Rethinking Solar Geometry and Design Education in the Tropics: Limitations and Opportunities of Current Teaching Methods

Repensando la geometría solar y la enseñanza del diseño en los Trópicos: Limitaciones y oportunidades de los métodos actuales

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HIGHLIGHTS

- Analyses limitations in teaching solar geometry in tropical architecture schools.
- Finds low understanding and application of solar geometry concepts among students.
- Proposes educational methods combining manual and digital tools in tropical contexts.

- Analiza limitaciones en la enseñanza de geometría solar en escuelas de arquitectura tropical.
- Detecta una baja comprensión y aplicación de conceptos de geometría solar en estudiantes.
- Propone métodos educativos que combinan herramientas manuales y digitales en contextos tropicales.

RESUMEN

Los métodos tradicionales de enseñanza en arquitectura presentan limitaciones para lograr un profundo entendimiento de la geometría solar y su impacto en el diseño de iluminación, especialmente en los trópicos. En el contexto del cambio climático, es imperativo avanzar en las metodologías educativas para mejorar la comprensión de los estudiantes sobre el rendimiento solar de los edificios. Aunque los métodos de análisis de iluminación están bien establecidos, los métodos de enseñanza de la geometría solar han recibido poca atención. Este estudio investigó las herramientas y métodos de enseñanza comunes que afectan el aprendizaje de los estudiantes. Realizamos una encuesta para comparar el conocimiento de los estudiantes en geometría solar y diseño de iluminación en dos escuelas de arquitectura en Costa Rica y Malasia (n=153). Nuestros hallazgos muestran que los estudiantes en ambos países tienen un bajo conocimiento autoevaluado de la geometría solar, una preferencia por la combinación de herramientas de aprendizaje manuales y digitales, y un fuerte consenso sobre la importancia del conocimiento de la geometría solar para su desarrollo educativo y profesional, lo que destaca la necesidad de mejorar los métodos y herramientas de enseñanza adaptados a los climas tropicales.

Palabras clave: *Geometría solar; calidad de la luz día; recursos educativos; proceso de aprendizaje; clima tropical.*

ABSTRACT

Traditional architecture teaching methods pose limitations in attaining a deep understanding of solar geometry and its impact on daylight design, especially in the Tropics. In the context of climate change, advancing teaching methods is imperative to enhance students' comprehension of buildings' solar performance. While methods for daylighting analysis are well established, teaching methods for solar geometry have lacked attention. This study investigated common teaching tools and methods affecting students' learning. We conducted a survey comparing students' knowledge in solar geometry and lighting design at two architecture schools in Costa Rica and Malaysia (n=153). Our findings show that students in both countries have low self-assessed knowledge of solar geometry, a preference for a combination of manual and digital learning tools, and a strong consensus on the importance of solar geometry knowledge for their educational and professional development, highlighting a need for improved teaching methods and tools tailored to tropical climates.

Keywords: *Solar geometry; daylight quality; educational resources; learning process; tropical climate.*

1. INTRODUCTION

According to the United States National Human Activity Patterns Survey (NHAPS), people spend on average 87% of their lives inside buildings [1], which exacerbates the lack of exposure to quality natural light. This emphasizes the importance of architects creating high-quality designs that prioritize optimal environmental conditions for the well-being of building occupants. However, spaces are frequently designed with insufficient natural light. This raises the question of why this is the case.

Daylighting implies the controlled use of natural light in buildings to achieve the desired visual, thermal and psychological comforts [2]. Therefore, it is essential that architectural education has a comprehensive pedagogical instruction on this subject. However, there is a gap in knowledge transfer that causes professional designers to overlook daylight's significance for human comfort by placing insufficient emphasis on it. Despite a large volume of published studies describing the role of daylight in Architecture [3], literature focusing particularly on the role of teaching methods in the understanding of daylight in architecture is limited.

The teaching approaches employed in today's undergraduate architecture courses are based on pedagogical proposals developed in Europe and the United States in the nineteenth century. Concerned about the challenges of lighting education in architecture, a recent review study [4] found that just one of 23 keyword-filtered articles published between 2002 to 2022 addressed the pedagogy of teaching lighting to undergraduate architecture students. The authors cautioned that outdated teaching and learning methods still used for current curricula may fail to satisfy the demands of today's students preparing for industry practice. As a result, future architects may be unprepared to address the challenges of 21st-century building performance and lighting design.

In the equatorial regions, formal aspects of building envelope design require a different approach demanding a response to the environmental conditions of the Tropics, controlling solar gains and creating shade with designed shading devices for more thermal comfort [5]. Even though the tropical environment provides ample natural light throughout the year, a considerable percentage of buildings suffer from overheating and excessive glazing on facades that transmit more heat than light, surpassing the energy efficiency index's acceptable level [6]. Additionally, the emerging widespread use of artificial lighting at the beginning of the 20ths century enhanced designers' tendency to overlook the inclusion of natural light into architectural design. The emphasis on lighting design quality that is currently prevalent is driven by the recently established energy-saving goals that are pursued by green-building certifying bodies. As a result, much of the research has concentrated on the quantitative aspect of illumination. Both academic education in university settings and practical applications in the industry are increasingly dominated by this quantitative approach.

