Daylighting Performance Assessment of Side-Lit University Lecture Theatres in the Hot-Humid Climate of Makurdi in Nigeria

Moses Iorakaa Ayoosu, Yaik Wah Lim, Pau Chung Leng

Abstract*: Daylighting is required to enhance visual comfort; whereas its illumination provides renewable functional interior lighting for specific programmes. Hence, this study examines the levels of daylight illumination for teaching and learning in two lecture theatres each located at the Federal University of Agriculture Makurdi (UAM) and Benue State University Makurdi (BSU) in Makurdi, Nigeria. The two buildings selected for the daylighting performance employed post-occupancy evaluation approach. A digital camera was employed to take photographs, whereas digital light meters were employed to evaluate the levels of illumination on the work plane. The results showed that 80% of the study space has inadequate indoor daylight illumination quantity and distribution as well as poor daylight ratios of 1.1and 0.9 for UAM lecture theatre and BSU lecture theatre, respectively Hence, the lighting conditions in the selected buildings fall short of the international lighting benchmarks (IESNA). Therefore, a pragmatic daylight design strategy is required to enhance daylight levels in the lecture theatres for energy-saving and visual comfort as well as onwards design and fusion in the national building code.

Keywords: Daylighting, lecture theatre, light levels, work plane illumination.

I. INTRODUCTION

The proposals for architectonic design typically adhere to normative criteria in different regions of the globe to guarantee sufficient daylight in the interiors of buildings. Daylight availability in Nigeria can be considered high, sustainable, and free throughout the year. Therefore, the effective harvesting of daylight in buildings is critical for energy efficiency, environmental sustainability, as well as the visual comfort of occupants and carbon dioxide (CO2) emission reduction [1]. Hence, the adequate light level in buildings such as the lecture theatres in universities is a critical functional requirement. More so, the epileptic power supply is the order of the day in Nigeria, as reported in the literature [2-5]. It is against this backdrop that the quest for optimisation of daylighting in the buildings is explored [6].

The use of daylight is a common practice in lecture theatres in educational facilities in Nigeria. For example, the lectures at the Benue State University Makurdi-Nigeria (BSU) and the Federal University of Agriculture Makurdi-Nigeria (UAM) are delivered mostly without artificial lighting. Moreover, the human preference for daylight over artificial light in spaces is established [7]; therefore, the research aim at evaluating the work plane illumination (WPI) in the lecture theatres towards understanding the problem associated with lecture theatre daylighting in Nigeria. Typically, for side-lit buildings, daylight drops from the external wall through the window into the building interior, the fraction of the sky component that distributes on the interior work plane denoted to as WPI [8]. The outlined research aim represents a significant gap in knowledge on daylighting in lecture theatres in Nigerian universities [9] and other developing nation.

The research further compares daylight levels and ratios in the lecture theatres with international benchmarks. This research is vital towards creating a background for optimisation strategy and onwards defining standards for the required lighting levels for the national building code of Nigeria. Besides, the study presents a comprehensive understanding of the problems associated with daylighting design in a side-lit lecture theatre that may be common in the tropics.

II. LITERATURE REVIEW

Windows are a critical component of daylighting building design [10]. Typically, the window admits the portion of sky-light into the building. The window's geometry impacts on daylighting for the tropical climate as studied by [11] has reported, 25% window-wall ratio (WWR) is required to achieve optimum daylight in buildings [11].

Visual comfort is the perception of building occupants on the degree of brightness or darkness of the interior building [12]. More so, the Building Research Establishment Environmental Assessment Method (BREEAM) rates visual comfort as critical credit for health and wellbeing [13]. Furthermore, the Leadership for Energy and Environmental Design (LEED) requires daylight in 75% of the space to ensure indoor environmental quality [14].

The green rating systems of buildings has advocated for building design above the mandatory requirements of the existing national building code of Nigeria [15].

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* Correspondence Author

Moses Iorakaa Ayoosu*, Department of Architecture, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai 81310, Johor-Bahru, Malaysia Country. Email: iorakaa@graduate.utm.my , arcayoosu@gmail.com

Yaik Wah Lim, Department of Architecture, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai 81310, Johor-Bahru, Malaysia Country. Email: lywah@utm.my

Pau Chung Leng, Department of Architecture, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai 81310, Johor-Bahru, Malaysia Country. Email: pcleng2@utm.my

Consequently, the buildings designed with the national building code of Nigeria may not have quality daylight since the code has no content for daylighting. However, there is limited literature on the levels of daylight in lecture theatres in Nigeria. The lecture theatre is a room for large classes with either fixed seating or traditional theatre type seating arrangement with a capacity exceeding 100. The evaluation of building illumination for comparison to facilitate the determination of compliance with specifications is an essential step to solving visual comfort challenges in buildings [16, 17].

