

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

A HOLISTIC DECISION SUPPORT TOOL FOR FACADE DESIGN



Ph.D. THESIS

Sinem KÜLTÜR

Department of Architecture

Construction Sciences Programme

NOVEMBER 2019

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Thesis Advisor: Prof. Dr. A. Nil TÜRKERİ
Thesis Co-Advisor: Prof. Dr. Ulrich KNAACK

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DOKTORA TEZİ

**Sinem KÜLTÜR
(502102017)**

Mimarlık Anabilim Dalı

Yapı Bilimleri Programı

**Tez Danışmanı: Prof. Dr. A. Nil TÜRKERİ
Eş Danışman: Prof. Dr. Ulrich KNAACK**

KASIM 2019

Sinem Kltr, a Ph.D. student of ITU Graduate School of Science Engineering and Technology student ID 502102017, successfully defended the thesis entitled “A HOLISTIC DECISION SUPPORT TOOL FOR FACADE DESIGN”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. A. Nil TRKERİ**
Istanbul Technical University

Co-advisor : **Prof. Dr. Ulrich KNAACK**
Delft University of Technology

Jury Members : **Prof. Dr. Alpin KKNEL YENER**
Istanbul Technical University

Assoc. Prof. Dr. Rana KUTLU
Istanbul Kultur University

Prof. Dr. Gl KOLAR ORAL
Istanbul Technical University

Prof. Dr. Mustafa ZGNLER
Mimar Sinan Fine Arts University

Assoc. Prof. Dr. İkbāl ETİNER
Istanbul Technical University

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To my family,



FOREWORD

This Ph.D. education was a truly life-changing experience. The period was challenging in many aspects which I believe made me grow stronger. I was lucky that I had precious people with me all along these years. I would like to thank them one by one for their support, guidance, and understanding. It would not be possible to accomplish this thesis without their existence.

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October 2019

Sinem KÜLTÜR
(Architect, M.Sc.)

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ABBREVIATIONS

ASHRAE	: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	: American Society for Testing Materials
BRE	: Building Research Establishment
BREEAM	: Building Research Establishment Environmental Assessment Method
BS	: British Standard
CASBEE	: Comprehensive Assessment System for Built Environment Efficiency
CIBSE	: Chartered Institution of Building Services Engineers
CWCT	: Centre for Window and Cladding Technology
DD	: Design Decision
DF	: Daylight Factor
DGNB	: Deutsche Gesellschaft für Nachhaltiges Bauen
DIN	: Deutsches Institut für Normung
E	: East
EA	: Effective Aperture
EN	: European Standard
ENV	: European pre-Standard
eq	: Equivalent
FT	: Facade Type
G	: Glazing
IBD	: Integrated Building Design
ISO	: International Organization for Standardization
LBNL	: Lawrence Berkeley National Laboratory
LEED	: Leadership in Energy and Environmental Design
Low-e	: Low Emissivity
N	: North
NE	: Northeast
NFRC	: National Fenestration Rating Council
NW	: Northwest
O	: Orientation
P1	: Structural Performance
P2	: Fire Performance
P3	: Water-related Performance
P4	: Air Permeability-related Performance
P5	: Thermal Performance
P6	: Moisture-related Performance
P7	: Daylighting Performance
P8	: Acoustic Performance
PVC-u	: Polyvinyl Chloride Un-plasticised
S	: Shading
S	: South
SE	: Southeast

SHGC	: Solar Heat Gain Coefficient
SRI	: Sound Reduction Index
STC	: Sound Transmission Coefficient
SW	: Southwest
TR	: Transparency Ratio
TS	: Turkish Standard
TSE	: Turkish Standards Institution
VT	: Visible Transmittance
W	: Wall Configuration
W	: West
WT	: Window Type
WWR	: Window-to-Wall Ratio



SYMBOLS

A	: Area
C₂H₄	: Ethylene
CO₂	: Carbondioxide
D_{nT,w}	: Weighted standardized level difference
g	: Gram
kg	: Kilogram
L_{Aeq}	: Equivalent continuous sound level
L_{AF}	: Sound level (L), frequency (A) and time (F) weighting
MJ	: Mega Joule
mm	: Milimeter
θ	: Angle
%	: Percent
R_w	: Weighted sound reduction index
s	: Second
SO_x	: Sulphur Oxides
U_{value}	: Overall Heat Transfer Coefficient
ΔT	: Temperature Difference
μ	: Water Vapour Diffusion Resistance Factor
Σ	: Total



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A HOLISTIC DECISION SUPPORT TOOL FOR FACADE DESIGN

SUMMARY

The facade is a significant building sub-system, with its multiple roles, needs to be designed through the consideration of a great number of factors all at once. Facade design is given shape as a result of a collaborative work by stakeholders from different disciplines considering environmental (outdoor) and spatial (indoor) conditions, as well as time/ budget limitations and legislation in order to fulfill functional, environmental and financial requirements of the project/ users. Even just functionality related performance attributed to a facade has several aspects such as structural, daylighting or acoustic. A single decision given on the facade may lead to different effects on each individual performance. For instance, to increase the transparency ratio of the facade may enhance the daylighting performance whereas it may have an adverse effect on thermal performance. Although in the 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.

The thesis proposes a tool developed to be used during the early stages of the facade design process and counts functional performance aspects altogether. The tool provides a holistic systematic approach in order to support the optimization in design. It is intended to assist decision-makers about facade parameters (design variables) to consider their interactions with functional performance aspects in possible environmental and spatial conditions. The tool is designed in the form of Microsoft Excel spreadsheet. It bases on the relationships among performance aspects, conditions and facade parameters. It highlights the interacting, and conflicting points of the process in order to see the whole with a holistic point of view.

The functional performance aspects included in the tool are structural, fire, water-related, air permeability-related, thermal, moisture-related, daylighting, and acoustic. The facade parameters defined as the main decision subjects in the tool are orientation, transparency ratio, facade type, window type, glazing, wall configuration, and shading. 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 tool users (facade design decision-makers) to make deductions for their specific options.

The tool consists of an input page, tool process pages, output and decision-making pages, and an evaluation page. Input page is designed for the users to define their specific environmental and spatial conditions by selecting from drop-down lists. In tool process pages, matrices having design options in rows and performance aspects in columns are established. Each intersecting cell in matrices proposes a rating (++ , + , 0 , - , --) or conditional ratings (the same rating scale is used).

The design decision support tool rates each option in terms of each performance aspect individually in accordance with the conditions defined in the input page. The tool has

the capability to adapt itself to different conditions. Within the context of the thesis, thus the tool, environmental conditions represent location, earthquake, climate, noise sources, and immediate surrounding (buildings, trees, surfaces) while spatial conditions refer to function of the building/ space, building height, spatial features of the room such as proportions and interior surface colors. Ratings and prescriptions proposed by the tool are taken shape in line with all these conditions. Even though the tool does not include other significant factors in the scope, it gives the opportunity to the decision-makers to compare the options for cost/ performance ratios by providing performance footprints of the design alternatives. Besides, decisions regarding aesthetics (due to not being a technical function) are left to the users to be made according to the project context, architectural intentions, etc.

The rating proposed by the tool is based on comparisons and indicates how superior/ inferior is a design option (belonging to a facade parameter) when compared to the others in terms of each performance aspect. In predefined conditions, for the performance in evaluation, the option that has direct superiority (advantage) when compared to the other options is given (+) by the tool.

Here, the ‘direct advantage’ means if the option is chosen instead of the other ones, the evaluated performance of the facade will be affected positively. On the other hand, the option that has a direct disadvantage is rated as (-). If the option has no direct effect or negligible difference, which means there is no superiority/ inferiority among the options, then it is given (0). Besides, degree of superiority/ inferiority among the options may increase for some environmental and/ or spatial conditions, then the values are multiplied by (2) and become (++), (--), and (0). For instance; in high-rise buildings, wind loads are more critical, so the structural performance, and the difference among the options. The tool setup is based on the information obtained through an extensive literature review. To exemplify, assuming that a research in literature indicates that acoustic performance of a facade glazing (sound insulation against outdoor noise) can be improved by one of the following design strategies: increasing the mass (number and/or thickness of glass layers), increasing the gap between the glass layers, filling the gap with heavy gases, and asymmetric assembly of glass layers. It is taken as the more the layer, or the more the thickness, or the thicker the gap, or heavier the gas or the more the difference in layer thickness the better the acoustic performance within the context of the tool. Options are rated gradually in line with this design-performance relationship. Decisions are given in an order starting from orientation and ending with shading. Consequently, the tool presents the decision-makers separate but interlinked rating charts for each facade parameter included in the scope. In the decision order, some of the given decisions may limit the options in subsequent decisions and/ or change the ratings. These are seen in detail in the tool process pages.

Moreover, an individual performance aspect can be affected by more than one design decision, and each design decision may have different weighted impacts on performance aspects. So, for each relationship between facade parameters and performance aspects, a weight coefficient is specified (5 for a strong relationship, 3 for a medium-strength relationship, 1 for a weak relationship). First, the relationships of design decisions and performance aspects are weighted by making inferences from the knowledge acquired by the literature review. Then, the assigned weights are cross-checked with expert opinions. These weights are integrated into the tool. However, the tool provides flexibility for decision-makers to change the assigned weights of the relationships between design decisions and performance aspects. All the relevant

adjustments can be made as long as they are grounded on the structure and logic of the developed decision support tool. The ultimate aim is to assist decision-making with a holistic systematic approach.

For the assessment of every single performance of facade design, firstly the orientation options are rated in line with the environmental and spatial conditions defined by the users. Then, these ratings are multiplied by the weights (the strength of the relationship between the decision subject and the performance aspect) specified within the tool. However, the user has the opportunity to change the weights for various reasons. In such a case, the tool gives the new weighted ratings according to the new coefficients given by the user. Users are expected to make a decision on one of the options by seeing the entire assessment of the orientation options in term of performance aspects. The decision on orientation option made by the user, which is the first design decision to be made, has an effect on definition and rating of the possible options in subsequent design decisions. Users are expected to make decision on one of the options for each design decision subject respectively (orientation, transparency ratio, facade type, window type, glazing, wall configuration, shading) by taking into consideration the ratings provided by the tool. When all the decision subjects are completed, the tool evaluates the facade design (preliminary) defined with the options selected by the user in terms of every performance aspect.

Assuming that the final design is the sum total of the decisions, the weighted ratings are added up. In accordance with the conditions defined and the initial options (such as orientation, transparency ratio) decided by the user, the ideal options that have the highest rates in total are specified by considering each performance. In terms of each performance aspect total ratings are calculated for the ideal facade design that is assumed to comprise of the ideal options specified by the tool. Then, the user has the opportunity to compare preliminary facade design with the ideal design suggested by the tool. The final evaluation of user's facade design and tool's ideal facade design are illustrated on a spider web graphic since which makes it possible to indicate each performance separately, independently of each other and to compare designs proportionally. This graphic gives the functional performance footprint of a facade which is composed of design decisions.

The tool is built upon the triangular relationship between performance, parameters, and conditions. While facade parameters define the performance, performance requirements are specified based on the conditions. For this reason, facade parameters need to be specified in line with the conditions in order to provide the required performance.

The tool provides a basis that enables all independently evaluated performance aspects to be seen all together. It brings out the effects of an individual design decision on different functional performance aspects simultaneously. 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 holistic facade design, better trade-offs, and transparency in decision-making especially in the early stages of the facade design process. Facade performance related consequences of design decisions can be traced holistically. Design is somewhat a process of limiting possible alternatives and the tool may guide this process. It is also anticipated to be time-saving due to its potential to prevent negative iterations in the design process. Although decisions need to be finalized by integrating some other important issues like costs, and aesthetic features

of design alternatives, the tool as is, enables to compare the alternatives in terms of functional performance aspects. Besides, the tool provides the notion of how (by changing which design decision/ decisions) to improve the performance of the final design.

Depending on the variety in project conditions, the importance of performance aspects may change, and design decisions may be given accordingly. The tool proposes a systematic approach instead of giving final outputs. By this means, it is open to be developed and flexible to be orientated according to new conditions. In future studies, design options can be increased in number and they can be rated by following the logic of the tool. Furthermore, the tool can be customized for specific climatic conditions or building/ facade types. This developed tool may evolve in future as new knowledge is incorporated into the tool.

The thesis consists of six chapters.

After the Introduction, in Chapter Two, the facade design process is described in detail with all relevant issues. First, the facade design process is figured with its phases and stakeholders in general. Then, driving factors of the process are explained. After that, integration of facade as a sub-system with building's other sub-systems are addressed. Lastly, facade construction industry is discussed with current trends and problematic issues.

In Chapter Three, facade performance is dealt with from various aspects: affecting agents, performance requirements, indicators of performance levels, criteria for various performance aspects, performance related facade parameters in different scales, forms of facade performance evaluation, and lastly high-performing facades. Performance requirements which come from user requirements fall into different categories/ aspects. Each aspect has its own performance indicators/ metrics, and all these are explained in detail. Facade parameters responsible for facade performance are categorized in different scales (settlement scale, building scale, building element scale, component and material scale) corresponding to different phases of the facade design process. Both qualitative and quantitative types of facade performance evaluation are briefly reviewed. Finally, state-of-the-art facades with high-performance facade technologies are exemplified to explore the relationship between design decisions and performance levels.

Chapter Four which is the original part of the thesis comprises the development of the proposed tool. Sections of the Chapters are; definition of environmental and spatial conditions, definition of facade parameters, generation of design options, establishment of design decision and performance matrices, rating design options, rating results and decision-making, and overall performance evaluation. In brief, the proposed tool is explained in detail in this chapter.

In Chapter Five, for validation, the tool is implemented for made-up scenarios and real projects. Scenarios are made up considering the variety in environmental and spatial conditions. After testing the tool for made-up scenarios, a sensitivity analysis is conducted for a single scenario in order to see the sensitivity of the performance to facade parameters (design variables). On the other hand, real projects are specified as both ongoing design projects and already constructed projects. Architects as decision-makers are let to use the tool for at least one of their projects. Besides, the tool is opened for use by different stakeholders, owner and engineers, for one of these projects. After the tool usage, feedback of the tool users is recorded through interviews with half-structured open-ended questions. Answers to the interview questions are

outlined in this chapter. Lastly, the feedback of the implementation is interpreted as contributions, deficiencies, and complexities of the tool. The full version of the interview records is presented at the Appendices.

In Chapter Six, after a brief discussions part, conclusions are drawn. Potential contributions of the thesis and its outcomes are emphasized. The literature gap filled by the thesis is underlined. Questions like who the thesis outcomes serve for, how and to what extent further studies can make use of the thesis are addressed. The goals at the beginning of the thesis and the outcomes are compared to see if the objectives are realized with the proposed tool in accordance with the hypothesis.

All Chapters except the Introduction and the Discussions and Conclusion (Chapter Six) end up with a section of ‘Summary of the Chapter’.





CEPHE TASARIMI İÇİN BÜTÜNCÜL BİR KARAR DESTEK ARACI

ÖZET

Cephe, binada üstlendiği çeşitli görevler ile, çok sayıda etmenin birlikte göz önüne alınarak tasarlanması gereken, önemli bir bina alt sistemidir. Cephe tasarımı; projenin/ kullanıcıların işlevsel, çevresel ve finansal gereksinimlerini yerine getirmek amacı ile, çevresel (dış ortam) ve mekansal (iç ortam) koşullar, zaman/ bütçe kısıtlamaları ve yasal düzenlemeler göz önünde bulundurularak, farklı disiplinlerden gelen paydaşların işbirliği ile oluşturulan çalışmalar ile şekillenir. Cephenin sadece işlevsellikle ilgili performansı bile strüktürel, güneşliği, akustik gibi çok yönlüdür. Cephe ile ilgili verilen bir karar, performans yönlerini farklı etkileyebilir. Örneğin; cephenin saydamlık oranını arttırmak, güneşliği ile ilgili performansa iyi yönde etki ederken, ısı performans üzerinde olumsuz etki yaratabilir. Literatürde cepheden beklenen performansın farklı yönlerine odaklanan çalışmalar olmasına rağmen, farklı yönleri aynı anda dikkate alan bütüncül bir bakış açısı eksikliği vardır.

Bu tez; cephe tasarım sürecinin erken aşamalarında yararlanılması amaçlanarak geliştirilen ve cephenin işlevsel açıdan performanslarını bir arada hesaba katan bir karar destek aracı önermektedir. Önerilen araç, tasarımda optimizasyona destek olma amacıyla bütüncül sistematik bir yaklaşım sağlamaktadır. Cephe parametrelerine (tasarım değişkenleri) ilişkin karar verirken işlevsel performanslar arasındaki etkileşimleri olası çevresel ve mekansal koşullar içerisinde göz önünde bulundurmaları için karar vericileri desteklemek amaçlanmaktadır. Tasarım destek aracı, Microsoft Excel yazılımı aracılığıyla elektronik çizelge (spreadsheet) formunda tasarlanmıştır. Araç, performanslar, koşullar ve cephe parametreleri arasındaki ilişkilere dayanmaktadır. Bütünün, bütüncül bir bakış açısıyla görülebilmesi için, sürecin etkileşen, çelişen noktalarını vurgular.

Karar destek aracına dahil edilen işlevsel performanslar strüktürel, yangın, su ile ilgili, hava geçirimsizliği ile ilgili, ısı, nem ile ilgili, güneşliği ile aydınlatma ve akustik performanslarıdır. Araç dahilinde ana karar konuları olarak tanımlanan cephe parametreleri ise; yön, saydamlık oranı, cephe tipi, pencere tipi, cam türü, duvar konfigürasyonu ve gölgelemedir. İlk olarak; her bir cephe parametresi için, karar destek aracını nispeten basit ve anlaşılır tutma amacıyla tasarım seçenekleri oluşturulmuştur. Tasarım seçenekleri mevcut cephe endüstrisi ve bilgisine uygun olarak belirlenmiştir. Seçenekler; tasarımda esnekliği sınırlandırmak için değil, araç kullanıcılarının (cephe tasarımı karar vericileri) kendi spesifik seçenekleri için çıkarım yapmalarına yol göstermek içindir.

Söz konusu araç; bir girdi sayfası, araç işlem sayfaları, çıktı ve karar verme sayfaları, ile bir değerlendirme sayfasından oluşmaktadır. Giriş sayfası, kullanıcıların çevresel ve mekansal koşullarını bir açılır listeden seçerek tanımlamaları için tasarlanmıştır. Araç işlem sayfalarında, satırlarda tasarım seçenekleri ve sütunlarda performans yönleri olmak üzere matrisler oluşturulmuştur. Matrislerdeki kesişen her hücre, bir

derecelendirme (++ , + , 0 , - , --) veya koşullara bağlı değişen derecelendirmeler önerir (aynı derecelendirme ölçeği kullanılır).

Araç, giriş sayfasında tanımlanmış koşullara göre her bir seçeneği her bir performans açısından ayrı ayrı derecelendirir. Araç kendini farklı koşullara uyarlama kabiliyetine sahiptir. Tez kapsamında, dolayısıyla önerilen araç kapsamında, çevresel koşullar ile yer, deprem, iklim, gürültü kaynakları, ve yakın çevre (binalar, ağaçlar, yüzeyler) temsil edilirken, mekansal koşullar ile bina/ mekan işlevi, bina yüksekliği, mekansal oran, iç mekan yüzey rengi gibi çeşitli özellikler temsil edilir. Aracın derecelendirmeleri ve önerdiği reçeteler/ tarifler bu koşullar doğrultusunda şekillenir. Araç, bütçe ve fizibilite gibi diğer önemli etmenleri kapsam dışında tutmasına rağmen; seçeneklerin performans ayakizlerini vererek, karar vericilerin fiyat/ performans oranlarına göre seçenekleri karşılaştırmasına imkan sunmaktadır. Bunun yanı sıra, estetik (teknik bir işlev olmadığından ötürü) ile ilgili kararlar; proje bağlamına, mimari amaçlara vb. uygun verilmek üzere kullanıcılara bırakılmıştır.

Aracın önerdiği derecelendirme karşılaştırmalara dayanmaktadır ve herhangi bir tasarım seçeneğinin (bir cephe parametresine ait) diğerlerine kıyasla her bir performans yönü için ne kadar üstün/ düşük olduğunu göstermektedir. Tanımlanan koşullar içerisinde, değerlendirilen performans açısından, diğer seçenekler ile karşılaştırıldığında doğrudan bir üstünlüğü (avantajı) olan seçenek, araç tarafından (+) ile derecelendirilir. Burada, 'doğrudan avantaj', diğerlerinin yerine bu seçeneğin seçilmesi durumunda, cephenin değerlendirilen performansının olumlu yönde etkileneceği anlamındadır. Diğer yandan, doğrudan bir dezavantajı olan seçenek, (-) olarak derecelendirilir. Eğer seçeneğin doğrudan bir etkisi yoksa ya da ihmal edilebilir bir fark yaratıyorsa, seçenekler arasında üstünlük olmadığı anlamına gelir ve (0) ile derecelendirilir. Ayrıca, seçenekler arasındaki üstünlük/ düşüklük derecesi bazı çevresel ve mekansal koşullar için artabilir, bu durumda değerler (2) ile çarpılır ve (++), (--), ve (0) haline gelir. Örneğin; yüksek binalarda, rüzgar yükleri daha kritiktir, dolayısıyla da strüktürel performans ve seçenekler arasındaki fark daha önemli hale gelir. Aracın kurgusu kapsamlı literatür taraması ile elde edilen bilgiye dayanmaktadır. Literatürdeki bir çalışmanın, bir cephe camının akustik performansının (dış mekan gürültüsüne karşı ses yalıtımı), şu tasarım stratejilerinden biriyle geliştirilebileceğini öne sürdüğünü varsayalım: kütlenin arttırılması (cam tabakalarının sayısı veya kalınlığı), cam tabakaları arasındaki boşluğun arttırılması, bu boşluğun yüksek yoğunluklu gazlar ile doldurulması, cam tabakalarının asimetrik olarak kullanılması. Literatürde yer alan bu tanım ve derecelendirmelerden yola çıkarak aracın işleyişi için çıkarımlar yapılmıştır. Örnek vermek gerekirse bahsedilen bu bilgi; cam tabaka sayısı ne kadar fazlaysa ya da tabaka kalınlığı ne kadar fazlaysa ya da tabakalar arasındaki boşluk ne kadar fazlaysa ya da arasındaki gazın yoğunluğu ne kadar fazlaysa ya da tabakalar arasındaki kalınlık farkı ne kadar fazlaysa akustik performans o kadar daha iyi olacaktır şeklinde tanımlanmıştır.

Kararlar, yön ile başlayıp gölgeleme ile sona ermek üzere sırasıyla verilmektedir. Sonuç olarak; söz konusu araç karar vericilere, kapsama dahil edilen her bir cephe parametresi için ayrı fakat birbiri ile bağlantılı derecelendirme tabloları sunmaktadır. Karar sırasında önce verilen kararların bir kısmı sonraki kararlar için seçenekleri sınırlandırabilir ve/veya derecelendirmeleri değiştirebilir. Bunlar aracın işlem sayfalarında detaylı görülmektedir.

Ayrıca, tekil bir performans birden fazla tasarım kararından etkilenebilir. Ancak, her tasarım kararının performans yönleri üzerinde farklı ağırlıklı etkileri olabilir. Bu

nedenle, cephe parametreleri ve performans yönleri arasındaki her bir ilişki için ağırlık katsayısı belirlenmiştir (5, güçlü ilişkiler için; 3, orta ağırlıkta ilişkiler için; 1, zayıf ilişkiler için). İlk olarak, literatür taraması ile elde edilen bilgi birikiminden çıkarımlar yapılarak tasarım kararı ve performans ilişkilerine ağırlıklar verilmiştir. Ardından, atanan ağırlıklar ile ilgili uzman görüşlerine başvurulmuş ve sağlama yapılmıştır. Bu ağırlıklar aracın içine entegre edilmiştir. Ancak, karar vericilere tasarım kararı ve performans arasındaki ilişkilere ait ağırlıkları değiştirebilme imkanı verilmiştir. Tüm ilgili düzenlemeler, geliştirilen karar destek aracı kurgusu ve mantığına dayandırıldığı sürece yapılabilir. Burada amaçlanan, bütüncül sistematik bir yaklaşımla karar vermeye yardımcı olmaktır.

Bir cephe tasarımının her bir performansının değerlendirmesi için; kullanıcıların çevresel ve mekansal olmak üzere tanımladığı koşullar doğrultusunda araç tarafından ilk olarak yön seçenekleri derecelendirilir. Sonrasında, bu derecelendirmeler aracın içinde tanımlı olan ağırlıklar ile çarpılarak kullanıcıya sunulur, ancak kullanıcının ağırlıkları çeşitli sebepler ile değiştirme imkanı vardır. Bu durumda kullanıcının atadığı yeni katsayılara göre araç yeni ağırlıklandırılmış derecelendirmeleri verir. Yön seçenekleri ile ilgili bütün değerlendirmeyi görerek kullanıcının seçeneklerden birine karar vermesi beklenir. İlk tasarım kararı olan yön seçeneğinde kullanıcı tarafından verilen karar, sonraki tasarım kararları için olası seçeneklerin belirlenmesine ve derecelendirilmesine etki eder. Kullanıcının sırasıyla her bir tasarım karar konusu için (yön, saydamlık oranı, cephe tipi, pencere tipi, cam türü, duvar konfigürasyonu, gölgeleme) araç tarafından sağlanan derecelendirmeleri göz önünde bulundurarak seçeneklerden birine karar vermesi beklenir. Tüm karar konuları tamamlandığında, karar destek aracı kullanıcı tarafından tercih edilen seçenekler ile tanımlanan cephe tasarımı (taslak) için her bir performans açısından değerlendirme yapar. Sonuç tasarımın, kararlar toplamından olduğu varsayımı ile ağırlıklı derecelendirmeler toplanır. Kullanıcı tarafından tanımlanan koşullar ve karar verilen ilk seçenekler (yön, saydamlık oranı gibi) doğrultusunda araç tarafından bütüncül bir yaklaşımla, tüm performans yönleri gözetilerek, toplamda en yüksek derecelendirmesi olan ideal seçenekler belirlenir. Araç tarafından belirlenen ideal seçenekler ile oluşturduğu varsayılan ideal cephe tasarımı için de her bir performans açısından toplam derecelendirmeler hesaplanır. Kullanıcıya taslak cephe tasarımı araç tarafından öne sürülen ideal tasarımla kıyaslama olanağı sağlanır. Her bir performansı ayrı ayrı birbirinden bağımsız olarak gösterebilmesi ve tasarımları oransal olarak kıyaslamaya imkan vermesi ile kullanıcının karar verdiği cephe tasarımı ve aracın ideal cephe tasarımının sonuç değerlendirmesi örümcek ağı grafiği ile gösterilir. Bu grafik, tasarım kararlarından oluşan cephenin işlevsel performanslar açısından ayakizini vermektedir.

Söz konusu araç; performans, parametreler ve koşullar arasındaki üçgensel ilişki üzerine kurgulanmıştır. Cephe parametreleri performansı belirlerken, performans gereksinimleri koşullara göre belirlenir. Bu nedenle, istenilen performansı sağlayabilmek için, cephe parametreleri koşullara uygun olarak belirlenmek durumundadır.

Araç, birbirinden bağımsız olarak değerlendirilen tüm performans yönlerinin bir arada görülebilmesine imkan tanıyan bir zemin oluşturur. Tekil bir tasarım kararının farklı işlevsel performans yönlerine etkisinin eş zamanlı görülebilmesini sağlar. Aracın, farklı performans yönleri arasındaki etkileşimlere, çelişiklere ve onların tasarım kararlarıyla olan ilişkilerine dikkat çekerken, bütün cephe performansı ile ilgili anlayış kazandıracağına inanılmaktadır. Böylelikle, özellikle cephe tasarım sürecinin erken aşamalarında, bütüncül bir cephe tasarımı, daha iyi ödün verme ve karar vermede

şeffaflık sağlanacaktır. Tasarım kararlarının cephe performansına ilişkin sonuçları bütüncül olarak izlenebilecektir. Tasarım bir anlamda olası alternatifleri sınırlama sürecidir ve araç bu sürece rehberlik edebilir. Tasarım sürecinde geriye dönük tekrarları önleme potansiyeline sahip olduğundan, aynı zamanda tasarımda zaman tasarrufu sağlaması öngörülmektedir. Her ne kadar tasarım seçeneklerinin maliyet ve estetik özellikleri gibi diğer önemli konuların da araç ile bütünleştirilip kararların sonlandırılmasına ihtiyaç duyulsa da, araç bu haliyle seçeneklerin işlevsel performansları açısından karşılaştırılabilmesini sağlamaktadır. Ayrıca, araç sonuç tasarımın performansının nasıl (hangi tasarım kararını/ kararlarını değiştirerek) iyileştirilebileceğine dair fikir vermektedir.

Proje koşullarındaki çeşitliliğe bağlı, performans yönlerinin önem derecesi değişebilir ve tasarım kararları bu doğrultuda verilebilir. Araç kullanıcıya sonuç çıktı vermek yerine yalnızca sistematik bir yaklaşım önermektedir. Bu sayede geliştirilmeye açık ve değişen önceliklere ve koşullara uyum sağlama konusunda esneklik. Gelecek çalışmalarda, araç kapsamındaki tasarım seçenekleri sayıca arttırılabilir ve aracın sahip olduğu mantık izlenerek derecelendirilebilir. Dahası, araç belirli iklimsel koşullar veya bina/ cephe tipleri için özelleştirilebilir. Geliştirilen bu araç, ileride yeni bir bilgi araca dahil edildiğinde, evrilip dönüşebilir.

Tez altı bölümden oluşmaktadır.

Giriş Sonrası, İkinci Bölümde, cephe tasarım süreci tüm ilgili konularla birlikte ayrıntılı olarak açıklanmaktadır. İlk olarak, cephe tasarım süreci evreleri ve genel olarak paydaşları ile tanımlanmaktadır. Daha sonra sürece yön veren faktörler açıklanmaktadır. Sonrasında, cephenin bir alt sistem olarak binanın diğer alt sistemlerine entegrasyonu ele alınmaktadır. Son olarak, yapı endüstrisi içinde cepheye ait güncel eğilimler ve sorunlu konular tartışılmaktadır.

Üçüncü Bölümde, cephe performansı çeşitli yönlerden ele alınmaktadır: etkileyen ajanlar, performans gereklilikleri, performans düzeylerinin göstergeleri, çeşitli performans yönleri için kriterler, farklı ölçeklerde performansla ilgili cephe parametreleri, cephe performans değerlendirme yöntemleri ve son olarak yüksek performanslı cepheler. Kullanıcı gereksinimlerinden kaynaklanan performans gereksinimleri, farklı kategoriler / alanlara ayrılır. Her yönün kendine ait performans göstergeleri / ölçütleri vardır ve bütün bunlar ayrıntılı olarak açıklanmaktadır. Cephe performansı ile ilişkili olan cephe parametreleri, cephe tasarım sürecinin farklı aşamalarına karşılık gelen farklı ölçeklerde (yerleşim ölçeği, yapı ölçeği, yapı elemanı ölçeği, bileşen ve malzeme ölçeği) kategorilere ayrılmaktadır. Nitel ve nicel cephe performans değerlendirme türleri kısaca gözden geçirilmektedir. Son olarak, tasarım kararları ve performans seviyeleri arasındaki ilişkiyi araştırmak için yüksek performanslı cephe teknolojileri olarak son teknolojiye sahip cepheler örneklenmektedir.

Tezin özgün kısmı olan Dördüncü Bölüm önerilen aracın geliştirilmesini içermektedir. Alt bölümler sırasıyla; çevresel ve mekansal koşulların tanımı, cephe parametrelerinin tanımı, tasarım seçeneklerinin oluşturulması, tasarım kararı ve performans matrislerinin belirlenmesi, tasarım seçeneklerinin derecelendirilmesi, derecelendirme sonuçları ve karar verme ile genel performans değerlendirmesidir. Kısaca, önerilen araç bu bölümde ayrıntılı olarak açıklanmaktadır.

Beşinci bölümde, aracın kurgu ve işleyişini doğrulamak ve uygulanabilirliğini ortaya koymak için, araç tanımlanmış senaryolar ve gerçek projeler için test edilmektedir. Çevresel ve mekansal şartlardaki çeşitlilik göz önüne alınarak senaryolar

oluřturulmuřtur. Geliřtirilen aracı, tanımlanmıř senaryolar iin test ettikten sonra, cephe performansının cephe parametrelerine (tasarım deęiřkenlerine) duyarlılıęını grmek iin tek bir senaryo iin hassasiyet analizi yapılmaktadır. te yandan, gerek projeler, devam eden tasarım projeleri ve hali hazırda inřa edilmiř projeler olarak belirlenmiřtir. Karar vericiler olarak mimarlar bu aracı projelerinden en az biri iin kullanmaktadır. Ayrıca, bu projelerden biri iin ara farklı paydařlar, mal sahipleri ve mhendisler tarafından kullanıma aılmaktadır. Aracın kullanımından sonra, yarı yapılandırılmıř aık ulu sorularla yapılan grřmelerle kullanıcıların geri bildirimleri kaydedilmektedir. Grřme sorularına verilen cevaplar bu blmde aıklanmaktadır. Son olarak, uygulamanın geri bildirimi aracın katkıları, eksiklikleri ve karmařıklıkları olarak yorumlanmaktadır. Grřme kayıtlarının tamamı Ekler Blm'nde sunulmaktadır.

Altıncı Blm'de, srecin ve sonuların tartıřıldıęı kısa bir blmden sonra, alıřmanın sonuları ortaya konmaktadır. Tezin ve sonularının potansiyel katkıları zerinde durulmaktadır. Tezin literatrdeki bořluęun doldurulması ynndeki saęladıęı vurgulanmaktadır. Tez ıktılarının kime ve neye hizmet ettięi/ edebileceęi, ileriki alıřmaların tezden nasıl ve ne lde yararlanabileceęine dair sorular ele alınmaktadır. Tez bařlangıcındaki hedefler ve sonundaki ıktılar, hedeflerin hipoteze uygun olarak nerilen arala gerekleřtirilip gerekleřtirilmedięini grmek iin karřılařtırılmaktadır.

Giriř ile Tartıřma ve Sonu (Altıncı Blm) dıřındaki tm Blmler, 'Blm zeti' ile sona ermektedir.



1. INTRODUCTION

1.1 Background and Motivation

Facade may rank first among building systems in terms of functions and responsibilities it fulfills within a building. Facades represent their buildings in urban/ rural context. They reflect buildings' identities socially, culturally, and politically. Their aesthetic features are given importance like no other building system. Their responsibility for the energy consumption of buildings like lighting, heating, cooling, etc. is much more than any building element/ system. It also affects indoor comfort conditions significantly. Their construction costs generally correspond to 20-30% of total building construction costs. In addition to this, facades are highly responsible for operation and maintenance costs. All these features necessitate a deliberation upon this building sub-system.

Over the last decades, new trends arose which stand for high-performance, green, or sustainable buildings. These trends and relevant authorities promote passive building design that indoor comfort is achieved by using relatively less energy with the help of proper design decisions regarding building orientation, material selection, etc. Passive design decisions are mainly associated with the building envelope, so the indoor comfort conditions. Especially, facades play an important role in thermal, visual, acoustic, and hygienic comfort of indoor spaces as they function as a regulator/ filter between interior and exterior. Also, they have the potential to conserve/ generate energy in buildings (Knaack, et al., 2007).

The facade 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 facade

design (Knaack, et al., 2007 ; Klein, 2013). The process can be regarded as complicated with all these dynamics. Also, decision-makers need to make decisions on a significant number of facade parameters that may possibly interact with each other. These make the process even more challenging. Just to keep updated on the latest developments and to follow the legislation are an exhaustive business.

