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Development of a holistic performance approach for facade design

Sinem Kültür¹, Ulrich Knaack², Nil Türkeri³

1 Bahcesehir University, Istanbul, Turkey, email: sinem.kultur@arc.bau.edu.tr

2 Delft University of Technology, Delft, Netherlands

3 Istanbul Technical University, Istanbul, Turkey

Abstract

As a significant building sub-system, facade needs to be designed through the consideration of a wide range of factors. Facade design is given shape as a result of a collaborative work by stakeholders from different disciplines based on outdoor (environmental) and indoor (spatial) conditions, as well as project specific constraints, time/ budget limitations, legislation in order to fulfil functional, environmental and financial requirements of the project/users. Even just functionality related performance attributed to a facade is multifaceted such as structural, daylighting, or acoustic. Although, in literature there are researches focusing on different aspects of facade performance, there is a lack of a holistic point of view that considers different aspects at once. Aim of the paper is to present (a part of) a tool developed to be used during the facade design process and counts functional performance aspects altogether. The tool provides a holistic systematic approach in order to support the design optimization. It is intended to assist decision-makers while giving decisions on facade parameters (design variables) to consider their interactions with functional performance aspects in possible environmental and spatial conditions. The tool is in the form of spreadsheet designed via Microsoft Office software. The functional performance aspects included in the tool are structural, fire, water related, air permeability related, thermal, moisture related, daylighting, and acoustic performances. The facade parameters defined as the main decision subjects within the tool are orientation, transparency ratio, facade type, window type, glazing, framing, shading, wall configuration, finishing, and detailing. First, for each facade parameter, design options are generated to keep the tool relatively simple and comprehensible. Then, matrices having design options in rows and performance aspects in columns are established. To support the decision-making, each intersecting cell in matrices proposes a rating or a rating prescription having conditional guidance. So, the tool user is expected to rate each option in terms of each performance in accordance with the prescriptions. The information provided in the tool is based upon an extensive literature review. The tool is composed of separate but interconnected rating charts designed for each facade parameter (the rating chart for orientation is presented in the paper). The overall facade performance is illustrated by a spiderweb graphic which has separate sections for each performance. Briefly, the tool is believed to enable the decision-makers to trace the consequences of their design decisions holistically, to give the decisions in a transparent way by highlighting the compromises in design, and to support the communication among stakeholders.

Keywords

Facade design, facade performance, decision-making, decision support tool, holistic design

1 INTRODUCTION

As a significant building sub-system, facade needs to be designed through the consideration of a wide range of factors. Facade design is given shape as a result of a collaborative work by stakeholders from different disciplines based on outdoor (environmental) and indoor (spatial) conditions, as well as project specific constraints, time/ budget limitations, legislation in order to fulfil functional, environmental and financial requirements of the project/ users (Knaack et al., Klein, 2013). Even just functionality related performance attributed to a facade is multifaceted such as structural, daylighting, or acoustic. Although, in literature there are researches focusing on different aspects of facade performance (Jin, 2013, Ramachandran, 2004, Hendriks & Hens, 2000, Aksamija, 2013, Oliveira & Melhado, 2011, Rivard, et al., 1999), there is a lack of a holistic point of view that considers different aspects at once. It is believed that there is a need for an approach through which all factors, variables, conditions, constraints, and interactions/ conflicts can be seen/ addressed together.

A guide focusing the whole, rather than the fragments may have a positive contribution to both the product (facade) and the process (design). Instead of testing and evaluating a considerable number of alternatives via simulation tools or field studies in real conditions, to follow a model having holistic point of view in line with design goals and to reduce the number of design alternatives in early stages of design process to a lesser amount and near-ideal options and thereafter to carry out the evaluation accordingly may have a significant contribution to the facade design process. Being within different disciplines' area of interest makes it essential to design this building sub-system in a systematic way. There is not any single resource which guide the stakeholders for all these subjects. The stakeholders need to apply for separate resources during the facade design process. Nevertheless, it is possible to provide a holistic support in the early stages of facade design process by reorganizing the information/ knowledge available in the literature by means of various researches conducted by different disciplines with different points of view and by establishing the relationships in-between to constitute a meaningful whole.

