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Research Article

Determining Educational Spaces' Orientation Based on Climate and Geographical Direction — A Decision Support System

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Keywords

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Architectural design,
Decision support system,
Educational buildings,
Spatial orientation,
Generative design.

Abstract

The orientation of educational building spaces has an impact on environmental parameters such as temperature and daylighting. These parameters influence students' cognitive functions and affect their learning performance. Therefore, improving the quality of the learning environments and physical comfort of the users is the main goal of the study. There is a lack of research in methods to find the best educational building layout in the context of spatial orientation. ArchSolvED, a decision support system is developed to help architects in designing educational buildings that comply with environmental rules from the educational buildings design guidelines. The system employs a heuristic search algorithm with heuristics derived from architectural design principles and educational building design guidelines to find the best layout regarding spatial orientation within a set of school design parameters given by the architect. The proposed decision support system can generate building layouts with on average 87% better spatial orientation score over a pre-approved school plan. The program allows rapid prototyping and provides numerous layouts suitable for the given inputs, making it possible to be used as a design tool.

1. Introduction

In today's conditions, there is a need to renew existing schools or build new ones, because of the increasing population [1], natural disasters [2], the inadequacy of buildings with pandemics [3], and changes in the education system [4]. It is expected that the expanding demand would increase the architects' workload, reducing the time available to design complex educational buildings while monitoring the compliance of projects with inspections, controls, and regulations tightening the timeline.

For this reason, the use of pre-approved designs in educational buildings has become very common in Türkiye among other countries [5]. Since school buildings are built in pre-designated sites in the city plans, the selected plan might not be compatible with the site, resulting in poor physical environments in educational buildings [6]. Previous studies have shown many existing schools cannot meet the climatic and spatial orientation requirements in the guidelines, and only a small number of schools met the expectations [7].

The physical environment in educational buildings affects the performance of users [8-10]. In a classroom where thermal [11] and visual comfort conditions are poor, focusing problems arise [12-21]. Experiencing such problems in classrooms, which are the center of the learning process, is an indication that the educational building does not fulfill its purpose. One of the factors that impact visual and thermal comfort is the geographical orientation of a school sub-unit (classroom, library, etc.) due to daylighting

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[9,22]. One of the earliest icons of bioclimatic design, Olgyay, demonstrated the importance of regional applications and differences in building shapes, building orientation, and orientation of sub-units in his studies [23]. The importance of orientation in the energy performance of buildings is supported by further studies [24]. The Ministry of National Education of Türkiye provides Minimum Design Standards Guidelines for Education Buildings (hereinafter referred to as "the guidelines") [25]. The guidelines provide tables showing the impact of the orientation of the sub-units on their daylighting performance. For projects to get approval from the ministry, it is necessary to comply with the guidelines.

When designing educational buildings, the spatial requirements should be well known by the architect, but there are a wide variety of rules in the guidelines [25]. It is difficult to make progress in school design by considering all these criteria. It is intended to improve the physical environment of educational buildings while not introducing additional workload on the architects. Therefore, a decision support system, ArchSolvED, is developed, to help architects in the early design phase [26]. In the literature, it is seen that decision support systems [27,28] and artificial intelligence methods [29,30] are employed in building design. However, no previous work on using decision support systems in educational building design in the context of spatial orientation has been found.

In the following chapters, the spatial orientation-based method and the search algorithm of the design tool are explained. For comparison, an extensive test is made between pre-approved school plans and ArchSolvED-generated layouts in all climate types and orientations. Spatial orientation scores are compared, and results are presented.

2. Method and Material

ArchSolvED is a decision support system, developed to help architects with the spatial orientation of units for designing educational buildings for better learning environments.

The study aims to address following questions:

- How should a school building and its sub-units should be defined programmatically?
- How can the best placement for sub-units of an educational building be found?
- Can the early design process be simplified for architects?
- Is it possible to create architectural designs by using generated layouts?

After receiving a set of information from architects, a search algorithm is executed to find the best spatial layout for the given inputs. The performance function of the buildings, which is used to calculate the spatial orientation success, is derived from the guidelines [25]. The orientation score of a school is calculated as the average of its sub-units' orientation score. This calculation can be formulated as:

$$C = Sub - unit\ count\ per\ orientation\ matrix \tag{1}$$

$$S = Sub - unit\ score\ per\ climate\ matrix \tag{2}$$

$$T = Total\ sub - unit\ count \tag{3}$$

$$Building\ orientation\ score = (C \cdot S)/T \tag{4}$$

Each solution is presented to the architect as a set of simplified schematic floor plans. It is a repetitive process until the architect is satisfied with both the building form (layout) and the score of the school units' spatial orientation.

In architectural design, circulation significantly influences the form of units within a building. Circulation paths in buildings can be likened to the veins in the human circulatory system, which define the body's lines (Figure 1).

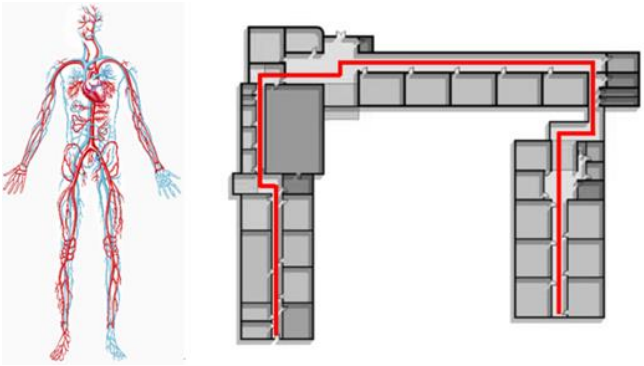


Figure 1. The connection between circulation and form through the human body and building

With this analogy in mind, the method for determining form based on circulation was applied to the educational buildings. The process follows a function-first design approach [31,32], consisting of two main stages. In the first stage, the circulation axes were identified. In the second stage, spaces were oriented and arranged around these axes.

2.1. Problem Model

The problem is finding the placement of a set of sub-units onto a given building that provides the best spatial orientation while adhering to architectural principles. Architectural design requires thinking in three dimensions. Designing an algorithm to solve architectural problems is challenging, and executing the algorithms requires much computational power [33,34]. The problem has been simplified to allow employing less complex algorithms.