Although there are a few research (Aksamija, 2013 ; Jin, 2013 ; Oliveira & Melhado, 2011 ; Ramachandran, 2004 ; Hendriks & Hens, 2000 ; Rivard, et al., 1999) in the literature, there is a lack of a holistic point of view (that engages multiple perspectives) in facade design. It is believed that there is a need for an approach through which all factors, variables, conditions, constraints, stakeholders, 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 (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 the early stages of facade design process to a lesser amount and near-ideal options and thereafter to carry out the evaluation accordingly may contribute significantly to the facade design process.

Being within different disciplines' area of interest and being driven by a wide variety of factors make it essential to design this building system (the facade) in a systematic way. An assistive resource may serve for this systematic. However, there is not a single resource that guides the stakeholders while making decisions in the facade design process. To develop a resource (considering the facade in a holistic manner) for the use of all stakeholders through the facade design process is the biggest motivation.

The motivation(s) behind the study can be itemized as follows:

1. The complex structure of the design process,
2. The potential of the facades for achieving high-performance buildings,
3. The need for a holistic point of view,
4. The goal to develop a guide-wise resource which will support all the stakeholders during the process with its holistic approach.

1.1.1 Literature review

In the literature, a wide range of researches regarding the facade (facade systems, facade design, facade performance, etc.) is available which approach ‘the facade’ from a variety of perspectives. Some focus on a certain facade type and its performances while some taking a specific performance aspect together with various facade types. Some draw a theoretical framework while some present simulation or experiment results. Some concentrate on comparisons of different facade types while some singularly present the features, performance of a case. Some concentrate on responsive features of facades to various conditions while some pay attention to how to develop these features. There are more than these examples.

The facade’s multifaceted structure leads to fragmented-type researches approaching the topic from a certain point. However, looking at the issues from own perspectives of different disciplines cause to ignore the whole. On the other hand, studies having a holistic approach are available, although they are very limited in number.

Nowadays, there are a vast number of publications regarding facades. Some of them are reference books (Yu, 2014 ; Aksamija, 2013 ; Boswell, 2013 ; Lovell, 2010 ; Watts, 2010 ; Krippner and Musso, 2008 ; Knaack et al., 2007 ; Schittich, 2006 ; Herzog, et al., 2004 ; Rich and Dean, 1999 ; Nashed and AIA, 1995) and some are digital publications of various organizations (LBNL, 2012 ; CWCT, 2017). Many of them are scientific articles (to give example: Kassem and Mitchell, 2015 ; Jin and Overend, 2014 ; Oliveira and Melhado, 2011) and academic dissertations (Konstantinou, 2014 ; Oraklibel, 2014 ; Jin, 2013 ; Klein, 2013 ; Bilow, 2012 ; Kutlu, 2008 ; Ramachandran, 2004). There are conference proceedings (ICBEST, 2017 ; ABS, 2016) and seminar/ course notes (ITU, 2013), as well.

In these publications, facade, facade system, building envelope, building enclosure, or building exterior wall can be interchangeably used terminologies. As mentioned, some of the publications focus on a single facade type. For instance, in recent years, researches about curtain walls increase incrementally since these systems are being used in various shapes and types, not only in new buildings but also in renovation of existing structures (Kassem and Mitchell, 2015). A study presents the test methods for curtain wall systems (Çelik Tekin, 2004), another study categorizes the aluminum and glass curtain wall systems and compares their types (aluminum panel, structural

glazing, aluminium capped) in terms of various performances (Şahin and Gökuç, 2014). One research reviews the curtain walls focusing on design problems and solutions (Kazmierczak, 2010) while another one defines performance criteria in terms of comfort conditions for light-suspended curtain walls (Şenkal, 2002). Yalaz (2017) evaluates the lifetime performance of a stick curtain wall system by full-scale testing. Klein (2013) makes future projections concerning curtain walls and searches for innovations in curtain wall design and construction. Oraklıbel (2014) proposes a checklist regarding performance criteria to be used for building integration of curtain walls. This study can be considered as a holistic one since it includes all possible performance aspects. On the other hand, it limits the scope to the curtain wall and to its integration with the building.

There are studies (Alberto, et al., 2017 ; Parra et al, 2015) investigating the performance of double-skin facades in different conditions (with ventilation options or in different climates). Some researches (Pelaz, et al., 2017 ; Ibanez-Puy, et al, 2017) concentrate on performances of building facades with claddings/ ventilation, etc.

On the other hand, there are researches that have performance point of views independent of a facade type. Şentop, et al. (2012) propose a catalogue to be used for noise control of exterior walls while Şener Yılmaz (2016) has a proposal of facade design approach considering daylighting performance. There are also studies that investigate the effects of facade parameters on certain performances. Erdemir Kocagil (2017) searches out the effects of building envelope and form on cooling performance in hot-dry climate zone. Şahinoğlu (2012) evaluates the effect of shading elements on thermal and visual performances of windows. Another study deals with the impact of the glazing area on visual and acoustic comfort (Catalina and Virgone, 2012). There are studies defining the design of building envelopes to ensure thermal, visual, and acoustic comfort conditions (Koçlar Oral, et al., 2004), or to improve energy efficiency (Sözer, 2010).

In the literature, there are studies framing the process of facade design as well (Oliveira and Melhado, 2011 ; Rivard, et al., 1995 ; Rivard et al., 1999). Oliveira and Melhado (2011) propose a conceptual model for the integrated design of building facades. Seok, et al. (2009) establish a design process for double-skin facades. Some studies (Deniz and Ekinci, 2016 ; Kassem and Mitchell, 2015) define a route for selection decisions

of facade design. Türkay (2017) proposes a framework for integrating aesthetics and technology in detailing facade cladding.

Some studies propose decision support models to be used in the design process. Ramachandran (2004) develops an integrated computation tool to support building envelope design process. It is one of the studies in the Literature that has a relatively holistic approach although it excludes some relevant issues and leaves them to further studies. Arroyo (2014) explores and compares multi-criteria decision-making methods for sustainable design in commercial buildings. Güzelçoban Mayuk (2017) proposes a fuzzy method to be used in the facade design process. A relatively older study has an approach to building envelope design with a knowledge-based system (Fazio, et al., 1989). Most of these decision support models are developed/ proposed to be used in early design stages. Donato, et al. (2017) develops an innovative app, Arup Solar, for a parametric, holistic, and multidisciplinary approach to early design stages. The app aims at investigating relationships between envelope features and cooling strategies. Schmid and Marinitsch (2016) address design methods and facade technologies for advanced building skin design.

Moreover, there are a substantial number of researches having the focus of optimization in facade design. Gagne and Andersen (2010) use a genetic algorithm to optimize facade design for daylighting performance. Zemella and Faraguna (2014) also use genetic algorithms in order to optimize the energy and space performances of facades. In that study, they search for an optimum facade design considering both engineering and architectural issues. But, it is also based on some assumptions, and the proposed methodology is validated/ implemented with a limited number of design variables. Another study (Goia, et al., 2013) tries to optimize the configuration of a facade module for office buildings from an energy perspective (thermal and lighting). Bilow (2012) deals with the optimization of facades from a climatic point of view. Glassman and Reinhart (2013) optimize the facade using parametric design and future climate scenarios. Jin (2013) develops an optimization model to identify optimal facades achieving optimal indoor environmental quality with the lowest cost and shortest carbon payback periods.

All the above-mentioned examples from the researches related to facades are valuable with the discussions they initiate and their findings. They provide a vast knowledge. However, it is questionable that the outcomes of these researches have reflections on

the facade designs being constructed around. It is not well known if the stakeholders involved in the facade design process have sufficient consciousness to utilize from the findings of the researches. They remain technical and mostly based on certain assumptions and situations. Scientific studies in the literature prefer to keep away from generalizations. On the other hand, in order to utilize from the researches, it is mostly needed to generalize and deduce from the outcomes of the researches and orient them to the conditions in question.

Even though there are a few computer tools (building envelope design generation tools such as BEADS, SEED-Config, EsQUIsE, etc.) to support the design process, they mostly fail in terms of user-friendliness and insufficient knowledge base (Ramachandran, 2004). These tools are experimental and remain non-holistic. Therefore, decision-makers take each requirement independently and accordingly need to revise the designs for several times or overlook some critical performance criteria.

In the literature, there are tools supporting the facade design process by means of design generation and/ or evaluation. In addition to those, representation tools like Autocad, SketchUp, etc. can also be considered as supporting tools. Some of them such as Revit have evaluation tools within itself. Nevertheless, for not being directly related to the thesis scope, they are not included in the following sections.

Porkka and Huovila (2005) recommend the following methods as decision support tools: Post-occupancy evaluation, checklists, requirements management, quality function deployment, multi-criteria decision making, design structure matrix, and iBuild. Also, there are a few number of tools that can be used to generate facade designs. These are; BEADS (The Building Envelope Analysis and Design System), SEED-Config (a module within Software Environment to support the Early phases in building Design), ENVSTD, EsQUIsE, Archie, Facade Design Tool (Url-1), ARUP Solar, Comfen (Early Design Tools for Commercial Facades and Fenestration Systems by Lawrence Berkeley National Laboratory), and Fassades (Facade Assessment and Design Tool for Solar Energy). However, these generally remain as experimental (Ramachandran, 2004).

On the other hand, there are evaluation tools based on scientific and analytical models developed through numerical and experimental researches (Ramachandran, 2004).

WUFI-ORNL/IBP, CONDENSE 2.0, Energy Plus, Ecotect, and TRNSYS are the common tools that are used to evaluate building envelope design performance. All these are computer simulation softwares which have limited capability in assessing facade performance aspects. They base on some assumptions and have some limitations in use. They have a contribution to the facade design process mostly in later stages due to the amount of detail they need to run.

1.1.2 Problem

The facade design is getting more complicated with each passing day. Design options increase in number thanks to advances in construction and material technology. There can be uncertainties during the design process, like anticipated changes in climate or spatial transformations in the future. Constraints are getting more strict/ harsh such as shortage of energy and material sources as a result of the growing population. Today's expectations of comfort conditions are raising, as well. In past times which was not a requirement can be a requirement of today. User requirements grow in parallel with raising awareness and technological opportunities. Time which also represents cost, means more than it used to be at this speed age.

In the last decades, sustainable concepts and ecological concerns gain importance in design. In this global world, design stakeholders can become responsible for a new standard that emerged or for scientific studies conducted anywhere in the world, even for their local designs. Information and knowledge become global. So, the stakeholders become responsible for being updated about the latest developments.

In short, more than ever, there are demands facade designs need to meet. Even these demands may conflict and interact among themselves. In some cases, to fulfill one requirement can have a negative effect on design for another requirement. For instance, to design a large-size window increases the user's amount of view, while causing overheated indoors. It is essential to see the big picture. Besides, stakeholders of the process may have insufficiencies regarding technical issues.

The main points taken as the problems of the thesis are given below:

1. The complex structure of the design process, even getting more complicated with today's requirements,

2. The necessity of the facade design to respond to today's trends like sustainability and ecology,
3. Limitless design options which make decision-making harder more than ever,
4. Increasing uncertainties,
5. Limited time reserved for the facade design,
6. Conflicting issues in design decision-making,
7. Technically incapable stakeholders of the design process.

Being within different disciplines' area of interest make it essential to design this building system (the facade) in a systematic way. There is not any single resource that guides the stakeholders for all these subjects. The stakeholders need to apply for separate sources of information during the facade design process. Moreover, they need to explore the relevant ones (resources) first.

1.1.3 Hypothesis

Instead of testing and evaluating a great 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 reduce the number of design alternatives in the early stages of design process to a lesser amount and near-ideal options and thereafter carry out the evaluation accordingly may have a significant contribution to the facade design process.

A holistic design approach may be a solution to the challenging structure of the process, which introduces different perspectives to the problem by integrating different disciplines into the process. Otherwise, to approach from a single discipline may be misleading for facade design.

It is possible to provide holistic support in the early stages of the facade design process by organizing 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.

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 the facade design process may give faster and more proper decisions and make more efficient

collaborations. In a sense, the design is a process of limiting possible alternatives, and here the tool may function as supportive guidance.

1.2 Objectives

The thesis aims at contributing to the facade design process in which stakeholders need to be supported, especially in technical issues.

The main objective of the thesis is to develop a system/ a user-friendly tool to be used in the early stages of facade design process.

Sub-objectives of the thesis are listed below.

1. To highlight the interacting, conflicting issues of the process in order to see the whole with a holistic point of view,
2. To assist design decision-making process and optimization in design,
3. To enable the stakeholders to gain holistic point of view,
4. To provide insight/ gives an impression of facade performance as a whole in the early stages of facade design,
5. To support the transparent and integrated facade design process, by doing so, to strengthen the dialogue and collaboration among the participants, in turn, to ensure/ improve the product (facade) quality,
6. To contribute to/ support the design of well-performing facades today and in the future.

The thesis aims to present a tool to be used in the early stages of the facade design process, which addresses the functional performance requirements of a facade all together and indicates their relationships with design decisions. Although priorities and conditions are unique for each design, an assistive document in which the relationships can be followed will let a transparent design process, thus provide an opportunity for the collaboration in design, and enable to follow the previous decisions, and contribute to preventing unnecessary revisions, repetitions (Arroyo, 2014).

1.3 Scope and Assumptions

The thesis proposes a design decision support tool. It is an aid-wise tool which contributes to develop/ enhance the design by giving the points to be considered and the information (preliminary evaluation) to be taken as a basis instead of offering a solution.

Performance approach is adopted for the tool. Among the performance aspects, functional performance aspects that are associated with the biological/ physiological and social/ psychological requirements of the user are taken as the focus of the thesis. Functional performance aspects are gathered under main headings by using common categories in the literature. Aesthetics and durability issues are kept out of the scope. Aesthetics is a subjective phenomenon, so it is hard to evaluate its performance. Besides, aesthetics is an issue related to the local cultural values of a place. However, the tool aims at supporting the decision-making for facade design on a global scale. On the other hand, durability has the meaning of the performance in time, therefore covers all the other performance aspects. It is decided to mention durability under each performance aspect; thus, it is not taken as a separate performance aspect within the thesis. The aspects included in the thesis (the proposed tool) are listed below:

1. Structural Performance
2. Fire Performance
3. Water-related Performance
4. Air Permeability-related Performance
5. Thermal Performance
6. Moisture-related Performance
7. Daylighting Performance
8. Acoustic Performance

It is a comparison based tool that concentrates on overall facade performance. Rather than real calculation results, the tool bases on a preliminary assessment of the advantages and disadvantages of compared options in terms of predefined performance aspects and conditions. For this, it adopts a basic scale: (+) for advantages, (-) for disadvantages, and (0) for negligible differences.

The tool aims to give support to the stakeholders for any facade type (except the self-supporting facades) in any location (except the Southern hemisphere), environmental condition, etc.. The proposed tool generally includes basic principles, concepts, rules, options, types, etc. rather than exceptional ones. It covers just non-self-supporting facades that constitute a vast majority of today's designs. Another significant assumption is about the location of facades on the globe. The tool ratings are structured based on thermal and daylighting conditions of the Northern Hemisphere, which is quite different from the Southern Hemisphere.

Besides, traffic noise is the only type of noise source included in the tool. As building typologies; residential, commercial, educational, medical, and cultural buildings are included with their limited type of spaces like the living room, bedroom, kitchen, shop/store, hotel room, classroom, laboratory, patient room, conference hall, and exhibition hall. These spaces are to exemplify the conditional relationship of facade parameters and facade performance.

It is a flexible design decision support tool which has the knowledge of how to rate different design options for different conditions in terms of functional performance aspects. It integrates prescriptions for various possible conditions within itself. By this means, the tool proposes ideal options based on its rules stretching for each project/condition.

Aesthetics and cost are excluded from the thesis scope, whereas they are the two major factors in facade design decisions. The proposed tool aims at giving the most proper options in terms of overall facade performance. At this stage, aesthetics, cost and other design driving factors can be decisive. Options can be compared for their performances within the tool, but decisions can be made after checking architectural intentions, budgets, etc. The tool gives the opportunity to follow the compromises in design and their reasons in a transparent way. Financial and ecological aspects are not included, as well; however, they are mentioned briefly within the thesis.

The thesis consists of six chapters.

After the Introduction, in Chapter Two, the facade design process is described in detail with all relevant issues. First, the facade design process is figured with its phases and stakeholders in general. Then, the driving factors of the process are explained. After that, the integration of the facade as a sub-system with the building's other sub-systems

is addressed. Lastly, the facade construction industry is discussed with current trends and problematic issues.

In Chapter Three, facade performance is dealt with from various aspects: affecting agents, performance requirements, indicators of performance levels, criteria for various performance aspects, performance-related facade parameters in different scales, forms of facade performance evaluation, and lastly high-performing facades. Performance requirements that come from user requirements fall into different categories/ aspects. Each aspect has its own performance indicators/ metrics, and all these are explained in detail. Facade parameters that are responsible for facade performance are categorized in different scales (settlement scale, building scale, building element scale, component and material scale) corresponding to different phases of facade design process. Qualitative and quantitative types of facade performance evaluations are briefly reviewed. Finally, state-of-the-art facades as high-performance facade technologies are exemplified to explore the relationship between design decisions and performance levels.

Chapter Four, which is the original part of the thesis, comprises the development of the proposed tool. Sections of the Chapters are; definition of environmental and spatial conditions, definition of facade parameters, generation of design options, the establishment of design decision and performance matrices, rating design options, weighting the relationships, overall performance ratings, and graphical representation of rating results. In brief, the proposed tool is explained in detail in this chapter.

In Chapter Five, for validation, the tool is implemented for made-up scenarios and real projects. Scenarios are made up considering the variety in environmental and spatial conditions. After testing the tool for made-up scenarios, a sensitivity analysis is conducted for a single scenario in order to see the sensitivity of facade performance to facade parameters (design variables). On the other hand, real projects are specified as both ongoing design projects and already constructed projects. Architects as decision-makers are let to use the tool for at least one of their projects. Besides, the tool is opened for use by different stakeholders, owner, and engineers, for one of these projects. After the tool usage, feedback of the tool users is recorded through interviews with half-structured open-ended questions. Answers to the interview questions are outlined in this chapter. Lastly, the feedback of the implementation is interpreted as

contributions, deficiencies, and complexities of the tool. The full version of the interview records is presented at the Appendices.

In Chapter Six, after a brief discussions part, conclusions are drawn. Potential contributions of the thesis and its outcomes are emphasized. The literature gap filled by the thesis is underlined. Questions like who the thesis outcomes serve for, how and to what extent further studies can make use of the thesis are addressed. The goals at the beginning of the thesis and the outcomes are compared to see if the objectives are realized with the proposed tool in accordance with the hypothesis.

All Chapters except the Introduction and the Discussions and Conclusion (Chapter Six) end up with a section of ‘Summary of the Chapter’. The scheme of the thesis is given below (Fig. 1.1).

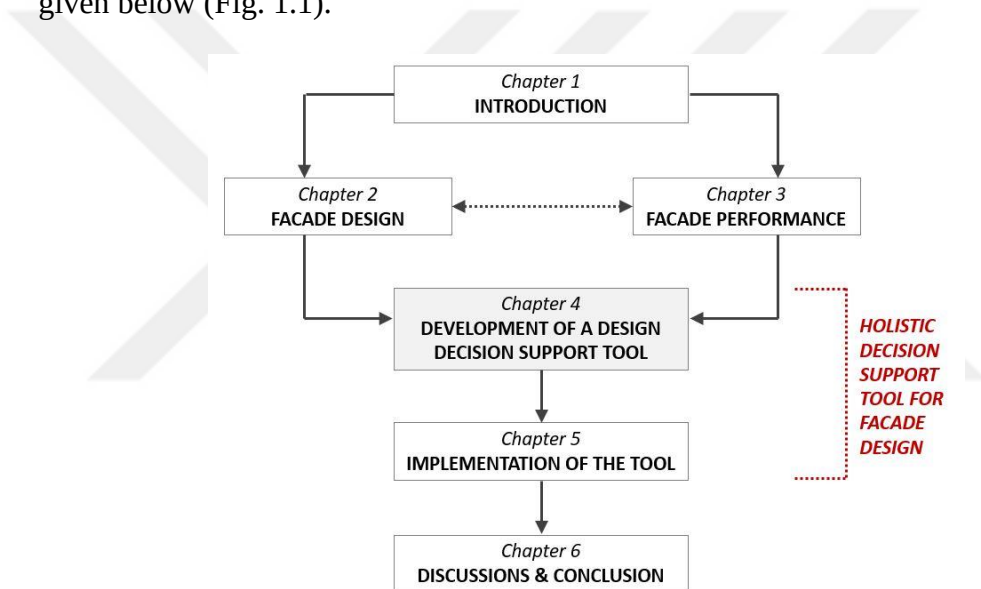


Figure 1.1 : Thesis scheme.

1.4 Methodology

It is found necessary to compile the researches/ studies of various areas/ disciplines regarding facade performance and to transform this compilation to a meaningful summary in which the relationships among performance, conditions, and parameters can be tracked, and consequently to evolve the summary to a design decision support tool. Due to this reason, the thesis is structured upon an extensive literature review. The literature review covers publications including books, e-books, journal articles, conference proceedings, theses, seminar/ course notes, standards, codes, regulations, commercial publications, encyclopedias, dictionaries, etc. The information and

knowledge gathered through the literature review are resolved/ filtered by relevant keywords and then related to each other in order to establish relationships among performance, conditions, and parameters. Firstly, performance aspects and facade parameters are specified. Then, design options are generated for each facade parameter by taking the existing facade industry and knowledge into consideration. After that, matrices having design options in rows and performance aspects in columns are established. This design decision support tool is designed via Microsoft Office Excel software in the form of a spreadsheet. A simple scale (++ , + , 0 , - , --) is adopted for rating the design options in accordance with the established relationships. The proposed rating bases on comparisons and indicates how superior/ inferior is that design option (for that facade parameter) when compared to the others in terms of a performance aspect. Then, each relationship between a performance aspect and a facade parameter is weighted by 5, 3, 1, 0 coefficients which correspond to strong, medium-strength, weak, and no relationships, respectively. Throughout the development of the tool, especially for rating the options and weighting the relationships, experts of various disciplines are asked for their opinions. Thus, the deductions made from the literature are able to be cross-checked.

Finally, for validation, the tool is tested with made-up scenarios and real projects. Besides, for one of the made-up scenarios, a sensitivity analysis is conducted. Then, the tool is opened for use by architects and some other stakeholders (owner, engineers) of the facade design process for real (on-going and constructed) projects. Opinions of the tool users (the stakeholders of the process) after they used the tool for the real projects are recorded through interviews. Half-structured open-ended questions are preferred for the interviews.

The methodology followed throughout the thesis is illustrated in Figure 1.2.

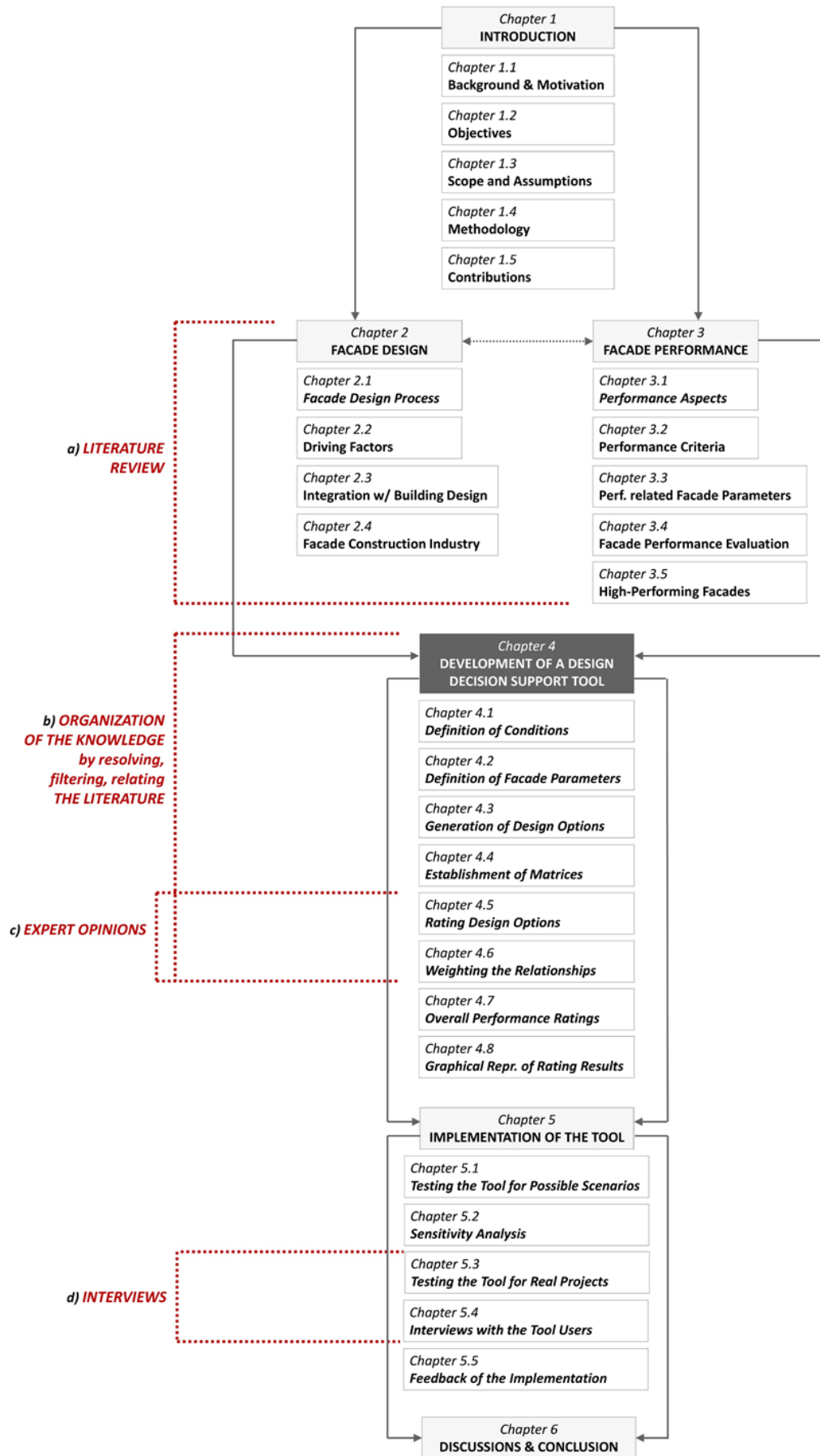


Figure 1.2 : Methodology followed throughout the thesis.

1.5 Contributions

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

The tool is expected to support the decision-makers not to skip any functional performance aspect when even deciding a single facade parameter, and to see the relationships of facade parameters with different performance aspects. With the help of the tool, a decision-maker will have the opportunity to check the facade parameters in relation to the functional performance aspects and will give the decisions in a transparent way by highlighting the compromises in design. It is believed that the tool will guide the decision-makers of facade design to give special emphasis on the interactions of functional performance aspects between each other, and with facade parameters.

The tool usage may prevent negative iterations in design and reduce the number of alternatives and the time reserved for their simulations accordingly. The tool, with these features, may be time-saving for the process of facade design, which is highly important in the age of fast decisions.

Each stakeholder may benefit from a different side of the tool while perceiving the whole facade design. It will enable facade designs to have optimized solutions by approaching the process holistically (from a multidisciplinary point of view) instead of fragmentally (from a single disciplinary point of view). It is expected to create consciousness about technical issues and their interactions among the stakeholders. The proposed tool can be assessed as a structured first step of decision-making. By providing a transparent design process, the tool will contribute to continuous learning. The tool is usable/ flexible for different kinds of design projects. Even though this tool can be used for facade design of any type of building; it can be customized for specific building types.

In future studies, the tool can be enlarged to include financial and ecological performance aspects, or the tool can be elaborated for a specific facade type such as double-skin facades. Even, it has the potential to evolve to a more comprehensive tool such as computer software by integrating the construction knowledge, and the material information into the existing tool. Further studies may focus on this area.





2. FACADE DESIGN

Architectural design is a process-oriented profession and activity. As being associated with architectural design, exterior building enclosure design is a process as well, dealing with one of the most visible and technically complex aspects of architecture (Boswell, 2013).

Architectural design forms the core in building design, which also incorporates structural design and services design (Watson and Perera, 1997). Building designs are context-dependent and unique for each project. It is also valid for the design of facades. From this point of view, each project has its own facade design process which makes it hard to describe a single common process.

The design process is often described as separate stages and phases. Although these are given different names in different countries, the division logic of the process has similar characteristics. The separation is due to the different information flow, focus points, planning and managing of these stages. Both the stakeholders and the information being delivered among them vary in each stage (Knotten, et al., 2015).

The design process has an iterative form, and each iteration is expected to contribute to the end value of the design (Kalsaas and Sacks, 2011). Design solutions based on design problems can be unlimited in number, which is hard to control during the process. Another critical issue to be considered in design is the dissimilarity of the process natures. The design process is an endless reciprocal process while the building production (construction) process is a strictly sequential one (Lawson, 1997). Likewise, as it is seen in the diagram (Fig. 2.1), designing a facade is not a linear process but rather depends on regular feedback (Knaack, et al., 2007).

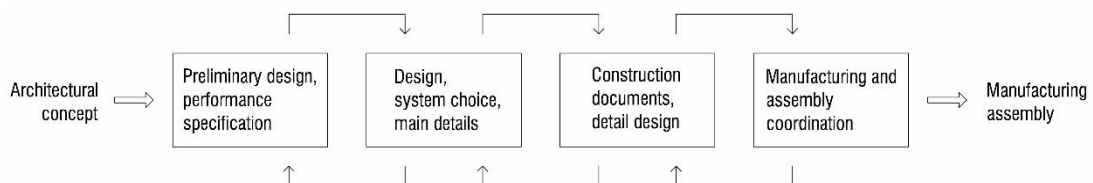


Figure 2.1 : Design process for a facade (Knaack, et al., 2007).

By considering the aim and scope of the thesis, only the design and construction processes of the facades (within the entire life-cycle of the facade) are examined. While reviewing the literature, either the facade or the building envelope is used as keywords. Building envelope design and construction process and its phases are defined and described by various countries with minor differences (CSB, 2017 ; Chung and Mutis, 2016 ; Klein, 2013 ; Oliveira, 2011). The comparison of the process stages is given in Table 2.1.

Table 2.1 : Facade design and construction process according to countries/ regions, comparison of the process phases.

Countries / Regions	Turkey (CSB, 2017)	China (Chung and Mutis, 2016)	Europe (Klein, 2013)	Brazil (Oliveira, 2011)
Facade Design & Construction Process Phases (in general)	-Avan Proje (Conceptual Design) -Kesis Proje (Design Development) -Tatbikat Projesi (Construction Drawings) -Sistem Tasarımı (System Design) -Projelendirme (Execution Design) -İmalat (Manufacturing) -Montaj (Assembly) -İnşaat (Construction)	-Conceptual Design -Preliminary Design -Pre-Design -Executive Design -Detailed Design -Construction Design & Engineering -Planning for Construction -Building Delivery	-System Design -Pre-Design/ Development -Architectural Design (Preliminary Design, Basic Design, Execution Planning, Technical Specifications) -Execution Design (Preliminary, Definite, Production Design) -Manufacturing -Assembly	-Conception -Product Development/ Preliminary Design -Pre-Detailing Design -Detailed Design (Product & Construction) -Construction Planning -Construction

earliest
↓
latest

Ramachandran (2004) describes the building envelope design process basically in three main stages: analysis, synthesis, and evaluation. In this document (Ramachandran, 2004), the synthesis part is defined as the core of the process. In the analysis stage; with the help of project and site analyses, the design problem is defined, and design objectives are fixed as performance requirements. In the synthesis stage, components of the envelope system are designed by trial and error and checked by analytical and logical methods. Selection, composition, and configuration of components of the envelope system are implemented during this part of the process.

This stage is subjected to the attitude, working trend, knowledge, and experience of the designer. After the completion of the design synthesis part, the overall performance of the building envelope is evaluated by the designer.

The building envelope design process is described by Ramachandran (2004) as a goal-oriented activity due to the design objectives set at the start. The objectives are mainly the functions of the building envelope and have both quantifiable and qualifiable features. For example, control of heat by conduction can be evaluated logically by using minimum R-value, while air infiltration can have a logical ‘yes-no’ type evaluation at the design stage (to be later measured on-site, if required), whereas aesthetics is subjective and up to the intervention of the designer (Ramachandran, 2004). Briefly, the design, here the facade, is a combination of the decisions driven by quantifying variables and logical rules and the decisions left to the designer’s subjectivity.

The facade design process may vary by type of building design process (traditional or integrated). In integrated building design, systems are considered in relation to others, allowing for full optimization rather than considering systems in isolation. Besides, time and energy are invested, and collaboration is exhibited in the early stages of the process (Aldrich, 2011). In the traditional building design process which is based on linear thinking, project team members are involved only when necessary. Generally, the emphasis is given on the initial investment costs, ignoring all the life-cycle costs and benefits. Design decisions are mostly made by fewer people in the traditional process while in an integrated building design process, decisions are made in teams, iteratively. The main differences between the traditional and integrated building design processes are given below (Table 2.2).

Table 2.2 : Traditional building design process vs. integrated building design process (Aldrich, 2011).

Traditional Building Design Process	Integrated Building Design Process
Linear	Whole Systems Approach
Team members involved only when necessary	Team members involved throughout
More decisions made by fewer people	More decisions made in teams, iteratively
Emphasis on up-front costs	Emphasis on full life-cycle costs and benefits
Systems considered in isolation	Systems considered in relationship
Less time, energy and collaboration in the early stages	Front-loaded time and energy invested early

2.1 Facade Design Process

The facade design is a significant sub-process of building design. Apart from functional roles a facade fulfills in a building, it is the appearance of the building taking the cultural, social, and political position of the building. It is the building itself perceived from the outside. As being the exterior view of the building, it is attached importance more than any other building part.

The facade design is a process of decision-making which is composed of design decisions given to achieve the predefined design objectives.

The process is multi-staged comprising decisions in different scales that require varying degrees of details. It is carried out by various actors that are named as stakeholders.

A scheme representing the design and construction process of a curtain wall is given in Fig. 2.2. The figure demonstrates the phases of the process, respectively, together with the stakeholders responsible, and the activities delivered for each specific phase.

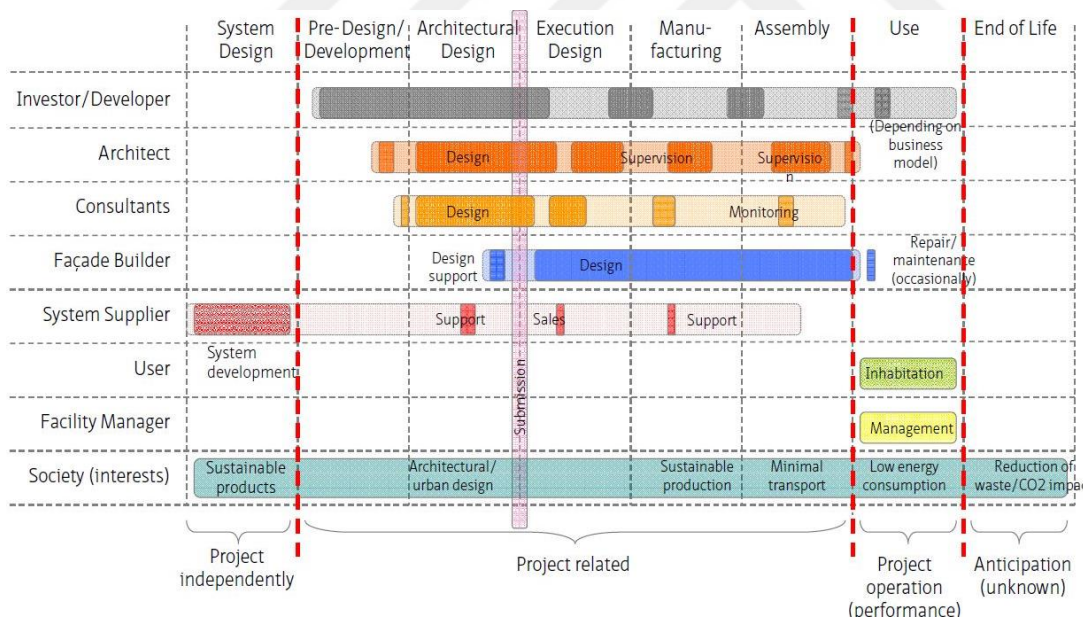


Figure 2.2 : Design and construction process of a curtain wall (Klein, 2013).