Higher education has an obligation to address climate action. As such, when teaching architecture and considering the study of natural and artificial light, research on the on-going climatic crisis must be a concern too. The IPCC report in 2021 highlights this by stating, that using high efficiency light bulbs, optimizing lighting configurations, and maximizing natural light can reduce energy consumption and adverse environmental impacts [7]. Therefore, it is important for architecture programs to incorporate sustainable lighting practices into their curricula.

However, despite the frequent call for action in the advent of climate change, there appears to be a disconnect between theory and practical application. Awareness of the costs and effects of electrical light, including environmental effects, has grown, suggesting daylight as the more beneficial choice. Nevertheless, there is a seemingly contradictory difference between the theoretical knowledge taught in architecture programs and its practical application in the design process due to the shift in focus in recent years from qualitative aspects to a more quantitative technology driven approach, with little exploration of light's possibilities and effects. This trend was underpinned in a study by Szokolay investigating the inclusion of lighting in undergraduate architecture course curricula [8]. The daylight skills learned in the classrooms seem to remain at a theoretical level and have a limited application in the design projects via advanced software tools and metrics [9]. Yet, as mentioned in a recent study by Treacy et al., architects may struggle designing with daylight if they lack a fundamental understanding of its physics and effects on our environment, health, and wellbeing [10].

A similar voice of criticism on how daylighting is taught in academia is also often expressed by stakeholders from the industry. Despite growing interest in daylighting, architectural and design education programs often fail to provide adequate training on this topic. As was pointed out in the study by Giuliani et al [9], once in business, practicing architects often claim that the daylighting calculation process is a delicate and complex task that requires much time. As a result, it is typically disregarded and not considered an essential component of design. Instead, it is frequently delegated to specialists for resolution, with little regard for the significant impact on the overall proposal. Problems in incorporating daylighting into design practice have been evidenced in previous surveys highlighting a widespread lack of understanding of daylighting metrics, standards, instruments for assessment, and computer programs. There appears to be a significant lack of information on daylighting challenges among professionals, building designers, and practitioners [11]. Integrating specific teaching units addressing these topics and filling the knowledge gap for the future professional practice would be a strategy yet to be applied in academia.

This situation is also evident in the current curricula of architecture schools, as for example at the University of Costa Rica, lacking courses specifically dedicated to lighting and its application in space design. Although technical courses such as Climatological Design and Building Installations cover solar geometry and artificial lighting design concepts, there is little evidence of a deep understanding and application of these concepts in subsequent design studios. Since students do not apply technical knowledge about lighting in architectural design, it is necessary to analyze the limitations of learning solar geometry in the Tropics and seek ways to promote a different pedagogical paradigm, with new tools. Solar geometry and natural light have been taught in tropical architecture schools such as the University of Costa Rica and Taylor's University in Malaysia. However, there aren't enough courses to address today's challenges, and there's a lack of understanding of its application in built-environment design, both in academic proposals and in architectural practice.

This situation has been highlighted in the literature, frequently expressing that new teaching methods are needed to equip students with tools and knowledge to see and experience daylight, allowing them to incorporate daylight as an essential performance parameter in their architectural designs [12]. Current teaching on solar geometry and daylighting primarily focuses on physics, geometry, and simulation, but should also include more comprehensive aspects. These include the cultural preferences of daylighting, its physical properties, relevant standards and regulations, and its impact on health. Additionally, non-visual aspects such as non-image forming effects, visual comfort, perception, and measurement should be covered. Energy aspects like solar geometry, energy management, protocols, and integration with lighting are crucial, as are advanced simulation methods, daylighting evaluation techniques [9]. Figure 1 shows typical tools (analogue and digital) used in current teaching practice to teach solar geometry.