Fig. 1 shows the tasks illumination levels from 20 lux to 20,000 lux. These values depend on the task type, which defines levels of illumination. Typically, lecture theatre requires around 500-1000 lux, whereas other tasks such as surgery can reach up to 20,000 lux.

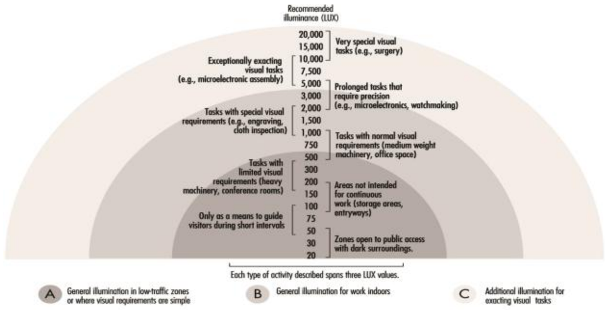

Fig. 1. Standard illumination Levels for various tasks [17].

III. RESEARCH METHODOLOGY

A case study method espoused for the study. The primary data were collected using a digital light meters – an illuminance measuring device: Display: 3½ digits, 10mm LCD, Range: 0~200,000 lux, three ranges, Size: 132x64x30mm, light sensor: 96x58x16mm; a digital camera: Sony A6000 E-mount Camera with APS-C Sensor ILCE-6000L, SNY-ILCE-6000L/B for photographs whereas a thirty-meter measuring tape used for the physical measurement of the building. Secondary data were through journals, books, publications of associations connected with lighting and online resources. The measurement was taken on the 16th February 2019 and 2nd March 2019 for UAM lecture theatre and BSU lecture theatre respectively. From the illumination measured, the daylight factor (DF) though in the scenario of Makurdi sky which is sunny sky as daylight ratio was evaluated and compared with the recommended standard and lastly, the indoor illumination also compared with the recommended standard by the Illuminating Engineering Society of North America (IESNA) which is peg at 500-1000 lux as shown in fig. 1 above. A Descriptive analysis employed using Microsoft excel 2016 and the results presented on graphs.

A. Case Study

Makurdi located on the banks of the River Benue in the central region of Nigeria, it lies on DMS latitude longitude of 7°44'27.96"N, 8°30'43.56"E and is 104 meters above sea level. Makurdi town is within the tropical, temperate humid climate of Nigeria, which is characterised by the average clearness index of 0.43, relative sunshine, diffuse ratio of 42-60% and relatively high diffuse coefficient [18]. It based on the annual average of the daily clearness index, the annual sky conditions which have six patterns, the harmattan-haze or dry season pattern from October/November, December, and January with occasional dust-free, dry season pattern from February, March, and April, and four rainy season patterns in August, July and September, June and / October and May [19]. The variations are in tune with these six patterns, while the diffuse coefficient has an almost constant value of about 0.24 the seasons [20]. The solar hours are relative 12 hours per day per annum from 6:42 am to 6:25 pm, with its pick at noon, as shown in Fig. 2. The campuses of UAM and BSU hosting the theatres examined in this study is in Makurdi, the capital of Benue state of Nigeria. Furthermore, UAM is located on the northern bank of the River, whereas BSU is on the southern bank of the River Benue [21].

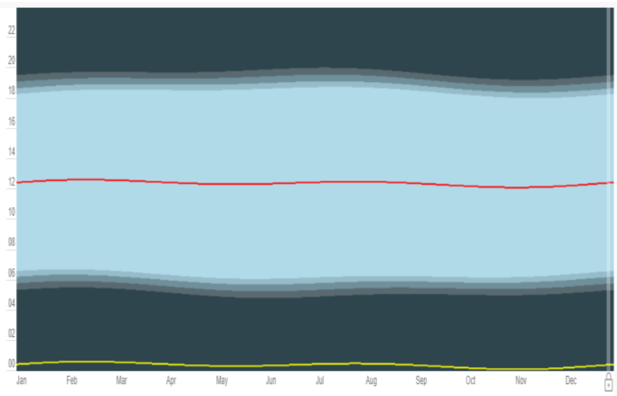

Fig. 2.Sunshine hours over Makurdi

UAM lecture theatre is at the College of Agricultural Education of the University with a seating capacity of 969 students. Fig. 3 shows the floor plan and photos of the venue, respectively. On the other hand, the BSU theatre is a twin lecture theatre of 1000 seating capacity each located at the Faculty of Social Sciences of the university, as depicted in Fig. 4.