The definition of a sub-unit's spatial orientation is the geographical direction its windows dominantly face. To be accessible, all units of a building need to be connected to a corridor (horizontal circulation). The side of the corridor matters as it shares the same spatial orientation with the attached sub-unit.

These facts allow for transforming the problem into placing a set of units onto the faces of the building's corridors with the goal of finding the highest spatial orientation score. With this approach, only the length of the units and corridors are taken into account, making it a single-dimensional problem.

2.2. Algorithm

Finding the best placement of a set of units into a set of corridors can be considered as a search algorithm. A search algorithm is a method of finding the best solution in a search space by iteratively exploring and evaluating possible solutions according to a set of criteria. Heuristic search was chosen as it is considered to be the optimal search algorithm for performance and computational intensity [35-37]. The heuristics are derived from architectural principles. Heuristic search algorithms differ from other search algorithms by incorporating domain-specific knowledge that aids search speed when searching for solutions and is useful when an exhaustive search is impractical [38].

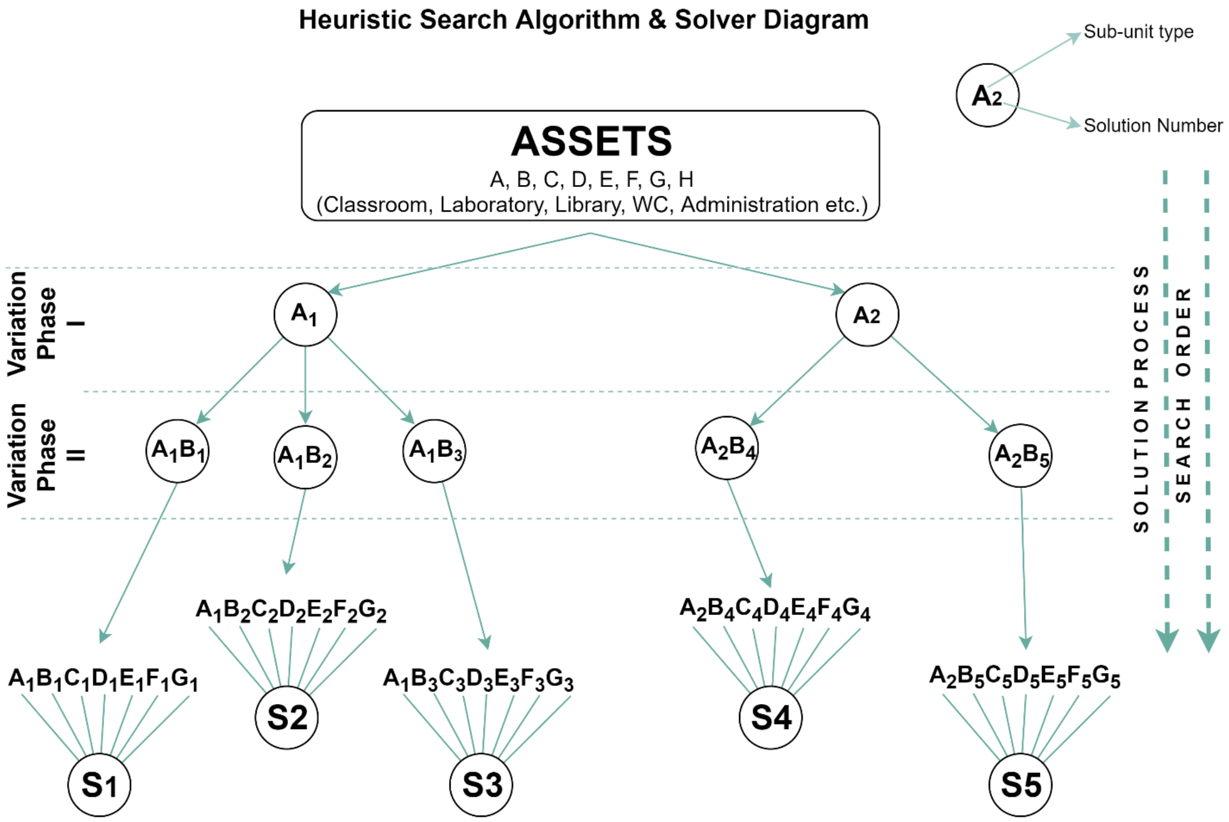


Figure 2. Search algorithm explanation diagram with processes and phases

The diagram above shows the working principle of the search algorithm used in decision support systems (Figure 2). First, it checks the floor rules and orientation scores of the 1st sub-unit (A) based on the place importance ranking from the given heuristics. It starts by placing the sub-unit in the possibilities where it can get the highest score. In this part, variations occur if possible (A1, A2). Each variation is handled as a separate solution for the 2nd sub-unit. The 2nd sub-unit (B) is placed again depending on the heuristics, resulting in solutions A1B1, A1B2, A1B3, A2B4, and A2B5. After the 2nd variation phase, the other units (C, D, E, F, G, etc.) are placed following the search sequence, resulting in solutions S1, S2, S3, etc.

2.3. Search Algorithm Heuristics

Architectural heuristics are divided into 3 categories for the algorithm. These can be listed as spatial orientation rules, floor rules, and the algorithm's search sequence.

2.3.1. Spatial Orientation Heuristics

In the section "6.1 Impact of physical factors on design" of the guidelines [25], four climate types are specified. These are cold climate, mild climate, hot-humid climate, and hot-dry climate. In the same section, the guideline provides evaluations of the geographic orientation of the spaces under the "Topography and Orientation" section with tables of each climate type with a 3-point Likert scale as good/mediocre/bad. In the algorithm, these evaluations are adopted as points of 100/50/0. Space and orientation evaluation scores based on these climate types are given in Tables 1-4.