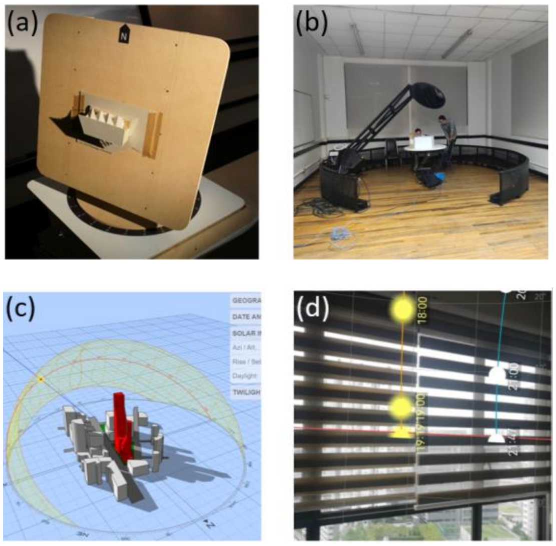

Fig. 1: *Solar Analysis Tools. (a) Heliodon, manual use; (b) Solar Simulator, automated use; (c) 3D sun path web application, digital use; (d) Augmented Reality solar path, smartphone application (picture "a" and "b" by the authors taken at the School of Architecture, Universidad de Costa Rica; picture c screenshot from Andrew Marsh web application "3D Sun-Path", picture "d" screenshot from "Sun Position"(Version 3.16.1) augmented reality smartphone application).*

This study aims to unravel the underlying problems and shortcomings in current teaching practice regarding solar geometry and daylight to establish potential pathways for developing novel teaching methods and tools that align with the pedagogical requirements of 21st century higher education. In order to obtain comprehensive information about the state of the art of current teaching practices we carried out a curriculum review of the two aforementioned case study architecture schools and deployed an explorative survey asking students about their knowledge on theory and practice regarding solar geometry and daylighting. This qualitative analysis will provide architecture educators with a clearer understanding of effective teaching methods for natural lighting design, enabling them to implement the most appropriate strategies. The findings will inform the creation of improved pedagogical strategies and teaching tools, ultimately enhancing the educational outcomes in this field.

2. MATERIALS AND METHODS

2.1 Literature Review

During this phase, an extensive literature review was conducted to investigate existing research, tools, and pedagogical techniques for teaching solar geometry and lighting design. The goal was to critically assess the strengths and limitations of existing knowledge in this topic. The review technique included comprehensive searches, meticulous screening, and rigorous analysis of relevant material using five main search terms: solar geometry, daylight quality, educational resources, learning processes, and tropical climate. Initially, 82 publications were found, and 33 were chosen for further review based on their titles and abstracts. These selected articles were then thoroughly classified according to their relevance (See Figure 2).

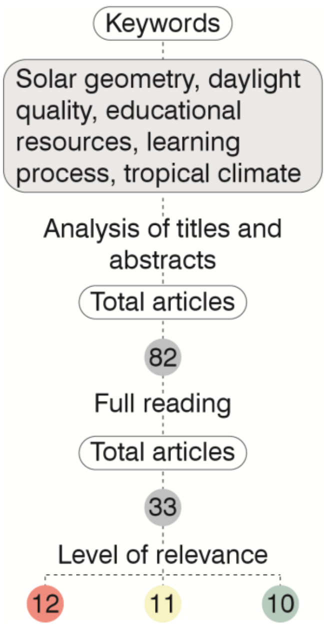

Fig. 2: *Systematic Literature Review Protocol. (Source: Authors)*

We constructed a content analysis matrix using the most important approaches, tools, and main findings from these papers. This technique enabled us to identify important challenges and instructional methodologies that would serve as the basis for our theoretical framework.

2.2 Diagnostic study

The second phase consisted of conducting a diagnostic study to evaluate students' understanding of solar geometry and daylight concepts at two tropical-latitude educational institutions: The University of Costa Rica (University A) and Taylor's University in Malaysia (University B). These universities were chosen due to their substantial educational recognition in their respective countries and their status as leading academic institutions in the field of architecture. As such, they are recognized for offering excellent educational possibilities, particularly at tropical latitudes.

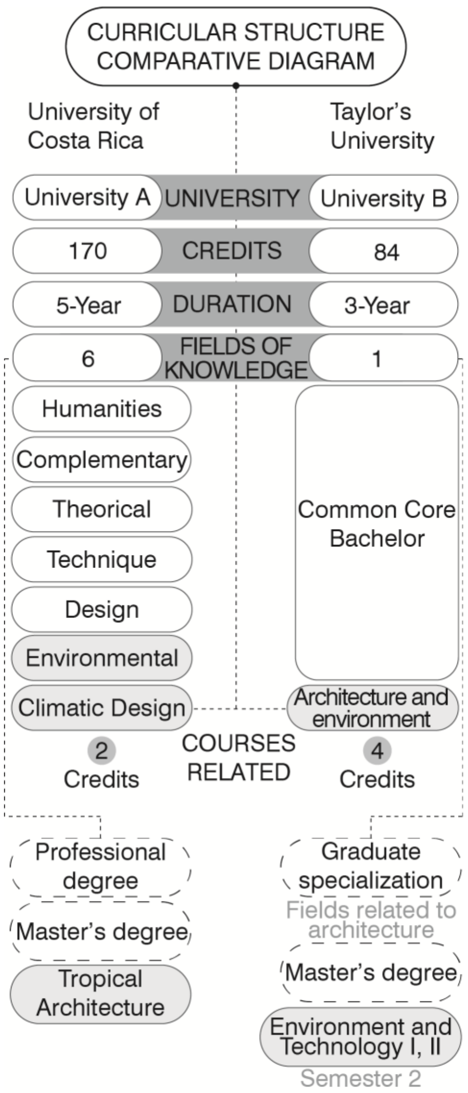

Fig. 3: *Curriculum comparison diagram between University A and University B. (Source: Authors)*

