thermal, acoustics, lighting, and ventilation. BPS applications also present students with an opportunity to expand their skill set and expertise, and gain constructive analysis proficiency with regards to complex building physics phenomena (Charles and Thomas, 2009). Calls for integrated de-

sign framework has been reinforced in particular in the last decade, mainly as a result of the compelling demands raised by governments and international bodies, and the use of advanced computing processing capabilities and algorithms that can support generating extensive data-sets as a result of complex simulations.

Recent years have seen notable increase in the number of surveys, research projects, and case studies (including the study and survey carried out as part of this research), that have been carried out with the clear intent of evaluating BPS tools' suitability and appropriateness within the architectural design educational context. These studies were based on some key criteria that fall under either the usability and information management of the BPS application interfaces, or the efficiency of the tools as a design decision support system. The outcomes of these studies were very useful; highlighting the main shortcomings and pragmatic issues surrounding the use of such tools within the architectural design context. Analysing these outcomes can provide opportunities to bridge the gap and address any concern, which is done through presenting guidelines for adopting a more 'Architect Friendly' approach for simulation and analysis.

This section discusses a compilation and taxonomy of the outcomes of these studies, which is based on three key questions; "Why use BPS tools", "How to use BPS tools", and "What to do with the simulation data".

Motivation for using BPS Tools

In this research project's survey, one section intended to probe the participants' motivation to incorporate environmental design concepts and measures. Responses indicate that the majority (79%) of participants' motivation for that matter is that 'they have to do it'; highlighting the pressure/obligation from governments and accreditation bodies, or -on a smaller scale- from the instructors as part of the assessment process to satisfy specific learning outcomes. Although the participants acknowledge that this inte-

gration is the ethical approach for reducing energy needs and preserving natural resources, they still admit that it wouldn't have been in their highest priorities without the pressure. This section investigates more into the factors affecting the designers' motivation for integrating environmental measures.

Cognitive Creative Nature of Design. The call for integrating environmental measures and concepts into the architectural design process has left the designers with a set of new variables to manage and incorporate. Many studies, including that by Srivastav et al. (2009), indicate that these variables were not deeply welcomed. They explain that most architects in general do not place environmental variables/measures at higher priorities, compared -for example- to design aesthetics. Designers are inclined more towards 'conjecture', where they think of visual, spatial, relational, proportional entities of their design elements. On the other hand, simulation data are perceived as series of mathematical analytical calculations that require extensive effort to familiarise with and make sense of; and that do not naturally fit the solution focused approach designers adopt for problem solving (Rutherford and Wilson, 2006).

In this sense, many design students develop different interpretation of the 'priorities'. For example, students may attempt to create a sense of indoors-outdoors continuity, with no consideration for the effect this decision can make on solar gains. The outcomes from the studies indicated that the benefits offered by an 'integrated design approach' can be missed by some students. On one hand, students may perceive the new variables as being 'unimportant', whereby they could be simply ignored. On the other hand, some may deem them 'vital', leading to impractical highly deterministic alterations 'just to make the numbers look good'.

Suitability to Early Design Stage. In building design, the earlier stages are the most critical in the process, where most of the key decisions are made. Any uninformed decisions at this stage can have severe consequences on all subsequent decisions, and in turn on the building capacity/performance and

energy consumption throughout its lifecycle. However, making informed decisions at this early design stage -where the available data are mostly intricate and inadequate- is quite challenging. Consequently, it is very common for designers to revisit these decisions after gaining more details and solid data in later stages of design.

A central method for students to improve their comprehension of environmental design measures and various cause-effect relationships; ultimately enriching their design decisions, is through the use of BPS applications. However, reaching this level of awareness and understanding, as argued by Bambardekar and Poerschke (2009), requires the gathering of a huge amount of preliminary data and projected building details, just to be able to start the simulation process. The required level of details is normally unavailable -and the information is thus insufficient- at the earlier stages of design, where there is constant alteration and revision to the building's geometry and configuration. In this regard, it is understandable that some students can see the use of BPS application to evaluate their building's design and performance at these early stages -to an extent- aimless, frustrating, and wasting valuable time and effort. This in turn have the capacity to expand the psychological gap between the two parallel processes of design and analysis. Designers in general, according to Mahdavi (2005), do not tend to prepare this entailed level of details until later stages of design, and only then a meaningful BPS analysis can be carried out. He added that this analysis will -most likely- not be carried out by the architects themselves, but rather by specialists and service engineers.

