An expert decision support tool for office buildings facades during early design stages: A parametric approach

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Abstract

Design decision-making during the early stages of facade development influences the final performance of buildings. The role of architects is to integrate their design with energy analysis. Thus, this process can lead to decision fatigue and significant time investment when using building simulation tools to consider the numerous possibilities and choices available. This study presents a parametric design approach for façades of office buildings in cities with a temperate climate. The study presents an expert decision-support tool that informs and facilitates decision-making. Furthermore, the research highlights the most critical decision-making parameters. In conclusion, the expert system alleviates design decision fatigue and informs architects and designers.

Highlights

- Improve decision-making at the early design stage of a facade design through parametric design.
- Reduce design decision fatigue and succeed in reducing design time and choice stress.
- The proposed design tool considers two daylight metrics: Annual Sunlight Exposure (ASE) and Spatial Daylight Autonomy (sDA).
- Develop expert systems to replace building simulations for visual and thermal comfort and energy use.

Introduction

One of the most crucial parts of a building is its façade. A façade is not just the exterior skin of a building. A façade design shall reflect the building type and aesthetic identity and impact visual and thermal comfort and energy performance (Krstic-Furundzic et al., 2019). Architects designing a façade require to address many parameters. Also, the design decision process and workflow require time and experience to involve occupants and environmental performance requirements. With the importance of the energetic aspects of buildings and occupants' comfort, the architects are under high pressure to address multiple criteria quickly and under uncertainty, which causes high pressure. Therefore, traditional design methods are gradually replaced by new strategies based on building performance simulation and computational methods (Han et al., 2018). Consequently, design decision-making involves comparing and selecting design alternatives within a large solution space based on various goals and performance criteria.

In Europe, facade designers for office buildings face numerous requirements related to the exterior environment, interior occupancy, energy efficiency, user comfort, and sustainability. To meet these demands, designers must consider a wide range of parameters, including a budget, views, orientation, window size, and type of glazing, among others (Namazi et al., 2016). Furthermore, it is essential to set clear design goals. A façade design must address the dynamic nature of climate by encouraging passive heating in winter and solar shading in summer to avoid overheating (Chi et al., 2017).

Glazed facades are famous in office and commercial buildings as they provide natural daylight and a view of the surrounding environment, improving occupant comfort and wellness (Mulville et al., 2016). Glazed facades symbolized modernity in Western European architecture after World War II and the advent of the modern architecture movement. Glazing surfaces in offices can cause discomfort due to direct solar heat, high equipment and employee density temperatures, and heat loss from large glazing. Choosing the right glass, with coatings, colors, or energy-saving properties, can control the amount of daylight entering and mitigate these effects (Hee et al., 2015). A sophisticated design process involving passive and active techniques must enhance building environmental efficiency, considering building geometry such as spatial arrangement, aspect ratio, and orientation (Chen et al., 2018).

Furthermore, some studies showed that late design choices, such as furniture density and window-sill height, can impact daylight levels to varying degrees (Bálint Palmgren & Tran, 2021). Other parameters and variables must also be considered to ensure high-quality living conditions, such as interior surfaces and building envelope characteristics (facade). Thus, we should be aware of many other parameters and variables to ensure high quality of living on the interior surfaces or the characteristics of the building envelope (facade).

New computer modeling techniques, including automated early daylight analysis, indoor comfort, energy performance, and sustainability, with parametric studies, are being developed due to the need for new technologies. Decision-making approaches, such as

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weighting averages, outranking, priority setting, and fuzzy principles, are used to consider conflicting and multiple objectives. The Analytical Hierarchy Process supports multi-criteria decision-making under uncertainty based on stakeholder preferences (Yan, 2018). This process is complicated by uncertainty in design parameters and probability distributions of performance indicators. Furthermore, Attia et al. (2019) also study new tools for bioclimatic design strategies in hot, humid climates.