Aim of the paper is to present (a part of) a tool developed to be used during the facade design process and counts functional performance aspects altogether. The tool provides a holistic systematic approach in order to support the design optimization. It is intended to assist decision-makers while giving decisions on facade parameters (design variables) to consider their interactions with functional performance aspects in possible environmental (outdoor) and spatial (indoor) conditions. It is expected to provide insight/ gives impression about facade performance as a whole. The tool highlights the interacting, conflicting issues of the process in order to see the whole with a holistic point of view. It bases on the relationships among performance aspects, conditions and facade parameters.

Briefly, the tool is believed to enable the decision-makers to trace the consequences of their design decisions holistically, to give the decisions in a transparent way by highlighting the compromises in design, and to support the communication among stakeholders. It is expected to assist design decision-making process and optimization in design, enable the stakeholders gain holistic point of view, and contribute to/ support the design of well-performing facades today and in future.

2 METHODOLOGY

The methodology followed throughout the tool formation is illustrated in Fig. 1. To develop the tool, firstly, detailed investigation is conducted on facade design and facade performance separately aiming at understanding the structure of the design process and the aspects of the performance (the upper part in Fig. 1 stands for it). A considerable amount of publications in the literature including books, e-books, journal articles, conference proceedings, theses, seminar/ course notes, standards, codes, regulations, commercial publications, encyclopedias, dictionaries, etc. are reviewed. Then, (the lower part in Fig. 1) the knowledge gained through the literature review is reorganized/ summarized in matrices by resolving, filtering and relating the information by keywords. In addition to this, expert opinions are gathered for rating the design options and weighting the relationships.

Functional performance aspects that are associated with biological/ physiological and social/ psychological requirements of the user are taken as the focus of the tool. The key performance aspects included in the tool are structural, fire, water related, air permeability related, thermal, moisture related, daylighting, and acoustic performances (Rich & Dean, 1999, Herzog, 2008, Boswell, 2013, Jin, 2013, ITU Seminar, 2013, Oraklıbel, 2014). On the other hand, the facade parameters that are taken as the main decision subjects within the tool are orientation (if it is left to be decided), transparency ratio, facade type, window type, glazing, framing, shading, wall configuration, finishing, and detailing. These parameters are defined after examining the facade design process in detail as analyzing the design decisions made in different design stages and architectural scales (T.R. Ministry of Environment and Urbanization, 2017, Boswell, 2013). Then, these design decisions are converted to key facade parameters.

The developed tool is in the form of spreadsheet designed via Microsoft Office software. First, for each facade parameter, design options are generated to keep the tool relatively simple and comprehensible. The design options are generated in accordance with the existing facade industry and knowledge. The options are not for limiting the flexibility in design, they are for guiding the

