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A Holistic Decision Support Tool for Façade Design

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ABSTRACT
The aim of this paper is to present a tool which will support decision-makers of façade design process while giving decisions on façade parameters to consider their interactions with functional performance issues. The tool is believed to contribute the holistic design of facades which is lacking in existing literature. The functional performance aspects included in the tool are structural, fire, water related, air permeability related, thermal, moisture related, daylighting, and acoustic performances. Façade parameters that are taken as the main decision subjects within the tool are orientation, transparency ratio, façade type, window type, glazing, framing, solar control, wall configuration, finishing, and detailing. First, for each façade 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. The proposed rating bases on comparisons and indicates for that façade parameter how superior is that design option when compared to the others in terms of that specific performance aspect. The tool not only proposes strict ratings, but also gives prescriptions that describe how to rate the options in various environmental and/ or spatial conditions. Consequently, the tool is composed of separate rating charts (matrices) designed for each predefined façade parameter. The proposed tool is in the form of spreadsheet designed via Microsoft Office software. The information provided in the tool is based upon an extensive literature review. The tool is believed to provide insight about the entire façade performance while addressing the interactions, conflicting issues among separate performance aspects and their relationships with design decisions. Thus, it will enable the decision-makers to give the decisions in a transparent way by highlighting the compromises in design and will support the communication among stakeholders.

KEYWORDS
Façade design, façade performance, decision-making, decision support tool, holistic design.

INTRODUCTION

Façade design is a significant sub-process of building design. This process is driven by a substantial number of factors such as user requirements (and performance requirements accordingly), environmental conditions, building/ space features, project conditions (various constraints, time/ budget limitations, feasibility issues, etc.), legislation, and stakeholders from different disciplines. Moreover, limitless variety of today's material and technology opportunities, changing conditions in time, designers' working trends (sense of aesthetics which is hard to assess) have influences on façade design (Knaack, et al., 2007, Klein, 2013). All these necessitate a holistic approach for façade design not to skip any significant factor and to make an optimization.

Although there are a few researches (Jin, 2013, Ramachandran, 2004, Hendriks & Hens, 2000, Aksamija, 2013, Oliveira & Melhado, 2011, Rivard, et al., 1999) in literature, there is a lack of a holistic point of view in façade design. It is believed that there is a need for an approach through which all factors, variables, conditions, constraints, and interactions can be seen/ addressed together.

A guide focusing the whole, rather than the fragments may have a positive contribution to both the product (façade) 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 make it essential to design this building system (the façade) 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 organizing all the information/ knowledge in the literature from various researches conducted by different disciplines with different points of view and by establishing the relationships in-between to constitute a meaningful whole.

Main objectives of the study are to develop a systematic/ methodology for design process based on functional performance issues, and to propose a user-friendly tool for the usage of stakeholders of façade design process. To achieve these goals, a tool is developed which provides insight/ gives impression about façade 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.

In this way, both time/ cost savings and quality improvement are expected. Through the use of the proposed design decision support tool, the stakeholders of facade design process may give faster and more proper decisions and make more efficient collaborations.

It will support transparent and integrated façade design process, by doing so, strengthen the dialogue and collaboration among the participants, in turn it will ensure/ improve the product (façade) quality. It will 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.

METHODOLOGY

The method followed in the study is illustrated in Figure 1. In the first part of the study, an extensive literature review regarding façade design and façade performance is conducted. The review of the existing literature covers all the relevant publications including books, e-books, journal articles, conference proceedings, theses, seminar/ course notes, standards, codes, regulations, commercial publications, encyclopaedias, dictionaries, etc. In the second part, during the development of the design decision support tool, the knowledge is organized by resolving, filtering, and relating the literature. 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, façade parameters that are taken as the main decision subjects within the tool are orientation, transparency ratio, façade type, window type, glazing, framing, solar control, wall configuration, finishing, and detailing.