Different kinds of participants involved in the design and construction process of facades. Interaction among these participants is complex, interactive, and iterative (Boswell, 2013). The main team structure for facade design, independent of contract type or delivery method, is shown in Fig. 2.3. It is seen from the diagram that the owner is the pinnacle of the team.

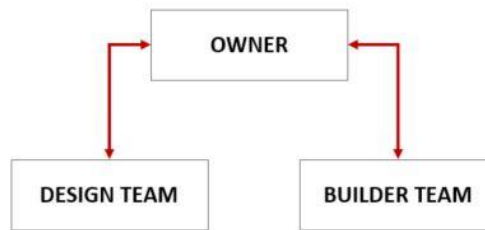


Figure 2.3 : Main team structure (Boswell, 2013).

Project delivery methods define the stakeholders' roles and responsibilities. Some project delivery methods are design-bid-build, design-build, design-assist, and integrated project delivery. In design-bid-build, the owner develops contract documents with a team including architect, engineer, and design consultant. Then, competitive bids are asked from contractors based on contract documents, and finally, a contract is awarded for construction. On the other hand, in integrated project delivery, project team participants, architects, engineers, contractors, and subcontractors, are engaged/ hired at the early stages of the design process in order to utilize from their knowledge and expertise. These are some examples; however, most facade design and construction delivery methods are tailored specifically to a project. Facade design is a process based on progressive steps (Knaack, et al., 2007). Nevertheless, it is important to make decisions as early as possible. If decisions are made early, changes in the design are still affordable. When they are made later, for instance during the construction phase, they are much more costly. Moreover, the team approach has several benefits. When all stakeholders start at the same point, they are able to understand project goals and priorities early on, from ambiance, aesthetics, and acoustics to services, sustainability, and technology.

2.1.1 Phases

Three separate design phases are taken as the basis for the thesis: conceptual, design development, and construction drawings. They are briefly explained in the following sections as what is done during these specific phases and what are the specific outcomes of the phases.

1. Conceptual design phase

The schematic design phase is the interchangeably used term. It is the first step of the design team (architects, engineers, consultants). Diagrammatic documents delineating room sizes, relationships, single line diagram of all systems, preliminary elevation

studies of building exterior are prepared during this phase. The conceptual design phase is conducted in accordance with the owner's project brief and the decisions given in the planning phase. Meetings are held between the owner and the design team. With the drawings, a project narrative and an estimate of the construction cost for review and approval are delivered at the end of the phase. The scales generally used for the drawings of this phase are 1/500, 1/200 or 1/100. In plans and elevations, the extent of opaque and transparent materials are defined, dimensions are roughly defined, materials are more or less identified, and in elevation drawings (see Fig 2.4) geometric decisions are presented, as well. In section drawings, in addition to the extent of opaque and transparent materials, relationships of the facade with structure and mechanical requirements (potential equipment) are specified. Isometric drawings are presented in accordance with the orthographic drawings (Boswell, 2013).

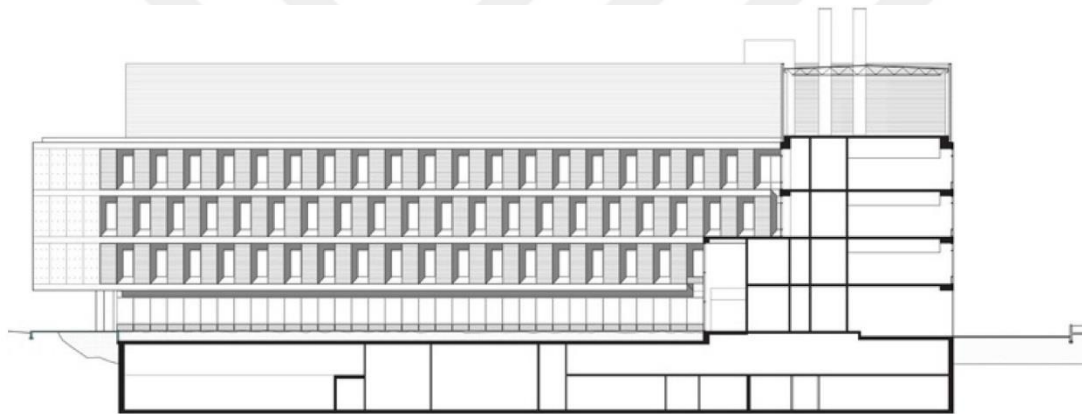


Figure 2.4 : A schematic section including elevation drawing, Arizona State University Interdisciplinary Science and Technology Building by Perkins + Will (Aksamija, 2013).

Fundamental issues to be checked for making design decisions in this phase are given in different scales as follows.

In settlement scale; climate, topography, surrounding landscape, surrounding buildings and noise sources need to be checked while in building scale, in addition to climate, topography, and surrounding, building/ space function needs to be considered. In building element scale; climate, surrounding facades, opaque-transparent balance, architectural effect need to be taken into consideration before making decisions, whereas in component and material scale, different from the other scales, surface characteristics of finishing material becomes more of an issue.

2. Design development phase

Design development phase starts with the end of the conceptual design phase. The outputs of the conceptual design phase are the inputs for this phase. The approved schematic design is developed into definite plans and elevations. Lighting fixtures, colors, patterns, materials are selected during this phase. In the end, detailed floor plans, sections, elevations, an outline specification defining materials, finishes, and systems as well as an updated construction cost estimate are submitted for review and approval. Architect(s), engineers, specialists, consultants, and the owner are the participants that may get involved in the phase. Design development drawings provide further material and detail definition. The scales used for design development drawings are generally 1/100 or 1/50. In plans, sections, and elevations, further and more detailed information is given when compared to the information provided in the schematic design drawings (see Fig. 2.5). Additionally, in this phase, facade relationship with structure is presented both in plans and elevations. Possible facade systems are identified. System interface details for projects with multiple facade systems and details of each facade system (such as head, sill, etc.) are designated in the design development drawings. Material selections and samples can also be delivered at this phase (Boswell, 2013).

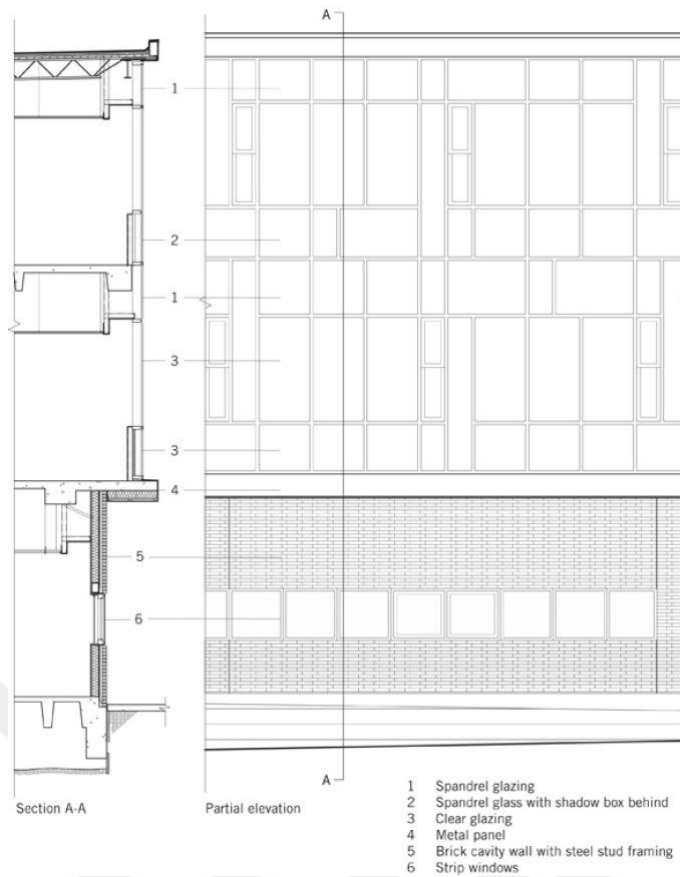


Figure 2.5 : An elevation from the design development phase, Hector Garcia Middle School by Peter Brown Architects (Aksamija, 2013).

Fundamental issues to be checked for making design decisions in this phase are given in different scales as follows. Settlement-scale decisions are generally made in the previous phase, so they are not given in the design development phase. In other scales, some decisions are revisited and/or confirmed, and some are considered for the first time.

Building scale: climate, topography, surrounding buildings, building/ space function.

Building element scale: climate, surrounding facades, opaque-transparent balance, architectural effect, function of the space, daylight factor, daylight distribution, daylight glare probability.

Component and material scale: climate, surrounding facades, architectural effect, surface characteristics of the material, function of the space, thermal bridge check, continuity of thermal insulation, continuity of vapour barrier, continuity of air barrier, solar characteristics of the glazing, sound reduction index (SRI) of the facade (wall and window).

3. Construction documents phase

The outcomes of the design development phase are taken as inputs of the construction drawings phase. The approved design documents are developed into comprehensive construction drawings and specifications which are used to secure a building permit, if required competitively bid the work and ultimately as the basis for the construction of the project. Thereby, construction drawings and specifications, and bid documents are delivered at the end of the phase. The following phases are bidding, and construction phases, respectively (Url-2). The scales of the drawings range from 1/50 to 1/1. 1/20, 1/10, 1/5 are common scales for this phase. The drawings of the previous phases are detailed and taken further. Atypical detail intersections are also provided at this stage. Full format specification together with the finalized basis of design (including anticipated movements, design loads, design temperature/ humidity ranges) is presented. Actual material selections and product data are delivered. At the completion of the construction documents phase, there will be a set of documents (drawings and specifications) which will include the information regarding facade type(s), visual requirements, the configuration of facades, interfaces with other systems, performance requirements, methods of construction (Boswell, 2013).

These construction drawing documents (see Fig. 2.6) set the basis to proceed to the construction phase. Fundamental issues to be checked for making design decisions in this phase are given for each scale as follows. Generally, it is late for making settlement-scale and building-scale decisions in the construction documents phase, since they might already be fixed in previous stages.

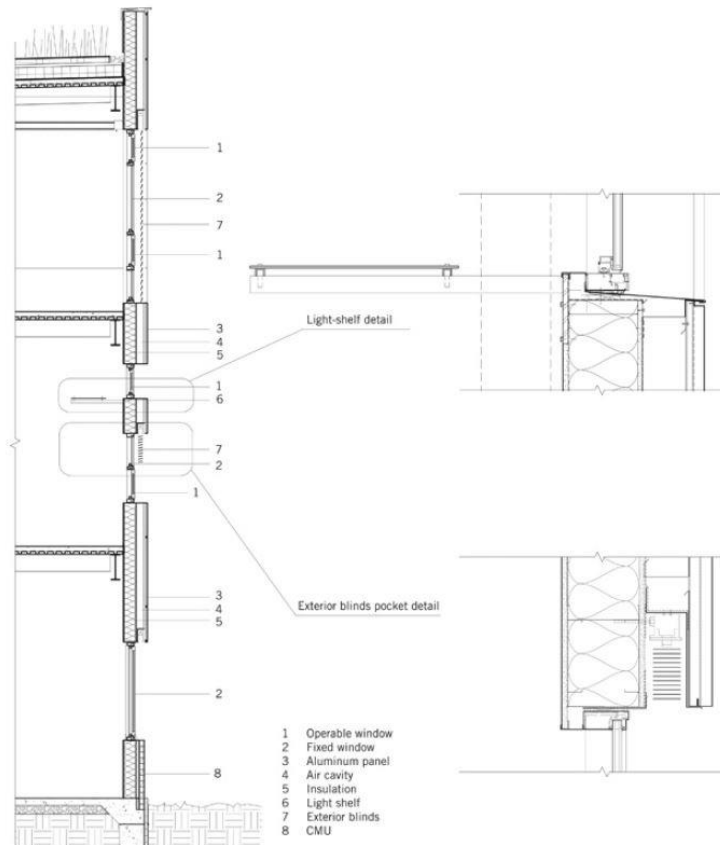


Figure 2.6 : An example of construction document drawings, Center for Urban Waters by Perkins + Will (Aksamija,2013).

Building element scale: climate, the function of the space, condensation check. Component and material scale: thermal bridge check, overall heat transfer coefficient (U-value), continuity of thermal insulation, continuity of vapour barrier, continuity of air barrier, solar characteristics of the glazing, sound reduction index (SRI) of the facade (wall and window), fire class of materials, fire resistance (REI) of the facade, conformance of different materials and finishes, tightness of joints and connections (air, smoke).

2.1.2 Stakeholders

In this section, stakeholders involved in the facade design process are briefly introduced with the roles they have within the process. The following are the main stakeholders that may take part in the process; however, specific to the project; there may be less (e.g. owner may be the same with the user) or different (involvement of specialized participants).

When the literature is reviewed, owner/ investor, architect, engineers, consultants, suppliers, contractors, subcontractors, and user are defined as the main stakeholders of the facade design process.

1. Owner/ investor

Owner is the person who owns the property and who often instructs work to be carried out. The contractors and architects in building projects undertake the works for the building owner (Gorse, et al., 2013). Another definition for the owner is “person or entity who awards a contract for a project and undertakes to pay for services of the contract” (Boswell, 2013). The owner/ investor of a building is the one who concerns about the high value/ investment ratio which can be achieved by good architectural quality, durable construction, low maintenance cost in combination with low investment (Klein, 2013). For the investor, the success of a facade is measured in its profit potential (Klein, 2013). The owner or the owner’s authorized representative sets the project budget and the project requirements; establishes, with the design team, the project goals and objectives (Boswell, 2013).

2. Architect

Architect or architectural designer is the stakeholder responsible for the conception and elaboration of the facade’s architectural design plans and defines the volumetric and aesthetic characteristics of the facade (Oliveira and Melhado, 2011). Architects have a unique role with the broad scope they are charged with. Bachman (2003) describes the architect as neither artist, scientist, engineer, nor craftsman; the architect is simultaneously a little of each and something different altogether.

The architect is the one to integrate the input of the different stakeholders in order to create the building/ facade, which necessitates bridging the gap between functionality, technical realization, and artistic expression. (Klein, 2013). The architect has to defend architectural qualities among the stakeholders while he has to rely on the expertise of consultants, facade builder, and system supplier throughout the design. Although the architects are central figures in the design process and have influences on most decisions, they are mostly generalists with limited knowledge of technical aspects (Klein, 2013). Architects often require design and detail assistance of specialized engineering disciplines (Boswell, 2013).

The architect is the person or entity in charge of developing the design that needs to respond to the programmatic and performance requirements, in conjunction with the owner (Boswell, 2013). There are two separate kinds of facade design process, in one kind, the architect's involvement is limited to only the composition and visual aspects of design, while in the other kind, the architect, in collaboration with the other design stakeholders, fully designs, details, specifies, and documents the facade (Boswell, 2013).

3. Engineer (structural, mechanical, electrical, etc.)

Structural, mechanical, electrical, and plumbing engineers whether contracted directly to the architect or the owner, provide services for their respective functions and collaborate with the design team on the interfaces between their systems and the facade (Boswell, 2013).

4. Consultant (facade, acoustic, lighting, project-specific types of consultants)

Potential consultants that may involve in the facade design process are facade consultants, acoustic, lighting or project-specific type of consultants like sustainability, LEED, etc. Facade consultant assists the architect in identifying and solving interface troubles (Boswell, 2013).

5. Supplier

Facade system/ material suppliers provide systems and materials together with their technical information regarding availability, limitations, applicability, and compatibility with adjacent systems and materials. Even though the facade builder buys the products (systems/ materials), the main focus of the supplier is towards the architect who makes the decisions about the selection and application of the products (Klein, 2013). The suppliers may assemble the systems as well. They can be hired by the project owner or the contractor (Oliveira and Melhado, 2011).

6. Contractor

The contractor, in other words, general contractor, supervises and directs the construction work (methods, techniques, sequences, and procedures) (Boswell, 2013).

The contractor is responsible for the construction of the facade and accounts for the construction of other parts of the building since the construction of facades affects the execution of the other systems at the building site (Oliveira and Melhado, 2011).

General contractors, depending on contract and project type, perform particular scopes of the work, and subcontract work to other specialized contractors (Boswell, 2013).

7. Sub-contractor

Facade builders/ assemblers are typically sub-contractors. Subcontractors range from masons (brick, stone, etc.) to carpenters (concrete), sealing, framers, ironworkers, curtain walls, and many others (Boswell, 2013). Their role is to provide the materials and labor necessary for the facade type and their systems' interface with adjacent construction systems (Boswell, 2013).

8. User

Users play a specific role with their requirements that lead the decisions of the other stakeholders throughout the facade design process. Fundamental demands of the users are comfort, low energy consumption, and little maintenance effort. A certain amount of flexibility is also required by the users for their changing needs (Klein, 2013).

As seen, there are different kinds of groups involved in the facade design process. In order to include the potential contributions of all involved parties in the design process, a high level of collaboration among the stakeholders is essential. Specifically, facade design requires a multidisciplinary collaboration and coordination effort.

An example of a relationship among stakeholders is given in Fig. 2.7.

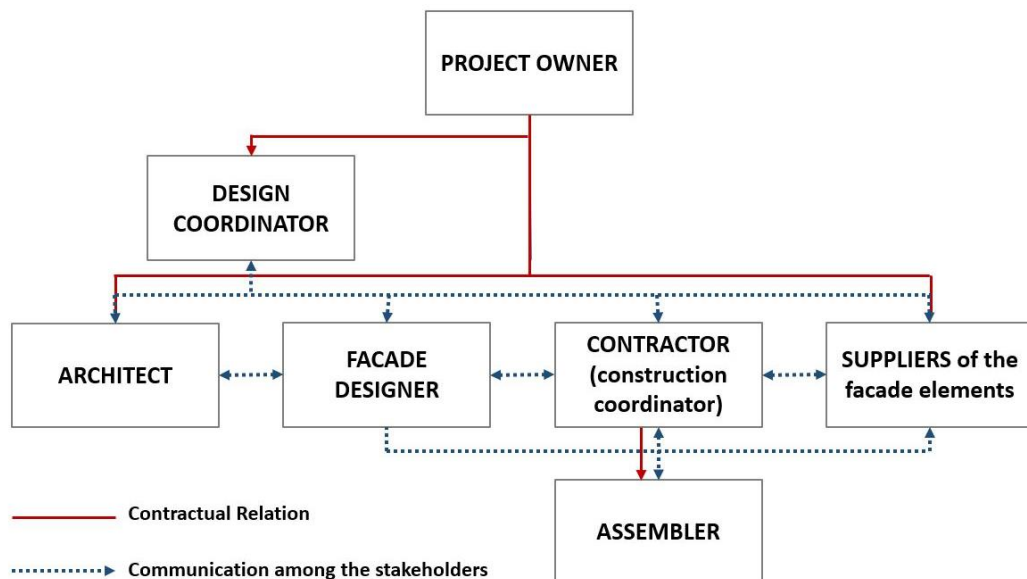


Figure 2.7 : A relationship among stakeholders (Oliveira and Melhado, 2011).

Figure 2.8 demonstrates the stakeholders' relationship during the design of a specific facade type, curtain wall. The roles of the stakeholders, hence the structure of the relationship among them vary based on the contract and project type, and the negotiations between the involved stakeholders. However, as seen in both figures (Fig. 2.7, Fig. 2.8), the user is not taken as a stakeholder that relates to the others. In some cases, the project owner or the client is the user, but in some cases, they are different.

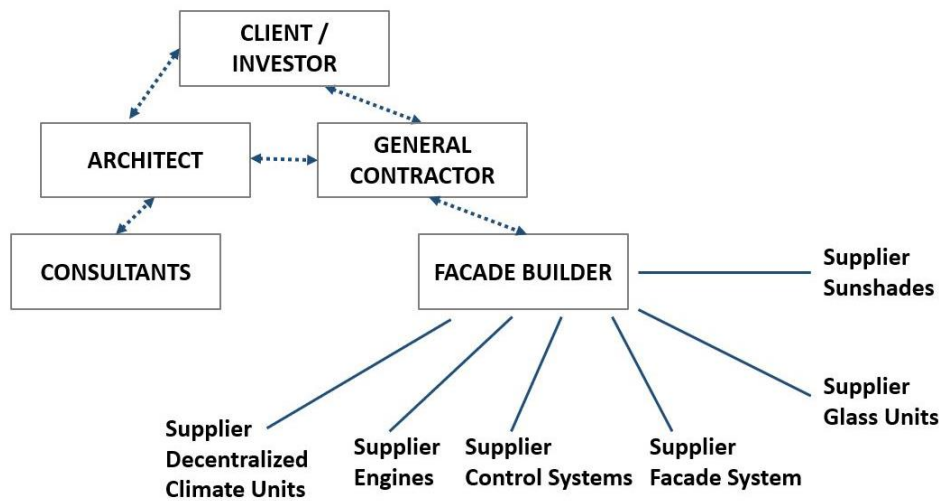


Figure 2.8 : Relationship among stakeholders for a curtain wall design (Klein, 2013).

Integrated Building Design (IBD), also known as Integrative Building Design and Integrated Project Delivery (IPD), as described by ASHRAE, is a collaborative process, resulting in optimized solutions from an engaged team that is committed to the process from start to finish. It brings the experts to the table from the very beginning of the project to look at it from a “whole systems” perspective. A “whole systems” approach or “systems thinking” assumes that individual parts/ roles are better understood in relation to others. So, with IBD all the players involved are asked to work together rather than on their own, from the inception of the project. A collaborative approach to a project means to optimize and integrate the efforts and abilities of the owner and all the other team members in an effective way (Aldrich, 2011).

2.1.3 Outcomes

2.1.3.1 Conceptual design

In the conceptual design phase, decision-makers make decisions on facade related design parameters (facade parameters) mostly in all scales starting from settlement

scale and ending with component and material scale. These are; building location, building orientation, the shape of the building, height of the building, facade orientation, transparency ratio, facade configuration, the position of the facade plane in relation to the structural system, location of the window, and facade exterior finishing. This phase comprises architectural scales of 1/500, 1/200 or 1/100.

This phase covers the majority of the analysis part of the design. Based on the analyses, synthesis trials are done. Evaluations done in this phase are mostly rudimentary since the decisions are not still fixed and detailed, and there are a great number of options to be evaluated at the beginning.

2.1.3.2 Design Development

In the design development phase, decision-makers generally make decisions on facade parameters starting from building scale. The settlement scale parameters are most probably fixed in the previous conceptual design phase. The parameters are; building shape, building height, floor height, transparency ratio, facade configuration, position of the facade plane in relation to structural system, location of the window, facade type, sequence of facade layers, drainage system within the facade, ventilation of air gap, facade exterior finishing, selection of all layers (materials, thicknesses), type and thickness of thermal insulation, air barrier layer, vapour barrier layer, and its position to other layers, glazing type (number of glass panes, infill gas, thickness, color, coating), shading elements (configuration), and integration with other subsystems. Architectural scales that decision-makers prefer in this stage are 1/100 and 1/50.

In this phase, the greater part of the decisions is fixed and conveyed to the subsequent construction documents phase to be detailed.

2.1.3.3 Construction documents

In the construction documents phase, stakeholders prepare and detail the design to be constructed. Decisions in all scales are finalized. Some of the decisions regarding facade parameters are about sequence of facade layers, drainage system within the facade, ventilation of air gap, facade exterior finishing, selection of all layers (materials, thicknesses), type and thickness of thermal insulation, air barrier layer, vapour barrier layer and its position to other layers, glazing type (number of glass panes, infill gas, thickness, color, coating), shading elements (configuration, type, sizes, color, material), integration with other subsystems, detailing of joints and

connections. The design decisions are represented in diverse architectural scales like 1/50, 1/20, 1/10, 1/5, 1/2, 1/1.

The decisions in this phase are generally given after some kind of evaluation such as checks for basic rules, calculations, simulations and/or field tests by relevant stakeholders.

In this Section, the facade design process is described in terms of design decisions. The process is composed of three stages: Conceptual Design, Design Development, and Construction Documents. Each comprises of different sub-levels. These sub-levels are referred to as different scales like Settlement Scale, Building Scale, Building Element Scale, and Component and Material Scale. All these are indicated in a chart (Table 2.3). The aim of this chart is to indicate the relevant design decisions and the essential issues, parameters to be checked at each level of each design stage. It is paid attention to all the design decisions to be related to facade performance. It can be easily traced from the chart that in each phase in which detail the decisions can be given and which issues should be checked, and what kind of responsibilities are taken based on the design phase being involved in.

Table 2.3 : Facade performance related parameters in relation to building design phases and scales.

Design Phases /	Conceptual Design (Scales 1/500, 1/200)		Design Development (Scales 1/200, 1/100)		Construction Drawings (Scales 1/50, 1/20, 1/10, 1/5, 1/1)	
	Design Decisions	Issues to be Checked	Design Decisions	Issues to be Checked	Design Decisions	Issues to be Checked
Settlement Scale	*building location *building orientation	*climate *topography *surrounding *noise				
Building Scale	*building shape *building height *facade orientation	*climate *topography *surrounding *building/ space function	*building shape *building height	*climate *topography *surrounding *building/ space function		
Building Element Scale	*transparency ratio *facade arrangement *facade position *facade configuration	*climate *surrounding *opaque & transparent bal. *architectural effect	*transparency ratio *facade arrangement *facade position *facade configuration *window position *type of facade *drainage system integration *ventilation of air gap *facade exterior finishing *wall layers *thermal insulation *air barrier layer *vapour barrier layer and its position for other layers *glazing type (no. of glazing, infill gas, thickness, etc.) *shading elements (configuration)	*climate *surrounding *opaque & transparent balance *architectural effect *space function *daylight factor *daylight distribution *daylight glare probability *climate *surrounding *material surface characteristics *architectural effect *space function *thermal bridge check *continuity of thermal insulation *continuity of vapour barrier *continuity of air barrier *solar characteristics of glazing *SRI of facade (wall & window)	*wall configuration *drainage system integration *ventilation of air gap	*climate *space function *condensation check
Material & Component Scale	*exterior finishing	*climate *surrounding *material surface characteristics *architectural effect			*facade exterior finishing *wall layers *thermal insulation *air barrier layer *vapour barrier layer and its position for other layers *glazing (no. of glazing, infill gas, thickness, color etc.) *shading elements (config., type, dimensions, materials) *integration w/ other subsys. *detailing of joints & connections	*thermal bridge check *continuity of thermal insulation *overall heat transfer coefficient (U-value) *continuity of vapour barrier *continuity of air barrier *solar characteristics of the glazing *SRI of facade (wall & window) *fire class of materials *fire resistance (REI) of facade *conformance of different materials and finishes *tightness of joints and connections (air, smoke)

2.2 Driving Factors

The facade design process is driven by a substantial number of factors. The main factors having influences on the process are user requirements, environmental conditions, building and space features, project conditions, standards/ regulations, and designers.

2.2.1 User requirements

User requirements are grouped under four headings. These are; biological/ physiological requirements, social/ psychological requirements, activities-related requirements, and physical dimensions related requirements (Coşkun, 2006).

2.2.1.1 Biological/ physiological

Biological/ physiological requirements are health and comfort-related requirements of the user. These are given in four different aspects: hygienic comfort, thermal comfort, visual comfort, and acoustic comfort.

Indoor air quality is meant with hygienic comfort. It is important that air is clean, fresh, and circulated effectively in the space. Fresh air helps people be alert, productive, and healthy. Clean air has pollutant and pathogen levels below certain thresholds. High ventilation (either natural or active) rates provide fresh air. Clean air can be achieved by filtering air, and by not contaminating the air with impurities, such as volatile organic compounds from paints or materials (Url-3).

Thermal comfort is described as the condition of mind, which expresses satisfaction with the thermal environment (Grondzik, et al., 2010). Personal, environmental, and psychological factors affect the users' thermal comfort. Definition (perception) of thermal comfort changes according to personal factors like metabolism and clothing. Metabolism rate is directly related to the activity type/ level. Environmental factors are air temperature, room surface temperature, air movement, and humidity. Psychological factors are difficult to quantify like color, texture, smell, aroma (Grondzik, et al., 2010).

Visual comfort is defined as adequate visibility to be able to perform a task in desired speed and accuracy (Kurra, 2010). Illumination level, unified glare rating, and color

rendering index proper to the space function and the activity type are three main indicators of visual comfort (Yener, 2013 ; EN 12464-1, 2002).

Acoustic comfort can be achieved by having the right level and quality of sound to use the space as intended. How humans perceive sounds and loudness is a subjective measure. However, a comfortable environment can be created through the control of objective measures like decibel level (sound pressure), reverberation time, and sound reflection/ absorption properties of the materials (Url-2).

2.2.1.2 Social/ psychological

Safety, privacy, and aesthetics are among the main social/ psychological requirements of the user. Here, the user is the user of the building, so the safety requirements are building-related. These requirements can be considered in normal and emergency conditions. In any condition, structural integrity and protection against intruders are the user needs. In case of earthquakes and/or fires, prevention from any damage, fire/ smoke protection, in other words, life safety becomes the primary need. Other needs remain less important when compared to the safety requirements of the user (Maslow, 1943).

Although being a social existence, human has the requirement of privacy to feel secure, safe and comfortable. This need should be satisfied when and where the user requires. Privacy can be to have a personal space or to have limited contact with others or to have access to operating systems for personal needs.

The user has aesthetics requirements as well. Aesthetics can be described as a set of principles concerned with the nature and appreciation of beauty (Url-4). Aesthetic pleasure varies from person to person; that is why it is hard to satisfy a group of people's aesthetic pleasure.

2.2.1.3 Physical dimensions related

Physical dimensions related requirements of the user can be defined with ergonomics. Ergonomics is to design and arrange things people use to make the people and things interact most efficiently and safely (Url-5).

2.2.2 Environmental conditions

Environmental conditions that may affect the facade design process are listed and briefly explained below. These are location, topography, earthquake, climate,

surrounding landscape, surrounding buildings, surrounding facades, urban/ rural patterns, physical obstacles, environmental noise, and social and cultural features.

As the facade is the interface between outdoor and indoor environments, the environmental conditions come first within the factors defining the performance criteria. The performance criteria differ by climate type for some performance aspects such as thermal performance. Similarly, possible earthquake loads, in other words, the seismic zone of the region, may change the expected performance from a facade. Suchlike, in a noisy environment, in order to fulfill the requirements of the standards, a facade may need to perform differently. Facades of the spaces which are intensively exposed to moisture like kitchens may need to take more/ different measures in terms of moisture-related performance. Sky type or light reflectance of exterior ground surface or light reflectances of room surfaces may affect daylighting performance expected from a facade. Surrounding obstacles/ landscape may change the performance criteria, particularly for thermal and daylighting performance of facades.

As it is seen from the above examples, there are certain environmental conditions that have the potential to change the expected levels for facade performances. These are; location (on the globe), topography, possible earthquake loads, climate type, wind pattern (direction, speed, period), environmental noise (direction, type, and level), sky type and light reflectances of exterior surfaces and height of surrounding buildings/ obstacles. There can be several scenarios for these environmental conditions. Each scenario may need a specific facade that performs in line with its conditions.

Environmental agents/ loads that have impacts on facade performance are solar radiation, air temperature, humidity, wind, air movement, water, earthquake, thermal/ settlement movements, sound, dirt/ dust, etc. The wind is responsible for the transportation of water vapour and dust through the gaps in the facade and for the heat transfer through the facade. Water in forms of wind-driven rain is considered as the affecting agents for facade performance since vertical rain is not one of the primary sources of water for facades and condensation. These are natural and artificial (noise) aspects of environmental conditions. There are also social, cultural, and economical aspects (Türkeri, 2008).

2.2.2.1 Location

Parameters defining the location are hemisphere, latitude, site features like earthquake criticality or topography. A facade can be located in the Northern or Southern Hemisphere. It can be close to the equator or poles; in other words, it can be in lower, middle, or high latitudes. It can be in a critical earthquake zone or in a zone having low/ no earthquake risk. A facade can belong to a building in different topographies, on a hill, valley or slope, on sloped or flat surfaces.

2.2.2.2 Climate

Climate can be considered in micro and macro scales. The main climatic elements are air temperature (elevated, depressed, and cycle), wind pattern (direction, speed, period), rainfall pattern, and relative humidity. Climate, in very general terms, can be sorted as heating-dominated climates, cooling dominated climates, and mixed climates.

Climates can be described by their annual average temperatures as cold, temperate, and hot, together with their annual rainfall as humid, arid, etc. Diurnal temperature range is also indicative for defining climates. It can be high or low. If it is high, it means the temperature dramatically change during day and night.

2.2.2.3 Surrounding

Surrounding implies the immediate context of the facade such as surrounding landscape, buildings/ facades, physical obstacles, and environmental noise. Social and cultural features are also part of the context. Environmental context can be urban or rural; according to it, building density, heights, solid-void balance, materials, and the panorama can change. Wind corridors can occur due to building density, or high buildings can lower visible sky angle. Shading effects (for sunlight, daylight, and noise) of close buildings or physical obstacles can influence facade performance. Surrounding facades can be a driving factor for facade design in terms of architectural styles, opaque-transparent balance, finishing materials. The surrounding landscape is important with light reflectances or sound absorptances of its elements. Ground material can be soft like green, or hard like concrete. There can be various types of noise source such as traffic, airport, construction, entertainment, and people.

2.2.3 Building features

Building typology and height are the main building features that influence facade performance. Building types can be residential, commercial, educational, medical, cultural, etc. Buildings can be categorized with their heights like high-rise, mid-rise or low-rise buildings. Performance requirements change with these features. Standards and regulations generally have different prescriptions for different building types. So, a facade needs to meet different requirements in different types of buildings. If a building type requires high fire safety requirements, required performance levels completely change. Fire performance criteria change with building type and height. Similarly, structural performance criteria vary with building height. High-rise buildings need to satisfy more challenging performance criteria.

2.2.4 Space features

The function of the space, occupation period, and location within the building (upper and lower floors) are the main features of the space that give an outline of noise-sensitivity, illumination type, and level, moisture content, etc. which in turn define the required performance levels. Space interior features are critical, as well. Space proportions and interior surface light reflectances (colors) have influences on daylighting performance. In spaces with dark interiors, there may require higher daylighting performance levels. Spaces having deep proportions may need light directing horizontal surfaces in order to provide daylight to deepest points. Again, with all these features, there can be several scenarios, and each may demand different performing facades.

2.2.5 Project conditions

Priorities and conditions are not generic; they are project-specific instead. Each project may have its own priorities, conditions, goals, and objectives. Potential factors that may drive the process are listed below.

1. Aesthetics (architectural intentions, etc.)
2. Cost (construction, operation, maintenance, lifecycle) / Budget limitations
3. Time (design, construction)
4. Feasibility (cost, construction technology, and materials)

5. Legislation (limitations from local authorities)
6. Visional (like smart, sustainable, high-tech, etc.)
7. Cultural/ social issues (traditions, etc.)

2.2.6 Standards, regulations

As previously mentioned, performance criteria are generally designated by standards, regulations, codes, etc. These mainly rooted in years of experience and scientific studies.

There are local and global codes. Countries generally have their own standards and regulations. There are codes customized for cities or towns, as well. ASTM (American), EN (European), ISO (International), BS (British), DIN (German), TS (Turkish) are some of the standards of different locations. In case that there is not a national standard, international standards are adopted and sometimes translated. The standard adds on the abbreviations of the other standards next to itself. It becomes like TS EN ISO 717-1. Beside the abbreviations, the standards are defined by the numbers indicating the standard itself and the version of it.

2.2.7 Designers

Design is a creative process throughout which the architects/ designers play the leading role. For this reason, aesthetic pleasures, personal tastes besides the echoes, movements adopted by the architect/ designer like sustainability, flexibility, modularity, universality, brutalism, etc. become important driving factors for design.