Consequently, there is a need for a user-friendly interface that simultaneously considers the environmental aspect inside buildings and facilitates façade decision-making. Knowledge-based or expert systems are a good solution in which human expert knowledge about the design domain is encoded in an algorithm or computer system (Gagne 2011). Expert systems are usually considered to be an application of artificial intelligence. Knowledge-based or expert systems typically consist of a simulation-based knowledge base containing domain-specific knowledge and an inference engine that applies the knowledge to a user-specified problem to determine an interactive solution with users.

Therefore, the research aims to develop a simple and easy workflow that reduces design decision fatigue, help the architect and designer to compare the percentage of glazing easily, and other variables to choose between scenarios according to their need. In addition, this tool shall help the designer to integrate the energy matter at the beginning of the project. The actual tendency in project design is to integrate all the study fields at the beginning of a project, knowing that energy now significantly impacts decision-making in architectural projects. However, most architects outsource energy performance calculations to late design stages. The tendency is to break the skills silos, remove the fences between the different disciplines, and allow them to work closely with each other more efficiently, similar to examples found in the literature on expert systems for facades (Ochoa and Capeluto 2015). Therefore, the specific objectives of the tool development criteria aim to:

1. Examine how to simplify designing a façade and reduce decision fatigue.
2. Identifying the most sensitive parameters influencing performance and reducing operational energy, comfort, and design time.
3. Try to make better decisions at the early design stage of a project to avoid backtracking the design process, which is very time-consuming and sometimes leads to the loss of motivation of the study teams.

The research's broader aim seeks to answer the following questions and is part of a Master thesis (Nassimos 2022) on the performance-based expert system:

1. How to simplify the decision-making of the facade's design during early design stages without using building performance simulation while relying on an expert tool?
2. To which extent do the facade criteria influence energy performance and visual and thermal comfort?
3. What are the most influential performance-based facade design parameters?
4. How do designers perceive the developed design support

Methods

The core of an expert system is the knowledge base, a database in which the results of 2900 combinations of the simulation were encoded. The knowledge base was used in feeding a parallel coordinator graph for facades. A user-friendly tool (Design Explorer) was used to couple the results of parametric design variations using Grasshopper, Honeybee, and Ladybug environmental plugins. The plugin was able to use EnergyPlus software for thermal simulations and in compliance with the major European standards, including CEN 13790, CEN 16798, and ISO 52016-3. Moreover, usability testing is necessary to ensure the developed tool's simplicity to check the interaction between potential users and this design tool and how effective the tool is.

To better understand the main steps of the study and the research methodology, Figure 1 illustrates the schema of the Conceptual study framework of this research.