Table 1. Spatial orientation scores for cold climate zone [25]

School Units	Geographical Orientation							
	S	SW	W	NW	N	NE	E	SE
Classroom	100	100	50	0	0	0	50	100
Library	50	50	50	0	0	0	100	100
Laboratory	0	0	50	100	100	100	50	0
Cafeteria	100	100	50	0	0	0	50	50
Dining Hall	100	100	50	0	0	0	50	50
Multi-Purpose Hall	0	50	50	100	100	100	50	50
Sports Hall	0	50	50	100	100	100	50	50
Conference Hall	0	50	50	100	100	100	50	50
Workshops	100	100	50	50	0	0	50	100
W.C.	0	0	0	50	100	50	0	0
Circulation Areas	0	0	50	100	100	100	50	0
Administrative Rooms	100	100	50	0	0	0	50	100

Table 2. Spatial orientation scores for mild climate zone [25]

School Units	Geographical Orientation							
	S	SW	W	NW	N	NE	E	SE
Classroom	100	100	50	0	0	0	50	100
Library	50	50	50	0	0	0	100	100
Laboratory	0	50	50	100	100	100	50	50
Cafeteria	100	100	50	0	0	50	50	100
Dining Hall	100	100	50	0	0	50	50	100
Multi-Purpose Hall	0	50	50	100	100	100	100	50
Sports Hall	0	50	50	100	100	100	100	50
Conference Hall	0	50	50	100	100	100	100	50
Workshops	100	100	50	50	0	0	50	100
W.C.	0	0	50	100	100	100	50	0
Circulation Areas	0	0	50	100	100	100	50	0
Administrative Rooms	100	100	50	0	0	50	100	100

Table 3. Spatial orientation scores for hot-humid climate zone [25]

School Units	Geographical Orientation							
	S	SW	W	NW	N	NE	E	SE
Classroom	100	100	0	0	0	0	50	50
Library	50	50	0	0	0	50	100	100
Laboratory	0	0	50	100	100	100	50	0
Cafeteria	100	50	0	0	0	0	50	100
Dining Hall	100	50	0	0	0	0	50	100
Multi-Purpose Hall	0	0	100	100	100	50	50	0
Sports Hall	0	0	100	100	100	50	50	0
Conference Hall	0	0	100	100	100	50	50	0
Workshops	100	100	50	50	0	0	50	100
W.C.	0	0	100	100	100	50	0	0
Circulation Areas	0	0	50	100	100	100	50	0
Administrative Rooms	100	100	0	0	0	0	50	50

Table 4. Spatial orientation scores for hot-dry climate zone [25]

School Units	Geographical Orientation							
	S	SW	W	NW	N	NE	E	SE
Classroom	0	50	100	50	0	50	100	50
Library	0	50	100	0	0	0	100	50
Laboratory	100	50	0	50	100	50	0	50
Cafeteria	0	50	50	0	0	0	100	50
Dining Hall	0	50	50	0	0	0	100	50
Multi-Purpose Hall	0	50	50	100	100	100	0	0
Sports Hall	0	50	50	100	100	100	0	0
Conference Hall	0	50	50	100	100	100	0	0
Workshops	0	50	50	50	0	0	100	100
W.C.	0	0	0	50	100	50	0	0
Circulation Areas	0	0	50	100	100	100	50	0
Administrative Rooms	0	50	50	0	0	100	100	100

2.3.2. Floor Placement Heuristics

The floor organization heuristics were developed according to the usage scenarios of the spaces in schools. These scenarios are based on the rules specified in the guidelines [25]. With these floor rules, it is aimed at achieving ideally functioning educational buildings. These rules are given in Table 5.

Table 5. Floor organization heuristics in 3 categories

	Organization heuristics		
	Units that need to be/can be placed on all floors	**Units that need to be/can be placed on specific floors**	**Units that have no floor restriction**
Sub-unit Name	Classrooms Laboratories WCs Assistant Headmaster's Rooms Workshops Vertical Circulation Areas	Headmaster's Rooms Counseling Rooms Cafeteria Conference Room Sports Hall	Library Multi-Purpose Hall Teachers Hall

2.3.3. Search Sequence Heuristics

The search sequence heuristics list the schools' sub-units to be placed on the circulation axes. Since the main purpose of the school is education, it is intended that the scores of the learning environments are high.

When the algorithm runs, it starts searching placement of the first unit for the highest possible score while following floor organization rules. This process sequentially applies to all sub-units in the building program. The search sequence is given in Table 6.

Table 6. Search sequence of schools' sub-units and their specifications

Order	**Unit Type**	**Reason for Preference/Action**	**User Intensity**
1	Vertical Circulation Areas	Vertical continuity	High
2	WC	Vertical continuity	Medium
3	Classrooms	Vertical continuity - Intensive learning	High
4	Laboratory	Vertical continuity - Intensive learning	Medium
5	Workshop	Vertical continuity - Intensive learning	Medium
6	Teachers Hall	Resting	Low
7	Administrative	Managerial Activities	Low
8	Library	Intensive Learning	High
9	Sports Hall	Physical Activity	Medium
10	Cafeteria	Resting	High
11	Dining Hall	Resting	Medium
12	Multi-Purpose Hall	Mixed	Low
13	Conference Hall	Mixed	Low

2.4. Workflow

ArchSolvED has been developed as a web-based decision support system to prevent problems such as licensing, installation, compatibility, and time-saving. The application's background processes are written in Python language [39] and Flask framework. Web page functionality and corridor drawing widget are written in JavaScript and the user interface is prepared in HTML and CSS. It uses Python packages-libraries such as EzDXF and Numpy [40].

ArchSolvED's workflow can be divided into 4 phases that start after the preliminary preparation phase. Phases and their steps can be seen in Figure 3.

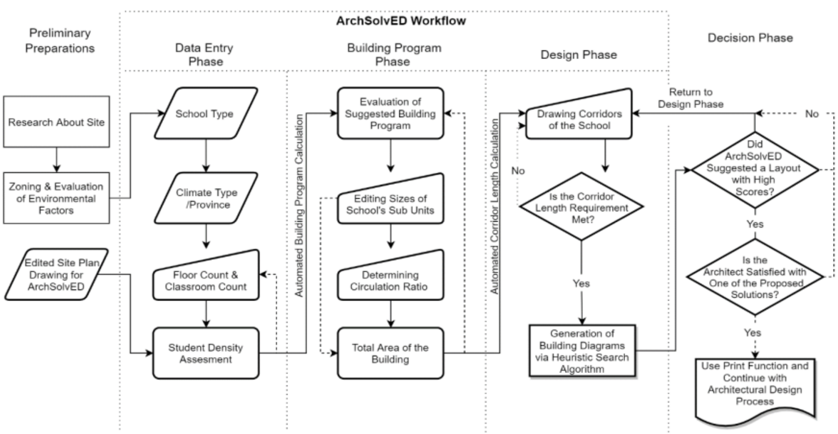


Figure 3. ArchSolvED Workflow and Phases

2.4.1. Data Entry Phase

The data entry phase is where the architect provides the needed information about the school type, climate type or province information, floor count, and classroom count. With this information, student density is assessed, and the designer is informed about the suitability between the building site size and the building program.