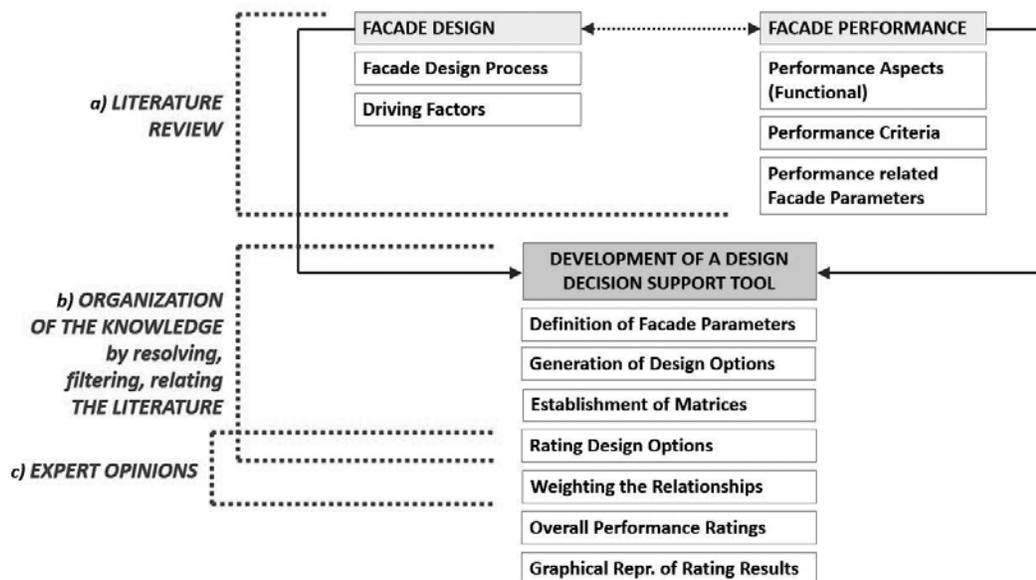


FIG. 1 Methodology followed throughout the tool formation

tool users (facade design decision-makers) to make deductions for their specific conditions. Then, matrices having design options in rows and performance aspects in columns are established. To support the decision-making, each intersecting cell in matrices proposes a rating (++ , + , 0 , - , --) or a rating prescription having conditional guidance (it also uses the same + , 0 , - rating scale). So, the tool user is expected to rate each option in terms of each performance in accordance with the prescriptions. The tool not only proposes strict ratings, but also gives prescriptions that describes how to rate the options in possible environmental and spatial conditions. In other words, the tool adapts itself to different conditions. Within the context of the paper, environmental conditions represent location, climate, and surrounding (e.g. buildings, landscape, noise sources) while spatial conditions are for function of the building/ space, building height, spatial features of the room (e.g. room proportions, surface colours, heating, cooling, ventilation, and lighting systems). So, the prescriptions are taken shape around these conditions. Even though other significant factors such as budget, feasibility, etc. are kept out of scope, the tool gives the opportunity to compare the options for their price/ performance ratios by providing their performance footprints. Besides, decisions regarding aesthetics (it is not a technical function) are left to the users to be made according to the project context, architectural intentions, etc.

The rating proposed in the tool bases on comparisons and indicates how superior/ inferior is that design option (for that facade parameter) when compared to the others in terms of that specific performance aspect. If the option has direct advantage for that performance when compared to the other options, it can be given (+). Here, the 'direct advantage' means if the option is chosen instead of the other ones, the performance of the facade will be affected positively. On the other hand, if it has direct disadvantage for that performance, it can be rated as (-). If it has no direct effect, or negligible difference, which means there is no superiority among the options, it can be given (0). Besides, degree of superiority/ inferiority among options may increase for some environmental and/ or spatial conditions, then the values can be multiplied by 2 and become (++), (--), and (0). Consequently, the tool is composed of separate but interlinked rating charts designed for each predefined facade parameter. Some given decisions inevitably limit the options to be selected for the other decision subjects. These are prescribed within the charts, as well.

Moreover, an individual performance aspect is affected by more than one design decision. But, each design decision may have different weighted impacts on that performance. So, each relationship between facade parameters and performance aspects is weighted (6 for a strong relationship, 3 for a medium-strength relationship, 1 for a weak relationship). According to Cross (2008), assigning weights to relationships is one of the systematic design methods. The weights (1-3-6) proposed by Cross (2008) are adopted within the tool (see Tab. 1). First, the relationships are weighted by making inferences from the information in the literature. Then, the assigned weights are crosschecked with the expert opinions. These weights are embedded within the tool to test how it works. However, decision-makers, based on their specific design options (that can change the strength of relationships), may need to assign different weights. All the relevant adjustments can be made as long as they are grounded on the developed tool. The main idea is to assist the decision-making by this holistic systematic approach.

For the assessment of each single performance of a facade design; firstly, each rate given by the tool users is multiplied by its weight (the strength of the relationship between the decision subject and the performance aspect), secondly, these multiplied scores are accumulated with the assumption that the sum total of the design decisions composes the facade design.