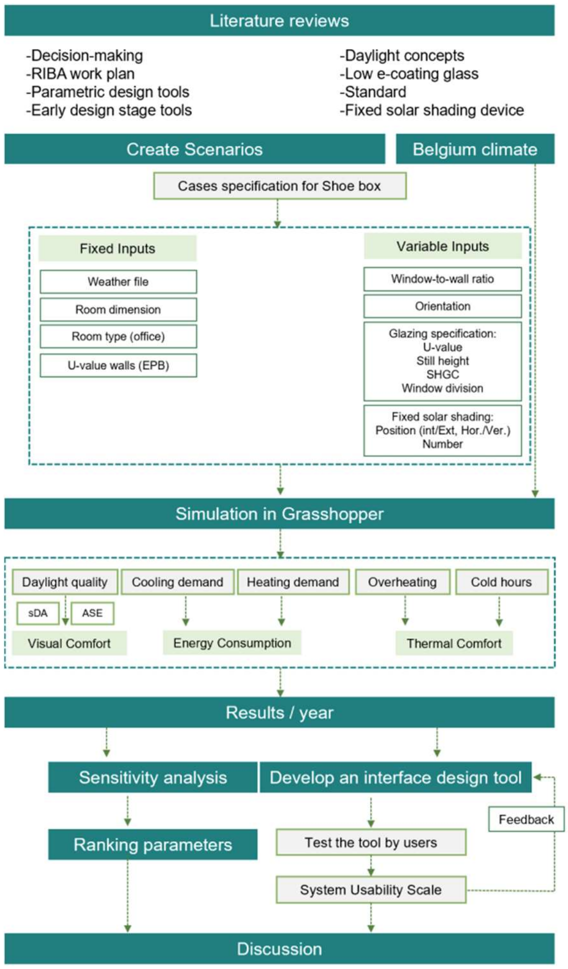

Figure 1: Conceptual study framework of expert system development process.

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Selected software

Using energy simulation software tools to evaluate the thermal behavior of buildings and energy performance. This software helps evaluate existing buildings' thermal behavior during operation time. Alternatively, they even predict their behavior during the decision-making stage before construction. Several energy simulation software tools (Attia et al., 2009) could be used for this parametric analysis, such as DesignBuilder or Grasshopper, which are interfaces designed to be easy to use. This research used Grasshoppers and Rhinoceros due to their ability to create innovative building forms and parametric facades. Rhinoceros is a dynamic design tool widely used for repetitive components. Figure 2 illustrates the software and plugins used in this study to generate parametric designs.

Fixed inputs

The reference building is a mid-size shoe box office for the Genk-Waterschei Campus EnergyVille. The shoebox building was selected as a representative mid-size rectangle box (Attia S. et al. 2019). The EnergyPlus weather file (EPW) was chosen based on the typical meteorological year for Brussels (Uccle). Both are introduced as fixed parameters.

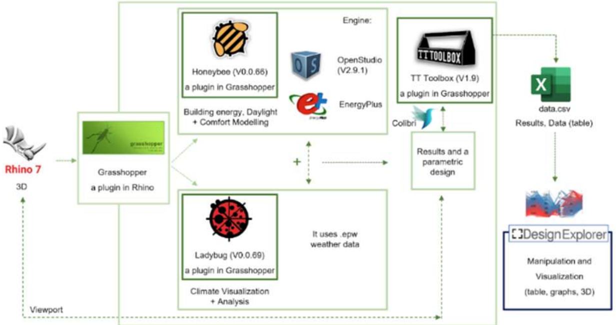

Figure 2 Framework represents links between software and plugins used as part of the parametric design workflow

Variable inputs

A set of variable geometric design parameters were considered: orientations, window areas, shading device, and non-geometric design parameters: HVAC and walls, based on the work of Bertrand et al. (2022). To sum up, Table 1 summarises all the fixed and variable inputs considered for this study. We should mention that many options exist, but justifications are mentioned for each choice and represented in the last column.

Table 1: Some of the optimal solutions regarding all parameters together- Input features

Components	Characteristics	Fixed	Parametric range	Justification
Office room	Width * Length * Height	-	7 m*11m*3.2m	Case Study
			7m*7m*3.2m	Optimization
	Window-to-Wall-Ratio	-	10% to 90%	
	Glazed façade orientation	-	0° (South),45°, 90°(East), 135°, 180° (Nord), 225°, 270 (West), 315°	
Exterior Wall	U-value (max)	0.24 W/m^{2}K	-	EPBD (Guide PEB 2018, n.d.)
	R-value (min)	4.16 m^{2}K/W		
	Solar reflectance	0.7		
Adiabatic Walls	U-value	1 m^2-K/W	-	EPBD
Floor	U-value	0.24 W/m^{2}K	-	
Ceiling	U-value	0.24 W/m^{2}K	-	
Window	Sill height	-	0.5m, 1m, 1.5m*	
	Distance between	-	2m, 4m*	
	Lintel level	-	0.3m*	
Glazing	Visible transmittance	-	0.3, 0.5	
	SHGC	-	0.3	Dark blue, low-E coating
		-	0.58	Clear, low-E coating
	Uw, max	1.5 W/m^{2}K	-	EPBD- double glazing (frame & glass)
		0.6 W/m^{2}K	-	EPBD - triple
Shading	Orientation	South	Hor.	
		East	Ver.	
		West	Hor./Ver.	
		South-East/ West	Ver.	
	Width	-	0.025m, 0.6m, 0.8m	
	Separation	-	0.3m, 0.6m, 0.8m	

*This input can be changed automatically when the glazing ratio is high.