2.4.2. Building Program Phase

At the building program phase, ArchSolvED suggests a base building program to users with the information provided during the data entry phase. The architect can edit the sub-unit count and dimensions at this stage. With the knowledge of the floor count and building program, ArchSolvED calculates the total area of the building and the length of the corridors/circulation axis that is needed to fit the set of sub-units.

2.4.3. Design Phase

During the design phase, the architect is asked to draw the corridors as lines on the uploaded site plan in the provided sketching widget. The total length of the drawn lines is mandatory to satisfy the corridor length requirement calculated in the previous phase. ArchSolvED dynamically shows the remaining corridor length for the completion of the design.

With all the data entered into the application, ArchSolvED runs the heuristic search algorithm and calculates all possible variations. If the number of variations exceeds fifty, it filters the solutions based on their success of sub-units' orientation scores. These outputs are given in a raw form that architects use in the early design stage. While it was possible to create detailed floor plans as outputs, the concern was limiting the architect's design input. The objective is to enable the architect to express their own design language.

2.4.4. Decision Phase

The decision phase focuses on the architect's ideas for the building layout and selecting one of the program's outputs as a template for the next design stage. The user can print the desired solution on paper or export it in PDF format. Generated outputs are given in a simplified format, shown in Figure 4. The architect can decide to go back to the design phase if none of the solutions meet their expectations or solution scores are mediocre. This phase is critical as building form and orientation are considered some of the most important design decisions [41-44].

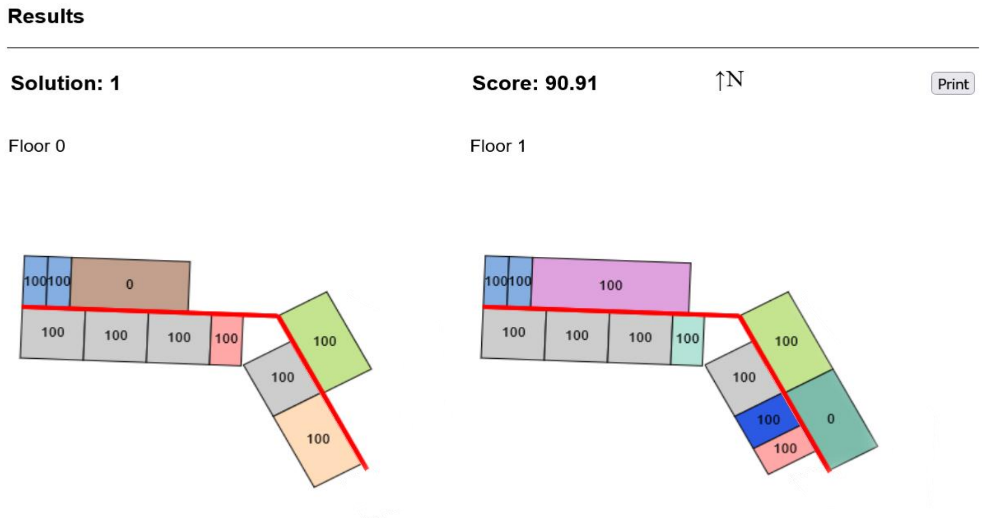


Figure 4. Simplified presentation of a sample school layout generated by the decision support system

The output of the ArchSolvED contains useful information about the building and its orientation. Thick red lines are the circulation axes, drawn by the architect at the design phase of the application. Each rectangle is a school sub-unit. Units have different colors depending on their types. Numbers on a unit denote its orientation score. Floor plan layouts are put side by side starting from the ground floor and labeled as Floor 0, Floor 1, etc. The north symbol is added for clarity of the spaces' geographic orientation.

2.5. Benchmark Material

In this study, to measure the performance of the decision support system, the spatial orientation performance of the outputs is compared with pre-approved projects. The design to be used in the comparison was chosen from among the pre-approved school projects, as they are heavily used in Türkiye. The middle school plan labeled MEB.OO.32.BZ3.36x59.BT.2022 [45] (hereinafter referred to as "pre-approved plan") was picked. It is chosen for its U-shaped plan layout and total sub-unit count of 60. A floor plan of the project is given in Figure 5. The side of the corridor matters as it shares the same spatial orientation with the attached sub-unit. The U-shaped plan increases the geographical directions the building form faces. A high sub-unit count increases the count of permutations. These two factors increase the number of possible designs for comparison.