DEGREE OF RELATIONSHIP (PROPOSED BY NIGEL CROSS)	NO DIRECT RELATIONSHIP		WEAK		MEDIUM		STRONG	
WEIGHTING	0		1		3		6	
Façade parameters & Performance rel.	Structural	Fire	Water	Air Permeability	Thermal	Moisture	Daylighting	Acoustic
Orientation	6	3	6	6	6	6	6	6
Transparency ratio	6	0	0	0	6	0	6	6
Façade type	6	0	3	3	6	6	0	3
Window type	1	3	1	1	6	6	6	1
Glazing	1	0	0	0	6	3	6	6
Framing	6	3	3	0	3	1	1	3
Shading	1	6	6	0	6	0	6	1
Wall configuration	6	6	6	6	6	6	0	6
Finishing	6	6	6	6	3	6	0	1
Detailing	6	6	6	6	3	6	1	6

TABLE 1 Weighting the relationships between facade parameters and performance aspects

3 TOOL

The tool bases upon the below triangular relationship (Fig. 2). The center of the triangle represents the decisions and the tool functions as a support for making these decisions. Façade parameters define the performance while performance requirements are specified based on the conditions. Therefore, facade parameters need to be specified in line with the conditions to provide the required performance.

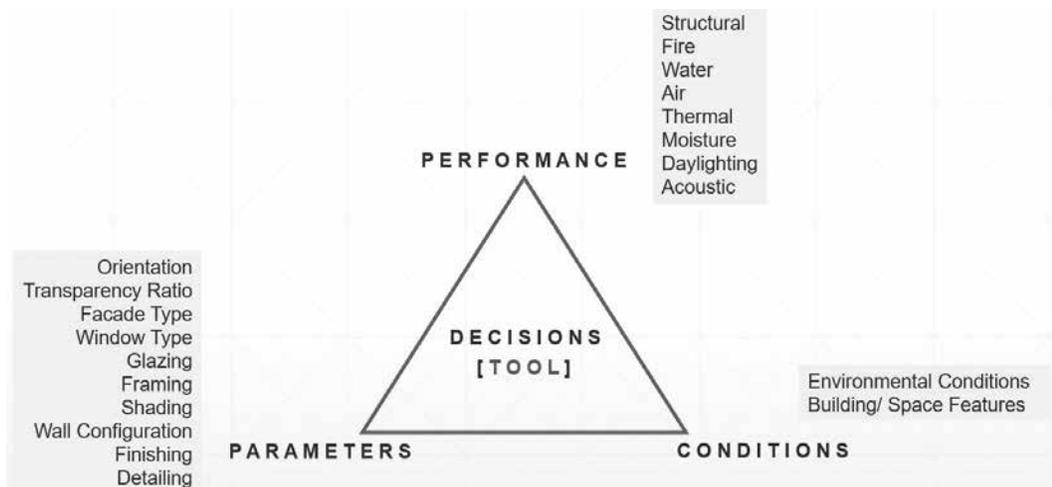


FIG. 2 Tool scheme

3.1 MATRICES

Separate but interlinked rating charts (matrices) are established for each predefined key facade parameter. The rating charts/ prescriptions, which belong to orientation parameter, are presented in this paper. Screenshots from rating charts are given in Fig. 3. The chart on the left (assume it without any rating) is the one that appears when the user clicks on the orientation decision subject on the tool's home page. Then, if the 'rate!' button under the thermal performance is clicked on, the chart on the right side appears. In this page, the user is expected to rate the options according to the given prescriptions. As soon as the options are rated, on the left chart, the empty cells are updated, and the tool highlights the ideal and worst options with a holistic point of view (based on the weights and the user's rates). Ultimately, the user is expected to make a choice by clicking on 'choose!' button. When the option is selected, the scores of that option is taken into account for evaluation.

The rating prescriptions for the orientation is given in Tab. 2. All the prescriptions in the chart are grounded on the information/ knowledge deduced from the literature. The options for the orientation are North (N), South (S), East (E), West (W), Northeast (NE), Northwest (NW), Southeast (SE), and Southwest (SW).