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Usability Testing

Since the design tool is for the early design stage and focuses on the tool's simplicity, we are not waiting for the results that represent the real scenarios. Undoubtedly, more profound studies will come up before passing the construction phase and before the conception design becomes a reality. However, this study collects data from the nearest weather data station, gets information from testing subjects, and is based on norms, standards, and literature reviews. Qualitative usability testing, user-based research, was done to ensure the developed tool's simplicity, check the interaction between potential users and this design tool, and determine how effective the tool is. The usability testing was performance based on ISO 9241-210 and the work of Attia et al. 2023. More detailed information on the user experience indicators and tested design tasks can be found in the master's thesis of Nassimos (2021, section 3.8).

Results

This part will present the answer to the first question of the study, the results obtained regarding the tool, and the results obtained from the simulation.

• *How to simplify the decision-making of the facade's design during early design stages without using expert systems?*

A performance-based expert system tool is developed and presented as a parallel coordinate graph, table, and several informative visualizations used in Design Explorer. Data exported by the building performance simulations using Grasshopper are added as a database for the tool. The tool visualizes different results interactively and compares different choices in a few minutes without passing by a simulation tool. Data for this study can be accessed online at the link below:

http://tt-acm.github.io/DesignExplorer/?ID=BL_3iQzicX

The expert system tool allows the exploration of 2600 solutions for high-performance facades with different design scenarios. The tool allows for variation in the performance results regarding daylight performances, indoor thermal comfort, heating, cooling, and electric lighting consumption while complying with the building performance requirements for new construction in Belgium in 2021.

Sensitivity analysis

A sensitivity analysis is carried out to answer the second question of the research:

• *To which extent do the facade criteria influence the energy performance and visual and thermal comfort?*

The degree of influence is studied for each parameter on the main objectives of this study: Daylighting, thermal comfort, and energy consumption. Moreover, it will discuss the most sensitive parameters that influence the overall results. The variable inputs chosen to study their influence are the Window-to-wall ratio, the orientation, SHGC, U-window value, the sill height, and different window breaking up as they are the main inputs for this study. Each studied input was considered variable, and all other information was considered fixed to evaluate the influence of the chosen input parameters. Thus, understanding the degree of change for each one of the outputs: ASE, sDA, overheating hours, cold hours, and heating and cooling demand. Finally, based on visualization results, sensitivity analysis on some outputs were skipped if there is no change. For more details, you can check the comprehensive research by Nassimos (2021).

Ranking of the influential variables

After the correlation study and the sensitivity analysis, this section will answer the third research question, which is:

• *What are the most influential design parameters?*

Figure 04 ranks the most influential parameters of the studied variables regarding the base case on ASE, sDA, overheating consumption, and cold hours. This ranking is based on the simulation results and the sensitivity analysis.

Figure 2: Ranking of the influential parameters.

Best scenarios

We can define our objective in Design Explorer by selecting the desired range, thereby choosing the maximum value acceptable of ASE, the minimum value of sDA, and the lowest results for overheating hours, cold hours, heating, cooling, and lighting consumption. Thus, we arrived at solutions that meet these objectives together (Figure 4: Design Optimum in Design Explorer that meets all objectives. Figure 4). We can find that the optimum WWR value related to visual comfort, thermal comfort, and energy consumption is 0.5. for a room of 7m*7m*3.2m.