To some extent, the design process is the conversion of generic requirements into specific requirements. The synthesis part of the design process is up to the designer's experience, knowledge, and working trend. There are various approaches for design synthesis like design by intuition, assembly build-up, case-based, component-selection and function satisfaction (Ramachandran, 2004).

Another important issue about the designers is that they are referred to as either experienced or inexperienced in the literature. Experienced designers can make intuitive decisions based on their previous experiences while inexperienced ones mostly prefer to follow a methodology not to skip any significant issue.

2.3 Integration with Building Design

Facade is a building element having direct relations to other building sub-systems like enclosure (roof), structural, mechanical (heating, cooling, air-conditioning) and indoor systems (floor, ceiling, interior wall) which makes the integration of the facade with the building important. Hence, facade design has a decisive impact on the entire building design and construction process (Knaack, et al., 2007).

Facade functions in concurrence with other subsystems, therefore its integration with the building has a significant role for its performance. Building systems integration is a hardware integration, whereas software integration is an integration in the design process.

According to Rush (1986), there are five levels of integration for building subsystems as remote, touching, connected, meshed, and unified (Fig. 2.9). On the other hand, Bachman (2003) defines three types of integration among the components of building systems as physical, visual, and performance integration.

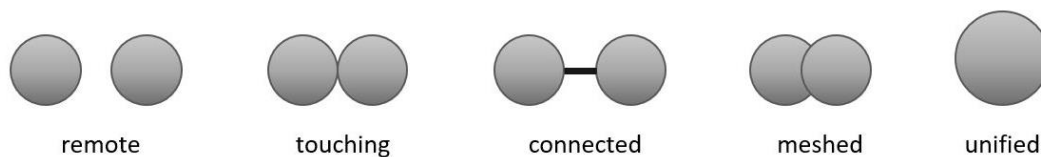


Figure 2.9 : Five levels of integration according to Rush (1986).

Physical integration is about how components and systems share space, how they fit together. To prevent interference between systems by providing adequate space for each individual system like structural beams, lighting equipment, HVAC ducts, etc. in the space above the ceiling. Connections between components and among systems constitute another aspect of physical integration. Architectural details are generated for these connections. For physical integration, components need to share space (Bachman, 2003).

Visual integration is used for defining the image created by the combination of exposed and formally expressive components of a building. For visual integration, components need to share the image. Color, texture, size, shape, and placement are common factors that can be manipulated to achieve the desired effect. So, knowledge about visual features of various components is essential (Bachman, 2003).

Performance integration is described as shared functions like a load-bearing wall unifying two functions (envelope and structure) into one element. This approach may have the potential to save costs and reduce complexity. Performance integration can also be achieved by meshing or overlapping the functions of two components, even without actually combining them which is named as “shared mandates” by Bachman (2003).

2.3.1 Building envelope

Facades and roofs compose the enclosure systems of the buildings. The integration of the facade systems with roof systems can be in various types and levels. An example of physical and visual integration of the facade with the roof system is given in Fig. 2.10. The facade and the roof together constitute inseparable visual integrity. Cladding materials are connected to form a curved building envelope having the roof as the continuation of the facade.



Figure 2.10 : Physical and visual integration of facade with roof system (Oseana Art and Culture Center, Bergen, Norway, Url-6).

2.3.2 Building structure

The integration of the facade systems with structural systems can be in various types and levels. An example of performance integration of the facade with structural system is given in Fig. 2.11. facade of the building is at the same time the part of its structural system.

Exposed structural systems become part of the facade systems by contributing to the visual appearance of the building. In shell structures, facade systems and structural systems can be the same.



Figure 2.11 : Performance integration of facade with structural system (Morongo Casino, Resort & Spa, California, USA, Url-7).

2.3.3 Building services

The integration of the facade systems with mechanical systems can be in various types and levels. An example of physical and performance integration of the facade with mechanical systems is given in Fig. 2.12. The scheme represents an integrated facade type which comprises numerous building services. By means of this facade type, the construction process can be shortened since additional components can be integrated into the facade elements during the industrial manufacturing process (Knaack, 2007).

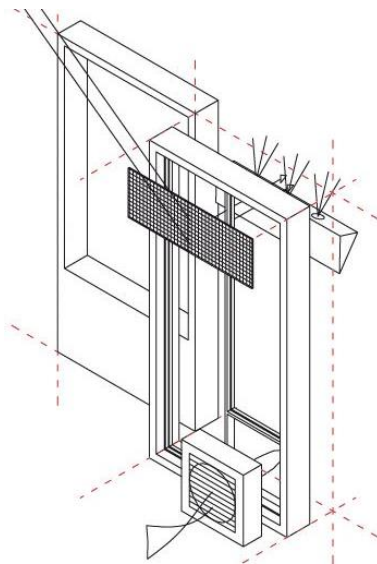


Figure 2.12 : Physical and performance integration of facade with mechanical systems (Knaack, 2007).

2.3.4 Building interior

Integration of the facade systems with indoor systems can be in various types and levels. An example of integration of facade with indoor systems is given in Fig. 2.13. Facade system and ceiling system (reflective ceiling) share the function of daylighting the interiors. Likewise, for cross ventilation, together with an opening on the facade, there needs to have an opening on the opposite side interiors. Facade systems and indoor systems need to perform together.

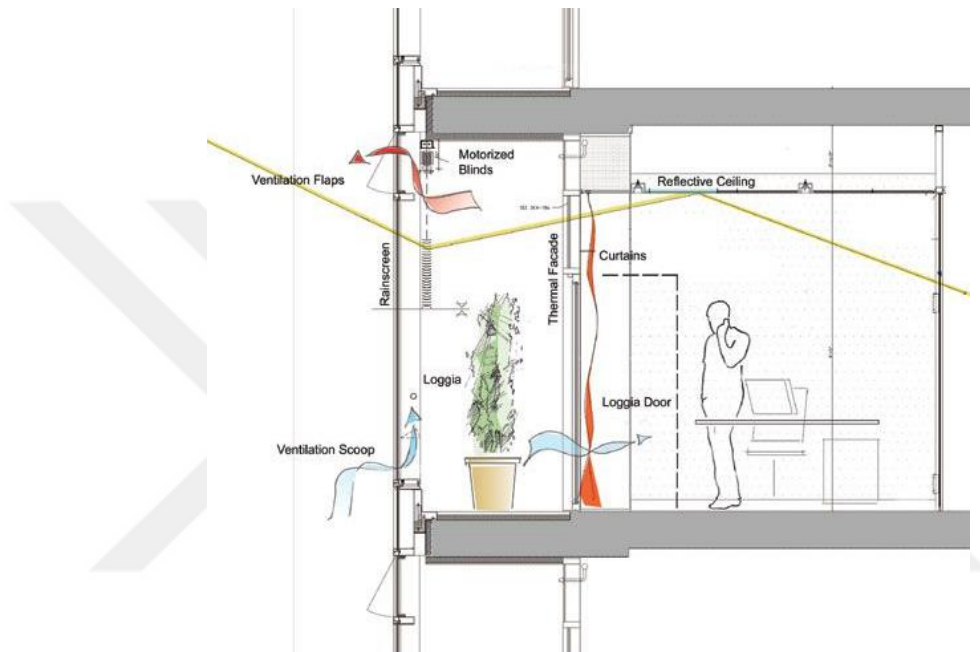


Figure 2.13 : Integration of facade with indoor systems (Genzyme Center Headquarter Building, Cambridge, USA Url-8).

2.4 Facade Construction Industry

The facade construction industry is discussed with its current trends and problematic issues. The industry is affected by several aspects, such as technological developments or raising environmental consciousness or changing design philosophies. In today's world, local problems can be considered as the reflection of global issues since there are worldwide brands, cosmopolitan project teams that are facing similar conditions.

2.4.1 Trends

Facade construction industry struggles to adapt itself to advancing technology, emerging materials, developments in construction techniques, new concerns and challenges in design. Today's material technology enables to improve the performance

of materials by changing their features in nanoscales. It is also possible in this age to design and construct a facade that can adapt itself to changing indoor and outdoor conditions in real-time and accordingly contributes to energy efficiency and economics (Aelenei, et al., 2016). Adaptive, responsive, interactive, dynamic, kinetic, adjustable, intelligent, smart, innovative, advanced, selective are some of the terms in the literature used for this kind of facade (Loonen, 2010). SDU Kolding building is a good example for adaptive facades with its changing facade modules for various shading scenarios (Fig. 2.14).

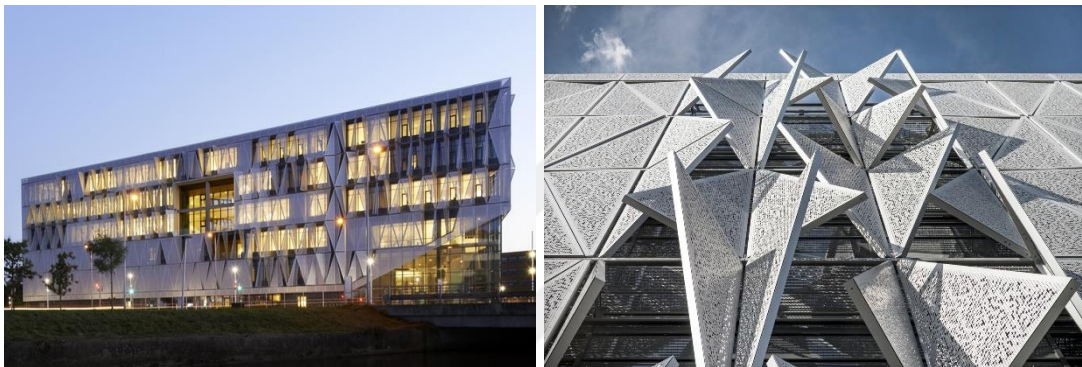


Figure 2.14 : An example of an adaptive facade, SDU Campus Kolding, Denmark (Url-9).

Parametric design, CNC (Computer Numerical Control) machines, 3D (3-Dimensional) printing techniques are today's developing design and manufacturing tools. In the parametric design concept, geometries are generated by establishing mathematical relationships among parameters with the help of advanced digital technologies.

In 100 Eleventh Avenue housing project of Jean Nouvel, facade units are different in angle, color, and transparency from each other. This differentiation originates from the facade's thermal and daylighting analyses. Similarly, in Torre Agbar in Barcelona, again by Jean Nouvel, colors of aluminium panels, transparency, and angle of glass louvers differ based on some numerical analyses. Both can be considered as examples for parametric design (Fig 2.15).



Figure 2.15 : Examples for parametric facade design, 100 Eleventh Avenue (on the left), Torre Agbar (on the right), both by Jean Nouvel (Url-10).

In recent years, prefabricated and preassembled systems are highly preferred due to providing quality assurance in production and time reduction in construction. However, their initial costs can be higher than the other systems.

For around twenty years, green building rating systems are widely used across the world. LEED (United States of America), BREEAM (United Kingdom), DGNB (Germany), Green Star (New Zealand), and CASBEE (Japan) are the prominent rating systems used to evaluate building performances. These systems consider not only the design stages but also the rest of the life-cycle process including the construction stage.

In addition to all these, experimental studies aim at expanding the vision for facade design and construction processes by making use of the technology of other disciplines (Knaack, 2009). Research and development studies increase in number each passing day.

2.4.2 Problematic issues

In this section, it is preferred to address the facade design and construction process in Turkey to give a brief insight regarding the problems.

Bertan and Tavil (2016) discuss the current situation of the design and construction process of curtain walls in Turkey based on face-to-face interviews conducted with the stakeholders of the process. The study identifies the deficiencies in the process. In Turkey, facade design and performance goals are not set with the involvement of all stakeholders. Instead of this, the owner, architect, and facade consultant set the goals, and the other stakeholders are expected to contribute to the process based on these goals. It may cause disagreements among the stakeholders and overlooking some important issues. Another critical point regarding the process is that in the design

development phase, static calculations of facades are prepared according to the building's primary structural system, without collaborating with the structural/ civil engineer of the building. The ideal is to optimize both primary and secondary structural systems and components within the collaboration of facade consultants and structural engineers. However, in most applications in Turkey, static calculations of the facades are prepared after the completion of static calculations of the building, even after the completion of the construction of the building's structural system. That prevents the opportunity to make minor revisions in the building's structural system and not to design unnecessary details that may cause financial loss.

One of the encountered problems in Turkey during the facade design and construction process is the facade consultant not being involved in the process. In the absence of a facade consultant, due to the incapacibilities of architects in terms of technical issues, there can be major revisions in the construction phase of the process. The owners/ investors may try to lower the costs by giving the job of the facade consultant to the facade builders (probably the subcontractors). But, it is a problematic issue since the facade builders may manipulate the process far from the facade consultant's supervision. Besides, the investors may resist to budgeting for facade design and construction expenses during the process.

Specific to curtain walls, the most common problem encountered is that the facade builders/ subcontractors may have not qualified staff which may result in imperfect assemblage/ installation. It is a fact that in Turkey, both in the industry and in the academy, employees having experience in facades are few in number. Not taking the support of experts (about materials and technical details) in every project may lead to the results not satisfying the performance expectations.

The last but not the least indication of the study is that in Turkey, the standards and codes followed throughout the facade design and construction process are translations of the EuroNorm standards and codes. Since they fail to satisfy the requirements in Turkey's conditions, stakeholders need to follow some other standards such as DIN, ASTM, BS, CWCT, ISO and rating systems like LEED and BREEAM (Bertan and Tavil, 2016).

2.5 Summary of the Chapter

Facade design is a process driven by a wide range of factors with the involvement of various disciplines. The multidisciplinary nature of the process (including conflicting issues) necessitates collaboration, especially in the early stages of facade design process. The facade design process comprises different phases. Each of them has its own dynamics and level of detail. Moreover, the design process can not be considered independently from the construction process, even the life-cycle process of the facade/building. All these make the facade design process highly complex. On the other hand, design support tools remain either experimental or limited in scope, although they are developed to assist the stakeholders in design generation and evaluation.

Facade design as being a design process is open-ended and project-specific. Contract type, stakeholders involved, environmental conditions, specific user requirements, project priorities, working trends of designers may change for the project, so the facade design process.

Although the phases of the facade design and construction process may vary by country/ region, there exist similarities. Specifically in Turkey, due to the lack of collaboration among stakeholders, and technically incapable architects, the facades may fail to satisfy the expectations.



3. FACADE PERFORMANCE

Performance for a building means the behaviour of various components that compose a system during use under natural and artificial circumstances. Performance approach in design is a design method which approaches design problems with the inclusion of performance concept. It is important for definition, analysis, and assessment of design problems, economical control of design products and feedback of design solutions. Performance concept can be integrated into development, invention, assessment, and selection of either product or process in every level of building production (Coşkun, 2006).

This Chapter tries to describe ‘facade performance’ with its components. Firstly, it subdivides the facade performance into various aspects, and then it gives the related indicators that indicate how a facade performs in that aspect. Factors defining the performance criteria and facade parameters affecting the performance are also explained in detail. Lastly, state-of-the-art facade designs are exemplified with high-performance facade technologies.

Performance is the behaviour of building in use when exposed to environmental factors. It can be defined by time as the initial (at 0-time) or for instance, at 3rd month. The second type of performance corresponds to durability (performance in time) which is not the subject of the thesis. In another explanation, performance is defined as the ability or the capacity or the attribute of a building (or elements or components) to meet user requirements when exposed to external factors (Türkeri, 2008).

Aygün (2003) describes the performance requirements as the expectations and stipulations of participants at any phase of the building life-cycle in a particular domain. These requirements are measured by performance indicators to which relative weights are then assigned and converted to a single overall indicator value (Aygün, 1999).

3.1 Performance Aspects

Performance, in one of its dictionary meanings, is defined as the action or process of performing a task or function. The term describes the capabilities of a machine, product, or vehicle (Url-11). Another dictionary defines the term as how well a person, machine, etc. does a piece of work or activity (Url-4). Some other definitions are as follows. The ability to perform (efficiency), how a mechanism performs, and execution of an action (Url-5). Out-of-context definitions are ignored. When the term is used together with ‘facade’, it is important to understand the content of its meaning. The Lawrence Berkeley National Laboratory (LBNL) in one of its reports defined ‘facade performance’ as a product of technological solutions based on fundamental building concepts for daylighting, solar heat gain control, ventilation and space conditioning. ‘High’ can also be added as to be ‘high-performance facade’ in order to signify an intelligent combination of strategies based on details unique to a project (Patterson and Matusova, 2013). Patterson and Matusova (Url-12) find the phrase ‘high-performance’ elusive and nebulous, which often incorporates the trending keywords like ‘sustainable’ and ‘technologically advanced’. It is because of the difficulty in pinpointing the most significant contributors to the performance of a facade.

Energy Independence and Security Act (EISA) developed a set of attributes for high-performance building envelope which was then leveraged by The National Institute of Building Sciences (NIBS). The building envelope is the nexus of many, often conflicting functional demands, or as NIBS states: “many high-performance attributes interact at the envelope”. The attributes are listed under the main headings. These are environmental impacts; safety and security; durability; cost-benefit and economic efficiency; human comfort, health and productivity; and sustainability (Url-12).

Jin (2013) compiles existing facade performance evaluation methodologies and tools in the literature. In order to evaluate the overall performance of a facade, it is necessary to assess several criteria that account for its multiple functions. For this, Hendriks and Hens (2000) provided a comprehensive list of the building envelope performance aspects while Chen and Clements-Croome (2004) proposed 37 key performance indicators for assessing the performance of a facade system. After giving the pros and cons of both approaches, the thesis describes the adopted whole-life value approach which encompasses social, economic, and environmental aspects associated with the

life-cycle of an asset. According to the whole-life value approach, the facade performance indicators fall into three categories: functional, financial and environmental sustainability (Jin, 2013). Performance indicators of each category are given in Tables, respectively. Since this categorization also fits the purpose of this thesis, for the following subsections similar category names are preferred.

The literature is reviewed to determine the functional performance aspects and indicators. However, each publication has its own categorization, and some use different expressions for the same subject. So, there needs a re-categorization. First, all the performance aspects available in the selected publications are listed. Then, common aspects are determined and based upon the availability rate of the aspects in the literature; some are eliminated. After that, these aspects are sorted and grouped under more general headings. It is because to simplify the holistic image and for later make it easy to handle the performance-related facade parameters. The aspects are given in Table 3.1. The excluded aspects are also indicated.

Not all of the publications take the subject as facades. Rich and Dean (1999) discuss it under External Walls Chapter, while Boswell (2013) considers it as exterior building enclosure.

After this performance aspects elimination process, it ends up with the following functional aspects: structural performance, fire performance, water-related performance, air permeability-related performance, thermal performance, moisture-related performance, daylighting performance, and acoustic performance.

Table 3.1 : Performance aspects reviewed, included (red ones) and excluded ones.

No	Performance Aspect	Publications	Headings & Subheadings
1	Structural Performance	Rich & Dean (1999)	-Strength and Stability
		Herzog (2008)	-Movement
2	Fire Performance	Boswell (2013)	-Facade Structure
		Jin (2013)	-Structural
3	Water-related Performance	ITU Seminar (2013)	-Seismic Performance
		Oraklibel (2014)	-Blast Performance
4	Thermal Performance	Rich & Dean (1999)	-Wind Drift
		Herzog (2008)	-Safety (Structural Performance, Blast Resistance)
5	Moisture-related Performance	Boswell (2013)	-Structural Performance
		Jin (2013)	-Structural related Performance
6	Acoustic Performance	ITU Seminar (2013)	-Fire Resistance
		Oraklibel (2014)	-Fire Protection and Smoke Control
7	Lighting Performance	Rich & Dean (1999)	There is no heading.
		Herzog (2008)	-Safety (Fire Protection)
8	Energy Performance	Boswell (2013)	-Fire Safety
		Jin (2013)	-Fire-related Performance
9	Health and Well-being Performance	ITU Seminar (2013)	-Weather Barrier (Rain, Snow)
		Oraklibel (2014)	-Durability
10	Material Performance	Rich & Dean (1999)	-Movement (Frost Action)
		Herzog (2008)	-Facade Structure
11	Environmental Performance	Boswell (2013)	-Weather tightness
		Jin (2013)	-Water Quantities and Directions
12	Security Performance	ITU Seminar (2013)	-Durability (Water Penetration Resistance)
		Oraklibel (2014)	-Control of Rain Water Penetration
13	Accessibility Performance	Rich & Dean (1999)	-Provision of Water Tightness
		Herzog (2008)	-Water-related Performance
14	Life-cycle Performance	Boswell (2013)	-Thermal Performance (Heat Gain, Heat Loss, Condensation Risk)
		Jin (2013)	-Movement (Thermal Movement)
15	Cost Performance	ITU Seminar (2013)	-Thermal Performance
		Oraklibel (2014)	-Sunlight Control
16	Quality Performance	Rich & Dean (1999)	-Temperature Range
		Herzog (2008)	-Air Quantities and Direction
17	Comfort Performance	Boswell (2013)	-Thermal Comfort
		Jin (2013)	-Indoor Environmental Quality
18	Health and Well-being Performance	ITU Seminar (2013)	-Heat Control
		Oraklibel (2014)	-Prevention of Thermal Bridges
19	Material Performance	Rich & Dean (1999)	-Control of Thermal Expansion
		Herzog (2008)	-Thermal Performance
20	Energy Performance	Boswell (2013)	-Thermal Performance (Condensation Risk)
		Jin (2013)	-Movement (Moisture Movement)
21	Health and Well-being Performance	ITU Seminar (2013)	-Rising Damp
		Oraklibel (2014)	-Facade Structure
22	Material Performance	Rich & Dean (1999)	-Water Vapour / Condensation Criteria
		Herzog (2008)	-Moisture Control
23	Energy Performance	Boswell (2013)	-Water Vapour Permeability
		Jin (2013)	-Moisture-related Performance
24	Health and Well-being Performance	ITU Seminar (2013)	
		Oraklibel (2014)	

Table 3.1 (continued) : Performance aspects reviewed, included (red ones) and excluded ones.

No	Performance Aspect	Publications	Headings & Subheadings
6	Daylighting Performance	Rich & Dean (1999) Herzog (2008) Boswell (2013) Jin (2013) ITU Seminar (2013) Oraklibel (2014)	There is no heading. -The Use of Daylight -Energy Efficiency -Visual Comfort -Daylighting Performance
		Rich & Dean (1999) Herzog (2008) Boswell (2013)	There is no heading. -Noise Barrier -Acoustic Performance -Defining Noise / Acoustic Performance Criteria
7	Acoustic Performance	Jin (2013) ITU Seminar (2013) Oraklibel (2014)	-Aural Comfort -Indoor Environmental Quality -Sound Insulation -Sound-related Performance
		Rich & Dean (1999) Boswell (2013) Jin (2013) Oraklibel (2014)	-Weather Barrier (Dirt, Dust, and Pollution) -Air Quantities and Directions -Air Quality -Air, Dust Tightness-related Performance
8	Air, Dust, Tightness-related Performance	Rich & Dean (1999) Herzog (2008) Boswell (2013)	-Durability
		Jin (2013) ITU Seminar (2013)	There is no heading. There is no heading. -Durability (Service Life, Condensation Resistance, Water Penetration Resistance)
9	Durability-related Performance	Oraklibel (2014)	-Durability Durability-related Performance (Chemicals, Biological effects, Mechanical Wearing Color Fading, Corrosion, High & Low Temperature, etc.)
		Rich & Dean (1999) Herzog (2008) Boswell (2013) Jin (2013) ITU Seminar (2013) Oraklibel (2014) Rich & Dean (1999) Herzog (2008) Boswell (2013) Jin (2013) ITU Seminar (2013)	There is no heading. There is no heading. -Energy Efficiency There is no heading. There is no heading. There is no heading. There is no heading. There is no heading. There is no heading. -Emissions There is no heading.
10	Energy Performance	Oraklibel (2014)	-Environmental Impact-related Performance (Harmful Emissions, Low Production Energy, Recyclable, Recycled, Renewable, Low Transportation Energy)
		Rich & Dean (1999) Herzog (2008) Boswell (2013) Jin (2013) ITU Seminar (2013)	-Inspection & Maintenance -Hygiene-related Performance
11	Environmental Impact-related Performance	Oraklibel (2014)	
		Rich & Dean (1999) Oraklibel (2014)	
12	Hygiene-related Performance	Rich & Dean (1999) Oraklibel (2014)	

Table 3.1 (continued) : Performance aspects reviewed, included (red ones) and excluded ones.

No	Performance Aspect	Publications	Headings & Subheadings
13	Optic-related Performance	Rich & Dean (1999) Boswell (2013) Oraklibel (2014)	-Weather Barrier (Sun) -Sunlight Control -Optic-related Performance
14	Maintenance, Repair-related Performance	Rich & Dean (1999) Oraklibel (2014)	-Inspection & Maintenance -Maintenance, Repair-related Performance
15	Movements-related Performance	Rich & Dean (1999) Boswell (2013) ITU Seminar (2013) Oraklibel (2014)	-Movement (Structural, Moisture, Chemical Action, Frost Action) -System and Structure Movements -Structural and Thermal Movements -Movements-related Performance
16	Cost-related Performance	Jin (2013) Oraklibel (2014)	-Economic Cost -Cost-related Performance
17	Security-related Performance	Rich & Dean (1999)	-Security
18	Pest Infestation	Rich & Dean (1999) Rich & Dean (1999)	-Pest Infestation -Construction
19	Feasibility-related Performance	Oraklibel (2014)	-Feasibility-related Performance (Easy to Assemble, Place, Transport, etc.)
20	Integrability	Oraklibel (2014)	-Integrability

Performance criteria and corresponding indicators (performance metrics) need to be explored to assess facade performance. They are available in the literature and designated by standards, regulations, codes, etc. Performance criteria may change according to conditions like building function or climate type. Required performance levels vary with these conditions, as well.

Similarly, indicators of financial aspects are listed. The below Table (3.2.) is taken from the thesis of Jin (2013) since this aspect, and its indicators are out of the scope. Indicators cover all life-cycle cost including initial capital cost, maintenance cost, operational energy cost, indoor environmental quality (IEQ) cost due to occupant productivity loss, replacement cost, and disposal cost. Production, transportation, and installation are the reasons for the initial capital cost. Cleaning strategies define the maintenance cost. All kind of energy demands like lighting, heating, cooling, equipment plus cost of the unit of energy determines the operational energy cost. The IEQ cost is due to the combination of satisfaction with IEQ and occupants' salary. The frequency of replacement defines the replacement cost while the sum of demolition, transportation, and disposal define the disposal cost.

Table 3.2 : Financial aspects and indicators (Jin, 2013).

Aspect	Impact Factors	Indicators (larger/ smaller values are preferable)
Economic Cost	▪ Production ▪ Transportation ▪ Installation	Initial Capital Cost (smaller)
	▪ Cleaning Strategies ▪ Lighting Energy Demand ▪ Heating Energy Demand	Maintenance Cost (smaller)
	▪ Cooling Energy Demand ▪ Equipment Energy Demand ▪ Cost of Unit of Energy	Operational Energy Cost (smaller)
	▪ Satisfaction with IEQ ▪ Occupants' Salary ▪ Frequency of Displacement	IEQ Cost due to Occupant Productivity Loss (smaller) Replacement Cost (smaller)
	▪ Demolition ▪ Transportation ▪ Disposal	Disposal Cost (smaller)

Ecological aspects and indicators are listed in the below Table (3.3). Ecological indicators are embodied energy, non-renewable energy, global warming potential, acidification potential, and photosmog. There are two separate ecological aspects as input and emissions. Embodied energy and non-renewable energy are related to the input aspect, while the rest indicators are to emissions.

Table 3.3 : Ecological aspects and indicators (Jin, 2013).

Aspects	Impact Factors	Indicators (larger/ smaller values are preferable)
Input	▪ The Energy required to Create 1kg of Material / Product	Embodied Energy (smaller)
	▪ Total Non-Renewable Energy: Embodied Energy and Energy Used for Production, Transportation, Maintenance, and Elimination (MJ)	Non-Renewable Energy (smaller)
Emissions	▪ Gas Emissions responsible for the Global Warming Process (g or kg eq. CO₂)	Global Warming Potential (smaller)
	▪ Gas Emissions responsible for the Acidification (g or kg eq. SO_x)	Acidification Potential (smaller)
	▪ Photochemical Ozone Production Process (g or kg eq. C₂H₄)	Photosmog (smaller)

3.1.1 Agents

Agents facades are exposed to are given for each functional performance aspect.

1. Structural performance: wind loads, impact loads, thermal expansion, and movements related loads, earthquake loads.

2. Fire performance: fire, smoke, heat, wind.
3. Water-related performance: rain water, snow water, wind (wind-driven rain).
4. Air permeability-related performance: air movement (air pressure difference), wind.
5. Thermal performance: heat, solar radiation, indoor-outdoor temperature difference.
6. Moisture-related performance: water vapour, temperature difference, vapour pressure difference.
7. Daylighting performance: skylight, sunlight.
8. Acoustics performance: airborne sound, noise, vibration.

3.1.2 Requirements

As being the interface between outdoor and indoor conditions, facades need to fulfill various performance requirements in accordance with user needs and in response to outdoor agents (Fig.3.1). These requirements are described below for each functional performance aspect.

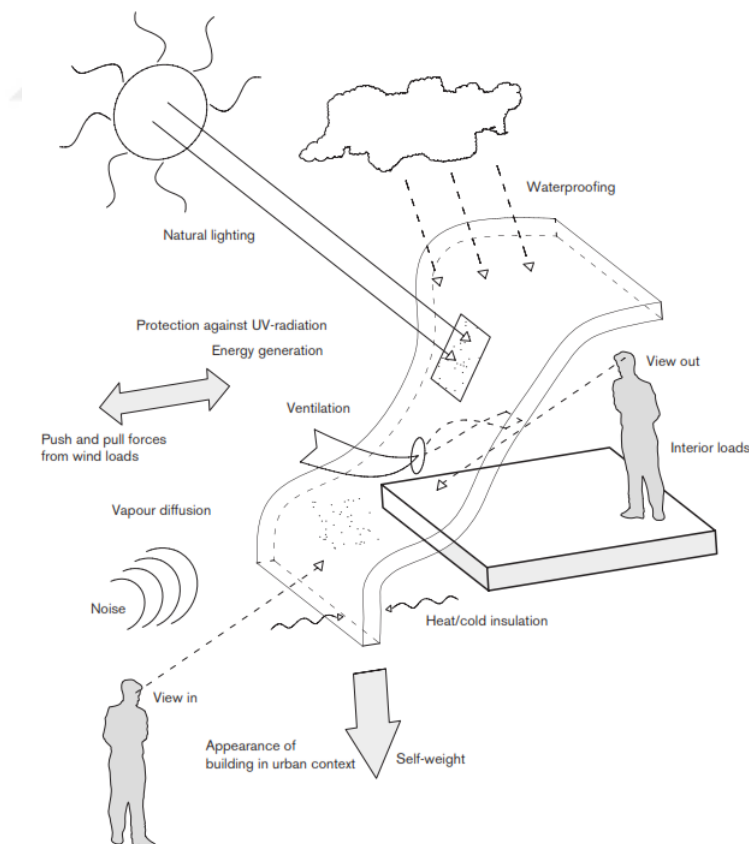


Figure 3.1 : Facades need to fulfill various performance requirements (Knaack, 2007).

1. Structural performance: A facade should not collapse and remain standing safely under possible load combinations; in other words, a facade should maintain its stability. A facade should be as light as possible to transfer less loads to the building structure unless extreme climatic conditions need it (Çelik, 2013 ; Herzog, 2008 ; Rich and Dean, 1999).
2. Fire performance: A facade should provide fire resistance for a length of time. A facade should limit the spread of fire and smoke. A facade should not cause fire with its components. A facade should prevent fire spread. A facade should protect from fire spread risk that can be caused by winds. A facade should contribute to fire escape (Özgünler, 2013 ; Türkeri, 2013 ; Jin, 2013 ; Herzog, 2008 ; Rich and Dean, 1999).
3. Water-related performance: A facade should prevent water penetration to the building. A facade should resist wind-driven rain forces (Türkeri, 2013).
4. Air permeability-related performance: A facade should prevent energy loss through air flow (Ramachandran, 2004).
5. Thermal performance: A facade should utilize or protect from solar radiation and/or winds when needed for optimum thermal comfort. A facade should provide thermal insulation. A facade should prevent energy losses and contribute to indoor thermal comfort. A facade should protect the indoors from the effects of low temperatures. A facade should avoid thermal bridges. A facade should utilize from solar energy (Grondzik, 2010 ; Koçlar Oral, 2013 ; Türkeri, 2013 ; Guardian, 2013 ; Sezer, 2005 ; Rich and Dean, 1999 ; Oraklıbel, 2014).
6. Moisture-related performance: A facade should control condensation. A facade should prevent moisture from passing through the facade (wind-driven rain is a major source of moisture). A facade should contribute to indoor comfort and long-lasting building (Altun, 2013 ; Oraklıbel, 2014).
7. Daylighting performance: A facade should provide proper daylight (both in quantity & quality). A facade should benefit from daylight for illumination (contribute to energy conservation). A facade should provide uniform daylighting. A facade should control glare. A facade should provide an optimum view out and contribute to occupants' wellbeing (Yener, 2013 ; Sezer, 2005 ; LBNL, 2013 ; Şener Yılmaz, 2016 ; Kutlu, 2008).

8. Acoustics performance: A facade should protect from noise. A facade should provide direct airborne sound insulation. A facade should reduce flanking sound transmission (Boswell, 2013 ; Tamer Bayazit, 2013 ; Jin, 2013 ; Guardian, 2013 ; Tamer Bayazit and Demir, 2016).

3.1.3 Indicators

Performance indicators (metrics) are listed below for each functional performance aspect.

1. Structural performance: wind resistance, impact resistance, thermal expansion and movements related resistance, and earthquake resistance. Higher the resistance better the performance. Lighter is better for earthquake resistance.

2. Fire performance: fire resistance REI (load-bearing, integrity, insulation), fire class (A, B, C, D, E, s1, s2, s3, d0, d1, d2) of materials, fire class (K1, K2) of claddings. Higher resistance and A, s1, d0, K1 classes are the best.

3. Water-related performance: water tightness (permeability), rate of leakage (classes of R4, R5, R6, R7, RE). Higher the tightness or lower the rate of leakage better the performance.

4. Air permeability-related performance: airtightness (permeability), rate of air leakage (classes of A1, A2, A3, A4, AE). Higher the tightness or lower the rate of air leakage better the performance.

5. Thermal performance: U-value (overall heat transfer coefficient), thermal bridging, heat capacity/ specific heat, solar heat gain coefficient (SHGC) or shading coefficient (SC) of glazing. Lower the U-value better the insulation performance. The absence of thermal bridge is preferable. The rest of the indicators can be better or worse depending on the conditions.

6. Moisture-related performance: a flow of water vapour through facade layers without any condensation, control of water vapour before reaching dew point, drainage of condensed water vapour at potential points, natural ventilation. Natural ventilation contributes to reducing the moisture content, so the condensation risk.

7. Daylighting performance: daylight factor, daylight distribution, daylight glare probability, visible transmittance (VT) of glazing, glare control, view. In no condition, glare is desirable. Rest of the parameters need to be optimized for the conditions.

8. Acoustics performance: sound reduction index (SRI) or sound transmission class (STC), airtightness. Higher the SRI or the STC better the insulation performance. Higher the tightness better the performance.

3.2 Performance Criteria

Performance criteria may change depending on various conditions like climate type or building typology. It may also vary by standards and regulations of different countries, even of local authorities. More detailed information is given in the following Sections.

3.2.1 Structural performance

To determine structural performance (evaluation) criteria for a facade, conditions having influences on facades need to be known. These can be environmental and/ or building/ space-related conditions. Environmental conditions are particularly earthquake and wind loads that facades are exposed to, and the angle between wind direction and facade plane while building/ space-related conditions are building geometry (has effects on wind behaviour) and building height (wind effect increases as it gets higher). These are essential for the evaluation of facade structural performance.