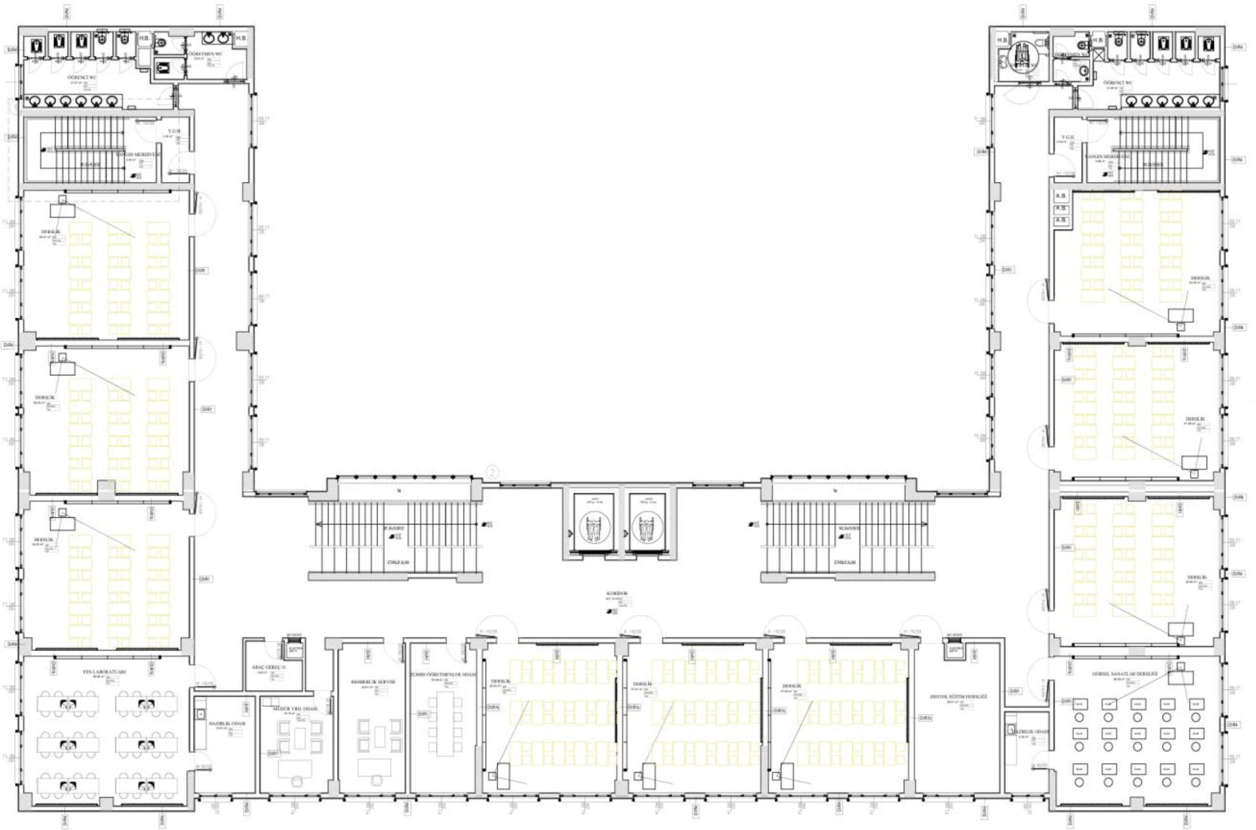


Figure 5. Floorplan of MEB.OO.32.BZ3.36x59.BT.2022 pre-approved middle school project, 2nd floor.[45]

3. Testing and Results

To measure the performance of this project in every environment it can be implemented, all parameters that can have an impact on spatial orientation performance have been considered. These parameters are climate types and orientation of the building in different locations.

There are 4 climate types (cold, mild, hot-humid, hot-dry) defined according to the guidelines [25]. The placements of sub-units are scored according to one of the 8 directions (4 cardinal and 4 intermediate) they are facing. In this case, rotating a building by 45 degrees will cause the geographical direction that the sub-units face to shift to the next one (e.g. from North to Northwest). Therefore, the building being rotated 8 times by 45 degrees, results in 8 orientationally distinct layouts. Orientation performance analysis for each pair of 4 climate types and 8 orientations yields 32 spatial orientation scores.

The parameters of the test are displayed in Table 7.

Table 7. Test parameters of comparison between the pre-approved school project and ArchSolvED

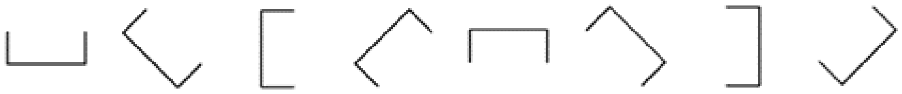
Constants	Independent Variables	Dependent Variables	Results
Building program Floor count Circulation axes Sub-unit dimensions	Climate Rotation of the building	Placement of sub-units	Spatial orientation score

To obtain the performance scores for the decision support system's designs, the system is run with the same circulation plan and building program of the pre-approved plan. 32 school layouts corresponding to the 4 climate types and 8 building layout combinations were generated. The performance of the pre-approved plan was compared with the performance of the design produced by the decision support system for each combination to measure how much improvement the system brought over the existing solutions.

To automate the process, building orientation score calculations are done using a script. Another script is made to automate plan generation. Since ArchSolvED is designed around user input, a module is written to read pre-approved plan data from a file. This approach prevented user error risks and made the process reproducible.

Orientation performance scores of the pre-approved and decision support system-generated plan in 32 scenarios are shown in Table 8.

Table 8. Spatial orientation scores of pre-approved and ArchSolvED generated plan, in 32 geographical orientation and climate type scenarios

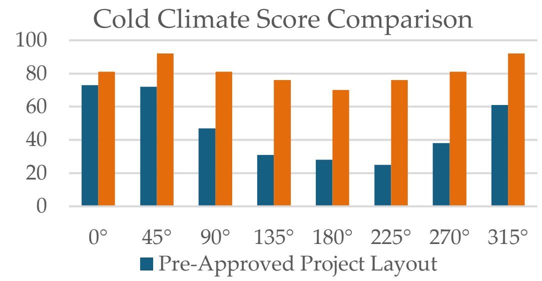
Geographical Orientation		**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Building Orientation Schematic									
School Layout Type	Climate Type	Score By Climate Type							
Pre-Approved Plan	Cold	73	72	47	31	28	25	38	61
ArchSolvED Generated	Cold	81	92	81	76	70	76	81	92
Pre-Approved Plan	Mild	73	79	54	31	28	35	53	71
ArchSolvED Generated	Mild	86	99	86	89	79	89	86	99
Pre-Approved Plan	Hot-Humid	64	61	30	32	17	16	52	51
ArchSolvED Generated	Hot-Humid	80	83	80	63	59	74	73	83
Pre-Approved Plan	Hot-Dry	61	52	29	33	46	53	38	36
ArchSolvED Generated	Hot-Dry	99	65	80	65	94	65	76	65

It can be observed that decision support system-generated plans scored higher than the pre-approved plan in all scenarios, with the geometric mean of improvements in each scenario being 87%, The Highest improvement is seen in the scenario of South-West orientation and hot-humid climate with 365%. The least improvement made is in the scenario of North orientation and cold climate with 10%.

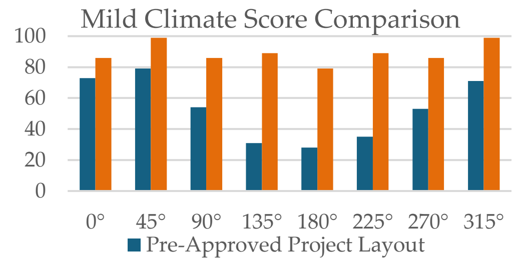
The benefits of using the decision support system in school building design are not only the ability to generate building plans with high orientation performance but also the opportunity for the architect to receive instant feedback for the form through circulation design. In this way, the architect can reach the optimum solution for the inputs of the site, climate, and building requirement list. For example, if the architect is not satisfied with the orientation score of this U-shaped design in a region with a hot-dry climate, they can try new solutions by changing the building form and orientation.