The south orientation with a WWR of 0.9 is a scenario that gathers all objectives together. A fixed shading device protects the glazed surface with a distance between slats of 0.025m. Another scenario is for a northwest room with a 1m window-sill height of two window surfaces.

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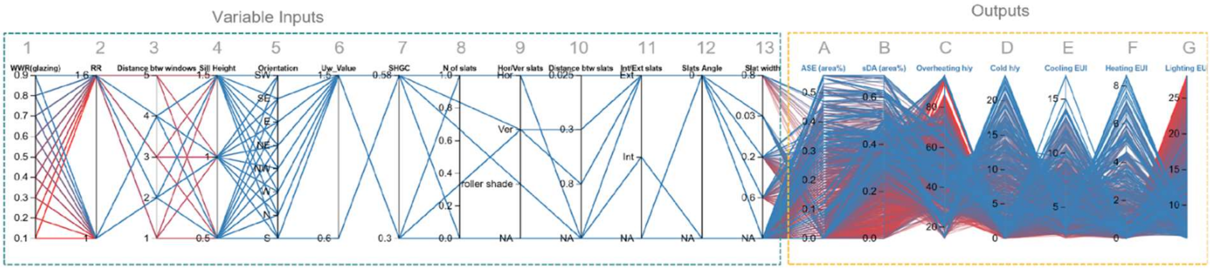
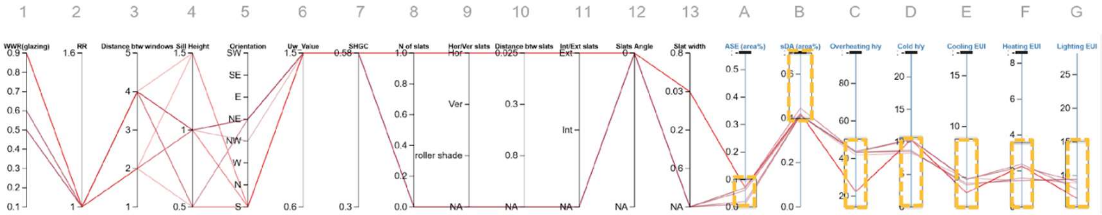


Legend:
Variable Inputs:
1.Window-to-wall ratio 2. Room ratio 3. Distance between windows 4.Sill height 5. Orientation 6.Uw-value (window) 7. SHGC
8. Number of slats 9. Hor./Ver. Slats 10. Distance between slats 11. Int./Est. shading 12.Slats angle 13.Slat Width
Outputs:
A. ASE B. sDA C. Overheating hours D. Cold hours E. Cooling consumption F.Heating consumption G. Lighting consumption

Figure 3: Diagram for the different implemented design options.



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Outputs:
A. ASE B. sDA C. Overheating hours D. Cold hours E. Cooling consumption F.Heating consumption G. Lighting consumption

Figure 4: Design Optimum in Design Explorer that meets all objectives.

s 2 and list some of the optimal solutions regarding all parameters together. They show the most efficient thresholds. These choices seem to be the best compromise between daylight metrics, energy consumption, and thermal comfort between the suggested alternatives and different variables.

Table 2: Some of the optimal solutions regarding all parameters together- Input features

id	WWR	RR	Distance btw windows (m)	Sill Height (m)	Orientatior	Uw_Value (W/m²K)	SHGC	N of slats	Hor/Ver slats	Distance btw slats (m)	Int/Ext slats	Slats Angle	Slat width (m)
1	0.9	1	_	_	S	1.5	0.58	NA	Hor	0.025	Ext	0	0.03
2	0.5	1	2	1	NW	1.5	0.58	0	NA	NA	NA	0	NA
3	0.5	1	2	1	NE	1.5	0.58	0	NA	NA	NA	0	NA
4	0.5	1	2	1	NE	1.5	0.58	0	NA	NA	NA	0	NA
5	0.6	1	_	1	NE	1.5	0.58	0	NA	NA	NA	0	NA
6	0.6	1	_	0.5	NE	1.5	0.58	0	NA	NA	NA	0	NA

