Architecture Students Experience on Optimizing Building Design using BPS – Lesson Learned

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Abstract. Including BPS in learning design processes in architectural colleges has been widely practiced. However, the use of BPS for undergraduate students is still very minimal because it is often considered too complex for undergraduate students. In an effort to introduce BPS to undergraduate students, in the Building and Environment Simulation course, an elective course offered by Architecture Department of Universitas Trisakti, students are asked to simulate natural lighting and provide design improvements to initial conditions using lighting passive design strategies. This study was conducted to evaluate students’ theoretical knowledge of passive lighting design strategies and experience using Dialux as a lighting simulation tools and to determine the relationship between theoretical knowledge and selected lighting passive design approaches. From the result of this study, there are important notes that can be used for the development of BPS and Building Physics learning in undergraduate level.

Keywords: Building Performance Simulation, Natural Lighting, Education, Passive Design, BPS

1. Introduction
Building performance simulation is a multidisciplinary computational modeling and simulation aimed at providing solutions that are close to real-world conditions[1]. BPS with computational methods is often used because it can model real conditions quite accurately, inexpensive and requires less time than other types of modeling. By conducting BPS in the design process, energy and cost waste during the building use phase can be reduced. Unfortunately, currently the use of BPS is still limited. At Universitas Trisakti, Indonesia, building and environmental simulations have only inserted to the learning curriculum starting in 2019, where previously there had never been any special courses that taught the...
use of the BPS program. Similar to other universities in Indonesia, at Universitas Trisakti, BPS was only briefly introduced to the Building and Environmental Physics course without the opportunity to actually try to use the BPS program in a case study.

Including BPS in learning design processes in architectural colleges has been widely practiced. Most of the BPS lessons are given parallel to the studio design [2]. In practice, the use of BPS software applications by architectural students and professionals still has problems, including: the BPS complexity, limitations in understanding the method of using software, the difficulty of choosing various options and alternatives related to modifying input variables. Therefore, many users only rely on the default method and default input available at BPS without knowing the impact of their design choices [3]. Furthermore, Rabenseifeir (2015) highlights that there are several problems faced by BPS software users, namely: the complexity of the quality of BPS software, the amount of time to make modeling, and too many different standards regarding building physics problems [4]. From the results of a survey conducted in Spain to architecture graduates, the use of BPS in the practical world is not as expected, one reason is that according to them using BPS is complicated, and they prefer to submit simulations to people who are already experts at BPS [5]. According to Göçer and Dervishi (2015), the ideal points for BPS software that are easy to understand for early level architecture students should be [6]:

- Easy and friendly to use
- Able export 2D or 3D data from other CAD tools
- Not need too detailed data input
- Provide comparative analysis for “what if” questions
- Easy to modify in the building models making process

There are various types of BPS software in the market, that help architects to calculate natural and artificial lighting for indoor and outdoor spaces, such as: Radiance, Dialux, Relux, Sefaira, Velux, etc [7]. Each of these BPS lighting simulation software offers their respective advantages. Even though there are many software options available, prospective users face the difficulty of selecting the appropriate program among this growing collection of BPS tools. It is necessary to identify different users need and identify what BPS tools can and can’t do to overcome the aforementioned barriers.

The use of BPS for undergraduate students is still very minimal because it is considered too complex for undergraduate students. However, there are several studies conducted by undergraduate students who are accompanied by their lecturers. Research conducted by Aisyah, the LSS Chronolux plugins on Google SketchUp is a tool for determining building shapes [8]. Luziani uses Autodesk Green Building Studio as a tool to simulate energy at the design stage[9]. Meanwhile, for the assessment and modeling of natural and artificial lighting, Dialux is a program that is widely used in previous BPS research in Indonesia, as it free and relatively easy to use [10], [11]. In an effort to introduce BPS to undergraduate students, in the Building and Environment Simulation course, an elective course offered by Architecture Department of Universitas Trisakti, students are asked to simulate natural lighting and provide design improvements to initial conditions using passive design strategies. Students are given live streaming tutorials in 4 sessions and given tutorials in the form of video recordings to facilitate learning while learning from home during the pandemic Covid-19. As their final project, each student is asked to simulate natural lighting in one of the rooms in their house and apply a passive design approach to improve the natural lighting conditions according to the simulation results of the initial conditions, whether it is in underlit or overlit condition. The desired percentage of daylight area is not less than 30%
of room’s floor area, in accordance with the Green Building Council Indonesia’s Greenship New Building and Existing Building criteria, but still considers lighting uniformity and glare in that simulation. In this task, an understanding of the concept of a passive design approach to natural lighting and the ability to use the Dialux program to model and analyze simulation results is needed. Similar studies have been carried out with the Dialux program by previous researchers [10]–[14].