The scores obtained by the pre-approved plan and the decision support system with the same inputs for each climate type and orientation are given in Figure 6.

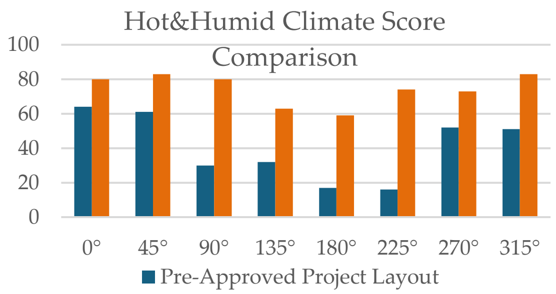
In Figure 6c, the heuristic search algorithm, even when the climatic conditions and form are the most incompatible, has achieved orientation success about 4 times better than the pre-approved plan. However, when Figures 6a, 6b, and 6d are analyzed, it is observed that the spatial orientational score for the same orientation is less than the other climate zones. It is clear that generating ideally scoring building layouts in a specific form won't be possible for every climate type. In these cases, the application's rapid prototyping capability will lead architects to design a better layout.



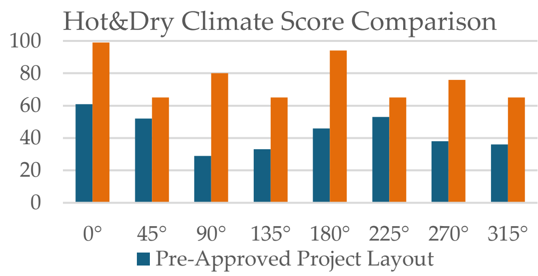
(a)



(b)



(c)



(d)

Figure 6. Spatial orientation scores' comparison chart for each climate type: (a) cold (b) mild (c) hot-humid (d) hot-dry

To illustrate the practicality of converting the generated layouts into architectural plans, a generated layout is picked, and a school building is roughly designed. The selected scenario is the hot-dry climate type and North orientation. This selection is made to emphasize the spatial orientation performance difference between the pre-approved and generated plans. 14840 plans were generated by ArchSolvED in 21,6 seconds for this scenario. Solution nr. 668 (Figure 7) was selected out of the best 50 solutions.

To provide a more digestible comparison, both designs are modeled to be able to compare differences visually side-by-side (Figure 8).

During the design of this school for a hot-dry climate, it was seen that most high-performing generated layouts had their south façade empty. This is due to there being no sub-unit suitable for placement according to the guidelines besides laboratories. Also, east/west facing corridors were highly utilized, especially by learning intensive units.

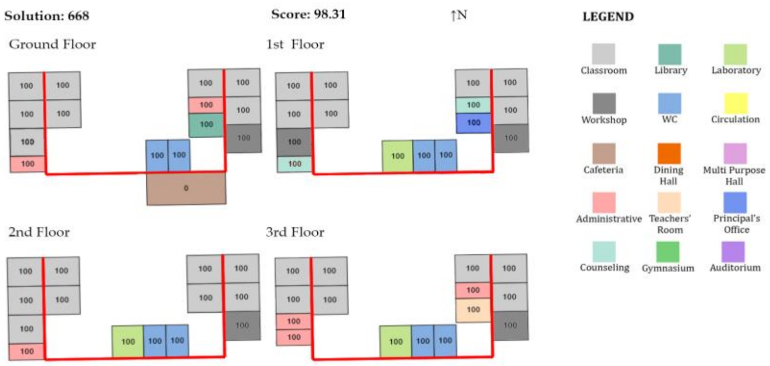


Figure 7. Example output of ArchSolvED scoring 98.31 points in hot-dry climate conditions

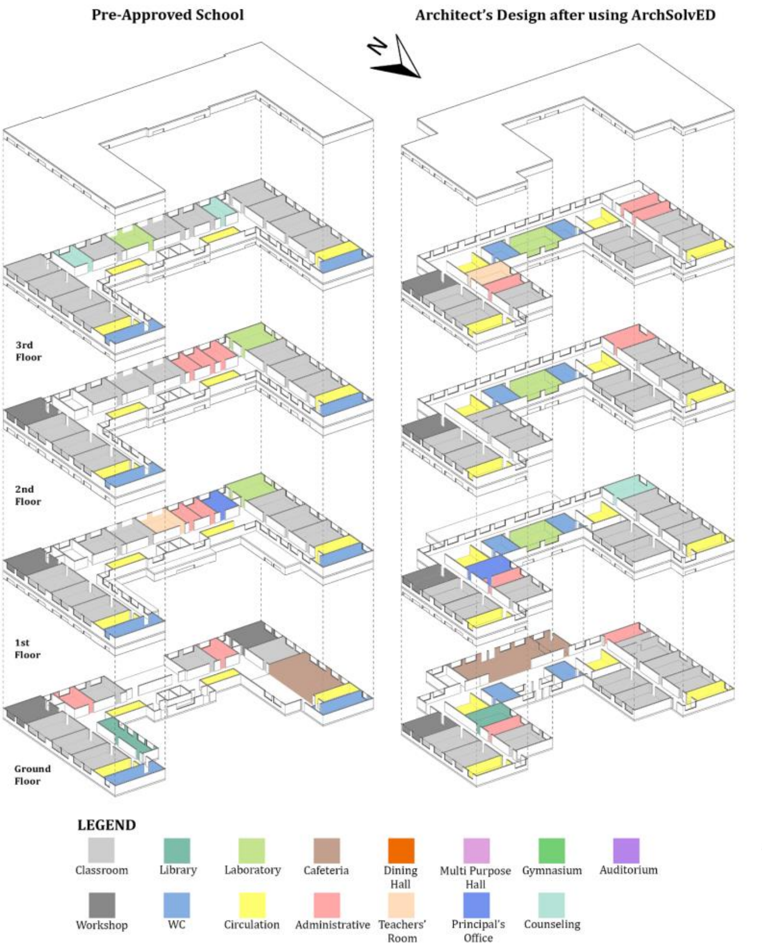


Figure 8. Exploded perspective view of pre-approved and generated school plan

4. Discussion and Conclusion

In this study, a decision support system, ArchSolvED, has been proposed. Previous studies have shown that the spatial orientation rules in the regulations are not followed in educational buildings, resulting in suboptimal learning environments. ArchSolvED addresses this by employing a heuristic search algorithm to optimize the placement of school sub-units, guided by performance functions derived from existing guidelines. The system, accessible via a web application, offers architects a range of plan options and checks for conformance to standards, presenting results in raw sketch form.