This study involved assessing the curricular frameworks of both universities, focusing on course offerings that incorporate solar geometry principles and daylight into their academic content. Notably, each university offers only one course dedicated to this subject: Climatic Design at University A and Architecture and Environment at University B. For this reason, these courses were selected for conducting student surveys. The study also examined the teaching materials utilized in these courses, as well as the academic work produced by students, to uncover elements that may be contributing to potential knowledge gaps.

2.3 Questionnaire Development

The following step involved creating a questionnaire to collect information on the effectiveness of current teaching methods, learning barriers, and potential areas for improvement in knowledge of solar geometry and daylight concepts. To ensure data consistency and comparability, we administered the identical survey in both universities, each in their corresponding language, Spanish and English respectively.

The questionnaire was designed to address a variety of themes and dimensions related to the study's objectives. Each question was aimed to gather specific information about the students' academic progress, current affiliation, level of expertise, application of solar geometry in design, preparedness, relevance of knowledge in professional practice, knowledge acquisition, comfort considerations, tool proficiency, learning preferences, skill development, and professional competence. Table 1 summarizes the questions and the topics or dimensions they assess.

***Table 1**: Questions and Dimensions assessed in the Questionnaire.*

#	Questions of Questionnaire	Dimension
Q1	What year of your studies are you in?	Academic Progression
Q2	Which design studio are you currently part of?	Current Affiliation
Q3	How knowledgeable are you about solar geometry?	Expertise level
Q4	Have you been requested to incorporate solar geometry strategies during the design studio?	Application in Design
Q5	Would you consider you have been given the correct education/tools to develop design exercises that include solar analysis?	Preparedness
Q6	Do you consider the knowledge of solar geometry important in the daily work of an architect?	Relevance in Architecture
Q7	Is it important for your educational development to acquire knowledge about Solar Geometry?	Acquisition of knowledge
Q8	Which factors related to solar geometry can affect user's comfort in an interior space?	Comfort considerations
Q9	Which of the following solar geometry tools do you know? Pick and mark from the following list.	Tool Proficiency
Q10	In which way would you like to learn about solar geometry? Are you interested in acquiring manual, digital or a combination of skills in this area?	Skill development
Q11	Which tools related to solar geometry do you consider essential for responsible performance in the profession?	Professional competence

The questionnaire was developed in stages, beginning with an initial draft, followed by pilot testing. The first draft was evaluated by the authors to ensure that the questions were clear, relevant, and comprehensive. The pilot test was administered to a small group of students to identify any ambiguities or concerns with the questions. Based on the feedback from the pilot test, the questionnaire was refined before its final distribution.

To improve the academic rigor of our questionnaire, several questions were based on the DAYKE (Daylight Knowledge in Education) framework [11], which is well-known for its comprehensive approach to assessing daylighting knowledge in educational contexts.

***Fig. 4:** (a) Students participating in the survey in the Architecture and Environment course at Taylor's University in Malaysia (b) Close-up to the QR code of the questionnaire. (Source: Authors)*

By connecting our questions with the DAYKE framework, we sought to ensure that our survey addressed critical areas of daylighting education and offered reliable data for analysis. Furthermore, we used the same online platform, Google Forms, to distribute the survey at both universities. This provided data consistency and simplicity of access for participants.

2.4 Data Gathering

The next step involved obtaining data from the distributed surveys. Students from the Climatic

Design course at Costa Rica's University and from the Architecture and Environment course at Malaysia's University provided responses. The authors completed the data gathering technique to achieve a representative sample of students and the highest feasible participation rate (Table 2).

2.5 Data Analytics

The methodology's final phase focused on analysing the acquired data to generate useful insights such as effective teaching methods and significant learning barriers. We began with data cleaning and preparation, which involved reviewing the raw data for completeness and quality, and addressing any incomplete or inconsistent responses to maintain the dataset's integrity. Descriptive statistics were used to summarize the data's overall quantitative tendencies. A comparative analysis was also performed to find parallels and variations in students' knowledge, perceptions, and educational experiences at the two universities. In addition, a thematic analysis of qualitative responses was conducted to uncover recurring themes and patterns linked to the effectiveness of teaching methods, learning hurdles, and opportunities for development.

3. RESULTS AND DISCUSSION

3.1 Sample description

The study included a total of 153 students from two universities located in tropical latitudes. Out of the total participants, 63 students were from Costa Rica (University A) and 90 students were from Malaysia (University B).