This study was conducted to evaluate students’ theoretical knowledge of passive lighting design strategies and experience using Dialux as a lighting simulation tool and to determine the relationship between theoretical knowledge and selected lighting passive design approaches. The hypothesis of this study is that the selection of a passive design approach is affected by student’s theoretical knowledge of available lighting passive design approach. The results of this study can be used as an evaluation for the Building and Environmental Simulation courses as well as Building and Environmental Physics, in which theoretical knowledge of lighting is taught.

2. Literature Review

2.1. Building Performance Simulation and Design Process

The design process is an activity that will be carried out by architecture students on campus as well as professional architects. In the architectural guidelines published by IAI (Indonesian Architects Association), stated that the building design process stages will include: the design concept, the pre-design or schematic design, the design development, drawing, procurement and construction supervision[15]. Some researchers believe that the use of BPS should be done at the initial design stage including pre-design, schematic and design development [16]–[18]. While using BPS, architects are expected to be able to run simulations in early design process as well as imagine, create and develop design space to meet high performance goals [19]. While, the use of BPS in architectural academies can increase students’ awareness of their design to the environment, for example when determining the shape of a building, orientation, layout, the ratio of windows to wall ratio, using environmental parameters so that they can solve design problems [2]. Reinhart et al. (2020); Togashi, et al. (2020) made BPS a tool for the building design process, by generating design alternatives and unlimited simulation technique possibilities [20], [21]. From many design alternatives, the optimum design with the best building design performance will be obtained. One example of the BPS learning method for issuing design alternatives was conveyed through the "game-based method", carried out by Reinhart et al (2020), the BPS teaching technique was given as a group assignment. Students are asked to choose a combination of building mass, building orientation, building envelope configuration, various types of lighting and control systems to get the lowest Energy Use Intensity (EUI) value and cost. From the use of BPS with this method, 400.000 possible design choices were obtained [20].

C.E Ochoa et al. (2012) in his research made a diagram of the stages of using BPS lighting applications for the building design process, these stages include: early design, design development, compliance with building codes, and building commissioning and operations[7]. At each of these stages, input and output information are essential factors for design exploration.

• Early Stage Design
At the conceptual stage, software users are asked to use an inspirational design and design intention. To support the design intention, bps software users need to enter technical and existing data input, such as: site, climate data, and building project functions.
• **Design development**
  At this stage the user begins to explore performance design, for example by changing design elements, such as determining geometry, window size, lighting type etc.

• **Compliance with building code**
  Compliance with the rules is needed so that the design can achieve design conformity in order to fulfil the standards, such as comfort standard, energy consumption and low consumption of electrical energy. For standards in Indonesia, building code, such as SNI or Greenship, can be used as a reference and parameter for design achievement.

• **Building Operation and Commissioning**
  At this stage, the required data input, for example, is the calibration of the lighting quality sensor, etc.

In the practice of using BPS in architectural learning Alsaadani and Bleil Souza named two types in BPS learning in architectural education, which is a domain-specific and a user-centered[2]. From these types, three teaching paradigms were obtained. The domain-specific types deepened the understanding in detail about BPS and searched many potential analysis offered by BPS. With this approach students are directed to become "experts", armed with a deep understanding of building physics theory when performing simulations. Whereas in the user-centered type, students are using BPS in their design process to help them decide which design should they use, in this approach students are trained only as "performers" or "consumers. As a "performer" is defined as being able to run and interpret the BPS simulation results. Meanwhile, as a "consumer" can interpret the simulation results - which have been made by BPS professionals and in the end the user can choose the design decisions based on simulation results.