The first criterion can be to let facades be exposed to less wind loads by not orientating them in the direction of predominant winds. In the direction of the winds, facades are exposed to both pressure and suction forces. However, for this criterion, there should be a dominance among winds; otherwise, it does not make any sense. Perpendicular directions can be assumed to be the most protected orientation options. Moreover, if the exposed wind speed is high, or the building is high-rise, then it becomes more critical to orientate the facade towards the most wind-protected directions (Khallaf and Jupp, 2017 ; Vongsingha, 2015 ; Çelik, 2013 ; Krem, et al., 2013 ; Krem, 2012 ; Herzog, 2008 ; Rich and Dean, 1999).

In earthquake zones, it is important to pay attention to transparency ratios in order to provide higher stability. So, the criteria can be to avoid high transparency ratios. Besides, if the facade is in the direction of predominant winds, then this criterion becomes more critical (Arnold, 2016 ; Doulkari, 2013).

The criteria for the determination of facade systems can be conditional, as well. If the facade is exposed to high-speed wind conditions, there needs to have heavier (more massive) facade systems. On the other hand, for the conditions other than that, lighter systems are desirable to transfer as less loads as possible to the building structure. Importance of these criteria increases as the facade is in an earthquake zone, or the building is a high-rise one (Hermann et al., 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; Boswell, 2013 ; Aksamija, 2013 ; Toydemir, et al., 2011 ; Knaack, et al, 2007 ; Schititch, 2006 ; Url-14). Similarly, in high transparency ratios, glazing becomes more important. In this case, single-layer glazings can be advantageous in terms of providing lighter systems (system components) whereas the triple ones are the most disadvantageous. (Bao, 2014 ; Guardian, 2013 ; Bennison, et al., 2008 ; Bennison, et al., 2002 ; Url-13).

3.2.2 Fire performance

Conditions having influences on fire performance are wind, building/ space type, building height, number of floors, and space location. These change the criteria for facade fire performance.

Facades are responsible for fire spread risk that can be caused by winds. So, the first criterion for fire performance can be to protect facades from predominant winds if there is dominance among winds. It can be possible with facade orientation. Building/ space types have different fire safety requirements that can be found in regulations. For instance, educational or medical facilities generally have high-safety requirements. In addition to this, high-speed winds increase fire spread risks. Both of them make that (protection from wind) criterion much more critical (Fitzgerald, 2017 ; Park, 2014 ; Özgünler, 2013 ; O'Connor, 2008 ; Fitzgerald, 2004 ; Rich and Dean, 1999).

In multi-storey buildings, lower transparency ratios (smaller share for glazed parts) are better for providing fire protection since they prevent fire spread between adjacent spaces with the help of opaque parapet walls. The importance of this criterion can increase with safety requirements and building height (for high-rise buildings) (Rukavina, et al., 2017 ; Giraldo, et al., 2012). The building height is defined by the number of floors instead of a metrical scale. It is preferred to keep the conditions simple as high-rise and low-rise. This may not match with some of the standards, but

does match with the scope of the tool. So, specific conditions need to be interpreted within this context.

Special fire protection measures need to be taken for some facade types like double-skin facades. As a type of double-skin facades, the second-skin type, particularly needs special precautions like fire stops. In any condition, continuous gaps/ cavities which contain fire spread risks need to be avoided. Compartmentalization is important in fire protection. In other types of double-skin facades, some divisions are provided, however in second-skin type, neither horizontal nor vertical separation is provided. Again, if the building/ space has high safety requirements or if it is a high-rise building, then criticality increases (İnan and Başaran, 2014).

Facades having operable windows can be desirable for single-storey buildings. It can be a criterion for this kind of buildings to have access to outdoors through facades in case of emergency. So, it becomes essential for facades to enable fire-escape. (Rukavina, et al., 2017 ; Giraldo, et al., 2012 ; Kılıç and Beceren, 1999 ; Url-14).

In any condition, non-combustible, or at least limited combustible and no flashover materials need to be used in all components of facade systems. Although facade claddings come first in importance, the rest of the components need to be paid attention.

Some of the insulation products especially the ones composed of polystyrene foams are combustible. Their use needs to be avoided particularly in ventilated facade systems.

Non-combustible materials are defined with one of the following fire classes: A1, A2-s1 d0, A2-s2, d0, A2-s3, d0, A2-s1 d1, A2-s2, d1, A2-s3, d1, A2-s1 d2, A2-s2, d2, A2-s3, d2. A represents the combustibility of the material while s and d are for smoke propagation and flaming droplets and particles, respectively. The smaller the number, the better the fire performance like a little or no smoke (s1) and no flaming droplets and particles (d0). Components of facade systems need to be of among these materials. (TS EN 13501-1). Moreover, in the selection of materials and components, fire resistance properties that are defined in time units (in minutes) need to be taken into consideration. Required fire resistance properties change with project, conditions, etc. (Demirel and Altındaş, 2005). It becomes more critical for buildings having high safety

requirements and for high-rise buildings (Rukavina, et al., 2017 ; Nguyen, et al., 2016 ; Uslu, 2013 ; Url-15).

In multi-storey buildings, to have horizontal projections (assuming that they are of fire-resistant materials) among floors is another criterion for facade fire performance. It can be provided by either recessed windows or horizontal shading elements. In high safety conditions or for high-rise buildings, this criterion becomes more of an issue (Rukavina, et al., 2017 ; Nilson, 2016 ; Fu, et al., 2015 ; Giraldo, et al., 2012 ; Bong, 2000 ; Kılıç and Beceren, 1999).

3.2.3 Water-related performance

Conditions in relation to water-related performance are rainfall, wind loads (direction and speed) and building height. Forces that cause rain penetration through gaps in facades are illustrated in Fig. 3.1. They are kinetic, capillary, gravity, air flow, wind pressure, and the combination of wind pressure and capillary.

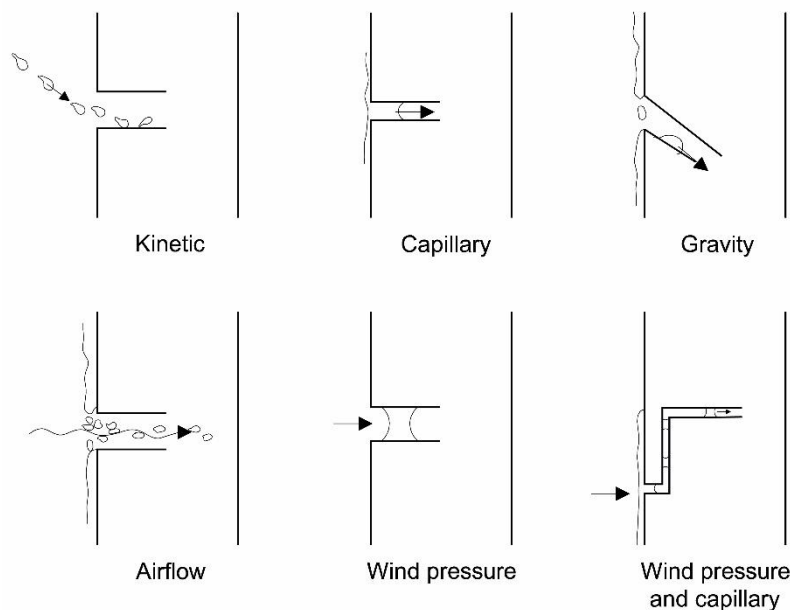


Figure 3.2 : Forces that cause rain penetration through gaps (Aksamija, 2013).

Wind-driven rain which is the rain driven by the wind is the primary source of water and moisture for the building. That is the reason why lower wind-driven rain loads are desirable in buildings. The first criterion for facade water-related performance can be to orient the facade towards any direction other than predominant wind directions if there is dominance among winds and if there is a considerable amount of annual rainfall (components of wind-driven rain). The criticality of the criterion increases if

it is a high-rise building or if the wind speed is high. Building height is critical since wind speed tends to increase with height, so the wind loads on the facade. (Gao, et al., 2017 ; Olsson, 2017 ; Künzel, 2015 ; Blocken & Carmeliet, 2015 ; Blocken, et al., 2013 ; Blocken et al., 2009 ; Türkeri, 2013 ; Gudum, 2003 ; Beall, 2000 ; Rich and Dean, 1999 ; Url-16).

If there is a higher risk of wind-driven rain penetration (a considerable amount of rainfall and exposure to predominant wind directions), higher protection is required. Double-skin facades, when compared to single-skin facades, offer a higher degree of protection against water with their second skin glass layers and gaps between two skins. If it is a high-rise building or wind speed is high, then this second-skin criterion becomes more important (Hermann, et al., 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; Boswell, 2013 ; Aksamija, 2013 ; ASHRAE, 2011 ; Carrie, et al., 2012 ; Toydemir, et al., 2011 ; Herzog, 2008 ; Knaack, et al., 2007 ; Schititch, 2006). Similarly, for wall configuration, to have water check layers in addition to water barrier layers provide an advantage in terms of weather protection. For instance, cavity walls offer two levels of defense as well as allow greater tolerances in materials and workmanship when compared to other types of wall systems (Fig. 3.3). Therefore, these systems are more reliable for water protection (Rich and Dean, 1999). Besides, if the exposed wind speed is high, then the water penetration risk increases and this criterion becomes more crucial.

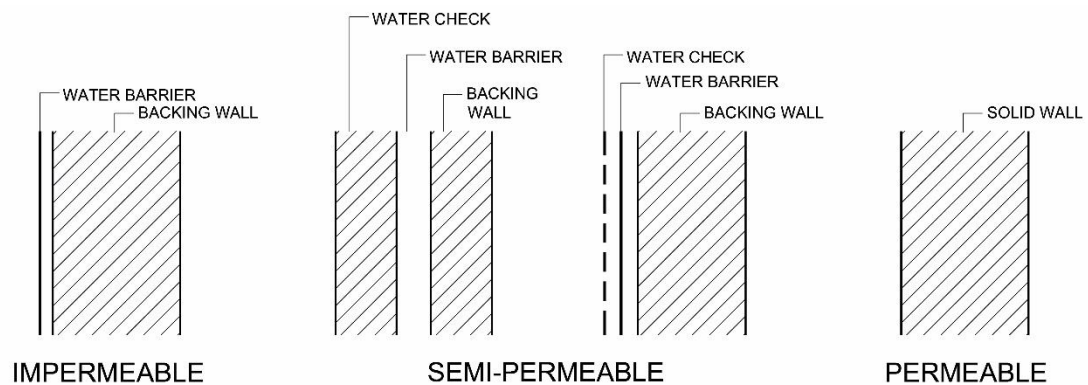


Figure 3.3 : Wall types according to water permeability (Rich and Dean, 1999).

In conditions that have a considerable amount of rainfall, to take additional measures can be a criterion to prevent water penetration through the facade. Horizontal projections and/ or recessed windows can serve for this purpose. In high-rise buildings and/ or for facades oriented towards predominant wind directions, the criterion becomes a lot more important (Chiu et al., 2015 ; Rich and Dean, 1999 ; Givoni, 1998).

3.2.4 Air permeability related performance

Air permeability related facade performance evaluation criteria depend on wind conditions, climate, and building height. Air flow (infiltration) through facade can cause energy loss. This air flow can be increased by wind loads. It is the reason why lower wind loads are desirable. In the first step, facades can be oriented towards more wind-protected directions if there is dominance among winds or if it is a temperate or hot climate. Because in cold climates, air flow is driven mostly by the temperature difference, not by wind effect. In high-rise buildings or in high speed wind conditions, the effect of wind increases, so the importance of this criterion (Vongsingha, 2015 ; Krem, et al., 2013 ; Krem, 2012 ; ASHRAE, 2011 ; Berge, 2011 ; Gudum, 2003 ; Rich and Dean, 1999 ; Forest, 1989 ; Wilson and Dale, 1985 ; Yu-Shaw, 1981 ; Shaw, 1980).

Similar to the water-related performance, for facades oriented towards predominant wind directions that need higher protection against air flow, double-skin facade types are more advantageous due to their additional protection layers (second skin). Again, in high-rise buildings and high speed wind conditions, criticality increases (Hermann, et al. 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; Boswell, 2013 ; Aksamija, 2013 ; Carrie, et al., 2012 ; ASHRAE, 2011 ; Toydemir, et al., 2011 ; Herzog, 2008 ; Knaack, et al., 2007 ; Schititch, 2006).

3.2.5 Thermal performance

Conditions to determine thermal performance (evaluation) criteria are the location (on the globe), climate type, diurnal temperature range, wind conditions (direction, speed, period), building height, space function, and space occupation period.

Thermal performance criteria basically change with location and climate. Northern and Southern Hemispheres have entirely different criteria. Southern Hemisphere is kept out of the scope of this thesis, so all the following descriptions are related to Northern Hemisphere conditions. In cold climates, the criteria are to utilize solar radiation and to protect from wind exposure as much as possible. In temperate-arid climates, the criteria are the same as the cold climates. On the other side, in temperate-humid climates, to utilize from solar radiation as much as possible and to protect from winds except for the cooling seasons are the performance criteria. In hot climates, optimum solar radiation is required (considering the overheating potential), however in hot-arid climates, it is needed to protect from winds while in hot-humid climates, wind

exposure is desirable for reducing humidity and contributing to comfort. For achieving the above criteria, orientation is the essential step. Southern directions (south, southeast, southwest) are the most proper orientations for utilization of solar radiation. In hot climates, where solar radiation exposure needs to be optimized, just south direction can be considered as the proper orientation. Because solar radiation in southeast and southwest directions (with turning half of their faces towards east and west) can be hard to control, as east and west orientations provide low-angle solar radiation that carries the potential risks for overheating indoors in mornings and afternoons, respectively. Northern orientations are not desirable for not receiving direct solar radiation in cold and temperate climates but can be less than ideal for hot climates. In addition to these, orientations need to be checked whether they are in the directions of the predominant winds. Then, relevant adjustments can be done accordingly. The space occupation period is also determinative for the criteria. For example, if the major occupation period is in Winters, then the criterion of orientating facades towards southern directions in cold climates gains much more importance. Or, again in cold climates, if predominant winds are in northern directions, then to protect from wind exposure becomes more of an issue (Halawa, et al., 2018 ; Dutta, et al., 2017 ; Natee, et al., 2016 ; Ibrahim, et al., 2016 ; Muhaisen and Dabboor, 2015 ; Aksamija, 2013 ; Kontoleon, 2013 ; Habibi, 2012 ; Abed, 2012 ; Al-Tamimi, et al., 2011 ; Herzog, 2008 ; Liping and Hien, 2006 ; Nayak and Prajapati, 2006 ; Koçlar Oral, 2013 ; Rosenlund, 2000 ; Rich and Dean, 1999 ; Gut and Ackerknecht, 1993 ; Givoni, 1976 ; Olgyay, 1963).

After orientation, there are interrelating facade parameters that need to be specified according to the orientation of the facade. In cold and temperate climates, if the facade is oriented towards northern directions, then the lowest transparency ratios need to be preferred. If it is oriented towards the rest of the directions, average transparency ratios, that balance solar radiation utilization and overheating risk reduction, can be considered to provide the optimum. On the other hand, in hot climates, in southern orientations, lower transparency ratios need to be preferred, whereas, in northern orientations, a bit more transparent facades can be acceptable. However, in hot climates, east and west orientations need to be avoided (Alwetaishi, 2017 ; Amaral, et al., 2016 ; Leonidaki, et al., 2014 ; Ghiai, et al., 2014 ; Lee, et al., 2013 ; Carmody and

Haglund, 2012 ; Rathi, 2012 ; Al-Tamimi, 2011 ; Yıldız, et al., 2011 ; Su and Zhang, 2010 ; Abdou and Elhinawy, 2007 ; Yellamraju, 2004 ; Bouchlaghem, 2000).

Another important criterion is to select facade systems and components considering their thermal conductivity and thermal storage properties in conformity with climatic conditions. In cold and hot-arid climates (they show similarities in that sense), lower thermal conductivity and higher thermal storage properties are required. If diurnal temperature variation is high, then satisfying this criterion becomes more critical. In hot and humid climates, lower thermal conductivity and lower thermal storage properties are desirable while in temperate climates, optimum properties for both of the parameters need to be preferred. To give an example; single-skin window facades or curtain walls have low thermal storage capacities and high thermal conductivities due to their relatively thin structures. On the other side, masonry or concrete structures because of their high densities have high capabilities to store heat within themselves (Lee, 2016 ; Hermann et al., 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; İnan and Başaran, 2014 ; Boswell, 2013 ; Aksamija, 2013 ; Toydemir, et al., 2011 ; Alakavuk, 2020 ; Haase and Amato, 2009 ; Haase, et al., 2009 ; Chou, et al., 2009 ; Herzog, 2008 ; Knaack, et al., 2007 ; Schititch, 2006 ; Gut and Ackerknecht, 1993).

In some conditions, especially combinations of certain climates and facade orientations (such as in hot climates and south oriented facades), additional measures are required in order to be protected from overheating effects of solar radiation. In such cases, to provide natural ventilation or to have elements/ components for shading the solar radiation can contribute to comfort indoors. If the major occupation period is cooling seasons, then these measures become highly critical. On the other hand, unnecessary measures can cause performance reduction; therefore the criteria are valid for the conditions having overheating potential (Al-Tamimi, et al., 2011 ; Gut and Ackerknecht, 1993).

One of the essential criteria for thermal performance is to provide proper thermal insulation. It needs to be considered separately for transparent and opaque parts of the facades. The criteria for transparent parts are about insulation and solar heat gain properties of glazings (Fig. 3.4). It has been shown that SHGC dominates a building's energy consumption in warm climates while U-factor plays a key role in cold climates (Seok, et al., 2009). In cold and hot climates, there needs to have higher insulation, but in cold climates, optimum solar heat gain properties are preferred while in hot climates

to have lower solar heat gain is better. In temperate climates, optimum insulation and lower solar heat gain properties are required. In addition to all these, facade orientations and transparency ratios can make the criteria more critical. Required performance levels can be achieved by changing number, thickness, and color of glass panes, infill gas type and thickness, and by applying special coatings on glass panes (Cellai, et al., 2014 ; Carmody and Haglund, 2012).

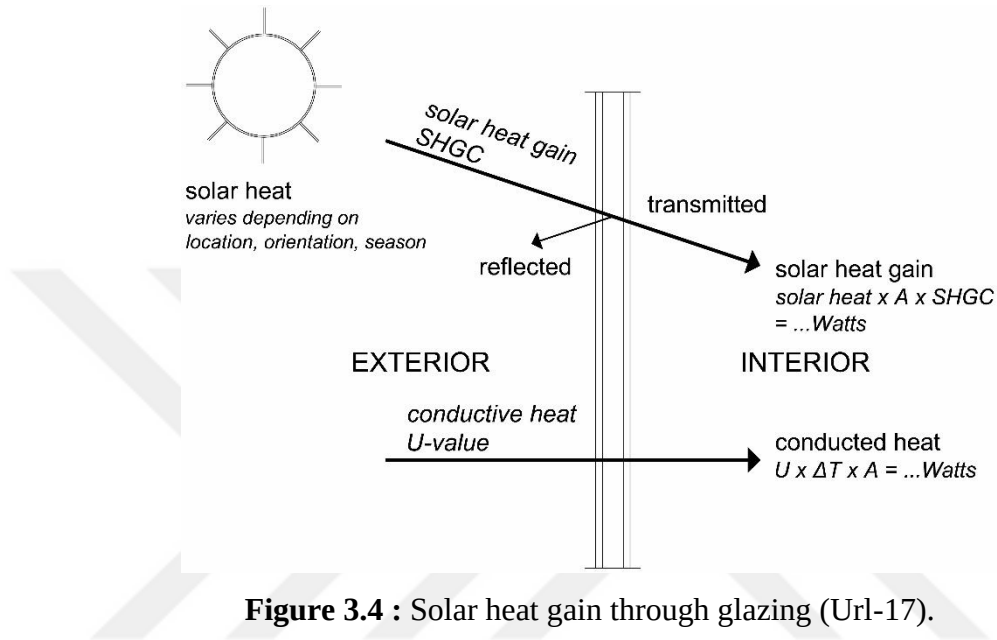


Figure 3.4 : Solar heat gain through glazing (Url-17).

In opaque parts, the criterion is to provide insulation through wall configurations. As including cavities, semi-permeable wall types offer higher insulation when compared to impermeable walls with similar components. Moreover, to have the insulation at the outer side of the wall provides the most effective thermal performance. Increasing thickness either for a cavity or for an insulation contributes positively to thermal performance (Al-Sanea and Zedan, 2011 ; Boostani and Mirzapour, 2015).

Equation 3.1 gives the calculation method for U-value of an opaque wall. As seen in the equation, the overall heat transfer coefficient of a component depends on the thermal conductivity and thickness of its layers. The lower the U-value, the higher the thermal resistance and the insulating performance. Thermal properties of materials need to be taken into consideration to provide the required insulation.

$$U = 1 / R_T = 1 / (R_{se} + d_1 / \lambda_1 + d_2 / \lambda_2 + \dots + R_{si})$$

U: heat transfer coefficient, $W / K \cdot m^2$

R_T: thermal resistance, $K \cdot m^2 / W$

R_{se}: thermal resistance of exterior surface, $K \cdot m^2 / W$

R_{si}: thermal resistance of interior surface, $K \cdot m^2 / W$

d: thickness of the layer, *m*

λ: specific thermal conductivity of the layer, $W / K \cdot m$

d / λ: thermal resistance of the layer, $K \cdot m^2 / W$

(3.1)

Apart from all these, there can be a need for shading depending on the orientations. In south-oriented facades, horizontal elements are preferred while in east and west oriented facades vertical elements are preferable. In higher transparency ratios, to have a shading element can become more important (Prowler, 2016 ; Cellai, et al., 2014 ; Givoni, 1998).

3.2.6 Moisture related performance

Conditions that determine moisture related facade performance (evaluation) criteria are location, climate type, wind conditions (direction and speed), building height, space function, and space occupation period.

Since wind-driven rain is the primary source of moisture, to protect from wind-driven rain loads can be the first criterion for moisture-related facade performance. Protection from wind can be possible with facade orientation if there is dominance among winds. However, for this criterion, there also needs to be a considerable amount of rainfall since it is the other component of wind-driven rain. In cases of wind-driven rain loads, wind-protected orientations are more advantageous in terms of moisture-related performance. As wind loads increase with height and wind speed, in high-rise buildings and in high-speed wind conditions, this criterion becomes more important (Binder, 2014 ; Altun, 2013 ; Toydemir, 2011 ; Nielsen et al., 2011 ; Abuku, et al., 2009 ; Künzel, et al., 2008 ; Künzel and Zirkelbach, 2008 ; Gudum, 2003 ; Rich and Dean, 1999 ; Forest, 1989).

Moisture related performance criteria have some similarities with water-related performance and thermal performance criteria. Double-skin facades offer a higher degree of protection against water with their additional layers when compared to single-skin facades. Building height and wind speed conditions change criticality of this criterion (Hermann, et al., 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; İnan and

Başaran, 2014 ; Boswell, 2013 ; Aksamija, 2013 ; Toydemir, et al., 2011 ; Herzog, 2008 ; Knaack, et al., 2007 ; Schititch, 2006 ; Gut and Ackerknecht, 1993).

Natural ventilation contributes to the reduction of condensation risk. In cold, temperate-arid, and hot-arid climates, in any of the cases, operable windows are desirable in terms of moisture performance. In humid climates (both temperate and hot), natural ventilation is preferred in most cases except for spaces that generate high levels of moisture such as kitchens or bathrooms. This criterion becomes highly important for spaces occupied all throughout the day (Seppanen and Kurnitski, 2009).

To provide insulation both in transparent and opaque parts of the facade is another criterion for moisture-related performance. In transparent parts, increasing number and/ or thickness of glass panes, or filling the cavity between glass panes with low-density gases, or increasing thickness of the cavity can contribute to insulation levels. It becomes much more important if the facade is oriented towards northern directions or if it has high transparency ratios (Carmody and Haglund, 2012 ; Bülow-Hübe, 2001). In opaque parts, semi-permeable walls are better for providing insulation and preventing condensation risk due to their air cavities. Besides, when applied at the outer side, thermal insulation performs better. Therefore, semi-permeable walls and wall configurations having thermal insulation at the outer side are preferable to provide higher insulation (Al-Sanea and Zedan, 2011 ; Boostani and Mirzapour, 2015).

3.2.7 Daylighting performance

Facade daylighting performance (evaluation) criteria need to be defined according to the location (hemisphere and latitude), surrounding obstacles and surfaces, space function, space occupation period, space proportions, and interior surfaces.

Northern and Southern Hemispheres have completely different daylighting criteria. Besides the hemisphere, distance from the Equator, or in other words, the latitude has a determinative effect on performance. Southern Hemisphere conditions are kept out of the scope of the thesis, so the following descriptions are for Northern Hemisphere conditions.

Daylight factor which is a ratio between indoor (at any point, generally at work plane height) and outdoor (unobstructed) horizontal illuminance levels can be considered as the main indicator of facade daylighting performance. It indicates at what rate building (facade) uses of available daylight.

Components of the daylight factor are illustrated in Fig. 3.5. They are sky component (SC), externally reflected component (ERC), and internally reflected component (IRC). As seen in the figure, the sky component is the diffuse light coming from the sky. The daylight factor assumes that the sky is overcast and excludes direct sunlight. The externally reflected component is related to the surrounding surfaces (ground) and physical obstacles (adjacent buildings), while the internally reflected component is associated with space proportions and interior surfaces (light reflectances).

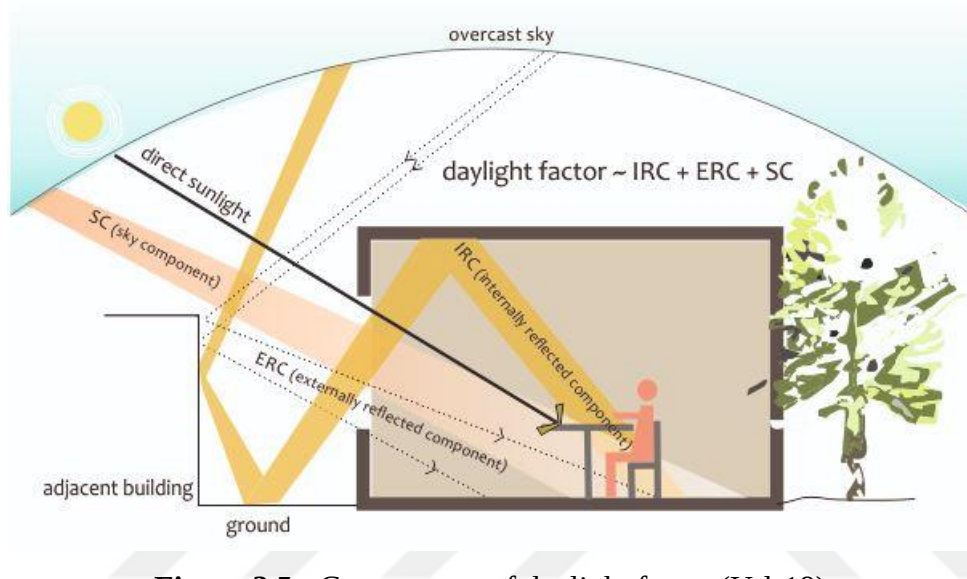


Figure 3.5 : Components of daylight factor (Url-19).

Daylight factor (DF) is a static metric and insensitive to location, climate, and orientation. Although there are dynamic daylight availability metrics like daylight autonomy (DA) and useful daylight illumination (UDI), as being less complex and easily integrated into the design process at the early stages, the daylight factor is the most preferred metric for daylighting performance.

BS 8206 recommends an average daylight factor of 2% and states that if it is at least 5% in space, there is no need for electric lighting during the daytime. BREEAM rating system asks for an average daylight factor of 4% in single-storey and 3% in multi-storey buildings to give 2 credits. The average daylight factor indicates the likely daylight appearance of a space in cloudy climates (Url-20).

The average daylight factor is calculated by the equation given in 3.2 (Url-20). The visible sky angle is illustrated in Fig. 3.6. Facade related parameters that affect the average daylight factor are the transparency ratio and transmittance of glazing. These

parameters need to be determined according to surrounding obstacles and interior surfaces (total area and mean reflectance).

$$D = (A_g \cdot \theta \cdot T) / A (1-R^2)$$

D: average daylight factor

A_g: glazed area of windows (not including window frames, etc.)

θ: angle of visible sky

T: transmittance of glazing to diffuse light including the effect of dirt

A: total area of interior surfaces

R: mean reflectance of interior surfaces

(3.2)

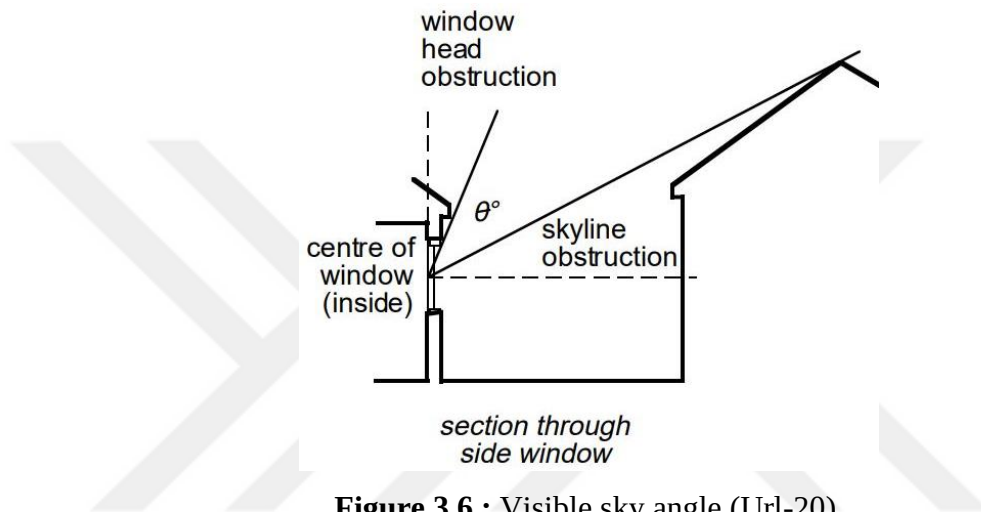


Figure 3.6 : Visible sky angle (Url-20).

Sunlight angles change with location (hemisphere and latitude). Besides, daily (morning, noon, afternoon) and seasonal variations in sun angles need to be considered in relation to space occupation periods.

Sun angles in Winter, Summer, and Equinox are illustrated in Fig. 3.7. Low angle sunlight can cause glare, while sunlight coming in higher angles have limited access to deep indoors.

Required daylighting performance can be to maximize daylight levels or to provide uniform light all throughout the day. Depending on the required performance, daylighting criteria may change. Southern directions provide a maximum amount of daylight while northern orientations have a more uniform daylight distribution throughout the day. However, in high latitudes, southern orientations have glare potential; in this case, north orientation can be preferable. East and west directions provide high levels of daylight; however, due to their low angle sunlight, these orientations face glare problems. In addition to these, the orientations need to be

reconsidered according to surrounding obstacles, which can lower the visible sky angle. Therefore, facade orientation needs to be optimized based on either condition. These criteria become even more critical if space requires high illuminance levels. (Saha, et al., 2017 ; BS EN 17037, 2016 ; Natee, et al., 2016 ; Fernandez, et al., 2016 ; Mahdavi, et al., 2015 ; Velux, 2014 ; Bourekri, 2014 ; Jovanovic, et al., 2014 ; Munoz, et al., 2013 ; Köknel Yener, 2013 ; Aksamija, 2013 ; Habibi, 2012 ; Carmody and Haglund, 2012 ; Lovell, 2010 ; Reinhart, et al., 2006 ; Koçlar Oral, et al., 2004 ; Ruck, et al., 2000 ; CIBSE, 1999 ; Url-21).

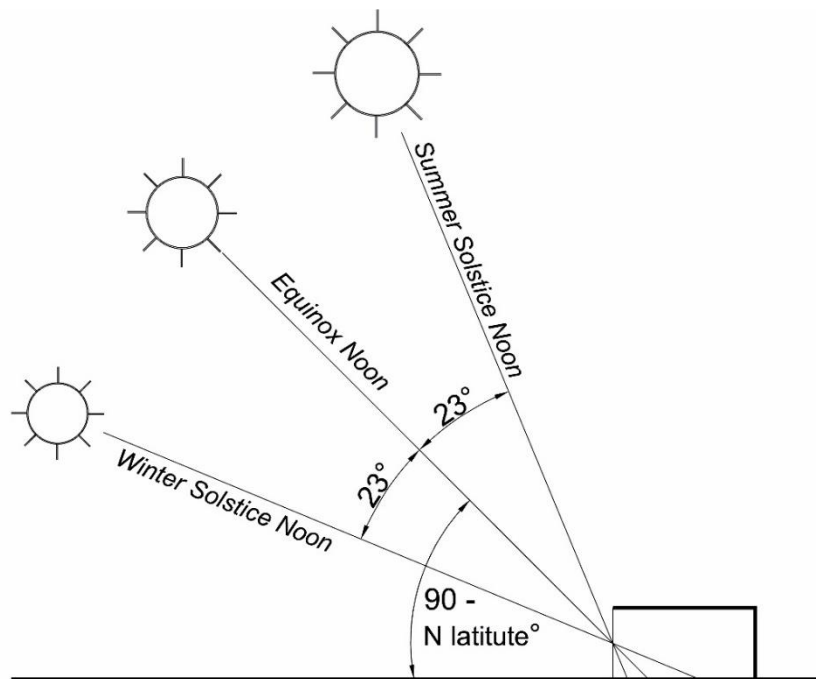


Figure 3.7 : Seasonal noon sun angles (Url-18).

Another daylighting performance criterion is to achieve a higher daylight factor to utilize from daylight as much as possible. Higher transparency ratios contribute to this purpose. It is much more important in surroundings having dark-colored buildings, obstacles, etc. Obstacles or ground surface in light colors have positive contribution to daylight factor (BS EN 17037 ; Muhaisen and Dabboor, 2015 ; Velux, 2014 ; LBNL, 2013 ; Rathi, 2012 ; Anderson, et al., 2008 ; Ko, et al., 2008 ; Kutlu, et al., 2012 ; Ibrahim and Hayman, 2005 ; Boyce, et al., 2003 ; Ander, 1995).

Space proportions are also determinative for daylighting criteria. Spaces that have uniform plan proportions may need uniform daylight, whereas spaces having deep plans require daylight deep interiors. In these circumstances, full-height or at least vision level windows provide uniform daylight while upper level or full-height

windows let the daylight reach deep interiors (Reinhart, et al., 2006 ; Ko, et al., 2008 ; Url-21).

Glazing component is one of the most essential parameters in daylighting performance. It needs to be evaluated in accordance with the orientation and transparency ratio. In this context, the criterion is to achieve an optimum effective aperture. Robinson and Selkowitz (2013) recommend an effective aperture around 0.30 for daylighting with windows. An equation to calculate the effective aperture is given in 3.3. In higher transparency ratios, glazings that have relatively lower visible transmittance, such as tinted glasses (comparing with clear glass) need to be preferred. These become more critical in southern, east, and west orientations in relation to the major occupation period of the space (Jin and Overend, 2017 ; Mahdavi, et al., 2016 ; Vanhoutteghem, et al., 2015 ; AGC Glass Company, 2013 ; Guardian, 2013 ; Rathi, 2012 ; Dubois and Johnsen, 2003 ; Url-22 ; Url-23 ; LBNL, 2013).

$$EA = VT \times WWR$$

EA: effective aperture (e.g. $0.60 \times 0.50 = 0.30$)

VT: visible transmittance of glazing (e.g. 0.60)

WWR: window to wall ratio (e.g. 0.50)

(3.3)

Daylight utilization needs to be optimized to provide adequate daylight and control glare. Facades oriented towards southern, east, and west directions generally need shading for glare control. Facades facing south requires for horizontal elements while vertical elements perform better for east and west oriented facades. In southeast and southwest orientations, the combination of horizontal and vertical elements are required.