As shown in Table 2, a majority of female students was observed in both universities, compared to male students (University A 28% vs. 13%, University B 35% vs. 24%).

Table 2*: Distribution of participant students by University (A=Costa Rica, B=Malaysia)*

Item	N	%
Total number of students	**153**	**100**
Students University A	**63**	**41%**
Male	21	13%
Female	42	28%
Students University B	**90**	**59%**
Male	36	24%
Female	54	35%

The participants ranged from 17 years old to 26 years old, with prevalence of students between 18 and 21 years old, ensuring a representation of students enrolled in undergraduate architectural education. At University A, all participants were in their second academic year of study, enrolled in the Climatic Design course. In contrast, at University B, where 61% of the students were in their first year and 39% were in their second year, the sample was selected from the Architecture and Environment class.

3.2 Quantitative Analysis

We performed a quantitative analysis of the questionnaire findings, focussing on students' comprehension and perceptions of solar geometry and daylighting (See figure 5). Key patterns and insights are uncovered to inform potential improvements in educational practices.

The analysis of responses to Q3 "How knowledgeable are you about solar geometry?" reveals a general tendency of low self-assessed expertise among both Costa Rican and Malaysian students. The majority of Costa Rican students (62%) and a significant portion of Malaysian students (39%) strongly opposed having adequate knowledge. Furthermore, 24% of Costa Ricans and 33% of Malaysian students disagreed with the assertion. Interestingly, a bigger percentage of Malaysian students (27%) chose a neutral response than Costa Rican students (8%), indicating that Malaysian participants were more uncertain or had moderate awareness. Overall, the statistics indicate a significant lack of understanding on solar geometry among students in both countries, with Costa Rican students showing a significantly bigger shortfall.

To gain insights into students' integration of solar geometry principles in design, we analyzed responses to Q4. Notably, there are significant differences between Costa Rican and Malaysian students. A large majority (47%) of Malaysian students strongly disagreed with the statement, indicating that they had not recently been required to implement these strategies. In comparison, only 14% of Costa Rican students strongly disapproved. Both groups had an identical percentage of students who disagreed (24%). Moreover, a significant proportion of Costa Rican students (24%) expressed neutrality, compared to 13% of Malaysian students, suggesting some uncertainty or mixed experiences. As a whole, while agreement with the statement was rather low, Costa Rican students indicated higher levels of agreement (14% agree, 24% strongly agree) compared to their Malaysian counterparts.

In order to evaluate students' perceptions of their preparedness to include solar analysis into design exercises, we examined their replies to Question Q5. This study found considerable differences in opinions between Costa Rican and Malaysian students. A considerable proportion of Costa Rican students (46%) strongly disagreed with the notion of being adequately equipped with the requisite education or tools, compared to 26% of Malaysian students who shared similar views. Furthermore, 21% of Costa Rican and 23% of Malaysian students disagreed with the statement. A higher percentage of students from Malaysia (32%) chose a neutral response, indicating uncertainty or moderate satisfaction with their education, than Costa Rican students (24%). While overall agreement with the concept was modest, Malaysian students agreed more strongly.

Responses to Q6 show that students from Costa Rica and Malaysia agree strongly on the necessity of solar geometry knowledge, but with some variance in intensity. A majority of Costa Rican students (94%) strongly agreed with the

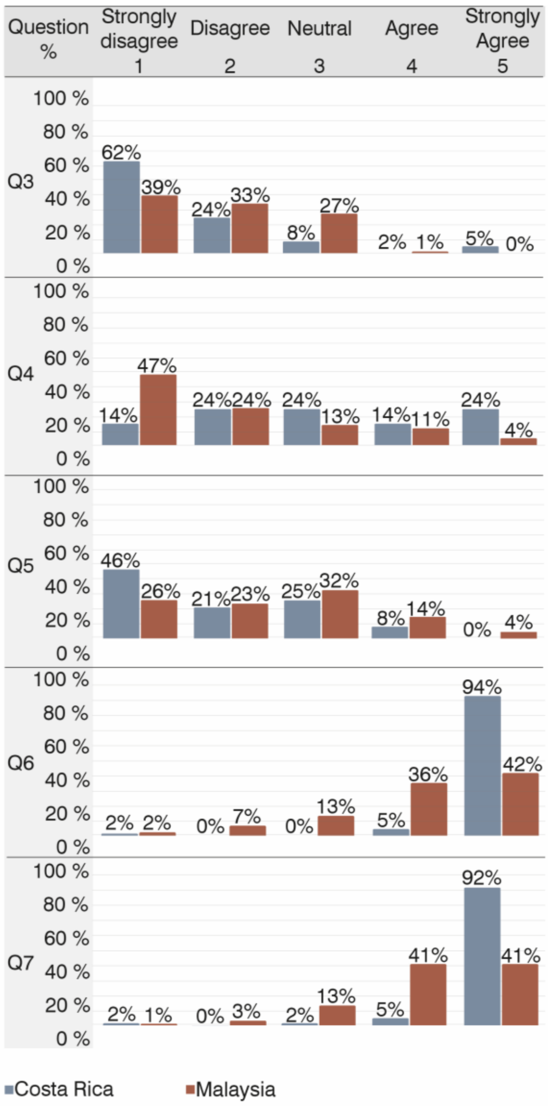

Fig. 5: *Students' responses to questionnaire questions Q3 to Q7(Source: Authors).*