Evaluation results indicate that ArchSolvED can generate school plans with improved spatial orientation scores by an average of 87%, with improvements reaching up to 365% compared to pre-approved plans, showing a significant improvement and validate the value of school plans generated by the algorithm. The system generates approximately 15,000 plans under a minute and presents the top 50 for architects to review. A demonstration showed that having access to multiple layouts and their orientation scores aids in the early design phase, enhancing decision-making and highlighting effective strategies of building spatial orientation. The demonstration also proved that the generated designs can be turned into actual school layouts.

However, the algorithm's heuristic universality may not align with all educational systems due to varying guidelines. A finer scoring system is also needed for more nuanced evaluations. Additionally, future work will address the lack of syntactic space analysis for sub-unit positioning and incorporate features for optimal vertical circulation. Future plans include developing a database to store architects' layout choices, which will support data analysis, machine learning, and AI training to refine the design process further.

Conflict of Interest Statement

The authors declare no conflict of interest.

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References

[1] A. Karaburun, A. Demirci, E. Saka, İstanbul Avrupa Yakasindaki Okul Bahçelerinin öğrenci Sayisina Göre Yeterliliklerinin Mekânsal Olarak Değerlendirilmesi, Marmara Coğrafya Dergisi. 0 (2015) 20. doi:10.14781/mcd.94461.

[2] O. Hastürk, M.F. Altan, Depremin Ardından Kentsel Dönüşüm, Avrasya Dosyası. 14 (2023) 146–170.

[3] S.A. TÜRK, R.M. SARI, Covid-19 Salgını Sonrası öğretmen ve Mimarların Eğitim ortamına ilişkin görüşleri, Pamukkale University Journal of Education. (2022). doi:10.9779/pauefd.1002810.

[4] F. Gün, G.A. Baskan, New education system in Turkey (4 +4 +4): A critical outlook, Procedia - Social and Behavioral Sciences. 131 (2014) 229–235. doi:10.1016/j.sbspro.2014.04.109.

[5] S. Tapki, Ç. Canbay Türkyilmaz, İlköğretim Yapilarinda Ergonomi Kavraminin İncelenmesi: Tip Proje İlkokulu İle Tasarim Projesi İlkokulunun Karşilaştirilmasi, Mühendislik Bilimleri Ve Tasarım Dergisi. 6 (2018) 220–233. doi:10.21923/jesd.360651.

[6] Ç. Köse, Ö. Barkul, A Study on The Problems of The Implementation of Project Type Primary Structures, Megaron. (2012) 94–102.

[7] A.B. İyican, An Evaluation of Primary, Secondary and High School Buildings in Terms of Orientation Principles from the Point of Education Buildings Minimum Design Standards Guideline: Karabük Example, dissertation, Karabük University, 2015.

[8] V.A. da Graça, D.C. Kowaltowski, J.R. Petreche, An evaluation method for school building design at the preliminary phase with optimization of aspects of environmental comfort for the school system of the State São Paulo in Brazil, Building and Environment. 42 (2007) 984–999. doi:10.1016/j.buildenv.2005.10.020.

[9] J. González, B.B. Da Costa, V.W. Tam, A. Haddad, Effects of latitude and building orientation in indoor-illuminance levels towards energy efficiency, International Journal of Construction Management. 24 (2023) 784–798. doi:10.1080/15623599.2023.2215087.

[10] T. İnan Günaydın, Investigation of illuminance levels of classrooms on different storey with or without artificial lighting, The Payam-e-Marefat-Kabul Education University. 9 (2023) 1–7. doi:10.61186/crpase.9.2.2846.

[11] F. Farasati, F. Mozaffar, F. Nasrollahi, N.M. Hashjin, Thermal Comfort in Rural Habitats of Mountainous Areas (Case Study: Roodbar, Iran), Computational Research Progress in Applied Science & Engineering. 03 (2017) 136–152.

[12] L.-R. Jia, J. Han, X. Chen, Q.-Y. Li, C.-C. Lee, Y.-H. Fung, Interaction between thermal comfort, indoor air quality and ventilation energy consumption of educational buildings: A comprehensive review, Buildings. 11 (2021) 591. doi:10.3390/buildings11120591.

[13] X. Wang, Understanding Occupants' Well-Being in an Educational Building: A Case Study in a College Building, dissertation, Purdue University, 2015.

[14] K. Lakhdari, L. Sriti, B. Painter, Parametric optimization of daylight, thermal and energy performance of Middle School classrooms, case of hot and dry regions, Building and Environment. 204 (2021) 108173. doi:10.1016/j.buildenv.2021.108173.

[15] A.A. Rocha, J.L. Nachez, School space and sustainability in the tropics: The case of Thermal comfort in Brazil, Sustainability. 15 (2023) 13596. doi:10.3390/su151813596.

[16] Y. Sun, X. Luo, H. Ming, Analyzing the time-varying thermal perception of students in classrooms and its influencing factors from a case study in Xi'an, China, Buildings. 12 (2022) 75. doi:10.3390/buildings12010075.

[17] S.-K. Kim, J.-H. Ryu, H.-C. Seo, W.-H. Hong, Understanding occupants' thermal sensitivity according to solar radiation in an office building with Glass Curtain Wall Structure, Buildings. 12 (2022) 58. doi:10.3390/buildings12010058.

[18] A. Bueno, A. de Paula Xavier, E. Broday, Evaluating the connection between thermal comfort and productivity in buildings: A systematic literature review, Buildings. 11 (2021) 244. doi:10.3390/buildings11060244.