Shading elements are not required for northern oriented facades since they cause a substantial reduction in daylight levels. Besides, in northern oriented facades, if the effective aperture is lower than 0.25 or visible sky angle is low, this criterion becomes much more critical. Likewise, in other orientations that require shading elements, if the effective aperture is higher than 0.35, then to provide shading within the facade becomes more of an issue (Robinson and Selkowitz, 2013 ; Saha, et al., 2017).

All the above mentioned principles and equations are used to rate the options generated for each design decision in terms of daylighting performance.

3.2.8 Acoustic performance

Facade acoustic performance basically depends on environmental noise (type, direction, level) and space function (its sensitivity to noise). Acoustic performance criteria change with noise levels facade exposed to and required indoor sound level.

In order to evaluate facade acoustic performance, required minimum values for airborne sound insulation need to be determined. It can be done either by a simple method or by a calculation method specified in Noise Regulation (2018).

The simple method is to check charts of the Noise Regulation that give sensitivity levels of spaces having facades (a section from the chart can be found in Table 3.4) and required sound insulation values based on outdoor noise level and indoor sensitivity levels (see Table 3.5 and Table 3.6), respectively. In addition to the criteria given in Table 3.5, at least 30dB sound insulation need to be provided in order to achieve A, B, C, or D acoustic performance classes.

Table 3.4 : Building and space functions dependant noise sensitivity levels, I is for the highest sensitivity (Noise Regulation, 2018).

Building Scale		Room Scale	
Building Function	Sensitivity Level	Space Function	Sensitivity Level
Residential	I	Living Room	I
		Bedroom	II
		Kitchen	III
Educational	II	Classroom	I
		Laboratory	II
Medical	I	Patient Room	I
Accommodation	II	Hotel Room	I
Commercial	III	Shop / Store	III
Cultural	I	Conference Hall	I
		Exhibition Hall	II

Table 3.5 : Minimum sound insulation values according to outdoor noise and sensitivity levels (Noise Regulation, 2018).

Noise sensitivity	Acoustic Performance Class					
	A	B	C	D	E	F
I	L _{eq} -14	L _{eq} -18	L _{eq} -22	L _{eq} -26	L _{eq} -30	L _{eq} -34
II	L _{eq} -17	L _{eq} -21	L _{eq} -25	L _{eq} -29	L _{eq} -33	L _{eq} -37
III	L _{eq} -20	L _{eq} -24	L _{eq} -28	L _{eq} -32	L _{eq} -36	L _{eq} -40

Table 3.6 : Minimum sound insulation values according to outdoor noise and sensitivity levels in relation to acoustic performance classes (Noise Regulation, 2018).

Noise Level	Sensitivity	Acoustic Performance Class					
		A	B	C	D	E	F
High $L_{AF, \max} > 75\text{dB}$	I	68	64	58	54	50	46
	II	65	61	55	51	47	43
	III	62	58	52	48	44	40
Middle $75 \geq L_{AF, \max} > 55\text{dB}$	I	62	58	52	48	44	40
	II	59	55	49	45	41	37
	III	56	52	46	42	38	34
Low $L_{AF, \max} \leq 55\text{dB}$	I	56	52	46	42	38	34
	II	53	49	43	39	35	31
	III	50	46	40	36	32	28

The calculation method that is used for the determination of required insulation values is given in equation 3.4. It is based on the noise level in the source environment and the maximum acceptable indoor noise level.

$$D_{nT} = L_{\text{source}} - L_{\text{criteria}} + 10 \log T / T_0$$

D_{nT} : standardized level difference, dB

L_{source} : noise level in the source environment ($L_{F, \max}$), dB

L_{criteria} : maximum acceptable indoor noise level, dB

T : maximum acceptable indoor reverberation time, s

T_0 : reference reverberation time, s

(for rooms with furniture 0.5 s, rooms without furniture 1.5 s)

(3.4)

Environmental noise can be due to various sources such as road traffic, airports, construction sites, entertainment facilities, people, etc. Road traffic is a very common source of noise that can cause acoustic problems in buildings and building sites. Outdoor noise levels can be determined by one of the following methods: measurements, calculations, noise maps, or building facade noise assessment graphs. The noise level depends on the type of noise (noise source), distance from the noise source, and environmental conditions (climate, surrounding) that affect the distribution of noise.

In case that there is at least one type of environmental noise, not to orient the facade towards the direction of the noise sources can be the first criterion to be exposed at least lower levels of noise. The criterion of orientation becomes much more critical if the space is noise sensitive due to its function or if the environmental noise level is higher than 55 dB which is defined as middle level noise in the regulation (Natee, et al., 2016 ; BS 8233, 2014 ; Murphy and King, 2014 ; Velux, 2014 ; Tamer Bayazit,

2013 ; Government of South Australia, 2017 ; Government of South Australia, 2012 ; Habibi, 2012 ; EPA, 2009 ; Rich and Dean, 1999 ; Karroum, et al., 1995 ; Berendt, et al., 1967 ; Url-24 ; Url-25 ; Url-26 ; Url-29).

Higher transparency ratios can be challenging in terms of outdoor noise protection. It may not be desirable in case of noise sources. Even, it becomes more critical if spaces having facades are noise sensitive, or if facade of the space is directly exposed to the noise source (closer to the noise source), or if the noise level is different than lower noise levels (middle or high-level noise) (GIB, 2017 ; Tamer Bayazit and Demir, 2016 ; MACH Acoustics, 2014 ; Ünver, et al., 2002 ; Url-26).

Although double-skin facade systems perform better against outdoor noise, measures need to be taken for noise transmission through the cavity between two skins. On the other hand, heavier systems provide higher sound insulation. Masonry systems are better in sound insulation when compared to window facades. These criteria are even more critical in noisy environments, or for noise-sensitive spaces, or for spaces directly exposed to the noise sources through their facades (Lee, 2016 ; Hermann, et al., 2015 ; Watts, 2014 ; Yu, 2014 ; Ching, 2014 ; Batungbakal, et al., 2013 ; Boswell, 2013 ; Aksamija, 2013 ; Toydemir, et al., 2011 ; Herzog, 2008 ; Knaack, et al., 2007 ; Schititch, 2006 ; NZCMA, 2013 ; Subasic, 1995).

As is the first criterion which is about the orientation of facades, less exposure to noise is the preferred situation. Facades oriented towards the direction of noise sources need to avoid operable windows since they (when opened) substantially lower sound insulation. However, upper-level windows can be tolerable in lower transparency ratios. They may have an opaque wall under which may function as noise barriers against for instance road traffic noise (Url-27).

Transparent and opaque parts of facades need to be considered separately in terms of acoustic performance. The acoustic performance of transparent parts can be improved through the selection of glazing. To increase the number of glazing, or to increase the thickness of glass panes, to assemble glass panes in different thicknesses (asymmetric assembly), to use heavier infill gas for cavity between glass panes improve the acoustic performance of facade. In higher transparency ratios, the criteria become much more important. In noise-sensitive spaces, or in spaces having facades directly exposed to noise sources, they are more important, as well (Cellai, et al., 2014 ; AGC Glass

Company, 2013 ; Guardian, 2013 ; Solla, 2012 ; Saflex, 2012 ; Bülow-Hübe, 2001 ; Foss, et al., 1999 ; Url-22 ; Url-23 ; Url-28 ; Url-27).

Cavity walls and thermal insulation components with open-cell materials are desirable for sound insulation. Rockwool can be configured in walls both for thermal and acoustic purposes. In higher noise exposures, or higher noise levels, or for noise-sensitive spaces, these criteria become more of an issue (Tamer Bayazıt and Demir, 2016 ; Url-27).

Moreover, shading elements designed primarily for thermal and daylight performance can be utilized in noise protection. For this, these elements need to be of sound-absorbing materials. Facades having external shading elements can be advantageous in that sense (Kang, 2017 ; Magrini and Lisot, 2016 ; Cellai, et al., 2014).

Airtightness is one of the most important indicators of acoustic performance. It can be achieved through proper detailing. Sealing of window components, insulation of joints between different components contribute to the airtightness of facade. Beside proper design of details, also implementation and workmanship play significant roles in airtightness performance.

3.3 Performance Related Facade Parameters

As being the design variables within the context of the thesis, facade parameters that define the relevant performances are listed. These are the only parameters that a designer can decide on/ change among all the factors having effects on the performances.

Agents as performance affecting factors, performance requirements, performance evaluation criteria which define performance metrics (indicators) in relation to environmental and spatial conditions and according to standards and regulations, and finally facade parameters as variables that can be under control of design decision-makers are given in a chart (Table 3.7) for each predefined functional performance aspect. The chart makes it easy to follow the interrelationships between the functional performance aspects and the facade design parameters and to see the potential effects of the facade parameters on different performance aspects. This chart is established with the help of the literature review. It is given importance to provide a common

wording for facade parameters and other factors. All the given design variables are among the parameters of passive design to match the scope of the thesis.

Aygün (2001) defines building elements as a function of building components and building components as a function of building materials. From this point forth, the following sections are structured as parameters of different scales: settlement scale, building scale, building element scale, and lastly component and material scale. Smaller-scale parameters influence larger-scale parameters.



Table 3.7 : Functional performance aspects and design variables chart.

Performance Aspects	Affecting Factors	Performance Requirements	to be checked Issues	Performance Evaluation Criteria		Design Variables (Facade Parameters)
				Standards, Regulations	Performance Metrics	
Structural Performance	*wind loads *impact loads *thermal expansion and movements related loads *earthquake loads	*not to collapse and remain standing safely under possible load combinations *to be as light as possible, to transfer less loads to the buildings	*building / space function *building geometry *building height *loads exposed *angle between wind direction and facade	*TS 498 *TS ISO 9194 *TS 13830 *Earthquake Code *EN 14019 *EN 15434	*wind resistance	*orientation (relation to wind direction)
					*impact resistance	*transparency ratio
					*thermal expansion and movements related resistance	*facade type
					*earthquake resistance	*strength and stiffness of materials
						*detailing of joints and connections
						*conformance of different materials and finishes
Fire Performance	*fire *smoke *heat	*to provide fire resistance for a length of time	*building / space function *building height	*TS EN 13501-1,2	*fire resistance REI (load-bearing, integrity, insulation)	*orientation (relation to wind direction)
		*to limit the spread of fire and smoke		*TS EN 13823		
		*to prevent fire spread		*TS EN 1364-1,3,4		
		*not to cause a fire with its components		*TS EN ISO 11925-2	*fire class (A, B, C, D, E, s1, s2, s3, d0, d1, d2) of materials	*type of materials (fire class)
				*TS EN 13823		
				*TS EN ISO 13943		
				*TS EN ISO 1182		
				*Fire Code	*tightness	*detailing of joints and connections

Table 3.7 (continued) : Functional performance aspects and design variables chart.

Performance Aspects	Affecting Factors	Performance Requirements	Performance Evaluation Criteria			Design Variables (Facade Parameters)
			to be checked Issues	Standards, Regulations	Performance Metrics	
Water-related Performance	*rain water *snow water *wind	*to prevent water penetration to the building	*building height *wind direction	*TS EN 12154	*water tightness (permeability)	*orientation (relation to wind direction)
				*TS EN 12155		*surface of cladding material
				*TS EN 13051	*rate of leakage (classes R4, R5, R6, R7, RE, etc.)	
				*TS EN 1017		
				*TS EN 12208		
				*TS EN 13830		
Air Permeability-related Performance	*air movement (air pressure difference)	*to prevent energy loss through air flow	*building / space function		*airtightness (permeability)	*orientation (relation to wind direction)
				*TS EN 12365-1		
				*TS EN 12152	*airtightness (permeability)	*air barrier layer
				*TS EN 12153		
				*TS EN 12207		
				*ENV 1991-2,4		
				*TS EN 1026	*rate of air leakage (classes A1, A2, A3, A4, AE, etc.)	*sealing of facade joints

Table 3.7 (continued) : Functional performance aspects and design variables chart

Performance Aspects	Affecting Factors	Performance Requirements	to be checked Issues	Performance Evaluation Criteria Standards, Regulations	Performance Metrics	Design Variables (Facade Parameters)
Thermal Performance	*heat *solar radiation	*to utilize or protect from solar radiation and/ or winds when needed for optimum thermal comfort *to provide thermal insulation	*building / space function *climate type *building orientation	*ASHRAE 90.1	*overall heat transfer coefficient (U-value)	*thermal conductivities of layers
				*TS 825		*thermal insulation layer and its continuity
				*NFRC Standard 100, 200		
				*EN ISO 13790		
				*EN ISO 10077-2		
				*TS EN 410	*thermal bridging	*thickness of layers
				*EN ISO 12631		*orientation
				*EN ISO 12567-1		
				*TS EN 13163		
				*TS EN 13164		
				*TS EN 13170	*heat capacity or specific heat	*transparency ratio
				*TS 3649		*detailing of joints and connections
				*TS 10981		
				*TS EN 12086		
				*TS EN ISO 12572		
				*TS EN ISO 10211	*solar heat gain coefficient (SHGC) or shading coefficient of glazing	*window & frame type
				*TS EN ISO 14683		*glazing type (number of glass panes, infill gas, thickness, glass color, glass coating)
				*TS EN ISO 6946		
				*TS EN 13165		
				*TS EN 13167		
				*TS EN 13168		*inclusion of shading elements (type, dimensions, color)
				*TS EN 13171		
				*TS EN 14316-1		

Table 3.7 (continued) : Functional performance aspects and design variables chart.

Performance Aspects	Affecting Factors	Performance Requirements	to be checked Issues	Performance Evaluation Criteria Standards, Regulations	Performance Metrics	Design Variables (Facade Parameters)
Moisture-related Performance	*water vapour	*to control condensation	*building / space function	*ASHRAE 90.1 *TS 825	*flow of water vapour through facade layers without any condensation	*thermal conductivities of layers
	*temperature difference		*climate type			*vapour diffusion resistance factors of layers
	*vapour pressure difference	*to contribute to indoor comfort and long-lasting building	*indoor relative humidity / moisture exposed		*control of water vapour before reaching the dew point	*thickness of layers
					*drainage of condensed water vapour at potential points	*wall layers (positions for each other) *inclusion of a vapour barrier layer and its continuity
					*natural ventilation	*inclusion of ventilated air gap

Table 3.7 (continued) : Functional performance aspects and design variables chart.

Performance Aspects	Affecting Factors	Performance Requirements	Performance Evaluation Criteria			Design Variables (Facade Parameters)
			to be checked Issues	Standards, Regulations	Performance Metrics	
Daylighting Performance	*skylight *sunlight	*to benefit from daylight for illumination *to provide proper daylight (both in quantity & quality) *to provide a view out (preferably a pleasing view) *to control glare	*building / space function	*EN 410	*daylight factor	*orientation
			*space proportions	*EN 13363-1,2	*daylight distribution	*transparency ratio
				*space volume	*BS 8206-2	*daylight glare probability
			*light reflectance of interior surfaces		*BS 6100-7	*visible transmittance of the glazing
				*EN 12464-1		
			*light reflectance of surrounding surfaces	*CIBSE Lighting Guide LG10	*glare control	
				*EN 12464-1		
				*EN 15193	*view	
				*NFRC Standard 100		
				*NFRC Standard 200		
Acoustic Performance	*airborne sound *noise *vibration	*to provide direct airborne sound insulation *to reduce flanking sound transmission	*building/ space function *noise sources *noise levels (frequency dependent sound pressure levels)			*orientation
						*transparency ratio

3.3.1 Settlement scale parameters

Building location (geographical location, topographical settlement) and building orientation (such as east-west axis) are settlement scale parameters. Site features such as level differences, property boundaries, landscape, and urbanscape generally force to certain decisions on these parameters. These indirectly affect facade design and performance.

3.3.2 Building scale parameters

Facade orientation can be considered as a building scale design parameter. A building can have facades in different orientations. Some of the building spaces face certain directions, and some others can have facades in the other orientation(s). It is very much related to building form and orientation. To give an example, if a rectangular building is oriented in the east-west axis, most of the spaces inevitably face north and south directions.

3.3.3 Building element scale parameters

Facade type (number of skin, construction type), transparency ratio (window-to-wall ratio), facade configuration, facade position (in relation to structural system), wall configuration (sequence of layers), window position (in relation to wall), drainage system integration within the facade, inclusion of air gap, ventilation of air gap can be considered as building element scale facade parameters. Variations in facade positions in relation to the structural system are given in Fig. 3.8.

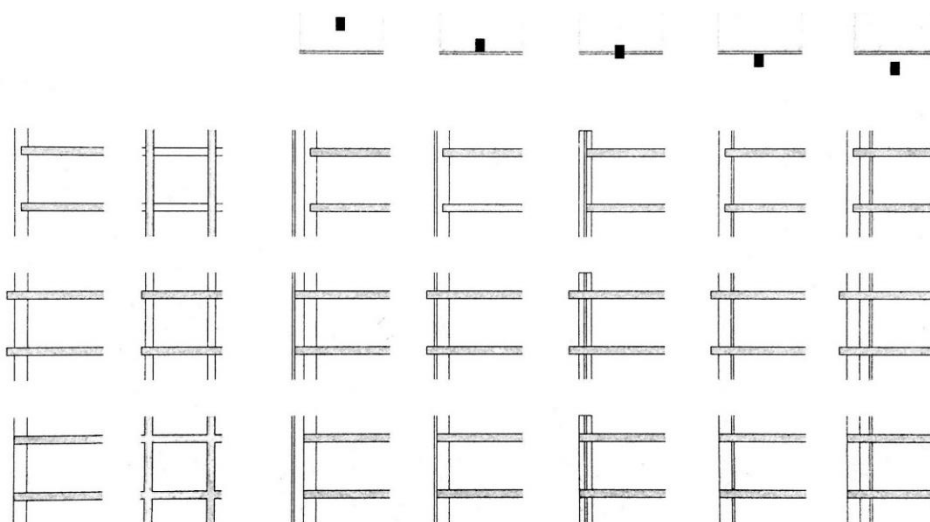


Figure 3.8 : Facade position in relation to the structural system (Herzog, et al., 2004).

3.3.4 Component and material scale parameters

Facade exterior finishing and its water-resistive features, wall layers (material and thickness), thermal insulation (material and thickness), water barrier (type), vapour barrier (material), air barrier (material), glazing (number and thickness of glass panes, infill gas and cavity thickness, color, coating), shading elements (type, sizes, color, material), detailing of joints and connections are among the component and material scale parameters.

Effects of different shading elements can be seen in Fig. 3.9. As seen in the figure, the ceiling can have a complementary role for daylighting or thermal performance. In addition to the geometrical effects, solar reflectance of the elements (material and color) can affect the facade performance (thermal and daylighting).

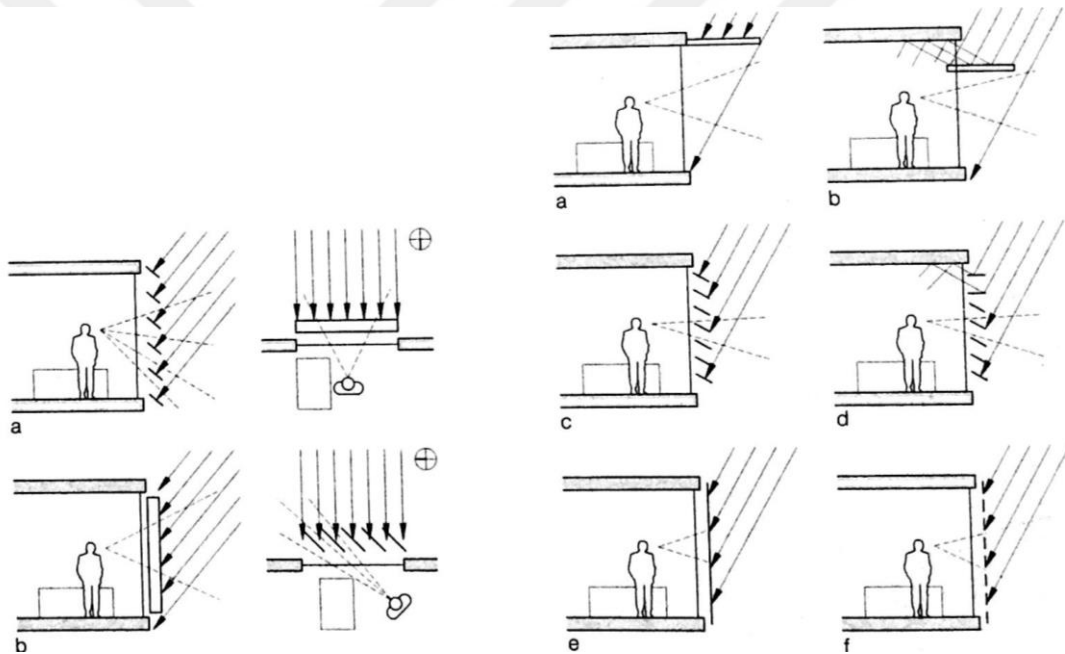


Figure 3.9 : Shading effects (Herzog, et al., 2004).

Detailing is important in every aspect of facade performance. Proper detailing and workmanship play a significant role. An example is given for basic principles of horizontal joints in facades for draining water (Fig. 3.10). There are plenty of detailing techniques for various reasons in facade design. Moreover, there can be customized solutions to the details. It can be possible to compensate incorrect decisions given in previous stages of design by a specific detailing. But, it can be costly or difficult to implement.

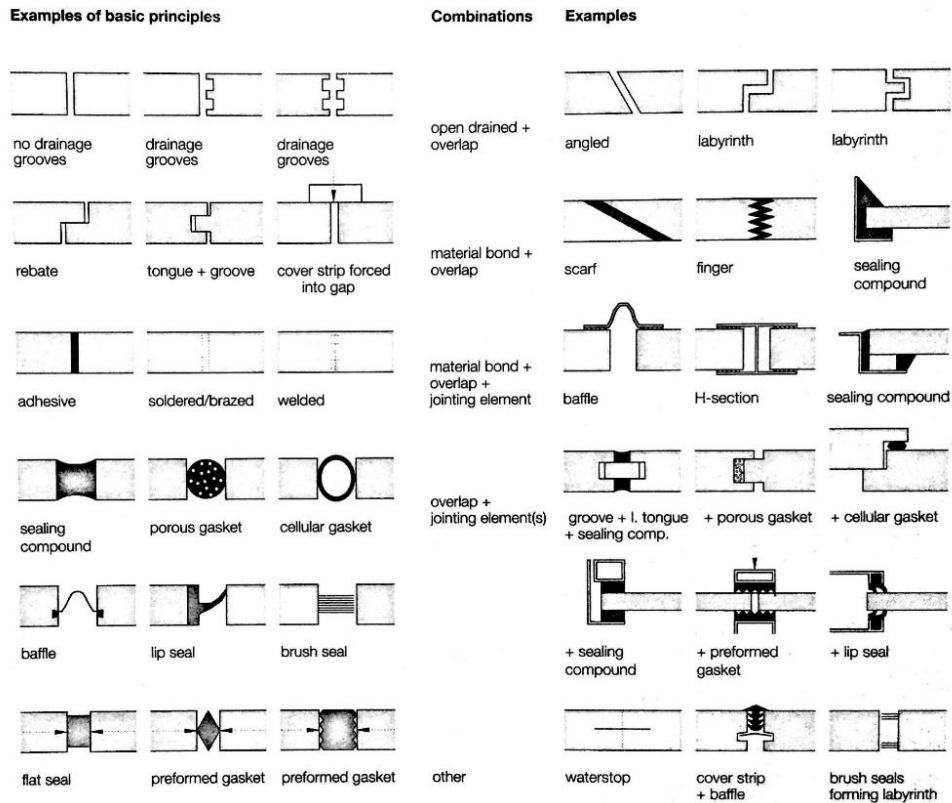


Figure 3.10 : Basic principles of horizontal joints in facades for draining water (Herzog, et al., 2004).

3.4 Facade Performance Evaluation

Facade performance can be evaluated by both qualitative and quantitative methods. Since the facade performance has different aspects, different kind of evaluation methods is defined by standards, regulations, etc. Either methods are required to achieve an overall performance evaluation for facades.

3.4.1 Qualitative evaluation

Observations and interviews regarding facade performance can be considered as one of the qualitative evaluation tools. These are briefly described and exemplified in the following sections.

3.4.1.1 Observations

It is not a typical method for evaluating facade performance. However, in some aspects, it can be the only and/or the quickest evaluation technique. For instance; glare occurrence on horizontal or vertical surfaces can be observed. The important thing in observations is to repeat the observations in different environmental and spatial conditions such as to observe at different times of the day, in different sky conditions,

in different seasons of the year. Besides, the shading effects of the surrounding buildings can be roughly recorded via observations. Environmental noise sources or the surrounding panorama which are directly related to facade design can be observed. Moreover, water penetration through the facade can be evaluated by observation.

3.4.1.2 Interviews

The interview is a very common method for recording the level of satisfaction for building designs. It is the same in the facade design. Comfort levels can be an indicator of facade performance evaluation, especially in thermal, visual, and acoustic aspects. Face-to-face interviews ensure the quality of the obtained data and increase the response rate.

3.4.2 Quantitative evaluation

Quantitative evaluation methods can be sorted as tests, simulations, mathematical equations, and surveys. Generally, quantitative methods are found more reliable for being objective rather than subjective in performance evaluation. However, it is always better to complement these tools with qualitative methods to provide a holistic evaluation (Bluyssen, 2014).

3.4.2.1 Tests

Tests refer to either field or laboratory tests. Field tests give the opportunity to evaluate the performance of the facade in real conditions. On the other hand, laboratory tests provide to test full-scale facade mock-ups in controlled environments. Although more realistic/ accurate evaluation results can be obtained, with being costly and time-consuming, these methods of evaluation can be infeasible, or they can be implemented for a limited number of test specimens. Figure 3.11 shows a test setup for the performance evaluation of facades.

3.4.2.2 Simulations

Simulations become the most commonly used methods for facade performance evaluation with the help of developing computational technology. Compared to the laboratory or field tests, they are more practical and inexpensive. But, simulation tools have limited capabilities in performance evaluation and are based on several assumptions. Figure 3.12 and Figure 3.13 are examples of facade performance evaluation by simulation software.



Figure 3.11 : Test setup for facade performance evaluation (Url-30).

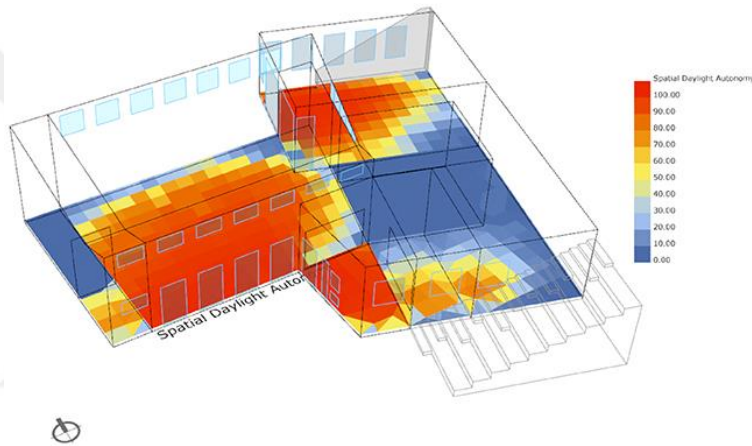


Figure 3.12 : Daylight analysis (Url-31).

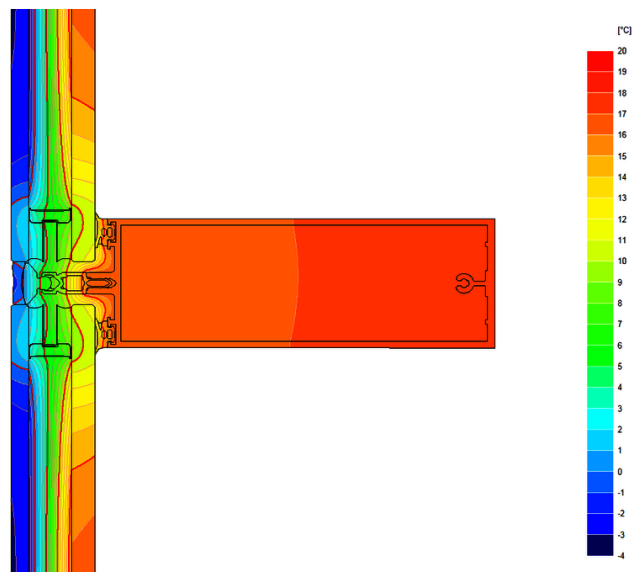


Figure 3.13 : Thermal analysis (Url-32).

3.4.2.3. Mathematical equations

Mathematical equations are the underlying algorithms of the simulations. But, here the equations refer to simple calculations done for performance evaluation of facades. Simulations are for more complex calculations. Calculations by hand provide a fast evaluation when compared to the others. In calculations, tested values, or values given in charts of standards and regulations are utilized. For instance, daylight factor or sound insulation provided by the facade, which are the indicators of daylighting and acoustic performances, can be calculated by relatively simple mathematical equations.

3.4.2.4 Surveys

Surveys/ questionnaires are one of the quantitative evaluation techniques. Attendants are asked to respond to the same questions. It is a very common method based on statistical analysis. Questionnaires are mostly used as a post-occupancy evaluation to determine user satisfaction. These methods are valuable since even the field tests, or the numerical values designated in the standards may not reflect the real performance requirements. Although these provide a holistic evaluation, questionnaires (kind of written interviews) need to be cross-checked with other types of performance evaluation. Besides, they need to be implemented for a considerable number of people in order to ensure the validity of the results.

In addition to the above methods, checklists can be used in both types of performance evaluation (qualitative and quantitative). They can be considered as an auxiliary method.

3.5 High-Performing Facades

Double-skin facades may be considered as one of the current technologies in facade systems. The fundamental difference between double and single-skin facades is double-skin facades consist of distinct exterior and interior glazed wall systems, separated by a ventilated air cavity while a single-skin facade is a single exterior wall system that may use double lines of defense against water and air infiltration with double or triple-glazed windows. The cavity within the double-skin facade creates a thermal buffer between the interior and exterior. There are three different modes of ventilation for the air cavity; it can be by natural convection, by mechanical devices,

or by a combination of two. In double-skin facades, the air cavity is partitioned vertically or horizontally (or both) by solid and/ or perforated partitions.

According to the partitioning style, there are four types of double-skin facades: Box window, Corridor, Shaft-box, and Second-skin (Multistory) (Aksamija, 2013). Box window facades have horizontal partitions at each floor level and vertical partitions between windows. Each air cavity is typically ventilated naturally. Corridor facades have no vertical partitions but horizontally partitioned at each floor level. All three ventilation modes are possible. Shaft box facades are like corridor facades but use vertical shafts for natural stack-effect ventilation. Hybrid mode ventilation is often used for this facade type. Second-skin or multistory facades have no horizontal and vertical partitions. Air cavities are full height and width of the facade. All three ventilation modes are possible (Aksamija, 2013). Schemes of double-skin Facade types are given in 3.14.

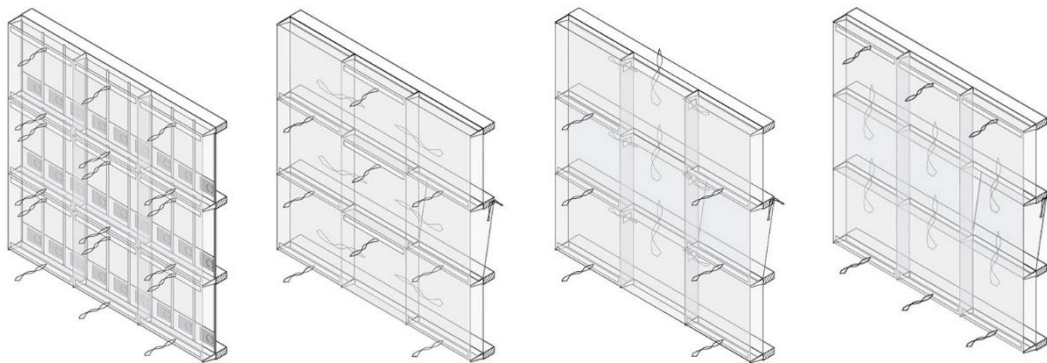


Figure 3.14 : Schemes of double-skin facade types, box-window, corridor, shaft-box, and second-skin, respectively (Knaack, 2007).

One of the high-performance facade technologies is to design facades as energy generators. Facades can be designed to take advantage of both passive and active solar energy. Passive solar energy can be utilized by using exterior materials with large thermal capacities as heat from the sun can be absorbed into the material during the day and dissipated to the building's interior at night. On the other hand, active solar energy can be utilized with devices such as solar collectors and photovoltaic (PV) panels to heat fluids or to generate electricity (Aksamija, 2013).

Moreover, double-skin facades can integrate not only ventilation functions but also active environmental control or lighting components. These facades are generally called modular or hybrid facades. This facade technology leads to a new concept that

incorporates all environmental engineering functions within the facade instead of the building core (Knaack, et al. 2007).

Adaptive facades can be considered among high-performing facades, as well. They contribute to building energy efficiency and economics, through their capability to change their behaviour in real-time in accordance with indoor and outdoor conditions, by means of materials, components, and systems (Aelenei, et al., 2016, Gosztonyi, 2015). Today, high-performing facades need to respond and adapt to variable conditions and changing user needs (Selkovitz, 2001).

3.6 Summary of the Chapter

On the one hand, there are performance requirements for facades derived from user requirements associated with facades; on the other hand, there are factors affecting the level of performance requirements. These performance requirements can be achieved by making design decisions regarding certain facade parameters. Throughout the Chapter, the following questions are tried to be answered. What are these parameters, and which scales they belong to? What can be the design options for these parameters? What types of methods are available for the evaluation of facade performance? What does 'high-performance facade' mean today, and through which facade features (parameters), facades become high-performing?



4. DEVELOPMENT OF A DESIGN DECISION SUPPORT TOOL

This Chapter describes in detail the developed design decision support tool. The development process of the tool is given in separate sections as definition of environmental and spatial conditions, definition of facade parameters, generation of design options, the establishment of design decision and performance matrices, rating design options, weighting the relationships, overall performance ratings, and graphical representation of rating results, respectively.

Firstly, the literature is reviewed to understand the nature and dynamics of facade design (Chapter 2) and the aspects of facade performance (Chapter 3). Then, with an in-depth analysis of the literature, relationships are established among facade design and facade performance, facade performance and conditions, conditions and facade design. The tool bases upon these interrelationships. In Figure 4.1, the center of the triangle represents the decisions, and the tool functions as a support for making these decisions. Facade 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.

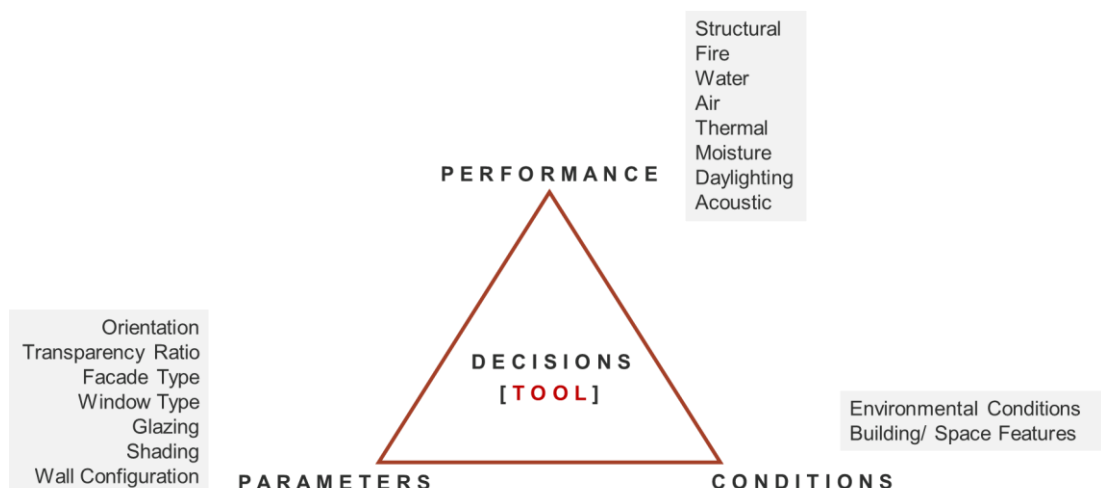


Figure 4.1 : Tool scheme.