statement, suggesting a firm belief in the importance of solar geometry in their professional activities. In comparison, 42% of Malaysian students stated strong agreement, which is a notable but relatively low number. Also, 5% of Costa Rican students and 36% of Malaysian students agreed with the statement, reinforcing the overall positive impression. Few people in either country strongly objected (2% each) or disagreed (0% Costa Rican, 3% Malaysian). The results indicate that Costa Rican students appreciate the vital function of solar geometry knowledge in design, whereas Malaysian students do as well, although with a greater range of agreement.

There is a strong consensus on the importance of acquiring knowledge about solar geometry for educational development among students from both Costa Rica and Malaysia, according to Q7. 92% of Costa Rican students expressed strong agreement, demonstrating their solid belief in its critical role in their education. Similarly, 41% of Malaysian students strongly agreed, with another 41% agreeing, indicating widespread recognition, although with a more evenly distributed response. Few students in either country strongly objected (2% Costa Rican, 1% Malaysian) or disagreed (0% Costa Rican, 3% Malaysian).

Figure 6 shows the factors Costa Rican and Malaysian respondents find crucial for lighting, visual, and thermal comfort, as well as their competence with relevant tools. For daylight design (Q8), both countries place a high value on direct sunlight, with 100% of Costa Ricans and 92% of Malaysians considering it critical. Malaysians are more concerned about solar heat gain (77% vs. 62% in Costa Rica). Window design and glare are also important, with higher priority in Malaysia (63% and 62%) than in Costa Rica (both 54%). Shading devices are important to 61% of Malaysians and 44% of Costa Ricans, while seasonal changes are important to 62% of Costa Ricans and 49% of Malaysians. Despite these differences, over 44% of respondents in both countries acknowledge these variables' importance.

The circadian cycle is less of a concern in both countries, with Malaysia slightly more concerned (27%) than Costa Rica (25%).

In terms of daylight analysis tools (Q9), Costa Rican students favor the sun path diagrams with 82% utilization, compared to 19% among Malaysian students. The 3D Sun-Path app is used by 62% of Costa Ricans and 56% of Malaysians. Velux Daylight Visualizer is more popular in Costa Rica (13%), than Malaysia (3%). Costa Rican students use Sketchup more frequently (38%) than Malaysian students (27%).

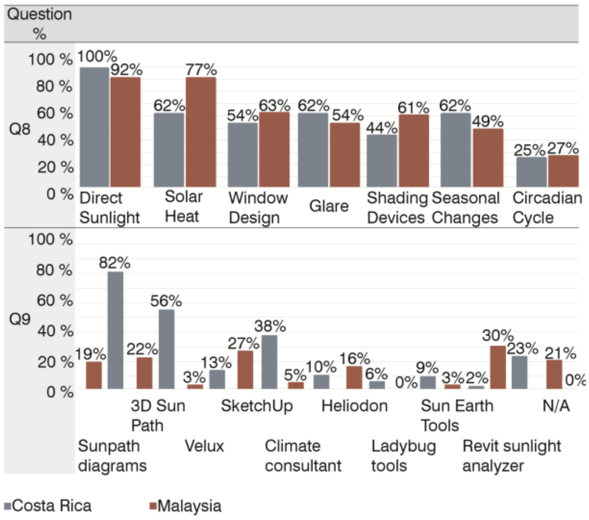

Fig. 6: *Students' responses to survey questions Q8 and Q9. (Source: Authors)*

A Heliodon is seldom used in Costa Rica (6%) and slightly more frequently in Malaysia (16%). Ladybug and SunEarth Tools have seen minimal uptake in both Universities, with the former being slightly more popular in Malaysia (9% versus 0% in Costa Rica). The Revit sunlight analyzer is more widely used in Malaysia (30%) than in Costa Rica (23%).

In Costa Rica, 92% students favored mixed tools, while only 6% favored digital tools and 2% favored manual tools. Similarly, in Malaysia students valued mixed tools more than digital tools and manual tools. This suggests that learning about solar geometry in both educational contexts is strongly inclined towards a hybrid strategy that combines both physical and digital abilities.

3.3 Qualitative Analysis

To better understand the tools and concepts that students believe are crucial for responsible architectural performance, we used a word cloud analysis to examine their replies to Question 11. The frequency and relevance of terms were measured in order to discover essential themes and concepts.