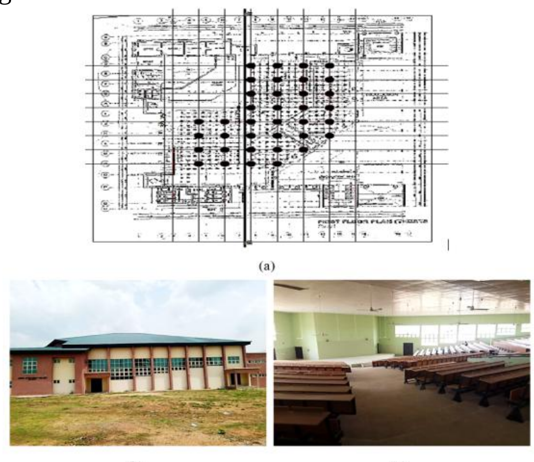

Fig. 3.UAM lecture theatre (969 capacity): (a) Floor plan; (b) Exterior view; (c) Interior view.

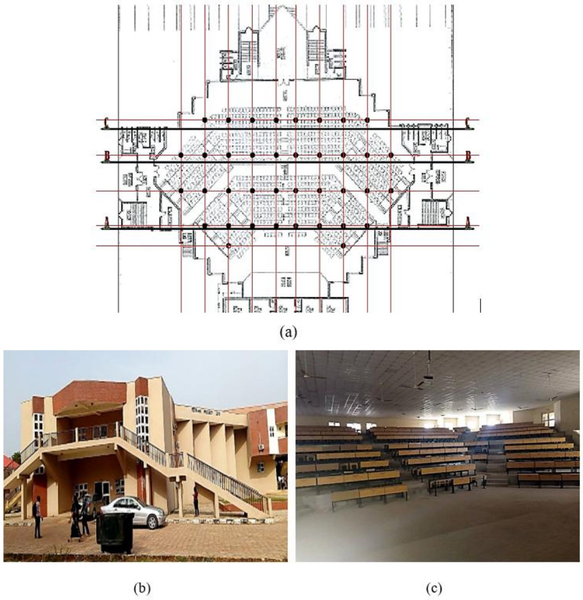

Fig. 4.BSU lecture theatre (1000 capacity): (a) Plan; (b) Exterior view; (c) Interior view.

The window fenestration design of the lecture theatres is bilateral. Though the BSU theatre utilised wall nodes as a shading device due to its orientation of west-east, where the hall large central core has no window facing, the strategy limits daylight penetration to the central core. Unlike the UAM theatre, the windows are parallel and face through the central core, thereby offering a better penetration of daylight.

The theatres selected are amongst the most modern academic/university infrastructure constructed by the Federal Government of Nigeria (FGN) and both delivered in 2018, the structures ought to have the most modern design standards. In both theatres, the walls finished with light- cream emulsion paint and white acoustics ceiling boards of 600 × 600mm bays, while the floors made of pale vitrified tiles, and both theatres windows made of tinted glass.

B. Light Level Assessment

The lighting assessment was carried out at thirty-seven (37) points in UAM lecture theatre and thirty-eight (38) points in BSU lecture theatre based on the room index. A post-occupancy evaluation (building survey and observation) propounded by Turpin-Brooks & Viccars,2006 and used in [11] was employed in this research. The selected ranges based on short term spot measurements of work plane illumination (WPI) on the occupant's work plane of 850 mm high. The measurements obtained from three sessions, i.e. morning (7 am – 10 am), noon (11 am – 1 pm) and afternoon (3 pm – 6 pm). The theatres' dimensions measured for the room index evaluation. The room index required for calculating the work plan illuminance in order to arrive at measurement points. The factor is calculated by Equation 1[11]:

$$Room\ Index\ (RI) = \left(\frac{length \times width}{Mounting\ height \times (length + width)}\right) \quad (1)$$

The RI is the minimum measuring points required to calculate the average illuminance of a space. Based on the RI (Equation 1) and Table I, the number of measured points required are 37 and 38 for UAM lecture theatre and BSU lecture theatre respectively. These numbers are also consonance of space division within the theatres.