[19] O. Toyinbo, Indoor Environmental Quality, pupils' health, and Academic Performance—A literature

review, Buildings. 13 (2023) 2172. doi:10.3390/buildings13092172.
[20] D.N. Androsics-Zetz, I. Kistelegdi, Z. Ercsey, Algorithmic generation of building typology for Office Building Design, Buildings. 12 (2022) 884. doi:10.3390/buildings12070884.
[21] S. Alghamdi, W. Tang, S. Kanjanabootra, D. Alterman, Effect of architectural building design parameters on thermal comfort and energy consumption in higher education buildings, Buildings. 12 (2022) 329. doi:10.3390/buildings12030329.
[22] S. Mirrahimi, N.L. Ibrahim, M.H. Nahi, A. Shirazi, Investigation of various window orientation in daylighting performance in hot-humid climate of Subang, Malaysia, Civil Engineering and Architecture. 10 (2022) 3165–3172. doi:10.13189/cea.2022.100728.
[23] V. Olgyay, A. Olgyay, D. Lyndon, Design with climate: Bioclimatic approach to architectural regionalism, Princeton University Press, Princeton, 2015.
[24] K.A. Khaled Albaioush, B.S. Bahar Sultan Qurraie, Energy performance optimization for a school building in Syria according to building shape and orientation, COMPUTATIONAL RESEARCH PROGRESS IN APPLIED SCIENCE & ENGINEERING. 8 (2022) 1–11. doi:10.52547/crpase.8.4.2825.
[25] Türkiye Cumhuriyeti Milli Eğitim Bakanlığı İnşaat ve Emlak Dairesi Başkanlığı, Eğitim Yapıları Asgari Tasarım Standartları Kılavuzu. (2015). https://iegm.meb.gov.tr/meb_iys_dosyalar/2015_08/17032245_2015asgaritasarmklavuzu.pdf (accessed March 4, 2024).
[26] A.B. İyican, Bilgehaniyican/ArchSolvED: A Web-Based Design Support Assistant on Educational Buildings for Architects. (2024). https://github.com/bilgehaniyican/archsolved (accessed August 1, 2024).
[27] S. Attia, E. Gratia, A. De Herde, J.L.M. Hensen, Simulation-based decision support tool for early stages of zero-energy building design, Energy and Buildings. 49 (2012) 2–15. doi:10.1016/j.enbuild.2012.01.028.
[28] K. Piira, J. Kantorovitch, L. Kannari, J. Piippo, N. Vu Hoang, Decision support tool to enable real-time data-driven building energy retrofitting design, Energies. 15 (2022) 5408. doi:10.3390/en15155408.
[29] E. Gilner, A. Galuszka, T. Grychowski, Application of artificial intelligence in sustainable building design - optimization methods, 2019 24th International Conference on Methods and Models in Automation and Robotics (MMAR). (2019). doi:10.1109/mmar.2019.8864698.
[30] J. González, F. Fiorito, Daylight design of office buildings: Optimisation of external solar shadings by using combined simulation methods, Buildings. 5 (2015) 560–580. doi:10.3390/buildings5020560.
[31] A. Seelow, Function, and form: Shifts in modernist architects' design thinking, Arts. 6 (2017) 1. doi:10.3390/arts6010001.
[32] X. Guanyi, D. Huifang, Function first or form first—a comparison of two design methods for the undergraduate basic course, E3S Web of Conferences. 189 (2020) 03038. doi:10.1051/e3sconf/202018903038.
[33] G. Canestrino, Considerations on optimization as an architectural design tool, Nexus Network Journal. 23 (2021) 919–931. doi:10.1007/s00004-021-00563-y.
[34] A. Zhang, R. Bokel, A. van den Dobbelsteen, Y. Sun, Q. Huang, Q. Zhang, Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China, Energy, and Buildings. 139 (2017) 371–384. doi:10.1016/j.enbuild.2017.01.048.
[35] R. Tariq, C.E. Torres-Aguilar, J. Xamán, I. Zavala-Guillén, A. Bassam, L.J. Ricalde, et al., Digital Twin Models for optimization and global projection of building-integrated solar chimney, Building and Environment. 213 (2022) 108807. doi:10.1016/j.buildenv.2022.108807.
[36] J. Mao, Y. Fu, A. Afshari, P.R. Armstrong, L.K. Norford, Optimization-aided calibration of an urban microclimate model under uncertainty, Building and Environment. 143 (2018) 390–403. doi:10.1016/j.buildenv.2018.07.034.
[37] P. Chen, L. Wang, A. Wang, J. Yu, G. Kong, Y. Wu, Suitability comparison of heuristic algorithms for the execution of Lighting Design Objectives (Lidos) procedure, Building and Environment. 242 (2023) 110539. doi:10.1016/j.buildenv.2023.110539.
[38] S. Edelkamp, S. Schrödl, Heuristic search: Theory and applications, Elsevier/Morgan Kaufmann, Amsterdam, 2012.
[39] G. VanRossum, F.L. Drake, The python language reference guido van Rossum author, Python Software Foundation SoHo Books, Hampton, NH, Redwood City, Calif., 2010.
[40] C.R. Harris, K.J. Millman, S.J. van der Walt, R. Gommers, P. Virtanen, D. Cournapeau, et al., Array programming with NumPy, Nature. 585 (2020) 357–362. doi:10.1038/s41586-020-2649-2.
[41] Y. Fang, S. Cho, Design optimization of building geometry and fenestration for daylighting and energy performance, Solar Energy. 191 (2019) 7–18. doi:10.1016/j.solener.2019.08.039.
[42] Z. Li, Y. Zou, M. Tian, Y. Ying, Research on optimization of climate responsive indoor space design in residential buildings, Buildings. 12 (2022) 59. doi:10.3390/buildings12010059.
[43] I. Kistelegdi, K.R. Horváth, T. Storcz, Z. Ercsey, Building geometry as a variable in energy, comfort, and Environmental Design Optimization—a review from the perspective of architects, Buildings. 12 (2022) 69. doi:10.3390/buildings12010069.
[44] E. Elbeltagi, H. Wefki, R. Khallaf, Sustainable building optimization model for early-stage design, Buildings. 13 (2022) 74. doi:10.3390/buildings13010074.
[45] Türkiye Cumhuriyeti Milli Eğitim Bakanlığı, MEB.OO.32.BZ3.36X59.BT.2022. (2022). https://egitimyapilariprojeleri.meb.gov.tr/detay/meb-oo-32-bz3-36x59-bt-2022/ (accessed May 13, 2024).