Table 3: Some of the optimal solutions regarding all parameters together- Output features

id	ASE (area%)	sDA (area%)	Overheating h/y	Cold h/y	Cooling EUI (kWh/m²/y)	Heating EUI (kWh/m²/y)	Lightning EUI (kWh/m²/y)
1	0.07	0.4215	22.275641	10.320513	3.4948	2.280814	6.603367
2	0.07	0.4132	41.923077	8.301282	4.93008	1.471628	9.456892
3	0.01	0.4132	43.269231	8.717949	4.252191	1.601387	8.891397
4	0.02	0.4132	43.397436	8.525641	4.431042	1.475936	9.449196
5	0.07	0.4463	43.397436	10.320513	4.795994	2.385645	7.954351
6	0.06	0.4132	43.878205	10.384615	4.825803	2.228449	9.098958

Usability testing

The fourth question of this research is related to the interaction with the design tool proposed in Design Explorer:

• *How do designers perceive the developed design support?*

Therefore, usability testing has been followed according to ISO 9241-210. The System Usability Scale (SUS) was adapted to quantify the user experience and evaluate their interaction with the design interface. Seven potential users have tested the tool. The SUS score for each participant is represented in Figure 5, which means the degree of satisfaction. It is out of 100 (a total score out of 100 and not a percentage). Thus, by calculating and comparing the satisfaction for each participant, the percentage of satisfaction should be more than 70.

The average SUS score by participants for the suggested design tool is **75/100**. That means that users are satisfied. However, tools need minor improvements.

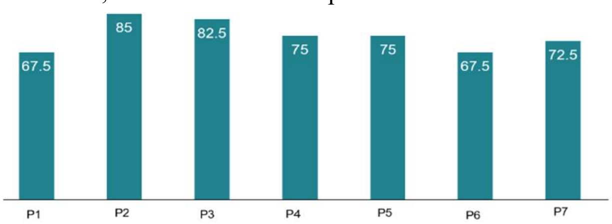

Figure 5: SUS score by participants

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It is important to measure each participant's average task completion time to try the tool and complete the task successfully, represented in Figure 6. The average time taken is four minutes and 47 seconds. However, this time is relative. It is the time needed to follow the exact instructions. So, we can evaluate the ease of use of the tool.

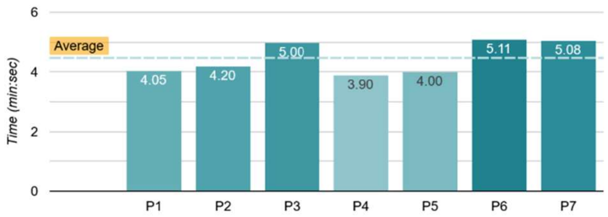

Figure 6: Average task completion time per participant

It is essential to mention that time-saving is a sign of productivity for design decision-making. Furthermore, it is not just about the efficiency of the tool. It is also to report user experience and satisfaction.

Discussion

The performance-based expert system tool is based on 2900 simulations representing a wide solution space of design alternatives. All comply with the Belgian construction code for the year 2021. The top three design scenarios for an office room designed according to the Belgium climate and the European norms (Cerutti 2022) are characterized as follows:

- A south face room with a WWR of 0.9. with fixed exterior blinds covering the glazed surface with a distance between slats of 0.025m.
- A northwest room has two windows with a sill height of 1m and 50% glazing.
- Another scenario is a WWR of 0.6 on the northeast and a window sill height of 0.5m without a shading system.

All of them were for a room of 7m (length),7m (depth), 3.2m (height), an SHGC of 0.58, and a U_{window} value of 1.5W/m²K. These choices seem to be the best compromise between energy consumption, thermal comfort, and daylight metrics: a percentage of spatial Daylight Autonomy of more than 40% ($sDA_{500lux/50\%}$). And a percentage of Annual Sunlight Exposure of less than 10% of the room surface annually ($ASE_{1000ux/250h}$). Those top three solutions are between the suggested alternatives and different variables regarding all the studied objectives.