Preference of Experience and Guidebooks. According to Pedrini and Szokolay's (2005) findings, mathematical simulation models are considered the least popular in the architectural design community. These findings rank the BPS applications in the lower ranks within a list of eighteen design decision support techniques. The main justification for this ranking is the technical analytical nature of these applications, which contradicts with the cognitive, reflec-

tive, deductive nature of the design process. Their research findings also noted that the designers' rely more commonly -particularly in early design stages- on their personal experience and intuition in decision making, with generic design guidelines and rules-of-thumb following that also in a higher ranking. These findings generally fall in line with earlier discussion of the designers' learning approach, as well as Hillier et al. (1984) depiction of the design as a "cyclic reflective deductive process".

The simplicity and usability of design guidebooks -as an efficient reference source- is the main justification for the high level of inclination shown by the designers towards them. This can be broken further down to the fact that these guidebooks are rather generic (with no particular building specification), thus making them simple to navigate and explore. More importantly, they do not require thorough level of details at any stage, making guidebooks comparatively more time and effort effective. However, the main factor that makes guidebooks easy to use can itself be a big hindrance. The generic nature and lack of building-specific details and zones' interoperability can deem these guidebooks rather passive with minimum level of interaction, and subsequently detached from the design specification. In other words, guidebooks can be helpful in suggesting what can be done on a generic basis, rather than highlighting a problem and reflecting on possible causalities in a specific design case.

Complexity of BPS Tools

Schmid (2008) indicates that design students in general are neither attracted nor keen to use the current environmental performance evaluation tools; mainly owing to the relatively complex and technical nature of these tools. Recent years have seen various attempts and approaches to make these tools more architect-oriented; owing to meet the designers' aptitude and expectations. However, there are still some raised issues relating mainly to the BPS interfaces' usability, information management, and lack of guidance throughout the simulation procedure (Attia et

al., 2009). This section investigates in more details these highlighted issues.

Steep Learning Curve. The designers' effective use of the BPS tools, according to (Schmid, 2008), entails a rather steep learning curve, where they are primarily required to develop a solid understanding and knowledge base of the underlying science and building physics; these comprise a huge set of concepts and technical terminologies. Designers also need to relate this knowledge base to the various features and functionalities implemented in the BPS tools, aiming to prepare the relevant settings and supply the required preliminary geometric and non-geometric design details to be able to run the simulation process.

From an architectural perspective, the interface of most BPS applications, as argued by many researchers including Punjabi and Miranda (2005), can be deemed rather too technical, complex, cumbersome, and uneasy to learn. Attia et al. (2009), relate this to the fact that most of these tools were built with an engineering-oriented directive with minimum consideration to the architectural community. More recent research and surveys, however, indicated that much work has been done towards this matter, leading to noticeable improvements in the usability of some BPS tools, in terms of adaptation to the architects' mentality and experience. One of these tools that are becoming more architect-friendly is Ecotect, which is gaining increasing popularity due to its comparatively simpler interface, highly visual representations, and interactive analysis mechanisms.

Simulation Process Procedure. Warburton (2003) argues that the effective implementation of the 'Conjecture Analysis' method for integrating sustainability in the design curricula - discussed earlier in this paper-, entailed the effective amalgamation of 'revelatory activities', which are responsible for enhancing the students' learning experience through assisting them to 'ask the right questions'. Bambardekar and Poerschke (2009), confirm that statement, explaining that this is accomplished through effective interpre-

tation of the theories and underlying science introduced in the lectures into profound set of tasks to be carried out within the simulation process. They noted that "*Architects are usually familiar with environmental concepts, but often do not clearly understand how to translate the design and performance inquiries into simulation tasks and evaluate them using ESP's [Energy Simulation Programs]*" (pp. 1307). Schmid (2008) also indicated that it is not difficult for students to properly understand theories and building physics, but what is really challenging for them is to formulate meaningful procedure that will efficiently help them assess and evaluate their building's performance.