Table 3*: Key Concepts identified from Q11 responses.*

Word	Count	Relevance
Sun Path Diagram	17	1
Sun cycle	9	0.56
Incidence of sun rays	7	0.48
Movement	7	0.39
Shadow settings	4	0.28
Sketchup	4	0.25
Climate analysis	3	0.22
Digital tools	3	0.22
Site analysis	3	0.22
Sun-path app	3	0.22

The "Sun-path Diagram" was the most frequently mentioned tool, highlighting its perceived value among learners. Other important concepts included the "Sun cycle," "Incidence of sun rays," and "Movement," all of which are critical for understanding solar geometry and its impact on architecture. Tools such as "Sketchup" and "Shadow settings" were frequently mentioned, indicating a reliance on digital tools for practical applications. These findings underscore the importance of incorporating solar analysis tools into architectural education and practice.

Additionally, 23 students, representing 22% of the total responses, answered with "I don't know," indicating that a significant minority of trainees are unfamiliar with or unclear about the fundamental techniques involved in solar geometry. These responses reflect a cohort of students who feel unprepared or lack sufficient knowledge of essential solar geometry tools. This identifies an area for potential curriculum development to ensure that all students acquire the necessary competencies in this critical aspect of architectural design.

3.4 Discussion

The findings of this analysis provided a thorough overview of the current situation of solar geometry and daylighting instruction at the two architecture schools in tropical latitudes, which is critical for identifying gaps and proposing specific modifications to the curriculum and teaching approaches.

The quantitative study revealed a common tendency of low self-assessed understanding of solar geometry across students in both countries, with Costa Rican students expressing notably lower levels of expertise. This disparity could be driven by a number of reasons, including differences in curriculum content, instructional styles, and resource availability. The literature emphasizes [13] the importance of daylighting in sustainable architectural design, highlighting the necessity for a strong educational framework to improve student's understanding and confidence in this topic. Addressing this gap is essential for preparing students to engage in environmentally responsible practices.

Students' experiences implementing solar geometry principles into their design workflows differed substantially. Malaysian students reported being required to apply these concepts in their design studio less frequently than Costa Rican students. This distinction may reflect differences in the focus placed on solar analysis in their separate training programs, as well as a lack of requests from design studio teachers to incorporate these concepts as a vital aspect of design at practically all educational stages of the career. However, there is widespread agreement among students from both institutions about the importance of solar geometry, demonstrating the necessity for a stronger emphasis on this part of the curriculum, which would aid in a better understanding and application of solar design principles.

The study also found that both Costa Rican and Malaysian students understand the value of learning about solar geometry for their academic progress. This agreement underlines its vital role in sustainable design methods. The statistics imply that, while both groups value this knowledge, more targeted instructional initiatives may be required to guarantee that all students feel appropriately prepared.

The qualitative analysis demonstrates that students' value digital and manual tools for understanding and implementing solar geometry ideas to their design work. However, the fact that 22% of respondents did not know or have used any tool demonstrates a huge knowledge gap. This provides a possible area for curricular modifications to guarantee that all students have the essential skills in using these technologies.

3.5 Limitations

This research has the potential to improve architecture and design students' education, allowing them to apply their knowledge to real-world projects, and contribute to the development of more sustainable and energy-efficient buildings that can aid in climate change mitigation.

While the study included participants from two tropical institutions, the sample size may not be large enough to apply the findings to all architecture students in these countries or elsewhere. Furthermore, while the survey instrument was designed to test students' understanding and perceptions of solar geometry and daylighting, it may not have covered all critical features or adequately reflected the intricacies of their experiences. Certain aspects of solar geometry knowledge or teaching methods may have been insufficiently reviewed.

4. CONCLUSIONS

This study set out to gain a better understanding of the underlying issues and shortcomings in current solar geometry and daylight teaching practices. The goal was to establish a theoretical basis for developing novel teaching methods and tools that more effectively transfer knowledge on solar geometry. With the objective to examine the relationship between taught and applied knowledge more in detail, we posed the question why students and professionals alike experience difficulties in applying this knowledge in design studios and practice? What are the hurdles and pain points in current pedagogy of technical architecture courses teaching solar geometry in the Tropics?

One of the more significant findings to emerge from this study is that overall, architecture students, of both groups in Costa Rica and Malaysia, perceive knowledge on solar geometry as crucial for their educational development. This is noteworthy because it underpins the importance of the topic for the wider academic discourse on the curricular development of undergraduate programs in architecture. However, the perceived importance of solar geometry for the architectural practice is in stark contrast with students generally feeling not well prepared to apply the knowledge to their design tasks, citing low self-assessed knowledge about solar geometry. This study has also revealed that students in both countries place a high value on direct sunlight as a variable influencing daylight design. The circadian cycle however was a lesser concern in both countries, expressing the views and perceptions typically corresponding to the lighting experience in tropical latitudes. Lack of the correct teaching method or tools for developing design exercises that include solar analysis, seem to be the overall perception among Malaysian and Costa Rican students.