In general, to control solar gains and maximize daylighting, it is suggested to be aware of window configuration, design, orientation, and WWR to achieve the optimum solution. From the sensitivity analysis, we can arrive that changing window dimensions without changing window lintel level has a negligible impact on the output data. Changing windows division for the same glazed ratio has a minor effect on the results. The WWR primarily influences the daylight metrics sDA and ASE more than the energy demand and thermal comfort.

Designing a room with a ratio equal to 1 (a square plan of 7m.*7m.*3.2m H.) gives us better results about spatial Daylight Autonomy and less cooling demand compared to a rectangular module. Using an interior roller shade that will be closed when the direct sun becomes undesirable deletes the impact of the ASE. In this case, the sDA is above the threshold when the WWR is 0.8 or 0.9. Also, the change in energy consumption is negligible.

Thus, the WWR and the building orientation are the two design parameters that impact all the results. The SHGC and U_{window} have no impact on daylight metrics, whereas they impact the overheating hours with a range of change of about 65%. When the minimum value required for sDA is 40%, and the maximum ASE is no more than 10% 250h/year, it is challenging to ensure both criteria simultaneously. However, the newest version of LEED v4.1 deemphasizes glare requirements (ASE) and encourages increasing daylight (sDA). *(Effective Daylighting Workflows for LEED V4, 2019)*.

Due to the repetitive nature of the design problem, we developed an expert system tool that can inform the decision-making and make the designer avoid spending a long time building performance simulations. The methodology developed in this research is suitable to become the basis for automated expert systems diagnosing the best alternatives, either as a standalone tool or integrated into a BIM system. The tool builds on existing literature (Gagn et al. 2011) and can also serve as a guideline for extremely complex façade designs that consider energy efficiency, among other aspects.

We believe the tool allows for an easy selection of design alternatives that comply with codes. At the same time, designers can use both building performance simulations and the expert tool database during the initial stages of advanced steps of the design process.

However, the tools are limited to rectangular shoebox geometry and can not be used beyond its limitations. Advanced simulation can be performed in a later design stage for energy performance variations and economic feasibility study to extend the tool's beneficial contribution. The proposed tool is also limited to the building regulation codes 2021; thus, future work should develop the tool to meet future environmental targets. We envision that the tool can allow us to select future dates for environmental compliance and offer a solution space depending on the performance target of the building expected in 2025 or 2030. Also, the inclusion of new facade technologies and their streaming into the environmental performance calculation and construction specification process can be done. Finally, we believe that the methodology allows integration in the design process by enabling designers to pass from a conceptual stage to a specification one by reducing guesswork and applying proven energy improvement directions.

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Conclusion

Small and middle-size architectural firms have serious difficulties adapting to new environmental and sustainability policy goals for reduced energy consumption and emissions. Architects and building designers are expected to subcontract and postpone sustainability aspects to later design stages, resulting in lost opportunities to design and build sustainably. Performance-based expert systems using building performance simulation tools like the one presented here will be extremely relevant to meet deadlines and comply with energy performance certification requirements.

The tool presented in the article is an outcome of an extended Master thesis research that can be transferred and scalable up to other building types and climatic regions. The addition of new decision trees, adaptable for use in decision-suggestion software, and integration of building performance simulations to create larger expert system databases can extend the tool's abilities. With some modifications, it can also be used to design new buildings using timber and biobased facades. The tool can be easily modified to cater to office design in European climates. The usability testing proves the utility of the user-interactive tool to reduce decision stress and decision paralyzes.

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References

Attia, S., Favoino, F., Loonen, R., Petrovski, A., & Monge-Barrio, A. (2015). Adaptive façades system assessment: An initial review. In 10th Conference on Advanced Building Skins. 978-3-98120538-1, Munich, Germany.