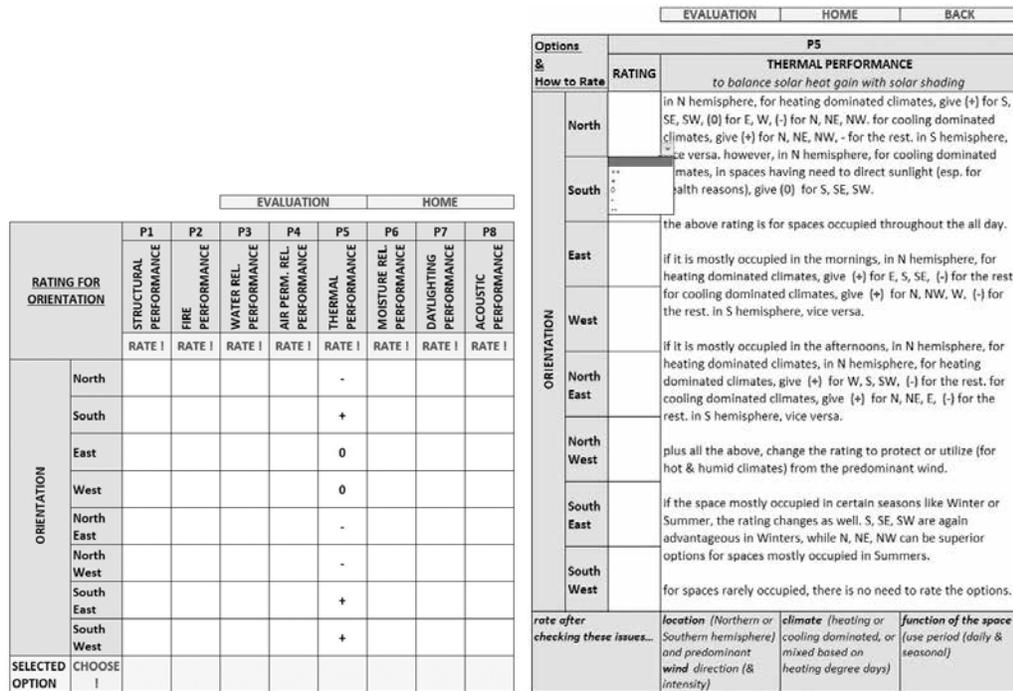


FIG. 3 Screenshots from rating charts (tool interface)