Table- I: Room Index and Number of Measuring Positions [11]

Room Index	Minimum Number of Measuring Positions
Less than 1	4
1 to below 2	9
2 to below 3	16
3 or greater than 3	25

Therefore, each lecture theatre area was calibrated based on the number of measuring points across the seating rows. Afterwards, two light meters were used each for the indoor illumination and outdoor illumination to collect data concurrently based on the measuring positions deduced. The indoor and outdoor illuminations were measured simultaneously by placing the illuminance sensor of the light metre at the calibrated points marked on the work plane in the lecture theatre and the corresponding outdoor illumination. The illuminance levels were recorded simultaneously in the absence of the artificial lights. Table II presents the indicators for lighting performance typically adopted in the literature.

Table- II: Daylighting Performance Indicator [11]

Performance Indicator: Daylight Factor	Interpretation
< 1	Unacceptably dark, negligible potential for daylight utilization
1 – 2	Acceptable, the small potential for daylight utilisation
2.5	Preferable, enormous potential for daylight utilisation
5	Preferable, Ideal for paperwork, too bright for computer work and total daylight autonomy

IV. RESULTS AND DISCUSSION

A. Daylight Factor (Daylight Ratio)

The desirable daylight factor (daylight ratio, DR) for spaces such as lecture theatres typically is between 2.5 -5 for daylight utilisation, based on Table 3. The formula for calculating daylight factor (DF) [22] is:

$$Daylight\ Factor\ (DF) = \left(\frac{DI}{DO} \times 100\right) \quad (2)$$

Where DI represents indoor illumination, and DO is the outdoor illumination, and 100 is a constant. The DF of 5 is ideal for paperwork and total daylight autonomy, a scenario in lecture halls. However, in this study, total points or area were unable to achieve the recommended factor of 5. The areas near the exterior walls with window recorded higher daylight ratios and diminished towards the middle of the theatre, as shown in fig 5 and 6, along the sections in fig 3 and 4 respectively.

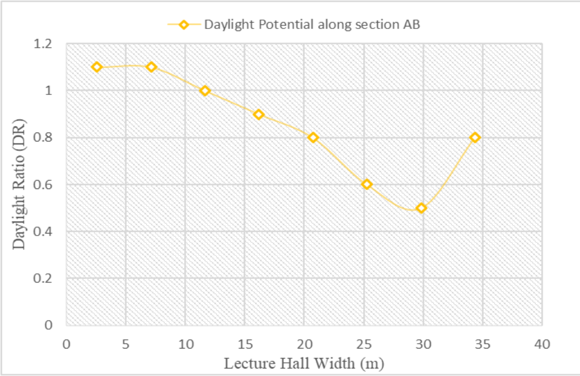

Fig. 5.Average daylight ratio in UAM lecture theatre.

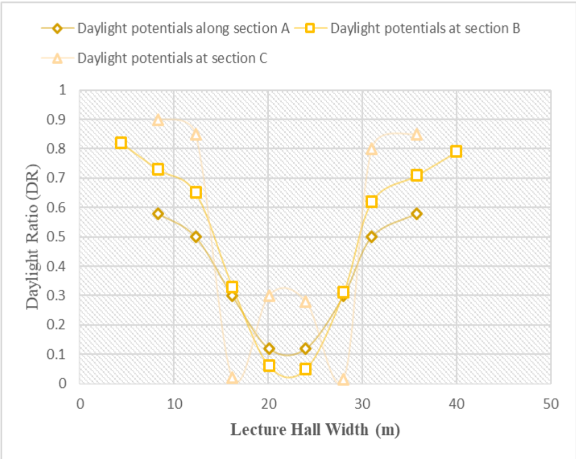

Fig. 6.Average daylight ratio in BSU lecture theatre.

The maximum values of daylight ratio found to be 1.1 in the UAM lecture theatre, and 0.9 in the BSU lecture theatre. There exists a considerable shortfall in the standard required for performing a task in space like a lecture theatre.

The results indicate that daylight enhancement strategies were not employed in the design and construction, as compared to standard. More so, the average indoor illumination at the three sessions found to be proportional to the corresponding average outdoor illumination base on the window fenestration design, as depicted in Fig. 7 and 8. These imply that when the right strategy for window fenestration design achieved, the daylight quality and quantity, as well as daylight autonomy, is possible.