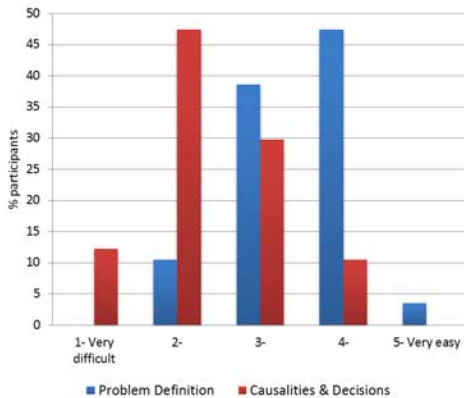
Design students, in this respect, should be guided and/or made aware of the set of assessments involved in the simulation, which is currently quite a challenge. Even for experienced users, Marsh (2006) argues that preparing a simulation model on the grounds of basic requirements targeting the analysis process, is still quite hard and demanding. It is thus evident that there is growing need for novel methods that can bridge the gap between design and simulation, aiding the students throughout the process and assisting them to ask the correct questions, leading subsequently to informed design decisions.

Simulation Data Visualisation and Analysis

One of the most crucial aspects in the building simulation process is communicating back the results and feedback to the designers in a simple manner they are familiar with. There is no doubt that the current BPS applications exploit highly advanced visualisation and data representation methods, however, many challenges and shortcomings are still being highlighted in relation to communicating simulation outcomes to the architects. Srivastav et al. (2009), for example argue that one of the key reasons for these shortcomings is the complexity of the resulting data, and thus the challenge to correlate the data to derive causalities and design decisions. This section discusses the challenges associated with data analysis and representation techniques utilised by BPS applications.

Design vs. Simulation Visualisation Techniques.

The rapid advances of current CAD and BIM tools had great benefits that go far beyond the sole expansion of productivity scale. These advances also supported the production of highly interactive and immensely graphical 3D design visuals. Visualisation is a fundamental aspect in the architectural design process, as it is a representation of the designers' conceptual models that directly relates to their cognitive schemata. On the other hand, simulation data representation techniques do not follow the same line; being mostly sophisticated and highly technical, as they are based upon empirical models that can fail to "reconcile the relationship between design actions and performance outcomes" (Toth et al., 2010, pp.315).



It can thus be argued that the analytical nature of the simulation and the resulting outcomes lack sufficient consideration to the existent norms dominant within the design realm, thus incapable of interpreting the resultants (as valuable as these are) into meaningful decisions. The survey carried out within this project supported that; indicating that the majority of participants indicated that the current data representation mechanisms are not as problematic in terms of defining performance problems as translating this definition into possible causalities and subsequent design decisions (Figure 1). Current BPS applications, according to Attia et al. (2009), are thus

falling short in terms of relating the design to the performance outcomes, which can compromise the effectiveness of these tools as decision support systems, and ultimately reduce the value of the "integrated simulation".

Spatiotemporal Dimension of Simulation Data.

The simulation data, as argued by Yan and Jiang (2005), is comprised of two essential dimensions; special and temporal, which should both be considered carefully in the means of analysis and representation. This, however, is quite challenging; the spatiotemporal 4D attribute of the simulation data has a rather convoluted nature, which is problematic to visualise and interpret. In the design community, whereby dealing with only three dimensional models is the norm, introducing an additional temporal dimension has the capacity to increase the level of uncertainty and confusion, and thus affecting the resulting decisions. It is thus essential to utilise a visualisation technique that can accommodate the temporal data and simplify the representation process. Most of the current BPS tools utilise visualisation approaches that fall short in dealing with the complexity of the nature of multidimensional simulation data.

A key factor in dealing with and effectively representing multidimensional data is through expanding the degree of interactivity offered to the users. One medium that has proven very effective in terms of incorporating high levels of interactivity and data visualisation is Virtual Reality (VR). This medium, according to Prazeres and Clarke (2003), has the capacity to 'bring alive the informational domain', and offer novel techniques to visualise information that is not relatively as simple in other techniques. Providing design students with additional levels of interaction, and opportunities to explore various multidimensional aspects of their design can assist in breaking down the complexity of the imbedded information, and thus help in the knowledge extraction and comprehension of the presented materials.

Figure 1
Participants' responses for evaluating BPS applications' effectiveness in defining performance problems, as well as identifying possible causalities and making subsequent decisions.