How to rate	Design Decision	ORIENTATION	Rate after checking these issues...
	Options	North South East West North East North West South East South West	
P1	Structural performance	<ul style="list-style-type: none"> give (-) for the options exposed to predominant wind directions (due to pressure & suction forces); (+) for the perpendicular directions; and (0) for the rest. if it is high-rise building and wind intensity is high, multiply the rating values by (2). if there is no predominance among the winds of different orientations, then there is no need for rating. 	predominant wind direction (& intensity)
P2	Fire performance	<ul style="list-style-type: none"> give (-) for the options exposed to the predominant wind directions; (+) for the most wind protected ones; and (0) for the rest. if building function has high importance in terms of fire protection, then multiply the rating values by (2). if there is no predominance among the winds of different orientations, then there is no need for rating. 	predominant wind direction (& intensity)
P3	Water related performance	<ul style="list-style-type: none"> give (-) for the options exposed to predominant wind directions; (+) for the most wind protected ones; and (0) for the rest. if it is high-rise building and wind intensity is high, multiply the rating values by (2). if there is no predominance among the winds of different orientations, then there is no need for rating. 	predominant wind direction (& intensity)
P4	Air perm. related performance	<ul style="list-style-type: none"> give (-) for the options exposed to predominant wind directions; (+) for the most wind protected ones; and (0) for the rest. if it is high-rise building and wind intensity is high, multiply the rating values by (2). if there is no predominance among the winds of different orientations, then there is no need for rating. if stack effect dominates the air infiltration (in cold climates), there is no need to rate the options according to wind directions. 	predominant wind direction (& speed) / building height (as high or low-rise)
P5	Thermal performance	<ul style="list-style-type: none"> in N hemisphere, for heating dominated climates, give (+) for S, SE, SW; (0) for E, W; (-) for N, NE, NW. For cooling dominated climates, give (+) for N, NE, NW; (-) for the rest. In S hemisphere vice versa. However, in N hemisphere, for cooling dominated climates, in spaces having need to direct sunlight (esp. for health reasons), give (0) for S, SE, SW. the above rating is for spaces occupied throughout the all day. if it is mostly occupied in the mornings, in N hemisphere, for heating dominated climates, give (+) for E, S, SE; (-) for the rest. For cooling dominated climates, give (+) for N, NW, W; (-) for the rest. In S hemisphere vice versa. if it is mostly occupied in the afternoons, in N hemisphere, for heating dominated climates, give (+) for W, S, SW; (-) for the rest. For cooling dominated climates, give (+) for N, NE, E; (-) for the rest. In S hemisphere vice versa. plus all the above, change the rating to protect or utilize (for hot & humid climates) from the predominant wind. 	location (Northern or Southern hemisphere) and predominant wind direction (& intensity) climate (heating or cooling dominated, or mixed based on heating degree days) function of the space (use period (daily & seasonal))
P6	Moisture related performance	<ul style="list-style-type: none"> give (-) for the options exposed to predominant wind directions; (+) for the most wind protected ones (except N orientations in N hemisphere and S orientations in S hemisphere due to low solar radiation that reduces the drying potential); and (0) for the rest. if it is high-rise building and wind intensity is high, multiply the rating values by (2). if there is no predominance among the winds of different orientations, then there is no need for rating. 	predominant wind direction (& intensity)
P7	Daylighting performance	<ul style="list-style-type: none"> according to the function of the space, define which of the following is desirable: diffuse & homogeneous skylight (a) or direct sunlight (b). For a, in N hemisphere, give (+) for N, NE, NW; (-) for the rest (high glare potential). For b, in N hemisphere, give (+) for S, SE, SW; (0) for E, W; (-) for the rest. In S hemisphere, do the rating reversely. if it has mainly winter and cloudy conditions during the year, then for some space functions, sky illuminance may not be sufficient in N orientations in N hemisphere. Check the latitude & climate and make the relevant adjustments (e.g. give (0) for N, and (+) for NE, NW). For b, give (+) for S since it provides direct sunlight and relatively easier to control; give (0) for E, W, SE, SW for providing low-angle direct sunlight which is hard to control in terms of glare; give (-) for the rest. plus all above conditions, surrounding obstacles (buildings, trees, etc.) or view change the rating. Highly reflective surrounding surfaces (including the ground) may contribute to the illumination levels or a pleasing view may be a desire. Adjust the above ratings accordingly. for spaces rarely occupied, there is no need to rate. 	location (Northern or Southern hemisphere, latitude) / climate surrounding obstacles (& solar reflectivities) /view function of the space (type of activity)
P8	Acoustic performance	<ul style="list-style-type: none"> give (-) for the options in the direction of noise sources; (+) for the most noise protected directions; and (0) for the rest. if the space is highly noise-sensitive, then multiply the rating values by (2). if the space is rarely used, there is no need for rating. 	surrounding noise sources and function of the space (use period, noise sensitivity)

TABLE 2 Rating prescriptions for the orientation

3.2 TESTING

The tool is tested with a case study (sample facade design) in Istanbul, Turkey. The key environmental conditions and spatial features are remarked in the tool as to be checked before rating. These features of the case study are given as follows. The case study is in Üsküdar, Istanbul, Turkey (Northern hemisphere). Istanbul has a heating-dominated climate. It has kind of a mild climate (temperate-humid) in which there are no extreme day-night temperature fluctuations. Predominant wind directions are Northeast and Southwest. There is a city panorama on the Northern side while there are mid-rise office buildings on the South and East directions. There is a highway (dense traffic) on the Northern side. The facade in question encloses a classroom which is at the first floor of a k-12 school building (low-rise). The classroom is mostly occupied in Winter periods.