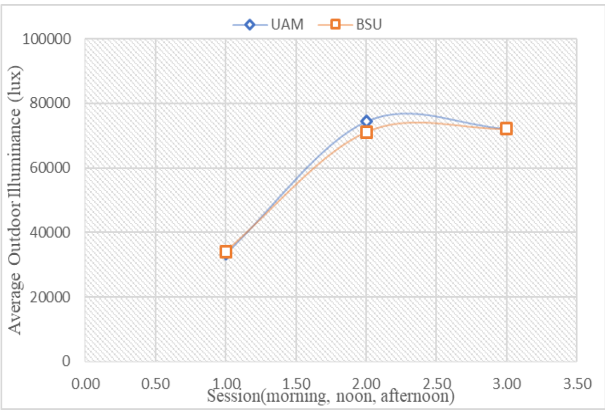

Fig. 7.Average outdoor daylight illumination at UAM and BSU lecture theatres.

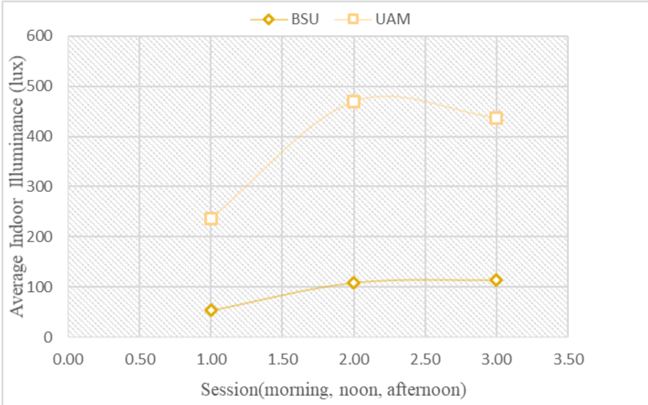

Fig. 8.Average indoor daylight illumination in UAM and BSU lecture theatres.

Furthermore, it observed that the indoor daylight illumination is proportional to the relative distance to the window. The UAM lecture theatre recorded higher indoor daylight illuminations compared to BSU lecture theatre, although the illumination seemed instinctively designed as the level of work plane illumination fluctuates randomly.

The disparity in the lecture hall design configuration could also pose a challenge in defining a critical design strategy. Daylight ratio in UAM lecture theatre ranges between 0. 500 to 1.100 and 0.015 to 0.900 in BSU lecture theatre. These imply that the evaluation of a base model of lecture theatre for strategic evaluation and optimisation would be desirable since each theatre has different spatial configuration and peculiar challenges. These will facilitate the generalisation and afterwards policy design and incorporation into building code of Nigeria.

B. Work Plane illumination

Work plane is the surface for performing the visual task. In the study buildings, the work plane is the top of the desk where student place their books for reading or writing and is 850 mm above the finished floor level.

In fig. 9, the daylight levels are grossly inadequate compared to the international standard, and the distribution is non-uniform. The IESNA benchmarked 500- 1000lux for a lecture theatre but in the cases studied, the range of work plane illumination is between 21- 687 lux amongst the 75 total points measured. Only 15 points (20%) achieved the recommended standard, of which 14 points recorded from UAM lecture theatre and BSU lecture theatre scored only 1 point. These imply that a total of 80% area do not have minimum standard work plane illumination (WPI). The UAM lecture theatre has a larger window opening area than the BSU lecture theatre, as shown in figures 3 and 4. These may be a contribution to WPI.

Aside from the energy-saving benefit of daylighting in schools, students perform better in daylit lecture halls, and it also improves the productivity of the instructors [23]. It is also crucial to achieving a more pleasant, sophisticated, excitingly coherent and spatially defined space [24] which creates aesthetics appeal.

Better student learning is attainable as a result of better aesthetic environment, and an aesthetically sound environment is apparent by way of influencing student attitudes and feelings, thereby contributing significantly to student cognitive performance. These then calls for a more defined strategy to quality daylight admission and distribution.

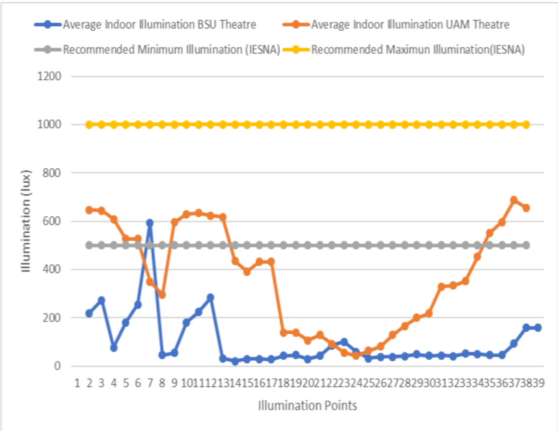

Fig. 9. Measured work plane illuminations and the IESNA standard Comparison.