The tool is composed of five major sections: input page, tool process pages, output and decision-making pages, and evaluation page. The working principle of the tool is given

below (Fig. 4.2). The sections of the tool are given in detail in further sections. Although the working flow of the tool given in Fig. 4.2 is kind of a final product, it is preferred to present it at the beginning of the Chapter to make easy to follow the sub-sections. Performance aspects included in the tool are structural, fire, water-related, air permeability-related, thermal, moisture-related, daylighting, and acoustic performances. These correspond to functional performance aspects (Oraklıbel, 2014 ; ITU, 2013 ; Jin, 2013 ; Boswell, 2013 ; Herzog, 2008 ; Rich and Dean, 1999). Facade parameters defined as the main decision subjects within the tool are orientation, transparency ratio, facade type, window type, glazing, wall configuration, and shading. The thesis proposes a comparison based design decision support tool that concentrates on overall facade performance. The tool covers just specific performance aspects and non-self-supporting facades for side-lit spaces having facade on one side in Northern Hemisphere.

4.1 Definition of Environmental and Spatial Conditions

4.1.1 Assumptions

For location; the Northern hemisphere with its all latitudes (high, middle, low) are taken within the scope of the thesis. Topographical conditions are not considered. Earthquake criticality is taken as high and low. For climate; annual temperature, annual rainfall, and diurnal temperature are taken into consideration while for predominant wind; direction, speed, and period (heating or cooling) are taken. For noise; availability, direction, and level are considered. Traffic noise is the only noise source included in the tool. As surrounding surfaces; buildings, trees, pavement, landscape and their colors (light reflectances) are considered. High-rise, low-rise and single-storey buildings are included. Various space functions are integrated within the tool, with their major occupation periods, and location (floor) within the building. For space interiors, two types of proportions (uniform, deep) and surface reflectances (light, dark) are considered.

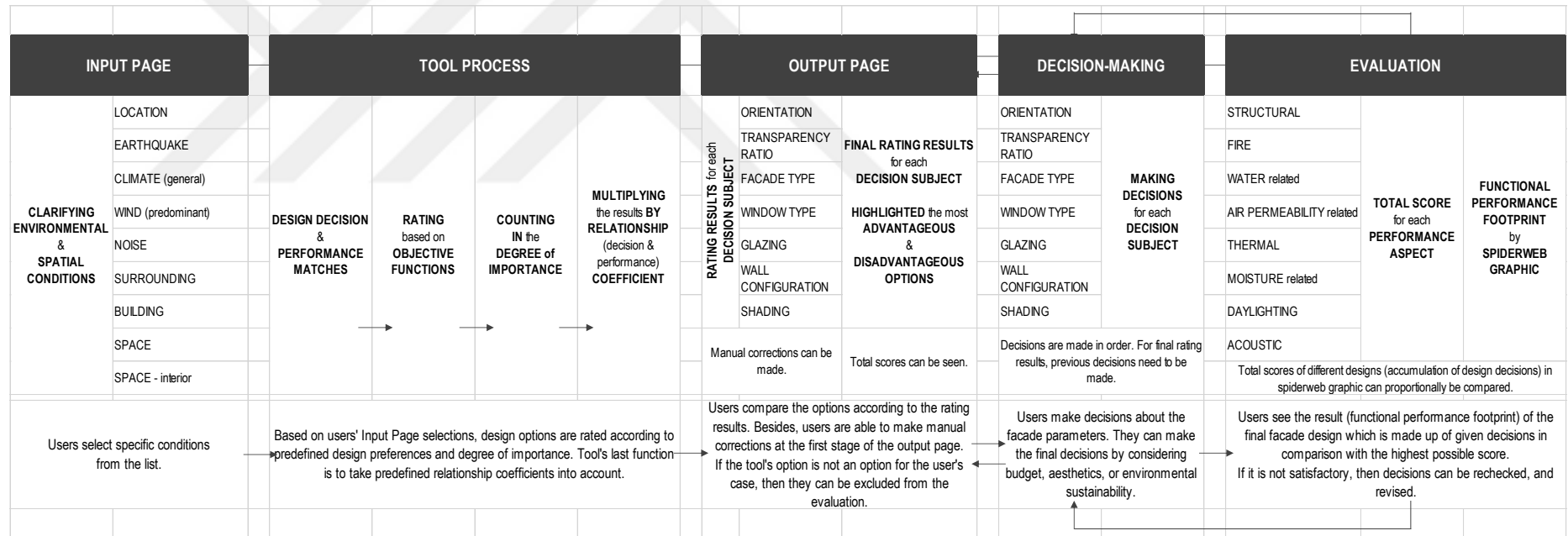


Figure 4.2 : Tool working principle.

Some of the building type and space function related assumptions are provided below (Table 4.1, Table 4.2, Table 4.3). Required performance levels need to be known for performance evaluation.

Table 4.1 : Assumptions for fire performance.

Building Type	Safety Requirement
Residential	Low
Commercial	Low
Educational	High
Cultural	Low
Medical	High

Table 4.2 : Assumptions for daylighting performance.

Space Function	Uniform Daylight	Required Illuminance Level > 500lux
Living Room	No	No
Bedroom	No	No
Kitchen	No	No
Office	Yes	Yes
Shop/ Store	Yes	Yes
Hotel Room	No	No
Classroom	Yes	No
Laboratory	Yes	Yes
Performance Hall	No	No
Conference Hall	No	No
Exhibition Hall	Yes	Yes
Patient Room	No	No

Table 4.3 : Assumptions for acoustic performance.

Space Function	Noise Sensitivity
Living Room	Low
Bedroom	High
Kitchen	Low
Office	High
Shop/ Store	Low
Hotel Room	High
Classroom	High
Laboratory	Low
Performance Hall	High
Conference Hall	High
Exhibition Hall	Low
Patient Room	High

4.1.2 Options

Environmental parameters included within the tool are location, earthquake, climate, wind, noise, and surrounding, while building, space and space-interior are spatial

parameters of the tool. Each parameter has sub-parameters such as; direction, speed, and period as sub-parameters of predominant wind parameter. In other words, to define the predominant wind, its direction, speed, and period need to be identified. The tool assumes specific options for each parameter. Also, parameters are related to each other. For instance; if there is not a noise source, then there is no need to define level and direction parameters. All of the environmental and spatial conditions of the tool which are the combinations of the parameters are given in Table 4.4 and Table 4.5, respectively.

The options for possible conditions are specified considering the definition of facade performance criteria. They are specified with some numerical values such as 7 floors or 55dB.

As mentioned earlier, Northern is the only option for the hemisphere; however, it is defined by latitude as high, middle, or low in the tool. Earthquake is defined by its criticality level as high or low. Climate is considered as the combination of annual temperature, rainfall, and diurnal temperature range. There are three types of climate in terms of annual temperature: cold, temperate, and hot. These climates are redefined with the annual rainfall as humid and arid. If the annual rainfall is higher than 600mm, it is assumed as humid, while if it is lower than 400mm, then it is considered as arid. Semi-arid options are kept out of the scope. Besides, the diurnal temperature range is important in climate definition. It is taken as high and low within the tool. Some of the options for the parameters are roughly defined to make the tool flexible for the users.

Wind parameter is taken as the predominant wind of the region and is defined by its direction, speed, and period. Cardinal and intercardinal directions are considered for the wind options while wind speed is specified as high that is greater than or equal to 20m/s and low that is less than 20m/s. The tool defines two types of periods for the wind as heating and cooling periods.

The tool has two types of options for the noise source. One is the absence of noise, and the other is road traffic noise (as being a very common noise source). Then, the noise sources are defined by their levels as greater than 55dB or less than or equal to 55dB. Again, all the cardinal and intercardinal directions are taken as the options for the direction of the noise. For the definition of the surrounding, surfaces are specified as presence (buildings, trees) and absence of obstructions (pavement, landscape).

Obstructions are redefined by their directions. Moreover, their surface colors are specified. Trees are assumed to have darker colors, which may absorb solar energy in higher amounts while obstructions can be either dark or light in color.

Table 4.4a : Environmental conditions within the tool.

Location		Earthquake	Climate			
Hemisphere	Latitude	Criticality	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	
Northern	High (61-90)	High	Cold	Humid	High	
	Middle (30-60)	Low		>600mm	Low	
	Low (0-29)			Arid <400mm	High	
					Low	
			Temperate	Humid	High	
				>600mm	Low	
			Hot	Arid <400mm	High	
					Low	
			Humid	High		
			>600mm	Low		
			Arid <400mm	High		
				Low		

Building types that are included within the tool are residential, commercial, educational, medical, and cultural. The tool provides a limited number of space functions for each building type. Living room, bedroom, and kitchen are for residential buildings; office, shop/ store, and hotel room (considering that hotel is kind of a commercial facility) are for commercial buildings; classroom and laboratory are for educational buildings, patient room is the only function specified for medical buildings, and lastly conference and exhibition halls are for cultural buildings.

As given in Chapter 4.1.1, the building types and space functions are essential for determining the performance requirements. Buildings are specified with their heights, as well. There are two types of building heights within the tool: high-rise which has more than 7 floors and low-rise, which has less than or equal to 7 floors. The numbers given as the limits for the options are taken from relevant standards.

Occupation period options are the combinations of seasonal (all year, Winter, Summer) and daily periods (morning, afternoon). Besides, space interior properties are defined. Room proportions and colors of interior surfaces, which indicate their light reflectance, are defined within the tool. It is assumed that spaces can have either uniform or deep proportions, and there can be light or dark surface colors. Colors having light reflectance higher than and equal to 50% are considered as light, while the ones having reflectance less than 50% are for dark colors in the tool.

Table 4.4b : Environmental conditions within the tool.

Wind (predominant)			Noise		Surrounding (urban / rural)			
Direction	Speed	Period	Availability	Level	Direction	Surfaces	Direction	Color (reflectance)
North	Low < 20 m/s	Heating	None	-	-		North	Light ≥50%
		Cooling			North		North	Dark <50%
	High ≥ 20 m/s	Heating			South		South	Light ≥50%
South		Cooling	Traffic Noise	≤ 55 dB	East	Buildings as obstruction	South	Dark <50%
	Low < 20 m/s	Heating			West		East	Light ≥50%
		Cooling			Northeast		East	Dark <50%
East	High ≥ 20 m/s	Heating	Traffic Noise	> 55 dB	Northwest		West	Light ≥50%
		Cooling			Southeast		West	Dark <50%
	Low < 20 m/s	Heating			Southwest		Northeast	Light ≥50%
West		Cooling	Traffic Noise	> 55 dB	North		Northwest	Dark <50%
	High ≥ 20 m/s	Heating			South		Northwest	Light ≥50%
		Cooling			East		East	Dark <50%
Northeast	Low < 20 m/s	Heating	Traffic Noise	> 55 dB	West		Southeast	Light ≥50%
		Cooling			Northeast		Southeast	Dark <50%
	High ≥ 20 m/s	Heating			Northwest		Southwest	Light ≥50%
Northwest		Cooling	Traffic Noise	> 55 dB	Southeast		Southwest	Dark <50%
	Low < 20 m/s	Heating			Southwest		North	Dark <50%
		Cooling					South	Dark <50%
Southeast	High ≥ 20 m/s	Heating	Traffic Noise	> 55 dB		Trees as obstruction	East	Dark <50%
		Cooling					West	Dark <50%
	Low < 20 m/s	Heating					Northeast	Dark <50%
Southwest		Cooling	Traffic Noise	> 55 dB		Pavement/ Landscape	Northwest	Dark <50%
	High ≥ 20 m/s	Heating					Southeast	Dark <50%
		Cooling					Southwest	Dark <50%
Southwest	Low < 20 m/s	Heating	Traffic Noise	> 55 dB		Pavement/ Landscape	-	-
		Cooling					-	-
	High ≥ 20 m/s	Heating					-	-

Table 4.5 : Spatial conditions within the tool.

Building		Space			Space-interior			
Typology	Height	Function	Occupation Period (major)	Location (floor)	Proportions	Surface Properties (color/reflectance)		
Residential	High-rise > 7 floors	Living Room	All year-all day	Upper	Uniform	Light ≥50%		
	Low-rise ≤ 7 floors		All year-morning					
	Bedroom	All year-afternoon						
		Winter-all day						
	Kitchen	Winter-morning	Lower (first 2 floors)	Deep		Dark <50%		
		Winter-afternoon						
Single-storey	Summer-all day							
Commercial	High-rise > 7 floors	Office	Summer-morning		Upper		Light ≥50%	
			Summer-afternoon					
	Low-rise ≤ 7 floors	Shop/Store	All year-all day					
			All year-morning					
	Hotel Room	All year-afternoon	Lower (first 2 floors)	Dark <50%				
		Winter-all day						
Single-storey	Winter-morning							
Educational	High-rise > 7 floors	Classroom	Winter-afternoon		Upper			
			Summer-all day					
	Low-rise ≤ 7 floors	Laboratory	Summer-morning					Lower (first 2 floors)
			Summer-afternoon					
	Single-storey	Patient Room	All year-all day	Upper				
			All year-morning					
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
				Winter-all day				
Low-rise ≤ 7 floors	Winter-morning			Upper				
		Winter-afternoon						
Single-storey	Conference Hall	Summer-all day			Lower (first 2 floors)			
		Summer-morning						
High-rise > 7 floors	Exhibition Hall	Summer-afternoon	Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
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Single-storey	Summer-all day		Upper					
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High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
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Low-rise ≤ 7 floors	All year-morning		Upper					
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Single-storey	Winter-all day	Lower (first 2 floors)						
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High-rise > 7 floors	Winter-afternoon		Upper					
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Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
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Single-storey	Summer-all day	Lower (first 2 floors)						
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Single-storey	Winter-all day		Upper					
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High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
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Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
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Single-storey	Summer-all day		Upper					
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High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
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Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (first 2 floors)						
			All year-all day					
Low-rise ≤ 7 floors	All year-morning		Upper					
		All year-afternoon						
Single-storey	Winter-all day	Lower (first 2 floors)						
			Winter-morning					
High-rise > 7 floors	Winter-afternoon		Upper					
		Summer-all day						
Low-rise ≤ 7 floors	Summer-morning	Lower (first 2 floors)						
			Summer-afternoon					
Single-storey	All year-all day		Upper					
		All year-morning						
High-rise > 7 floors	All year-afternoon	Lower (first 2 floors)						
			Winter-all day					
Low-rise ≤ 7 floors	Winter-morning		Upper					
		Winter-afternoon						
Single-storey	Summer-all day	Lower (first 2 floors)						
			Summer-morning					
High-rise > 7 floors	Summer-afternoon		Upper					
		All year-all day						
Low-rise ≤ 7 floors	All year-morning	Lower (first 2 floors)						
			All year-afternoon					
Single-storey	Winter-all day		Upper					
		Winter-morning						
High-rise > 7 floors	Winter-afternoon	Lower (first 2 floors)						
			Summer-all day					
Low-rise ≤ 7 floors	Summer-morning		Upper					
		Summer-afternoon						
Single-storey	All year-all day	Lower (first 2 floors)						
			All year-morning					
High-rise > 7 floors	All year-afternoon		Upper					
		Winter-all day						
Low-rise ≤ 7 floors	Winter-morning	Lower (first 2 floors)						
			Winter-afternoon					
Single-storey	Summer-all day		Upper					
		Summer-morning						
High-rise > 7 floors	Summer-afternoon	Lower (						

The tool usage starts with an input page in which the tool user is asked to define environmental and spatial conditions from drop-down lists. Location (hemisphere, latitude), earthquake (criticality), climate (annual temperature, annual rainfall, diurnal temperature variation), predominant wind (availability, direction, speed, period), noise (availability, type, direction, level), surrounding (surface, direction, color), building (typology, height), space (function, occupation period, floor location), space interior (proportions, surface light reflectances) are the issues to be defined. Southern

Hemisphere conditions and types of noise sources other than traffic noise are not included in the tool. Input page (screenshot from the tool) is given in Fig. 4.3.

INPUT PAGE									
LOCATION	Hemisphere	Latitude	EARTHQUAKE	Criticality	CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	
Define	Northern	Middle (30-60)	Define	High	Define	Temperate	Humid > 600mm	Low	
WIND (predominant)	Direction	Speed	Period		NOISE	Cold Temperate Hot	Level	Direction	
Define	NorthEast	Low < 20km/h	Heating Period		Define		Traffic	High > 55dBA	West
SURROUNDING	Context	Surfaces	Direction	Color (reflectance)		BUILDING	Typology	Height	
Define	Urban	Buildings as obstruction	East	Light (50-100%)		Define	Residential	Low-rise (≤7 floors)	
SPACE	Function	Occupation Period (major)	Location (floor)			SPACE-interior	Proportions	Surface Properties (color/ reflectance)	
Define	Living Room	All Year-All Day	Upper			Define	Uniform	Light (50-100%)	

Figure 4.3 : Input Page (screenshot).

4.2 Definition of Facade Parameters

4.2.1 Assumptions

Parameters are defined by considering facade performance related design decisions given in the early stages of the design process. The second assumption for definition of the parameters is to have a substantial share in facade design, and accordingly affect facade performance. Briefly, among the parameters, essential ones are included in the tool. Framing is kept out of the scope for not having a big share in facade design, especially when compared to the glazing portion. Finishing material is not included in the tool since it identifies the appearance, so it can be various in color, texture, material, etc. It is hard to define an optimum among limitless design options. But, its properties can be defined as the wall layers. Besides, the finishing material can be dominated by facade type. In certain facade types, a specific range of materials is preferred. Detailing parameter is kept out of the scope of the tool, as well. Decisions regarding details are generally fixed at later stages of design.

4.2.2 Design decisions

Orientation, transparency ratio, facade type, window type, glazing, wall configuration, and shading are the parameters that are specified as the design decision subjects within the tool. Orientation can be either a facade parameter or a condition (if it is an already given decision) for decision-makers. Transparency ratio is one of the most crucial design decision that defines the architectural expression like opacity/ transparency.

The decision regarding the transparency ratio is given in accordance with the facade orientation. Facade type that can define structural (load-bearing properties), constructional (wall configuration) and material properties (finishing material) of the facade is mostly specified by the transparency ratio decision. Similarly, window type decision is dominated by the transparency ratio decision or vice versa. Window position within the facade is important. Glazing is strongly related to orientation and transparency ratio while wall configuration bases on the facade type. The last decision subject within the tool is shading. It is specified for the orientation, transparency ratio, window type, and glazing.

Relationships between design decision subjects and performance aspects need to be discussed. Orientation is the only parameter that is directly related to all aspects of facade performance while the rest of the parameters cannot affect certain performances such as the effect of glazing type decision on water-related performance.

Glazing parameter has sub-parameters like thickness and number of glass panes, thickness of cavity between glass panes, infill gas, color, and coating. Likewise, shading has sub-parameters like availability and type of shading. Wall configuration can be considered in various parameters such as thermal resistance, water resistance principles, etc.

4.3 Generation of Design Options

4.3.1 Assumptions

Options are generated for each design decision (facade parameter) subject in accordance with the existing facade construction industry and knowledge (passive design principles/ measures related to facade performance). Options can be countless; therefore common options are preferred for the tool. The strategy provided by the tool can be followed for project-specific options that are not available within the tool. The options are not for limiting the flexibility in design; they are for keeping the tool relatively simple, comprehensible, and for guiding the tool users (decision-makers) to make deductions for their specific options. The options are chosen from the systems, components, materials widely used in today's construction industry, some of which cover performance-improving strategies. The tool also provides written and visual information describing the options for the users. Since the tool is aimed to be used in

the early stages of the facade design process, it is not always preferred to define the options (which can be the possible options in real cases) with numerical values.

Design is a combination of design decisions given in different design stages/ scales. When the architectural design process is examined, basically, it is seen that it starts from larger-scale decisions and ends with detail decisions. There is an order among design decisions. Besides, some design decisions dominate others. It is inevitable that the orientation of the building/ facade is decided before the decision of the materials. In conceptual design stages, orientation decisions are most probably given, whereas, in the construction documents stage, the decisions that finalize the design; in other words, all the decisions needed to construct the design are made.

4.3.2 Orientation

Options for orientation are the cardinal and the intercardinal directions: North, South, East, West, Northeast, Northwest, Southeast, Southwest. Side-lit spaces having facade on one side are included in the tool, so the orientation indicates the direction of that facade. Orientation options are illustrated in Fig. 4.4.

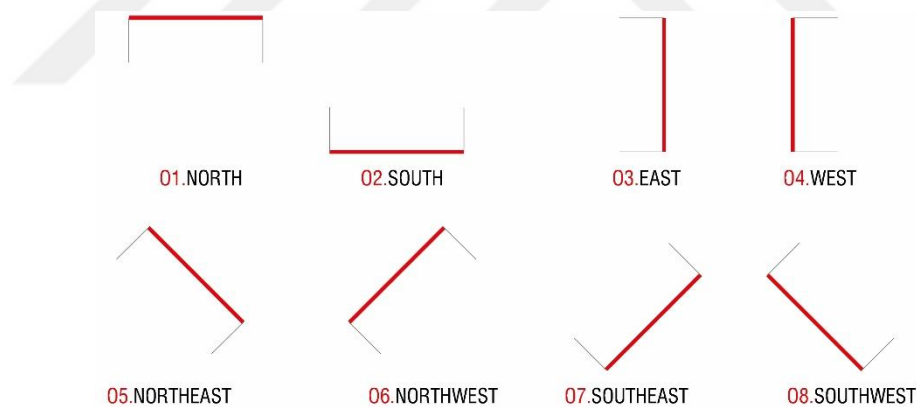


Figure 4.4 : Orientation options.

4.3.3 Transparency ratio

Options for transparency ratio are 0%, 25%, 50%, 75%, and 100%. These correspond to minimum, maximum, and three mid values. They can be seen in Fig. 4.5.

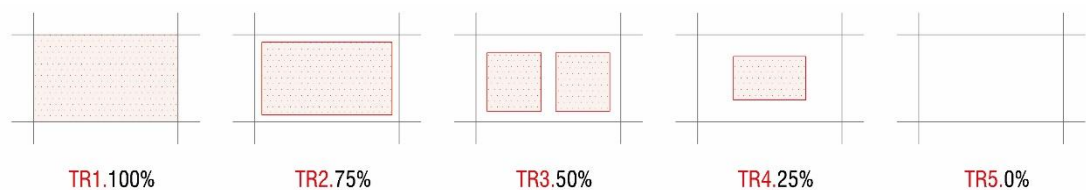


Figure 4.5 : Transparency ratio options.

4.3.4 Facade type

In order to determine the types of facades, ten different reference publications about facades (Hermann, et al., 2015, Ching, 2014, Watts, 2014, Yu, 2014, Aksamija, 2013, Boswell, 2013, Toydemir, et al., 2011, Herzog, 2008, Knaack, et al., 2007, Schittitch, 2006) are reviewed and their categories of facades are listed (Table 4.6). Then, based on the categories, facades are recategorized according to three main aspects: structural, constructional, and material (Fig. 4.6). Non-self-supporting facades are taken within the scope since they constitute a great majority of today's designs. The options are combinations of the number of skin (single-skin, double-skin) and construction type (infill, cladding). Second-skin type of double-skin facades is included in the tool. Box-window, corridor, and shaft-box types are kept out of the scope. Masonry, frame, monolithic, and window are adopted as types of infill construction. Light-weight curtain walls (here taken as curtain walls) and heavy-weight curtain walls (concrete claddings) are taken as types of cladding construction. Facade type options are shown as sections in Fig. 4.7.

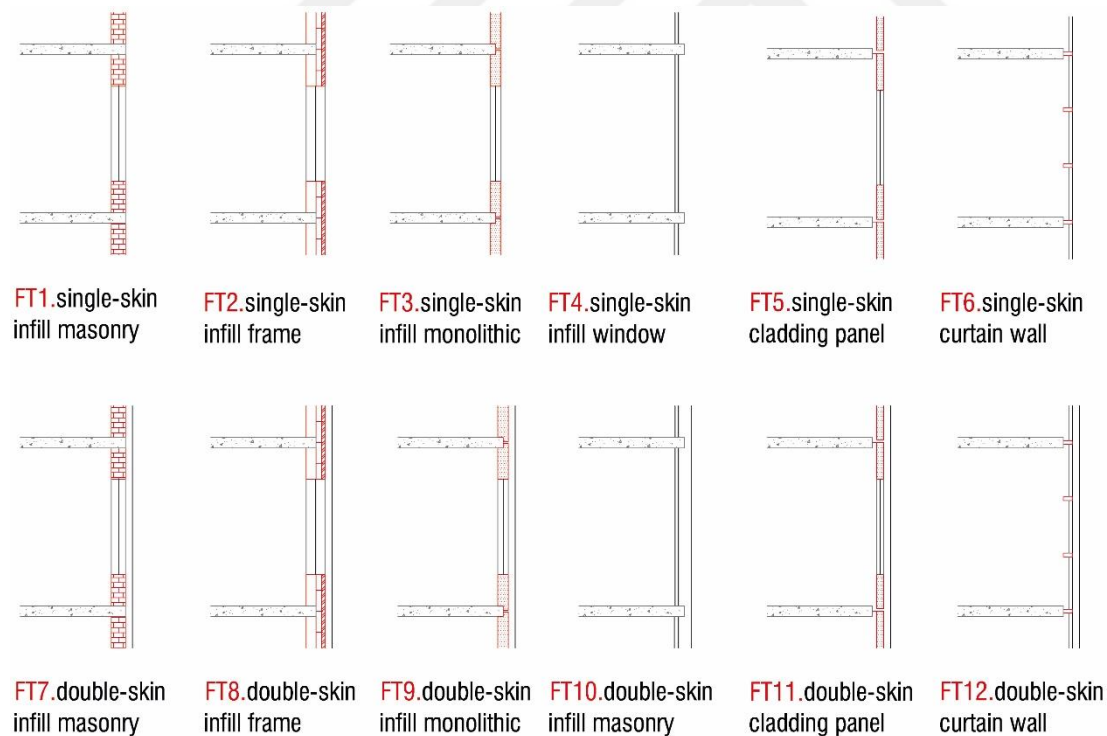


Figure 4.7 : Facade type options.

Table 4.6 : Comparison of facade categories.

	Facades Principles of Construction <i>Knaack, et al., 2007</i>	Modern Construction Envelopes <i>Watts, 2014</i>	Exterior Building Enclosures <i>Boswell, 2013</i>	Enclose Build <i>Hermann, et al, 2015</i>	Sustainable Facades <i>Aksamija, 2013</i>	Facade Construction Manual <i>Herzog, 2008</i>	Skin, Envelopes, and Enclosures <i>Yu, 2014</i>	Building Skins <i>Schittich, 2006</i>	Building Construction Illustrated <i>Ching, 2014</i>	Yapı Elemanında Malzeme <i>Toydemir, et al., 2011</i>
Facade Types	Solid Wall	Metal Wall	Brick Masonry Wall	Self-Supporting	Opaque Building Facade Cavity Wall (Rainscreen)	Facade Material	Load-Bearing Construction Monolithic Bearing Walls	Load-Bearing	Concrete Wall	Cladding Wall
	Warm Facade	Sheet Metal				Natural Stone		Non-Load-Bearing	Precast Concrete Wall	External Plaster (Warm Wall)
	Cold Facade	Profiled Metal Cladding	Curtain Wall	Masonry	Brick	Clay	Masonry			Rigid Cladding
		Composite Panel		Concrete	Precast Concrete Panel	Concrete	Stone	Single-Shell	Masonry Wall	Ceramic
	Post-and-Beam Facade	Metal Rainscreen	Framed Masonry Natural Stone Wall	Timber	Metal	Timber	Concrete	Multi-Shell	Unreinforced Masonry Wall	Glass
	Post Facade	Mesh Screen			PER (back-ventilated)	Metal	Load-Bearing Cavity Walls Light-Frame Construction		Reinforced Masonry Wall	Brick
	Beam Facade	Louvre Screen	Masonry Brick Cavity	Non-Self-Supporting		Glass		Single-Layered		Natural/ Artificial Stone
	Curtain Wall	Glass Wall			Glazed Building Facade	Plastics	Balloon Framing	Multi-Layered	Adobe Construction	Metal
	System Facade	Stick Glazing	Natural Stone Masonry (Rainscreen)	Suspended Facade (Rainscreen)	Curtain Wall		Platform Framing		Rammed-Earth Construction	Polymer
		Unitized Glazing		Face Brickwork	Stick System			Transparent		Timber
	Double Facade	Clamped Glazing	Precast Architectural Concrete	Brick Panels	Unitized System		Non-Load-Bearing Construction Frame and Infill Construction	Translucent	Glass Block	Prefabricated Panel
	Second-Skin Facade	Bolt-Fixed Glazing		Natural Stone				Opaque		
	Box-Window Facade	Glass Block	Metal Framing & Glass	Metal	Double-Skin Facade		Window Facade		Steel Construction Timber Construction	Curtain Wall
	Corridor Facade	Window	Window Wall System	Fire-Cement Board	Box- Window					
	Shaft-Box Facade	Steel	Storefront System		Corridor		Cladding System			
	Alternating Facade	Aluminum	Curtain Wall, Stick System, Unitized System	Sandwich System	Shaft-Box				Cavity Wall	

Table 4.6 (continued) : Comparison of facade categories.

Facades Principles of Construction	Modern Construction Envelopes	Exterior Building Enclosures	Enclose Build	Sustainable Facades	Facade Construction Manual	Skin, Envelopes, and Enclosures	Building Skins	Building Construction Illustrated	Yapı Elemanında Malzeme
Integrated Facade	PVC-u		Double Skin Facade	Multistory		Curtain Wall		Masonry Cladding	
Adaptive Facade	Timber	Window Wall		+Ventilation Types				Stone Panel Cladding	
	Concrete Wall		Curtain Wall Mullion/ Transom Facade					Timber Cladding	
Masonry Cladding	Cast-in-Situ/ Cast-in-Place	Curtain Wall							
Solid Concrete Facade	Story-Height Precast Panel		Element Facade					Curtain Wall	
Free-form Metal Facade	Small Precast/ GRC Cladding Panel	All Glass Enclosures						Glass	
Timber frame structure with multiple cladding	Masonry Wall	Glass, Cable, Truss Support	Structural Glass					Metal (Sandwich System)	
	Masonry Load Bearing Wall	Through Glass, Clamped, Adhered Attachment						Precast Concrete	
Free-form Facades	Masonry Cavity Wall	Through Glass (Point Support, Spider)	Timber Facade						
Modular Construction	Stone Cladding	Barrier Design Principle	Membrane Facade					Window System	
	Terracotta	Mass Design Principle						Metal	
	Rainscreen	Rainscreen Design Principle	Glass Facade					Wooden	
	Plastic Wall	Pressure Equalized Rainscreen							
	Plastic-based Cladding								
	Rainscreen								
	Timber Wall								
	Cladding the Timber Frame								
	Cladding Panels and Rainscreens								

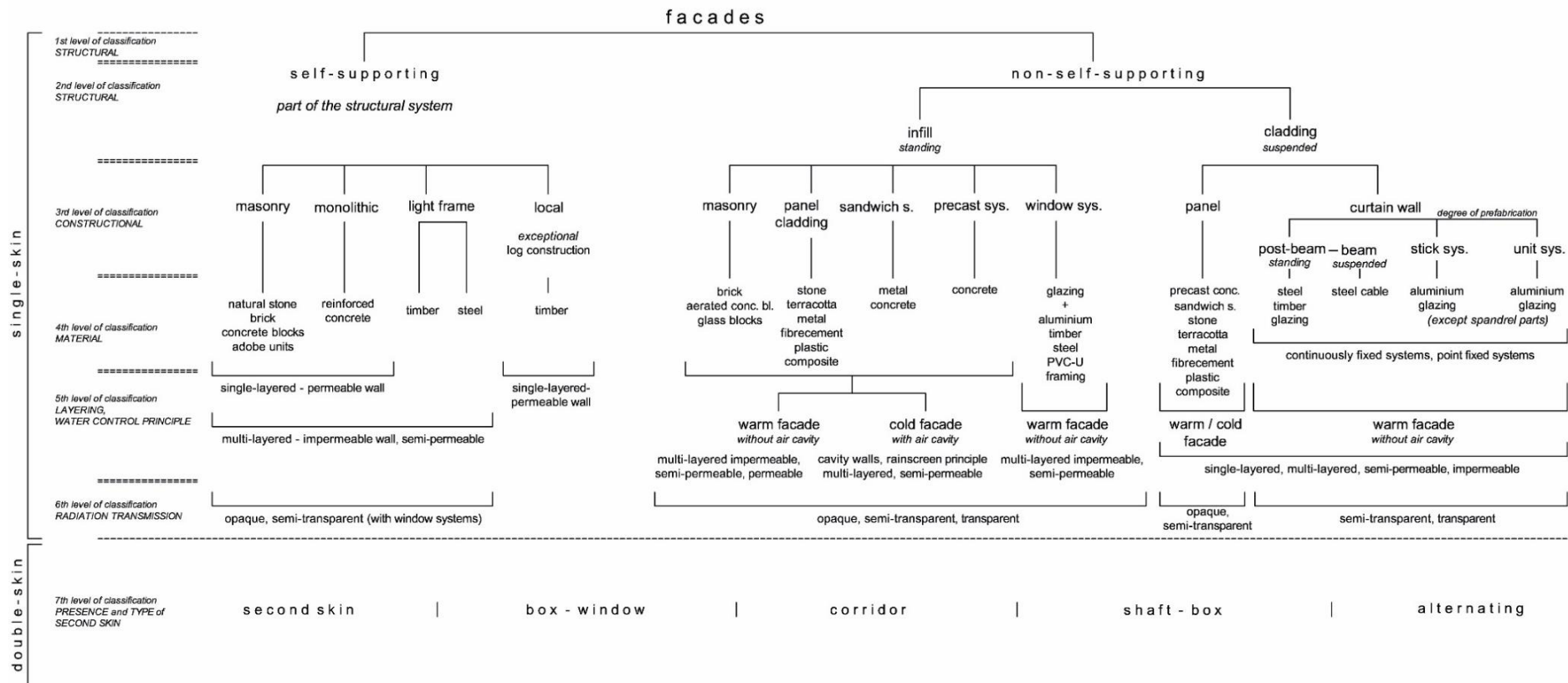


Figure 4.6 : Categorization of facades.

4.3.5 Window type

Window types are combinations of window position in height (vision level, upper level, full-height) and in depth (flush, recessed) and window operability (operable, fixed). Possible options for window positions in relation to walls are illustrated in Fig. 4.8. There are 12 window types in total and in Fig. 4.8, the options in the second row are the operable versions of the first row windows.