The design options (for orientation) in the predominant wind directions are given (-) for structural, fire, water related and air permeability related performances in accordance with the rating prescriptions. Northern orientations (N, NE, NW) are given (-) for not taking advantage of solar radiation while Southern orientations (S, SE, SW) are given (+) for providing maximum amount of sunlight. The rest are assumed as mediocre options and given (0). For moisture related performance, the options in the predominant wind directions are given (-), the most protected ones are given (+) except for NW (it is given (0)), and the rest are given (0). For daylighting performance, S is given (+) and SE, SW, E, W are given (0) for having glare risk. N is given (0) since it provides homogenous but not sufficient daylight, so one advantage plus one disadvantage make it neutral (0). NE and NW are given (-) assuming that they have the disadvantages of both insufficient daylight and glare risk. Lastly, for acoustic performance, the Northern orientations are given (-) for being in the traffic (potential noise sources) side while the opposite directions are given (+), and the rest are given (0).

RATING FOR ORIENTATION		P1	P2	P3	P4	P5	P6	P7	P8
		STRUCTURAL PERF.	FIRE PERFORMANCE	WATER REL. PERF.	AIR PERM. REL. PERF.	THERMAL PERF.	MOISTURE REL. P.	DAYLIGHTING PERF.	ACOUSTIC PERF.
DESIGN DECISION <i>(building scale)</i>	Options	RATE !	RATE !	RATE !	RATE !	RATE !	RATE !	RATE !	RATE !
		ORIENTATION	North	0	0	0	0	-6	0
South	0		0	0	0	6	0	6	6
East	0		0	0	0	0	0	0	0
West	0		0	0	0	0	0	0	0
North East	-6		-3	-6	-6	-6	-6	-6	-6
North West	6		3	6	6	-6	0	-6	-6
South East	6		3	6	6	6	6	0	6
South West	-6		-3	-6	-6	6	-6	0	6
SELECTED OPTION	North West	6	3	6	6	-6	0	-6	-6
IDEAL OPTION	*for that specific condition, the most advantageous orientation is SE in terms of overall facade performance.								
WORST OPTION	*for that specific condition, the most disadvantageous orientation is NE in terms of overall facade performance.								

FIG. 4 A representative spiderweb chart

4 RESULTS

The proposed tool can be regarded as a user-friendly tool since the tool user just need to follow the prescriptions, almost taking no initiative, and it takes approximately ten minutes to rate the options for a single design decision (here it is the orientation). The results of the tool testing for orientation is presented in Fig. 4. The options are rated according to the environmental conditions and spatial features of the case study. For instance, since there is traffic noise on the Northern side, these options are given (-), which in turn multiplied by its weight and turns into (-6). Another example is that Southern directions are given (+) for thermal performance based on the prescriptions provided within the tool. On the other hand, if the case was in Southern hemisphere, the results would be completely different for thermal and daylighting performances, such as the N option would be advantageous.

The tool gives the ideal design option(s) for each decision subject (here for orientation) based on the rates and weights. The ideal option of the tool stands for the best option when considered all the performance aspects holistically. However, it is not always possible to choose the ideal option proposed by the tool. It may be due to space organization, land settlement, etc. Under these circumstances, the tool implicitly recommends paying attention to the inferior performances in other design decisions (facade parameters). Here, while the ideal option is Southeast, the selected option is Northwest which is neither the ideal nor the worst one. The ratings of the selection indicate that thermal, daylighting, and acoustic performances should be paid attention at least in making decisions for other facade parameters. The numbers are calculated by the tool itself. The tool user just needs to check the highlighted parts (ideal and worst options) and compare the rest as bigger or smaller numbers.