Morrison (2019) proposed a BPS learning method with an “expert” teaching paradigm using the Experiential Learning Model method and developed into a BPS learning spiral, in this method it is a BPS learning cycle consisting of four stages: theoretical debriefing, simulation, results analysis / autopsy, a reflection of the results against the interrelated theory. The aim of this method is to teach the basics of BPS so that users have a solid understanding of the theoretical concept and fundamental of BPS, thus it can develop an understanding of the implications of choosing modeling [3]. By modifying the Experiential Learning Model, Gentile et al. (2020) conducted a BPS learning experiment using the BPS learning spiral principle, which is called the "control method" in this method, there are several stages including: provision of building physics theory, manual basic calculations using excel, introduction to theory and BPS practice, comparing manual calculation results with BPS results. With this method students are needed to identify the differences between the manual results and the BPS results so that they can find out the error indications made in the simulation process [22]. From the two types of methods in teaching BPS, there are two stages that are considered crucial, namely the analysis of the results / autopsy and reflection of the BPS simulation results on the theory. Gentile et al. (2020) mentions that in using BPS it is very important to understand the very complex relationship between building physics, design and simulation processes [22]. Architecture students can understand the simulation software and the context on when, how, or
where they should use BPS tools if they understand the theoretical knowledge of building physics [23].

2.2. Passive Lighting Design Approach
The passive design approach emphasizes a low energy consumption design strategy. The advantages of using a passive strategy in buildings include low extra investment and the potential to reduce energy consumption costs [24]. Maximizing natural lighting in buildings can reduce energy consumption, especially from the use of artificial lighting [25]. Some passive strategies for maximizing natural lighting in buildings include adjusting window shape, window size and dimension, and choosing the proper glazing properties [26].

Daylight design where permitting natural light into the building and giving access to the outside view through the window opening will contribute to a good indoor environment and occupants comfort[27]. The common strategy to get the maximum natural lighting is to make a large glass opening, but this condition will cause potential problems to arise, the heat entering the building will increase. Due to the consideration of window dimension, shape and glazing properties, it must be considered as a penetration system that must be balanced with the need to reduce heat gain. [26]. In addition to the problem of solar heat gain, Picollo & Simmone (2009) said that the excess daylight level that enters the interior can be able to provide an extreme luminance value in the visual field and can caused unwanted discomfort such as glare[28].

3. Methods
To prepare better learning experience of Building Performance Simulation for the next term, an evaluation is needed. This quantitative study is conducted through questionnaire and secondary data from students’ final project posters. Respondents are 33 undergraduate students who participated in Building and Environmental Simulation course from February – June 2020. For this study, the questionnaire asked about students’ theoretical knowledge of passive design strategies, experiences in installing, operating, reading result and learning Dialux as simulation tools, while the secondary data about students’ selected lighting passive design approach is taken from students’ final project posters. Each student has a different case study, due to Covid-19 pandemic, where students are asked to evaluate natural lighting condition and propose an alternative design of a room in their house, which the area of selected room between 16 m² – 20 m². Data about students’ experience are analyzed using descriptive method, while data of theoretical knowledge and selected design approach are analyzed using Pearson correlation to know the relationship between both variables.

4. Findings and Discussion
First, students’ experience using Dialux as lighting simulation tool was observed and analyzed. Students described their experience and answered some statement which can be used to assessed their theoretical knowledge. The questionnaire answer is ranged using 6-point Likert scale where the respondents can show disagreement using option strongly disagree, disagree and slightly agree, or show agreement by choosing slightly agree, agree, strongly agree. From the questionnaire, it is known that 85% of the students have a positive experience with Dialux installation, while the other 15% have negative experience. It is
shown from the Figure 1 that 55% strongly agree, 15% agree, and 15% slightly agree with “Dialux is easy to install” statement, while 6% slightly agree, 3% disagree, and the other 6% strongly disagree that Dialux installation is easy. This can be caused by Dialux limitation, where currently they can be installed only in Windows Operating System. Some of the students have a MacOS laptop, so they need to find a way to install Windows OS in their laptop or borrow relative’s laptop, which can be inconvenience.

To the “Dialux functions and features are easy to understand” statement, 21% students strongly agree, 40% agree, 27% slightly agree, while the other 12% showed disagreement to the statement. This can be caused by language limitation, where student have different proficiency level of understanding English. In Building and Environmental Simulation course, all live tutorial and video recording presented in Bahasa Indonesia, but they still have to explore deeper by themselves. But still, it can be said that Dialux functions and features can be easily understood by undergraduate students.