V. CONCLUSION

The study evaluates UAM lecture theatre with 969 and BSU lecture theatre with 1000 seat capacity for daylighting performance; both located in Makurdi Nigeria. A daylighting post-occupancy evaluation and descriptive analysis employed. The building assessment showed that the daylight levels examined in the study buildings were grossly inadequate compared to the international standards even though sufficient outdoor daylight was available. The findings suggest that the buildings were designed with little or no consideration for the daylight utilisation as 80% of the space study fall under the standard illumination as specified by IESNA. The maximum daylight ratios of 1.1 and 0.9 for UAM and BSU lecture theatres respectively were only possible, this fall short of the recommended value of 5. These maybe not far from the deficiency in knowledge and lack of code in the National building code for the design and implementation. The windows were slightly insentient designed as the light distribution was random in terms of value and distribution. Therefore, proper daylighting design strategy, inquiry, and framework are required to enhance the performance in the lecture theatres. Lastly, the design and fusion of a comprehensive policy framework are required to reform the existing national building code of Nigeria can be replicated in the tropical region.

Further study is required to determine an enhanced configuration that promotes even daylight level in the lecture theatre and by extension other building.

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AUTHORS PROFILE

Ayoosu, Moses Iorakaa, received bachelor and master of technology degrees in Architecture from the present Modibbo Adama Univesity of Technology Yola, Adamawa State Nigeria. He is currently a PhD research scholar in the field of Architecture at the Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai, Johor-Bahru, Malaysia. His area of interest is sustainable architecture, building construction, building information modelling (BIM), building information science, daylighting, sustainability performance study and environmental impact assessment. Aside from design and construction, he has four research articles published in international journals and one conference paper to his credit as well as some articles under review.

Dr. Lim, Yaik Wah, is currently an Associate Professor of Architecture in the Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia. He received his B.Arch. in the year 2008 and PhD (Architecture) in the year 2011. His area of expertise includes sustainable architecture, daylighting, building information modelling (BIM) and sustainability performance study. He teaches environmental architecture design studios, architectural technologies, BIM and building simulation. He has experience in conducting and leading several interdisciplinary research and consultancy projects in sustainable architecture and BIM. His research findings have been published in leading journals and conferences in the relevant fields and a book publication. He is also an editorial board member of Journal of Daylighting and reviewers of several indexed international journals. He is also a member of the Board of Architects Malaysia and Malaysian Green Building Confederation.

Dr. Leng, Pau Chung, received his PhD in Architecture from the Universiti Teknologi Malaysia (UTM), Skudai Johor Malaysia. He is currently a senior lecturer for the Architecture Programme at The Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia. Furthermore, currently, a committee member of the Malaysia Green Building Council (Southern Chapter) and seconded the position of Architecture Computer Laboratory UTM and CAD Centre of Faculty of Built Environment and Surveying UTM. Also, he is a graduate member of the Board of Architects Malaysia (LAM), Malaysia Board of Technologists (MBOT), and Malaysian Institute of Architects (PAM).

Besides supervising postgraduate students and conducting research, he also teaches Design Studio 3 & 4 (Undergraduate Second Year Studio), Basic of Computing in Architecture & CADD and BIM applications. Other than that, he is also involved in the teaching of Master of Architecture (Offshore Programme UTM) for subjects Advance Architectural Technology and Integrated Environmental Design, Environmental Pre-Thesis Studio, Urbanism Pre-Thesis Studio as well as supervising Master of Architecture Thesis Students in both Mainstream and Offshore Programme.

His research interests lie in the Sustainable Architecture in Passive Cooling Design, Sustainable Housing Design, Industrialized Building System (IBS) Design, Education in Building Information System (BIM), as well as Sustainable Planning. His interest is much enthusiastic towards the sustainable built environment development and its impact on the natural environment. He has seven articles published in international journals, four books publication (joint authorship), four book chapters and thirteen conference papers. Also, he is currently the Principal Investigator for Research University Grant (Tier II) entitled Optimization of Natural Ventilation with Solar Chimney For Single Storey Terraced House in Tropical Climate and National Real Estate Research Coordinator Grant (NAPREC) entitled Challenges in Adopting Open Industrialized Building System (IBS) in the Malaysian Affordable Housing Construction Industry.