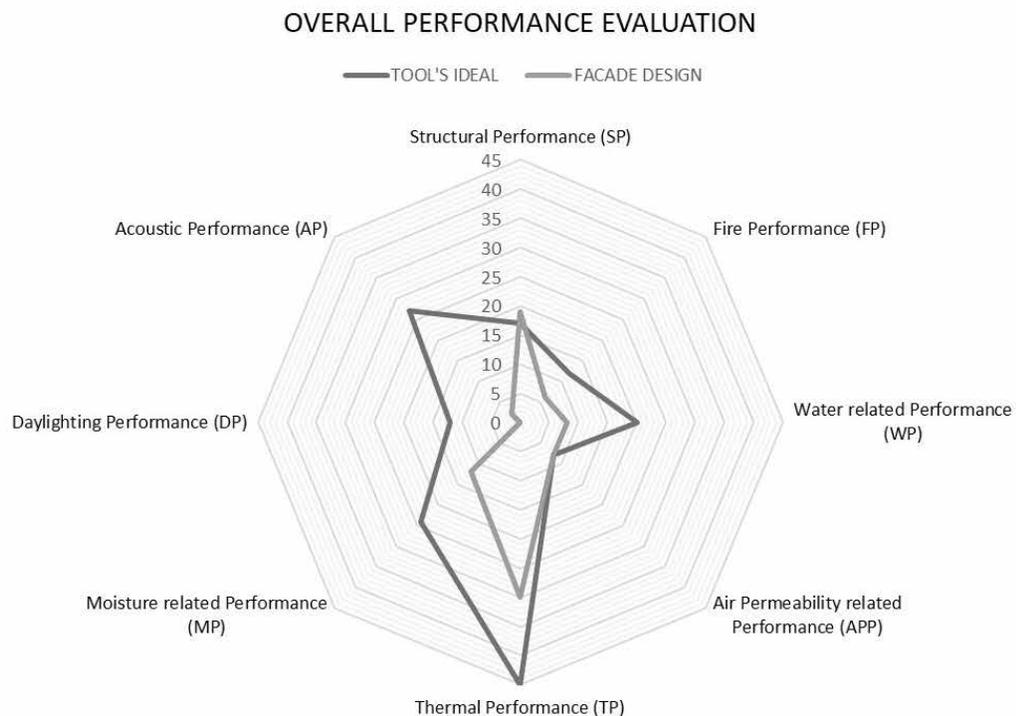


FIG. 5 A representative spiderweb chart

Finally, the scores obtained from separate charts are accumulated (the sum of + and - is 0, one advantage plus one disadvantage make the design neutral) for the overall performance evaluation

of facade design. Then the results are illustrated by a spiderweb chart (the format is given in Fig. 5). The final spiderweb graphic, which includes separate sections for each performance aspect, gives the opportunity to compare the facade design alternative with the tool's ideal. The tool does not give real performance values, instead it relatively compares alternative designs in terms of performance aspects and provides their overall functional performance footprints. Tool's ideal appears as soon as the user completes to rate the options for all facade parameters. It does not represent an absolute ideal and it assumes that all the facade functions are equally important, so it approaches the facade performance holistically without overlooking any functional aspect. On the other hand, in some cases, one performance aspect of the facade may be given much more importance than the rest. In that case, the results of the tool (performance footprints) can be interpreted accordingly.

5 CONCLUSIONS

The tool is believed to provide insight about the entire facade performance while addressing the interactions, conflicting issues among separate performance aspects and their relationships with design decisions. Thus, it will lead to a holistic facade design, better trade-offs, and transparency in decision-making, especially in early stages of facade design process. Consequences of design decisions regarding facade performance can be traced holistically. Design is a process of limiting possible alternatives and here the tool may function as a supportive guidance. By having the potential to prevent negative iterations in the design process, it will be time-saving, as well. Although the decisions need to be finalized by integrating some other issues like costs, and aesthetic features of the design alternatives, by means of the tool, options can be compared in terms of their functional performances. Besides, the tool provides the notion of how (by changing which design decision(s)) to improve the performance of the final design. Project conditions may vary, so the importance factors of the performance aspects. In that case, design decisions can be given accordingly which makes the tool flexible to changing priorities/ conditions. In future studies, design options within the scope of the tool can be expanded and rated by following the similar logic. Furthermore, the tool can be customized for specific climatic conditions, or building/ facade types. It may evolve in future, as new knowledge is incorporated into the tool.

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