THE PROPOSED METHOD AND EXPERIMENT

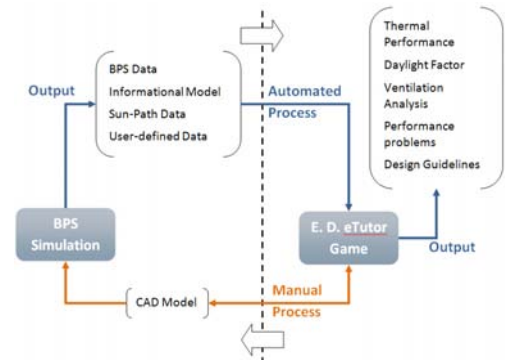
Based on the taxonomy of challenges presented earlier, this research proposed a new method to resolve these challenges, and to facilitate integrating environmental measures in the architectural design curriculum. The proposed method is an environmental design e-tutor game (Sarhan and Rutherford, 2011), which presents an interactive narrative 3D virtual experience for the design students, to examine their design geometric and non-geometric parameters. The method is based on the utilisation and integration of Multi-Agent Systems and Data Mining Techniques to create additional software modules on top of the basic game engine technology (C4 Game Engine in this project). These additional modules are responsible for communicating with the BPS application and pulling data from it, and later formatting and storing the data in its own Data Warehouse. Once the game is run, the design model is analysed and coupled with the stored simulation data to form an informational model, which will be the basis for the communication and feedback with the design student.

A Reporting Agent (part of the implemented MAS), is responsible for creating a dialogue with the students; presenting them with initial findings after analysing the simulation data (using DM and knowledge extraction mechanisms). This dialogue can either be feedback in the form of reports, or 'interrogation routines' that attempt to fill in the missing gaps in the informational model and get feedback from the student according to their experience and preferences. The Reporting agent can finally present the student with a set of zone-specific design guidelines that can resolve any raised issues/problems in the design, and ultimately improve the building performance. The student can then manually update the design and the CAD model, and thus the process can be repeated to assess the effect of the new design updates. Figure 1 presents an abstract overview of the main entities in the proposed method, with the flow of information and main outputs of these entities.

After the initial survey, the development and

implementation process, the proposed method and the game demo were tested to stand upon the key advantages and areas of improvement for this approach. The testing and evaluation sessions involved 28 design students and 11 instructors from three UK universities. The testing session was a combination of questionnaires and structured interviews aiming to gather both quantitative and qualitative feedback that can support the assessment of this method conceptual basis. The participants were also presented with the e-Tutor game as part of the testing session, and were subjected to the different features implemented and discussed earlier. Figure 2 presents a screenshot of the proposed method's demo game that was part of the testing sessions.

Figure 2
Abstract illustration for the proposed method, depicting the outputs of each key node (simulation and ED Game), as well as the tasks that are automatically performed, and those that require manual intervention from the students (Image from Sarhan, 2012).



The feedback provided from this experiment - although only indicative; representing the small sample involved in testing and evaluation- was quite valuable and informative. One of the main highlighted advantages of the proposed approach is its positive effect in motivating the students, through offering a higher level of interactivity within a 'game' context; one that their generation is well accustomed to and familiar with, and thus can be more engagement in. Another noted advantage was the capacity to assist students in asking the right questions through encouraging them into more in-depth investigate more of the simulation data. The method also attempts to act as a building-specific guidebook; offering simple guidelines to improve the design and

performance. The method also exploits the cause-effect relationships; depicting the consequences of the strategies and decisions that the students choose to make. Finally, another advantage mentioned was that the method offers a tutoring system that the students can exploit in their own time and convenience.

However, there were also some highlighted disadvantages and areas for further development and improvement. One of the main shortcomings (expressed mainly by the instructors) is that the method offers only abstract level of information, without enough links to the underlying building physics, to allow students to exploit the information in more depth. Another noted shortcoming was that there is no compilation of information provided during the game; the students mainly wanted the problems and guidelines compiled in a printable format acting as a checklist for design updates. Learning new interface (the game engine) and having to build 3D models were also considered to be risks in consuming time and effort required before running the game. Finally, the transformation of data between the applications involved in this method is considered cumbersome and rather problematic in terms of the time and effort required, as well as jeopardising the data. These advantages and disadvantages were considered in formulating the set of guidelines presented in the next section.