Students also think Dialux is easy to operate, both modeling and simulating lighting condition in Dialux is easy, where only 9% of the students showed disagreement to “Modeling in Dialux is easy” statement and 3% disagreement to “Simulating lighting condition in Dialux is easy” statement. The user interface is quite familiar and easy to locate and the buttons are located sequentially, from site settings to detailed settings i.e. surface material properties. The simulation result from Dialux is also can be easily understood by undergraduate student, where 91% of respondents agree with the statement and the other 9% disagree. The customizable report offered by Dialux are helpful for students to present their simulation result properly. Students also think that there are a lot of available source of knowledge about Dialux, where Dialux’s developer posted a lot of tutorials in their social media channel and provided a forum for users. However, 34% of respondents disagree with this statement. Regarding the time required to study modeling and simulating using Dialux, 49% of the students need 2 learning sessions, 45% need more than 3 learning sessions, while 6% said they only need 1 learning session. When asked whether they will use Dialux for lighting simulation and modeling, 85% said that they will use Dialux in the future, while the other 15% said will not use it. From these results, Dialux are fulfilled the ideal points of BPS software that are easy to understand for early level architecture students, where it is easy and friendly to use, able to export 2D or 3D from other CAD tools, does not require data input to be detailed, provide comparative analysis for “what if” questions and easy to modify in making building models.
Second, students’ theoretical knowledge about lighting passive design was analyzed. All students know that opening position, size and amount affects illumination level of a room. There are 9% of students did not know that window glazing properties can affect room’s illumination level, 9% of the students did not know that surface material also affects the illumination level, and 12% did not know that shading devices on facades can affect interior illumination level.
It also can be seen from the frequency of passive design strategies chosen by the students that there are 30 students manipulated the opening positions, 32 students manipulated opening size and amount/window-to-wall ratio, but only 8 students manipulated window shading device, 2 students manipulated glazing properties, and 9 students manipulated interior surface properties in their simulation. On the other hand, some of the students failed to understand that overlit condition also are not welcomed. When they got a case with overlit lighting condition, they still tried to manipulate opening size and amount in one wall without considering lighting uniformity nor glare prevention. Figure 3 shows the most picked design approach are the opening design, either the position or size and amount of window. This also corresponds to the answer of theoretical knowledge questions about lighting passive design. It may be happened because in Dialux modeling, students are more familiar with changing

Figure 1. Students’ experience using Dialux as lighting simulation tools

Reference: Author’s own work
or making window in a wall, and it is quite difficult to manipulate room surface and window glazing material because the students need to find the technical specification of glazing by themselves.

![Students' Lighting Passive Design Approach](image)

**Figure 2.** Students' theoretical knowledge about lighting passive design approach

Furthermore, the correlation between theoretical knowledge and the selected passive design approaches are analyzed using Pearson Correlation. The only proven correlation is between Theoretical Knowledge (TK) of opening position with Design Approach (DA) of opening position, where Pearson correlation (r) significance at 0.05 level (2-tailed) is 0.396, but the rest theoretical knowledge variable and its related design approach variable is not showing significant correlation. Table 1 shows the result of Pearson Correlation between Theoretical Knowledge (TK) variables and Design Approach (DA) variables.

**Table 1.** Pearson Correlation between Theoretical Knowledge and Design Approach variables

| Variable 1 (Design Approach / DA) | Variable 2 (Theoretical Knowledge / TK) | Pearson Correlation | Sig. (2-tailed) | N  |
|----------------------------------|----------------------------------------|---------------------|----------------|----|
| DA - Opening Position            | TK - Opening Position                  | 0.396               | 0.022          | 33 |
| DA - Opening Size and Amount     | TK - Opening Size and Amount           | -0.085              | 0.637          | 33 |
| DA - Window Shading              | TK - Window Shading                    | -0.056              | 0.758          | 33 |
| DA - Glazing Properties          | TK - Glazing Properties                | 0.220               | 0.219          | 33 |
| DA - Surface Properties          | TK - Surface Properties                | 0.238               | 0.182          | 33 |

*Reference: Author’s own work*
5. Conclusion

Building Performance Simulation needs to be introduced to undergraduate students in order to enhance their design process and implemented their building physics theoretical knowledge to their design. However, undergraduate students have limitations in understanding the theoretical knowledge or numerical calculation behind the process carried out by Building Performance Simulation tools. This leads to two important notes, 1) Theoretical knowledge learning in Building Physics course needs to be improved and 2) The selection of the BPS tools for undergraduate students must be considering ease of use and availability of online/digital learning source in order to optimize BPS utilization, especially in early design process. Dialux as lighting analysis tools is appropriate for introducing BPS to undergraduate students because of its ease of use and availability of learning source, by its developer and users. Future research should be focused on BPS utilization in early design process in Architectural Design course, where students should be implementing their theoretical knowledge of building physics on their design and simulate it through BPS.

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