Attia, S., Garat, S., & Cools, M. (2019). Development and validation of a survey for well-being and interaction assessment by occupants in office buildings with adaptive facades. Building and Environment, 157, 268-276.

Attia (2023) Usability testing for building performance simulation tools: a framework to support simulation tools adoption and fitness in the design process, Journal of Building Simulation, under review.

Bertrand, S., Cuchet, M., Yang, S., & Tabadkani, A. (2022). Comparison of Thermal Energy Saving Potential and Overheating Risk of Four Adaptive Façade Technologies in Office Buildings. Sustainability, 14(10), 6106.

Bálint Palmgren, O., & Tran, D. T. (2021). The Impact of Late Design Choices on Daylight and Energy Use in Buildings.

Cerutti, E. A. (2022). Parametric facade modelling for visual comfort optimization and overheating mitigation. A new workflow for advancing net zero competition.

Chen, X., Yang, H., & Zhang, W. (2018). Simulation-based approach to optimize passively designed buildings: A case study on a typical architectural form in hot and humid climates. Renewable and Sustainable Energy Reviews, 82, 1712–1725. https://doi.org/10.1016/j.rser.2017.06.018

Chi, D., Moreno Rangel, D., & Navarro, J. (2017). Design optimisation of perforated solar façades in order to balance daylighting with thermal performance. Building and Environment, 125. https://doi.org/10.1016/j.buildenv.2017.09.007

Gagne, J. M. L. (2011). An interactive performance-based expert system for daylighting in architectural design (Doctoral dissertation, Massachusetts Institute of Technology).

Gagne, J. M., Andersen, M., & Norford, L. K. (2011). An interactive expert system for daylighting design exploration. Building and Environment, 46(11), 2351-2364.

Han, T., Huang, Q., Zhang, A., & Zhang, Q. (2018). Simulation-Based Decision Support Tools in the Early Design Stages of a Green Building—A Review. Sustainability, 10, 3696. https://doi.org/10.3390/su10103696

Hee, W. J., Alghoul, M., Bakh, B., Elayeb, O., Shameri, M. A., Alrubaih, M. S., & Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. Renewable and Sustainable Energy Reviews, 42. https://doi.org/10.1016/j.rser.2014.09.020

ISO 9241-210 (2018): Ergonomic requirements for office work with visual display terminals (VDTs): Part 11: Guidance on usability." ISO.

Krstic-Furundzic, A., Vujosevic, M., & Petrovski, A. (2019). Energy and environmental performance of the office building facade scenarios. Energy, 183. https://doi.org/10.1016/j.energy.2019.05.231

Mulville, M., Callaghan, N., & Isaac, D. (2016). The impact of the ambient environment and building configuration on occupant productivity in open-plan commercial offices. Journal of Corporate Real Estate, 18, 180–193. https://doi.org/10.1108/JCRE-11-2015-0038

Namazi, M., Eshrati, P., Eshrati, D., & Fadaei Nezhad Bahramjerdi, S. (2016). The Study of Effective Components in Façade Engineering Towards Developing a Conceptual Framework. Journal of Applied Environmental and Biological Sciences, 6, 61–68.

Nassimos (2021). Expert decision support for the early design stage of facades for office buildings in

https://doi.org/10.26868/25222708.2023.1260

Belgium: A parametric approach, Masters' thesis, Liege University, Liege Belgium

Ochoa, C. E., & Capeluto, I. G. (2015). Decision methodology for the development of an expert system applied in an adaptable energy retrofit façade system for residential buildings. Renewable Energy, 78, 498-508.

Yan, M.-R. (2018). Improving entrepreneurial knowledge and business innovations by the simulation-based strategic decision support system. Knowledge Management Research & Practice, 16(2), 173– 182. https://doi.org/10.1080/14778238.2018.1442994

https://doi.org/10.26868/25222708.2023.1260