GUIDELINES FOR RESOLVING THE CHALLENGES

A set of key guidelines can now be presented, based on the taxonomy of challenges discussed earlier. This set is also based on this research survey experiment and findings, and recommendations and conclusions presented in number of research projects and case studies. These guidelines present some basic specification for developing new methods and technologies for integrating environmental measures in the design curriculum.

- The approach should adopt a 'revelatory' nature (Warburton, 2003); guiding students through the simulation process, and allowing them to 'ask the right question' through exploring different attributes of their design.
- The method should support the conjecture analysis approach through constant reports to cause-effect relationships, and highlighting any pragmatic data patterns that can affect the building performance. This should be carried out while highlighting any possible causalities for problems, and linking these reports to the underlying science and building physics.
- The method should offer constant communication with the students through Q&A routines and feedback reports. In so doing, the students' decisions and their impact on the building performance can be rapidly assessed and criticised. This communication will also enrich the students' interactive narrative virtual learning experience.
- The directive of being an effective decision support system should be rigidly accommodated, through the presentation of zone and building-specific design guidelines. This should be done while presenting clear rationale behind these suggestions in light of the theories presented in the lectures. This ap-

Figure 3
A screenshot from the proposed method's demo game (Sarhan 2012); presenting the initial basic reports and interrogation routines generated by the Reporting Agent.

proach has the capacity to offer instant dynamic analysis; offering simplified feedback and outcomes similar to those of generic guidebooks, but with higher levels of interaction and specification.

- The method should adopt advanced data representation visualisation mechanisms (for both geometric and non-geometric design parameters); that can accommodate the conceptual visual nature of design and the multidimensional spatiotemporal nature of the simulation data. One medium that has been proven effective in this accommodation is the 3D interactive narrative virtual context, like that of the 3D games.
- A 'layered' approach like Prazeres and Clarke's (2005) "*Integrated Performance Views*" can be adopted, which presents information in a simple hierarchical style. It starts with a rather abstract level, which can be further investigated by students according to their decisions. Such approach can overcome overwhelming students with excessive information at the initial stages, which can be a clear barrier in comprehending and analysing this information.
- The method should focus on 'simplicity' and 'abstraction', while offering a reasonable level of interactive interrogative mechanisms. Higher levels of control and interaction in the learning context can ensure greater sense of control, and more freedom for investigating various aspects of the problem. This in turn can have a positive effect on the students motivation and engagement in the learning process, and subsequently on the level of comprehension and decision making.
- The method can dynamically provide any initially required data using default values, to reduce the preparation time needed before starting the simulation. In this case, it is important for the students to be well informed

about these default values and their implications. Reducing the preparation time can inject more confidence to run the simulation, and resolve some of the motivational barriers noted earlier.

- The method should be of instructive nature, acting like a personalised e-Tutor. It should be able to analyse the massive amount of simulation data and present abstract knowledge back to the students. In order to achieve this, utilising techniques like Data Mining for data analysis and knowledge extraction can be very effective in uncovering and simplifying details that can otherwise be difficult to uncover, investigate, and act upon.
- A modular built-in Data Warehouse should be incorporated, where it can pull in all the required simulation data. In so doing, a reliable informational model can be dynamically constructed and updates, and a flexible structure for storing, arranging, searching, and retrieving data can be attained.
- The method should address the huge demand for smooth transition of information between the design and simulation, which can be accomplished through creating a more centralised informational model that can hold all the information related to the building. Currently, the huge progress in BIM applications can address this guideline where the informational model can work in conjunction with the BPS tools.

CONCLUSION

Integrating sustainability in the architectural design process is an emerging imperative. Subsequently educational institutions are challenged to prepare new generations of architects that can effectively accommodate sustainability in their design and concepts. This integrated design education framework has proven to be rather pragmatic, and its attainment

depends on addressing and resolving number of barriers and challenges. The paper presented a brief outline of the authors' research project, which proposed a framework for facilitating an effective integration of environmental measures in the design process. The paper focused mainly on presenting a taxonomy of the challenges in light of the study and survey carried out as part of this research project. The paper also presented guidelines for adopting new methodologies/approaches for effective integration of sustainability, taking into consideration the architects' mentality, expectation, and approach to learning and problem solving. The research is currently in the process of developing an updated version of the environmental design eTutor, acting upon aforementioned criterion.

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