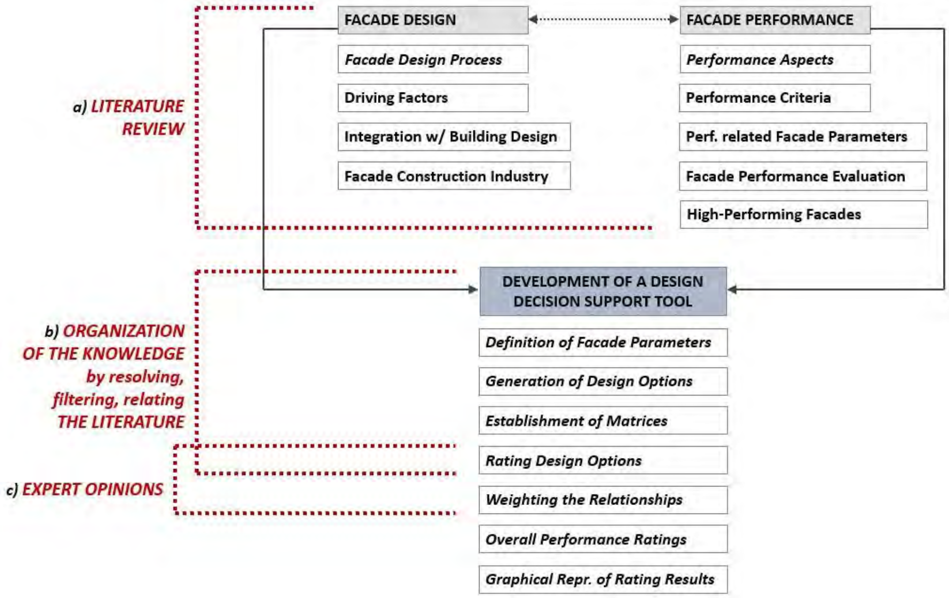

Figure 1. Methodology of the study

The proposed tool is in the form of spreadsheet designed via Microsoft Office software. First, for each façade parameter, design options are generated to keep the tool relatively simple and comprehensible. The design options are generated in accordance with the existing façade industry and knowledge. The options are not for limiting the flexibility in design, they are for guiding the tool users (façade design decision-makers) by indicating the consequences of various design decisions. So, the tool user can 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 sentences. 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 various environmental and/ or spatial conditions. These conditions may totally change the rating. Within the context of the study, 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). Some other significant factors as budget, feasibility, aesthetics, etc. are kept out of the tool and left to the user to make decision regarding these issues according to the project conditions, architectural intentions, etc.

The rating proposed in the tool bases on comparisons and indicates how superior is that design option (for that façade 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 other ones, the performance of the façade 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 façade 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, for each performance aspect, each design decision is weighted according to the strength of relationships (6 for a strong relationship, 3 for a medium-strength relationship, 1 for a weak relationship). The tool gives the ideal design option(s) for each decision subject based on the rates and weights. 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. For the assessment of each single performance of a façade 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 façade design.

RESULTS

The results of the study are the separate but interlinked rating charts (matrices) prepared for each predefined key decision subject. The rating charts/ prescriptions which belong to orientation are presented in this paper. Screenshots from rating charts are given in Table 1. 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.

Table 1. Screenshots from rating charts (tool interface, and sample rating)

EVALUATION | HOME

RATING FOR ORIENTATION		P1 STRUCTURAL PERFORMANCE	P2 FIRE PERFORMANCE	P3 WATER REL. PERFORMANCE	P4 AIR PERM. REL. PERFORMANCE	P5 THERMAL PERFORMANCE	P6 MOISTURE REL. PERFORMANCE	P7 DAYLIGHTING PERFORMANCE	P8 ACOUSTIC PERFORMANCE
		RATE !	RATE !	RATE !	RATE !	RATE !	RATE !	RATE !	RATE !
ORIENTATION	North					-			
	South					+			
	East					0			
	West					0			
	North East					-			
	North West					-			
	South East					+			
	South West					+			
SELECTED OPTION	CHOOSE !								