Taken together, the results of this study indicate that current teaching practices in architecture lack the adequate tools and methods for teaching solar geometry and daylighting and point to a need for more comprehensive and practical education. By addressing these gaps, educational institutions can better equip future architects with the skills and knowledge necessary for sustainable design. Despite its exploratory nature, this study offers some insight into the educational needs for light and daylight design for a specific latitude. This research supports the idea that teaching methodologies should be in accordance with the specific regional climatic conditions, take into account the effects of climate change, and address an increased sensitivity and awareness towards environmental comfort and its benefits and potential challenges.

Future studies could perhaps assess the long-term effects on the career development of future architects. A follow up study could focus on interviewing final year students or graduates, and evaluate how much they have learned about solar geometry during their study program, and explore novel learning tools through controlled in class application.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Klepeis, N., Nelson, W., Ott, W., Robinson, J., Tsang, A., Switzer, P., Behar, J., Hern, S., Engelmann, W. (2001). The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants. Journal of Exposure Science & Environmental Epidemiology, vol. 11(3), pp. 231–252. https://doi.org/10.1038/sj.jea.7500165

[2] Reinhart, C. F. (2014). Daylighting and Sustainable Design. En R. Stein (ed.), Daylighting Handbook I: Fundamentals and Designing with the Sun (p. 9). Cambridge.

[3] Ayoub, M. (2019). 100 Years of Daylighting: A Chronological Review of Daylight Prediction and Calculation Methods. Solar Energy, vol. 194, pp. 360–390. https://doi.org/10.1016/j.solener.2019.10.072

[4] Scarazzato, P., Fonseca Matos, J., Limongi França, A., Pavani, T. (2022). Challenges in Lighting Education: A Recommended Practice. The 8th International Light Symposium: Re-thinking Lighting Design in a Sustainable Future, Copenhagen, Denmark. IOP Conference Series: Earth and Environmental Science, vol. 1099.

https://doi.org/10.1088/1755-1315/1099/1/012040

[5] Koenigsberger, O. H., Romero, E. (1977). Viviendas y edificios en zonas cálidas y tropicales. Madrid.

[6] Al-Masrani, S. M., Al-Obaidi, K. M., Zalin, N. A., Isma, M. I. A. (2018). Design Optimisation of Solar Shading Systems for Tropical Office Buildings: Challenges and Future Trends. Solar Energy, vol. 170, pp. 849–872. DOI: https://doi.org/10.1016/j.solener.2018.04.047

[7] Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Chen, Y., Goldfarb, L., Gomis, M., Matthews, J. B. R., Berger, S., Huang, M., Yelekçi, O., Yu, R., Zhou, B., Lonnoy, E., Maycock, T., Waterfield, T., Leitzell, K., Caud, N. (2023). Intergovernmental Panel on Climate Change (IPCC), Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp. 3–14.

[8] Szokolay, S. V. (2004). Architecture, Science and Technology. The 38th International Conference of Architectural Science Association ANZAScA "Contexts of Architecture". Launceston, Tasmania.

[9] Giuliani, F., Khanie, M., Sokół, N., Gentile, N. (2020). Discussing Daylight Simulations in a Proposal for Online Daylighting Education. En BuildSim Nordic 2020 – International Conference Organized by IBPSA-Nordic, 13th-14th October, Oslo: Book of Abstracts (pp. 86–93). Oslo Metropolitan University (OsloMet).

[10] Treacy, G. (2019). Out of "Touch"? – An Experiential Pedagogical Approach to Daylighting in Architecture and Interior Design Education. SHS Web of Conferences, vol. 64, art. 02010. https://doi.org/10.1051/shsconf/20196402010

[11] Giuliani, F., Sokol, N., Lo Verso, V., Viula, R., Caffaro, F., Paule, B., Diakite, A., Sutter, Y. (2019). A Study About Daylighting Knowledge and Education in Europe. Results from the First Phase of the DAYKE Project. Architectural Science Review.

[12] Grønlund, L. (2022). The Appearances of Daylight – An Educational Method for Studying Daylight. IOP Conference Series: Earth and Environmental Science, vol. 1099(1), art. 012021. https://doi.org/10.1088/1755-1315/1099/1/012021

[13] Lo Verso, V., Giuliani, F., Caffaro, F., Basile, F., Peron, F., Mora, T., Bellia, L., Fragliasso, F., Beccali, M., Bonomolo, M., Nocera, F., Costanzo, V. (2021). A Survey on Daylighting Education in Italian Universities: Knowledge of Standards, Metrics, and Simulation Tools. Journal of Daylighting, vol. 8(1), pp. 36–49. https://doi.org/10.15627/jd.2021.3