EVALUATION | HOME | BACK

Options & How to Rate		P5 RATING	P5 THERMAL PERFORMANCE *to balance solar heat gain with solar shading*		
ORIENTATION	North		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, ce versa. however, in N hemisphere, for cooling dominated mates, in spaces having need to direct sunlight (esp. for alth 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, 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. if the space mostly occupied in certain seasons like Winter or Summer, the rating changes as well. S, SE, SW are again advantageous in Winters, while N, NE, NW can be superior options for spaces mostly occupied in Summers. for spaces rarely occupied, there is no need to rate the options.		
	South				
	East				
	West				
	North East				
	North West				
	South East				
	South West				
rate after checking these issues...			***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)*

The rating prescriptions for the orientation is given in Table 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).

Table 2. Rating prescriptions for the orientation

<table>
<tr><td colspan="2">Options for the Design Decision & How to Rate Them</td><td>P1</td><td>P2</td><td>P3</td><td>P4</td><td colspan="3">P5</td><td>P6</td><td colspan="3">P7</td><td>P8</td></tr>
<tr><td>DESIGN DECISION</td><td>Options</td><td>STRUCTURAL PERFORMANCE</td><td>FIRE PERFORMANCE</td><td>WATER related PERFORMANCE</td><td>AIR PERMEABILITY related PERFORMANCE</td><td colspan="3">THERMAL PERFORMANCE</td><td>MOISTURE related PERFORMANCE</td><td colspan="3">DAYLIGHTING PERFORMANCE</td><td>ACOUSTIC PERFORMANCE</td></tr>
<tr><td rowspan="8">ORIENTATION</td><td>North</td>
<td rowspan="8">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.</td>
<td rowspan="8">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.</td>
<td rowspan="8">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.</td>
<td rowspan="8">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.</td>
<td colspan="3" rowspan="8">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, 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.

if the space mostly occupied in certain seasons like Winter or Summer, the rating changes as well. S, SE, SW are again advantageous in Winters, while N, NE, NW can be superior options for spaces mostly occupied in Summers.

for spaces rarely occupied, there is no need to rate the options.</td>
<td rowspan="8">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.</td>
<td colspan="3" rowspan="8">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).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.</td>
<td rowspan="8">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.</td></tr>
<tr><td>South</td></tr>
<tr><td>East</td></tr>
<tr><td>West</td></tr>
<tr><td>North East</td></tr>
<tr><td>North West</td></tr>
<tr><td>South East</td></tr>
<tr><td>South West</td></tr>
<tr><td colspan="2">rate after checking these issues…</td>
<td>predominant wind direction (& intensity) / building height (as high or low-rise)</td>
<td>predominant wind direction (& intensity) / building function</td>
<td>predominant wind direction (& intensity) / building height (as high or low-rise)</td>
<td>predominant wind direction (& speed) / building height (as high or low-rise) climate</td>
<td>location (Northern or Southern hemisphere) and predominant wind direction (& intensity)</td>
<td>climate (heating or cooling dominated, or mixed based on heating degree days)</td>
<td>function of the space (use period (daily & seasonal)</td>
<td>predominant wind direction (& intensity) / building height (as high or low-rise)</td>
<td>location (Northern or Southern hemisphere, latitude) / climate</td>
<td>surrounding obstacles (& solar reflectivities) / view</td>
<td>function of the space (type of activity)</td>
<td>surrounding noise sources and function of the space (use period, noise sensitivity)</td></tr>
</table>

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 façade design. Then the results are illustrated by a spiderweb chart (the format is given in Figure 2). The final spiderweb graphic, which includes separate sections for each performance aspect, gives the opportunity to compare the façade design alternative with the tool's ideal. The tool does not give real performance values, instead it gives the opportunity to relatively compare alternative designs in terms of performance aspects and to see the overall performance footprint.

DISCUSSIONS AND CONCLUSION

The tool is believed to provide insight about the entire façade performance while addressing the interactions, conflicting issues among separate performance aspects and their relationships with design decisions. Thus, it will lead to a holistic façade design, better trade-offs, and transparency in decision-making, especially in early stages of façade design process. 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.

Figure 2. A representative spiderweb chart

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/ façade types. It may evolve in future, as new knowledge is incorporated into the tool.

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