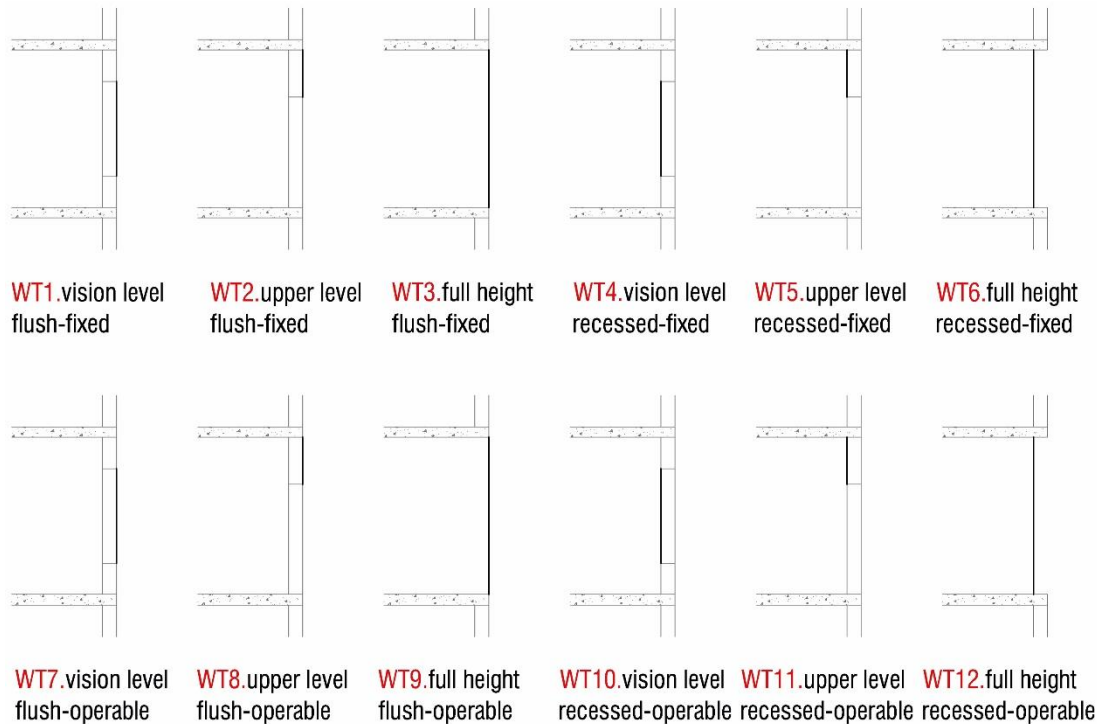


Figure 4.8 : Window types.

Also, windows can be classified/ named by their components, glazing and framing systems, e.g. aluminium/ timber/ plastic windows, or spectrally selected windows. Aluminium, timber or plastic are the materials of window frames while spectrally selective is the feature of its glazing. Since the framing is kept out of the scope, it is assumed that the windows have frames that are properly detailed.

4.3.6 Glazing

Number and thickness of glass panes (single, double, triple in various thicknesses), gap thickness and type of infill gas (air, krypton), color/ coating of glass panes (clear, green-tinted, low-e coated), assembly of glass panes (symmetric or asymmetric) are the variables in glazing options. Glazing options are given in Fig. 4.9.

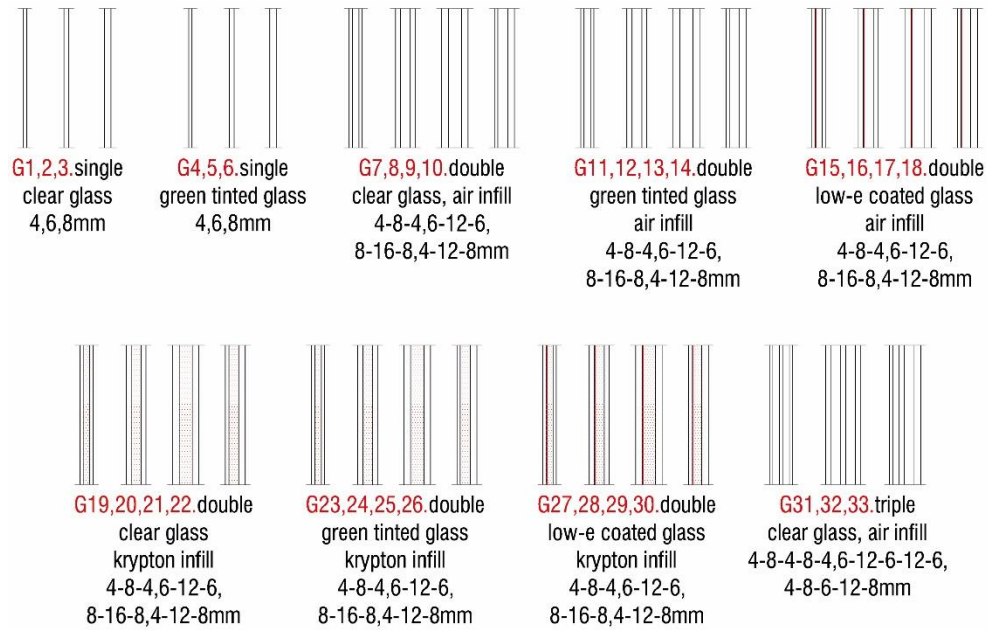


Figure 4.9 : Glazing options.

As is known, these options are generated to be evaluated by the tool for various performance aspects. So, there are some assumptions regarding the options. To give an example, for daylighting performance evaluation, each glass type is assumed to have certain visible transmittance value (see Table 4.7).

Table 4.7 : Assumptions for glazing (to calculate effective aperture).

Glass type	Visible Transmittance
Clear	80%
Green Tinted	40%
Low-e Coated	60%

4.3.7 Wall Configuration

Wall configuration options are generated by considering permeability of cladding (impermeable, semi-permeable) and presence of air cavity (available, none), position (outer, middle, inner) and type of thermal insulation (rockwool, XPS, EPS). Options are shown as cross-sections in Fig. 4.10. Basically, there are 5 types of configuration; however, with three different thermal insulation materials, there become 15 wall configuration options in total.

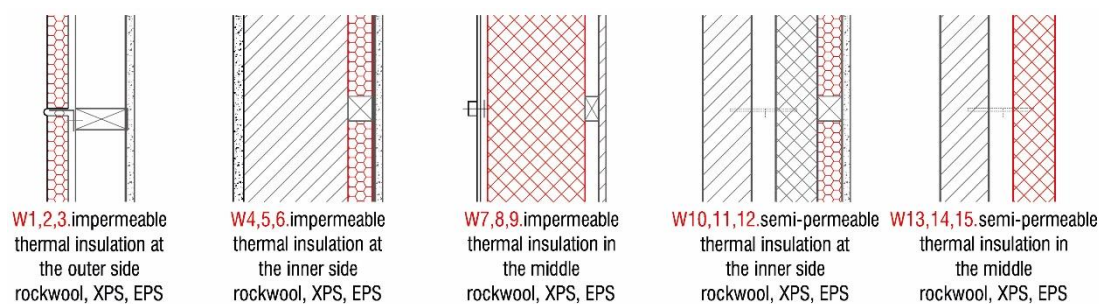


Figure 4.10 : Wall configuration options.

4.3.8 Shading

Shading options are generated in consideration of the following parameters: availability (available, none), direction (horizontal, vertical, both), and type (overhang, lightshelf, louver). 6 types of shading included in the tool can be seen in Fig. 4.11.

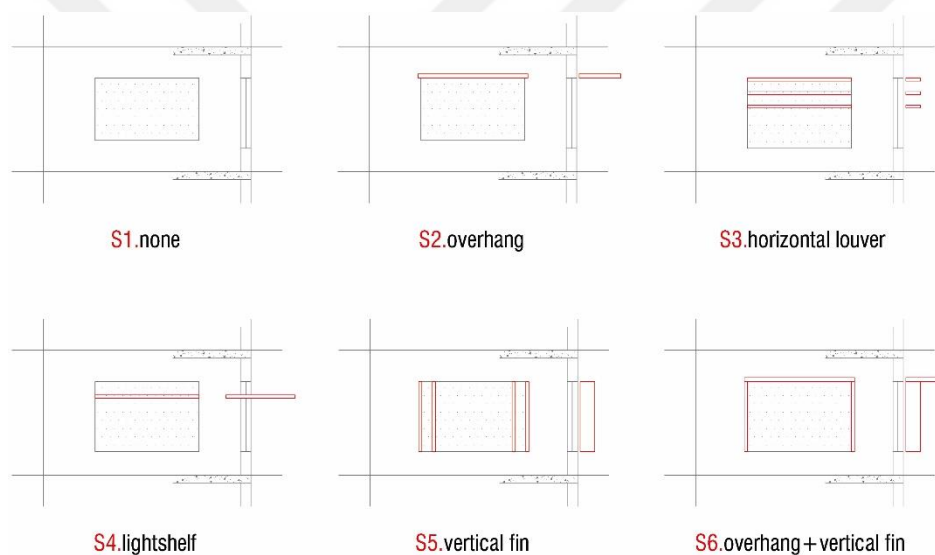


Figure 4.11 : Shading options.

Lastly, all the options generated for the predefined design decisions within the tool are presented in Table 4.8, Table 4.9, and Appendix A (larger versions of the drawings).

Table 4.8 : Tool options (part-1).

Orientation	Transparency Ratio		Facade Type			Window Type		
1.North	Opaque	1.0%	Single-Skin	Infill	1.Masonry	Vision Level	Fixed	1.Flush
2.South		2.25%			2.Frame			2.Recessed
3.East	Semi-Transparent	3.50%		Cladding	3.Monolithic	Upper Level	Operable	3.Flush
4.West		4.75%			4.Window			4.Recessed
5.Northeast	Transparent	5.100%	Double-Skin	Infill	5.Curtain w.	Full Height	Fixed	5.Flush
6.Northwest					6.Panel		Operable	6.Recessed
7.Southeast				Cladding	7.Masonry			7.Flush
8.Southwest					8.Frame			8.Recessed
					9.Monolithic			9.Flush
					10.Window			10.Recessed
					11.Curtain w.			11.Flush
					12.Panel			12.Recessed

Table 4.9 : Tool options (part-2).

Glazing			Wall Configuration			Shading	
Single Glazing	4mm		1.Clear 2.Green tint	Thermal insulation at the outer side	1.Rockwool 2.XPS	Non-available	
	6mm		3.Clear 4.Green tint.		3.EPS	Available	1.None 2.Overhang 3.Lightshelf
	8mm		5.Clear 6.Green tint.	Thermal insulation in the middle	4.Rockwool 5.XPS		4.Louver
			7.Clear 8.Green tint.		6.EPS		5.Louver
	4-8-4mm	air	9.Low-e c. 10.Clear	Thermal insulation at the inner side	7.Rockwool 8.XPS		6.Overhang + Louver
		krypton	11.Green tint. 12.Low-e c.	Thermal insulation in the middle	9.EPS 10.Rockwool		
Double Glazing			13.Clear 14.Green tint	Thermal insulation at the inner side	11.XPS 12.EPS	Available	
	6-12-6mm	air	15.Low-e c. 16.Clear		13.Rockwool 14.XPS		
		krypton	17.Green tint. 18.Low-e c.		15.EPS		
			19.Clear 20.Green tint.				
	8-16-8mm	air	21.Low-e c. 22.Clear				
		krypton	23.Green tint. 24.Low-e c.				
Triple Glazing			25.Clear 26.Green tint.			Available	
	4-12-8mm	air	27.Low-e c. 28.Clear				
		krypton	29.Green tint 30.Low-e c.				
	4-8-4-8-4 mm		31.Clear				
	6-12-6-12-6 mm	air	32.Clear				
	4-8-6-12-8 mm		33.Clear				

4.4 Establishment of Design Decision and Performance Matrices

To evaluate each design decision option in terms of each performance aspect, matrices having design options in rows and performance aspects in columns are established. The matrices are designed via Microsoft Office Excel software in the form of a spreadsheet. There are separate matrices (7 in total) for different design decision subjects. The first of the matrices is for the orientation parameter (design decision). The separate matrices have an order among themselves and are linked to each other thanks to the capabilities of the software. Each intersecting cell in matrices is reserved for rating the option for the performance aspect in question. These matrices are called rating charts within the context of the tool. An example of these charts is given in Fig. 4.12.

1st design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
ORIENTATION	North									
	South									
	East									
	West									
	NorthEast									
	NorthWest									
	SouthEast									
	SouthWest									
	SELECTION									

Figure 4.12 : Orientation and performance chart.

The matrices are established as a base for the presentation of rating results. In Fig. 4.12, all the empty cells are the places for the rating scores. Orientation decisions can affect all the separate aspects of facade performance, so all the cells are ready for ratings. However, not every design decision has a potential effect on all the performance aspects. In that case, the matrices have light gray highlighted parts that have the meaning that it is not possible to evaluate the options for these specific performance aspects. In other words, since the tool is based on the information in the literature, it means the tool has no data for this evaluation. As an example of the charts, the one established for shading (the last parameter in the order of decision-making) is given in Fig. 4.13. As it is seen, shading options are not evaluated by the tool in terms of air permeability and moisture-related performances.

7th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
SHADING	not available									
	Overhang ≥ 60 cm									
	Lightshelf (50+50, 100+50cm)									
	Horizontal Louver ≤ 30 cm, every 20-30cms from floortop to vision level									
	Vertical Louver ≤ 30 cm, every 20-30cms from space edges to vision area									
	Vertical Louver ≤ 30 cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)									
	SELECTION									

Figure 4.13 : Shading and performance chart.

The charts after the rating process are for the decision-makers to make decisions regarding the facade parameters (to select an option). They correspond to the output and decision-making pages within the tool working flow. Since the ultimate aim is to develop a tool with a holistic approach, these matrices define a framework for an overall evaluation by gathering all separate aspects in one platform.

4.5 Rating Design Options

4.5.1 Assumptions

Existing research results are compiled to make generalizations for the interrelations between design decisions (facade parameters) and facade performance aspects in conjunction with outdoor and indoor conditions. After specifying affecting agents and performance indicators/ metrics for each performance aspect, these are used to analyze, filter, and resolve the information/ knowledge available in the literature.

The tool is designed to rate the options based on ‘if-then’, ‘unless-then’ relationships (conditions-functions) derived from the literature. For instance, assuming that a research in literature indicates that acoustic performance of a facade glazing (sound insulation against outdoor noise) can be improved by one of the following design strategies: increasing the mass (number and/or thickness of glass layers), increasing the gap between the glass layers, filling the gap with heavy gases, and asymmetric assembly of glass layers. It is taken as the more the layer, or the more the thickness, or the thicker the gap, or heavier the gas or the more the difference in layer thickness, the better the acoustic performance. Options are rated gradually in line with this design-performance relationship. To run the rating function, the first condition of the tool is

the availability of traffic noise. If there is traffic noise, then the tool rates the options. In some cases, difference among the options has more critical effects on the performance such as; if transparency ratio is higher ($\geq 50\%$) or if the facade is in the direction of the noise source or if the space is highly noise-sensitive like patient rooms, then the previous ratings for the glazing options are readjusted by making the advantageous and the disadvantageous options get more higher and more lower scores, respectively. These are the assumptions of the tool to provide a rough but holistic impression about facade performance in the early stages of facade design. Conversely, if there is no traffic noise, options are not rated by the tool and given NA (Not Assessed). Other types of noise sources such as construction, entertainment, people, etc. are not taken within the scope of the tool.

Within the scope of the tool, optimum means to achieve the maximum performance (for all functional aspects included in the tool) with minimum effort/ energy (passive design strategy). The tool performance evaluation bases upon multi-objective decision-making. It is also important to emphasize that the performance levels of the facade need to comply with the relevant standards and regulations. The levels can be obtained through several methods. These ratings need to be considered as just a preliminary evaluation.

4.5.2 Rating Scale

Decision-making is, in one sense, a selection process in which the decision-makers need to decide on an option (select an option) among several others. They need to make comparisons considering various aspects. It is the inherent nature of decision-making. Due to this reason, a comparison-based assessment methodology is preferred for the tool. To evaluate all aspects in one equation, a simple rating scale (++, +, 0, -, --) is adopted. This method allows for assessment of design in terms of separate performance aspects regardless of their specific metrics.

The tool proposes a simple scale for the rating of the options. It has a (+), (-) and (0) scale. If the option has a direct advantage for that performance when compared to the other options, it is 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 a direct disadvantage for that performance, it is rated as (-). If it has no direct effect or negligible difference, which means there is no superiority

among other options, it is given (0). In some cases, the difference among the options has more critical effects on the performance; then the previous ratings are multiplied by (2) as to be (++), (--), and (0).

The rating system within the tool is based on comparisons and indicates how superior/inferior is that design option (for that facade parameter) when compared to the others in terms of that performance aspect.

4.5.3 Prescriptions

Ratings are done in accordance with the prescriptions provided within the tool process pages. The tool links conditions to rating functions by means of the Excel spreadsheet in order to fulfill objective functions defined by the tool. Each facade parameter has its process page that includes conditional sentences prescribing how to rate the options for different performance aspects. A template for tool process pages is given in Table 4.10. All the rating charts (tool process pages) can be seen in Appendix A.

Prescriptions (conditional functions) are taken their shape around objective functions that are derived from performance requirements, while the condition and function relationships are deduced from the researches in the literature. The tool user can access the prescriptions and corresponding references available in tool process pages. The tool process pages are not visible at first hand, but if required they can be accessed. A section from the orientation tool process page is given in Fig. 4.14. The user can check the logic/ reasons behind the ratings and make a decision afterward.

ORIENTATION Decision & PERFORMANCE	PERFORMANCE CRITERIA	OBJECTIVE FUNCTIONS	CONDITION -1	FUNCTION - 1	CONDITION -2	FUNCTION - 2	REFERENCES
O-P3 Orientation & Water related Performance	to prevent water penetration through the facade, to resist wind-driven rain forces	LOWER WIND-DRIVEN RAIN LOADS	if there is dominance among winds and if annual rainfall is higher than 400mm	give (-) for the options in the predominant wind directions give (+) for the most protected ones give (0) for the rest	if it is high-rise building or if wind speed is high	multiply the ratings (function - 1) by (2)	Gao, et al., 2017, Olsson, 2017, Künel, 2015, Blocken & Carmeliet, 2015, Blocken, et al., 2013, Blocken, et al., 2009, Türkeri, 2013, Gudum, 2003, Beall, 2000, Rich & Dean, 1999, Uri-15

Figure 4.14 : A section from orientation tool process page (screenshot).

In the background, there are assumptions for design options that the tool takes into account in its evaluation (rating) process. For instance; clear, low-e coated, and green-tinted glasses are assumed to have visible transmittance of 80%, 60%, and 40%, respectively. There are design options of 25%, 50%, 75%, and 100% transparency ratios in the tool. Then, the tool rates (evaluates) the options according to the optimum

effective aperture (0.30, ± 5) which is another assumption. There are some numerical values and simple calculations behind the descriptions. Similarly, there are assumptions for required illumination levels or noise sensitivity levels for space typologies. For instance, laboratories are assumed to require lighting levels of more than 500lux and have low noise sensitivity. There are acceptances for fire safety requirements and fire class of materials, as well. All these are from the literature, existing standards and regulations.

Table 4.10 : Template for tool process pages.

Design Decision & Performance	Objective Functions	Condition-1	Function-1	Condition-2	Function-2	Condition-3	Function-3
DD-P1							
DD-P2							
DD-P3							
DD-P4							
DD-P5							
DD-P6							
DD-P7							
DD-P8							

The tool has some expressions related to wind direction such as opposite and perpendicular. To clarify the matter, assumptions regarding wind directions are given in Table 4.11.

Table 4.11 : Assumptions regarding wind directions.

Wind Direction	Opposite	Perpendicular
North	South	East, West
South	North	East, West
East	West	North, South
West	East	North, South
Northeast	Southwest	Northwest, Southeast
Northwest	Southeast	Northeast, Southwest
Southeast	Northwest	Northeast, Southwest
Southwest	Northeast	Northwest, Southeast

As the tool user defines the conditions in the input page, the tool process starts to run, and firstly gives the rating results for the orientation in the output page. The options are rated by the tool based on the conditional functions defined in the tool process. They are grounded on the references and can be accessed by the user if required. For instance, for rating the orientation options according to water-related performance, the tool's objective function is to be exposed to lower wind loads to prevent water penetration through the facade and to resist wind-driven rain forces. The first condition is the dominance among winds and annual rainfall intensity higher than 400mm. If there is a predominant wind, and if it is not an arid climate, the tool gives (-) for the options in the predominant wind directions, (+) for the most protected ones (the opposite side of the predominant wind direction), and (0) for the rest of the orientation options. The second condition is the height of the building or the level of wind speed. If it is a high-rise building or if the wind speed is high, the tool multiplies the ratings given for the first condition. These condition-function relations are supported by relevant references (Fig. 4.14). To exemplify, if South orientation is presumed to be the predominant wind direction in a humid climate, then South option is given (-), North option is given (+), and the other options (Northeast, Northwest, Southeast, Southwest, East, West) are given (0). Besides, if it is a high-rise building, then South is given (-2), North is given (2), and the rest is given (0).

The tool's function is not about fulfilling the water resistance. In any case (orientation, wind direction, etc.) water resistance needs to be fulfilled by the facade. The tool aims at minimizing the wind-driven rain loads, so the level of measures to achieve water-related performance criteria. Reducing the required water resistance level in the early stages of facade design can compensate for probable defects that may occur due to detailing or workmanship in later stages.

4.5.4 Weighting the relationships

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 a performance aspect and a facade parameter is weighted for a holistic evaluation (see Table 4.12). (5), (3), (1), (0) are the assigned coefficients that correspond to strong, medium-strength, weak, and no relationships, respectively. Weighting the relationships is considered as one of the systematic design approaches

(Cross, 2008). Again, a simple scale is adopted to keep the calculations relatively simple, and the results comprehensible.

Table 4.12 : Weights of the relationships.

Facade Parameter & Performance	Structural	Fire	Water	Air	Thermal	Moisture	Day- lighting	Acoustic
Orientation	5	3	5	5	5	5	5	5
Transparency ratio	5	3	0	0	5	0	5	5
Facade type	5	3	3	3	5	5	0	3
Window type	0	3	1	0	5	5	5	1
Glazing	1	0	0	0	5	3	5	5
Wall configuration	0	5	5	0	5	5	0	5
Shading	1	5	5	0	5	0	5	1

The strength of relationships is determined in two ways. Firstly, assumptions are made based on the literature. Secondly, the assumptions are checked with experts and refined. At least one expert for each performance aspect is interviewed. Throughout the development of the tool, especially for rating the options and weighting the relationships, experts of various disciplines are asked for their opinions. Thus, the deductions made from the literature are able to be cross-checked. Nevertheless, the above weights are the numbers proposed by the tool, which can be debatable. For instance, the weight of the relationship between shading and fire performance can be given 3, as well, that corresponds to the medium-strength relationship. But, when the tool's options and assumptions are considered, it is preferred to give 5.

4.6 Rating Results and Decision-Making

Rating results for each design decision subject are presented in matrices. The tool rates each option in terms of each performance aspect. The scores are the products of ratings and weightings (rating of the tool x weight of the relationship). Based on the multiplied scores, the tool highlights the most advantageous and disadvantageous options. These options are determined by the tool in a holistic way. All the performance aspects are taken into consideration for the evaluation. Facades designed by the most advantageous decisions are assumed to be the ideal design. The rating results are

presented in the output pages (Fig. 4.15). In the Figure, the last row demonstrates the scores of the user's decision. It is open to manipulation by the users.

OUTPUT PAGE - O R I E N T A T I O N										
Detailed descriptions + References	O-P1	O-P2	O-P3	O-P4	O-P5	O-P6	O-P7	O-P8		
relationship coefficient:	5	3	5	5	5	5	5	5		
1st design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
ORIENTATION	North	0	0	0	0	-5	0	-5	0	-10
	South	0	0	0	0	5	0	5	0	10
	East	0	0	0	0	0	0	-5	10	5
	West	0	0	0	0	0	0	0	-10	-10
	NorthEast	-5	-3	-5	-5	-5	-5	-5	0	most disadvantageous -33
	NorthWest	5	0	0	0	-5	0	-5	0	-5
	SouthEast	5	0	0	0	5	0	5	0	15
	SouthWest	-5	3	5	5	5	5	5	0	most advantageous 23
	East	0	0	0	0	0	0	-5	10	selection 5

Figure 4.15 : A sample for rating results for orientation.

When the user selects an option, the tool rates the options for the subsequent decision subject. Decisions are assumed to be made in an order starting from orientation and ending with shading. The tool has separate but interlinked output and decision-making pages (matrices). A decision made in a previous decision subject can affect the ratings of the further decision subjects. Also, it can limit the options to be selected in other decision subjects. These are defined within the tool, as well. To see the ratings of the options, the user needs to select an option (make a decision) for the previous design parameter. For instance, according to the orientation decision, ratings for the transparency ratio options can change, so without orientation decision, transparency ratio options can not be rated.

A sample is given in Fig. 4.16 for rating results for transparency ratio. As can be seen, the most advantageous and disadvantageous options can be more than one.

OUTPUT PAGE - TRANSPARENCY RATIO										
Detailed descriptions + References		TR-P1	TR-P2			TR-P5		TR-P7	TR-P8	
relationship coefficient:		5	3	0	0	5	0	5	5	
2nd design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
TRANSPARENCY RATIO	0%	5	3			0		-5	10	most advantageous
	25%	5	3			5		0	0	most advantageous
	50%	0	-3			-5		5	0	
	75%	-5	-3			-5		5	-10	most disadvantageous
	100%	-5	-3			-5		5	-10	most disadvantageous
	50%	0	-3			-5		5	0	selection

Figure 4.16 : A sample for rating results for transparency ratio.

The tool highlights the most advantageous option(s) for each facade parameter. The most advantageous option corresponds to the optimum option (in terms of all performance aspects) among the options within the tool. The ideal facade design is the one that composes of the optimum decisions given in an order (it is important since the previous decisions change the optimum in subsequent decisions). The tool provides a rough holistic impression and a comparison basis to support decision-making.

The tool user proceeds from the input page to the output and decision-making pages, and finally to the evaluation page. If required, the tool process pages can be accessed to see the logic behind the ratings. Step by step, the tool user defines the conditions by selecting from drop-down lists, then sees rating results for decision subjects, and selects an option for each, respectively. After that, the tool user checks the comparison chart for overall performance evaluation. Finally, if the results are satisfying, then the user finishes the decision-making, if not, goes back and re-checks the decisions. The evaluation part is described in the following section. Flowchart of the tool is given in Fig. 4.17.

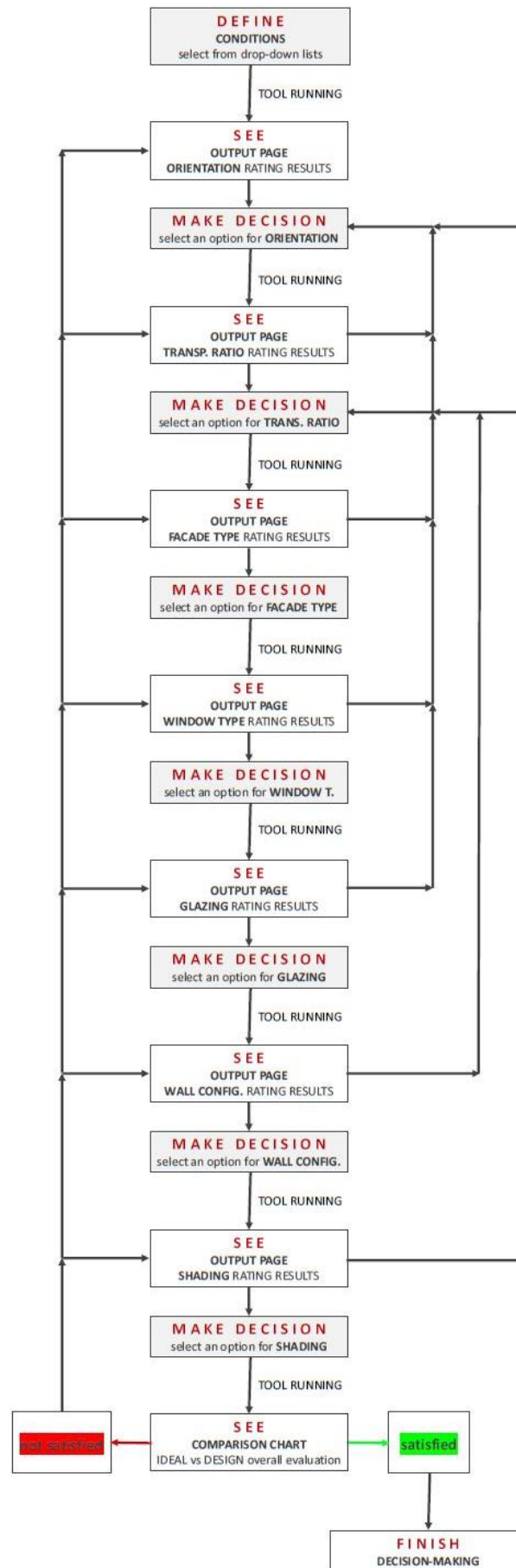


Figure 4.17 : Tool flowchart.

4.7 Overall Performance Evaluation

4.7.1 Overall rating results

Aygün (1999) defines the components as discrete parts of the elements that intend to satisfy one or more of the functional performance requirements about that element. Thus, the resultant overall element performance depends on the performances of individual components (Aygün, 1999).

The rating scores given for all decision subjects are accumulated for each performance aspect individually (see equation 4.1). It is assumed that the sum total of the design decisions composes the facade design.

$$\text{the final score of individual performance aspect} = \sum \text{design decision scores} \quad (4.1)$$

(rating x weighting)

The sum of + and - is 0. One advantage scored due to a decision plus one disadvantage scored due to another decision make the facade design neutral (having no superiority) for that performance aspect. 0 has no effect on the results.

A sample for overall rating results is given in Fig. 4.18. The numbers represent the accumulation of the ratings for each performance aspect separately. These indicate the advantages and disadvantages of a specific facade design among all possible design alternatives for each performance aspect. The numbers do not represent real performance values.

Performance Aspect	TOOL's Ideal	Facade Design
Structural Performance	5	1
Fire Performance	22	-13
Water related Performance	6	0
Air Perm. related Performance	0	0
Thermal Performance	40	5
Moisture related Performance	23	21
Daylighting Performance	25	5
Acoustic Performance	40	19

Figure 4.18 : A sample for overall rating results.

4.7.2 Graphical representation

Since it is a comparison-based decision support tool, it is preferred to present the final evaluation graphically. The overall facade performance is illustrated by a spiderweb graphic that has separate sections for each performance. The graphic helps to make comparisons holistically. Neither the tool nor the graphic does not give the real performance values, but better than that gives the impression for the overall facade performance which is believed to be more comprehensible for decision-makers of facade design.

After the last design decision (shading) is given, the tool directs the user to the evaluation page. In the evaluation page, the overall scores are presented by a spiderweb graphic in which each corner corresponds to a performance aspect. The graphic is designed to adapt itself to different scores of minimum and maximum.

A representative comparison chart for overall performance evaluation is demonstrated in Fig. 4.19. The blue line represents the tool's ideal which means if holistically evaluated it is the best design for the defined conditions. The orange one is the graphic of the facade design which is the aggregation of the design decisions made by the tool user.

The user can check the preliminary design decisions with the help of this graphic. It is obviously seen in the sample spiderweb graphic that the performance of the facade design is far from the tool's ideal in thermal, daylighting, and acoustic performance aspects. The evaluation results can lead the user to revisit the decisions regarding facade parameters and to check how to (by which design decisions) change the performances positively.

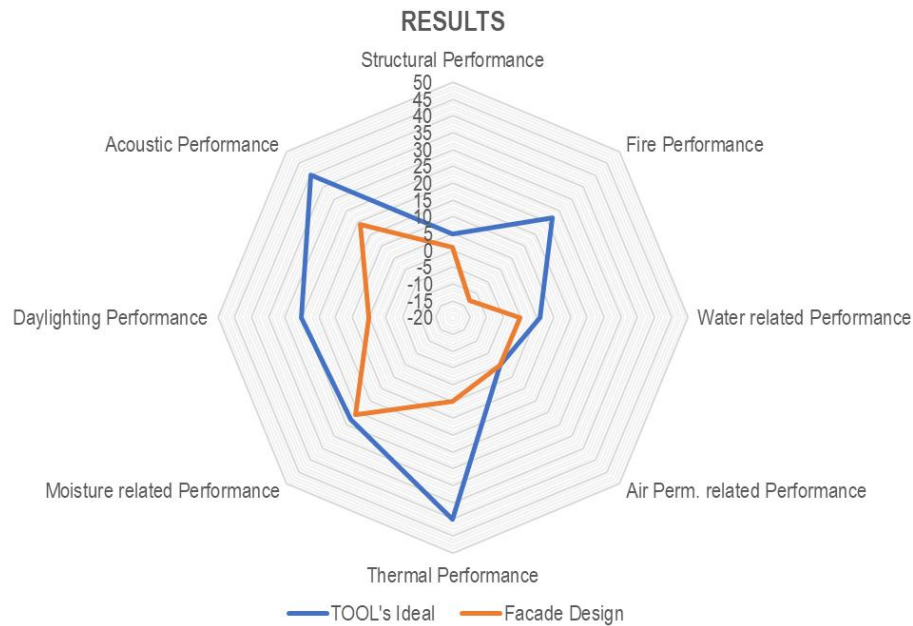


Figure 4.19 : A representative comparison chart for overall performance evaluation.

4.8 Summary of the Chapter

In this Chapter, the tool is described in detail, the methodology followed throughout the tool formation, and the working principle of the tool are provided. Firstly, environmental and spatial conditions and facade parameters are defined. Then, design options are generated for the defined facade parameters. After that, separate but linked design decisions and performance matrices are established for each design decision subject (facade parameter). Subsequently, the rating of the design options is explained with a rating scale, prescriptions and weighting. Then, the rating results and decision-making process are presented. The tool is designed in the form of an Excel spreadsheet, by using the software capabilities. Lastly, overall performance evaluation is described by overall rating results and their graphical representation. The summary of the tool flowchart is presented in Fig. 4.20.

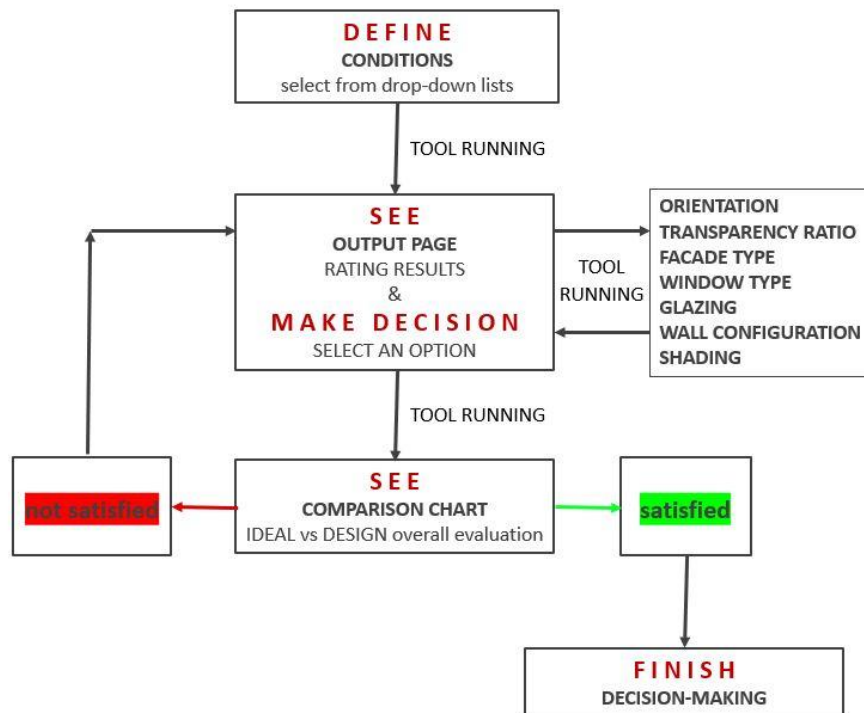


Figure 4.20 : Summary of the tool flowchart.

5. IMPLEMENTATION OF THE TOOL

In this Chapter, the tool is implemented for made-up scenarios and real projects. Scenarios are made up of considering the variety in environmental and spatial conditions. After testing the tool for made-up scenarios, a sensitivity analysis is conducted for a single scenario to see the sensitivity of facade performance to facade parameters (design variables). On the other hand, real projects are specified as both ongoing design projects and already constructed projects. Architects as decision-makers are let to use the tool for at least one of their projects. Besides, the tool is opened for use by different stakeholders, owner, and engineers, for one of these projects. After the tool usage, feedback of the tool users is recorded through interviews with half-structured, open-ended questions. Answers to the interview questions are outlined in this chapter. Lastly, the feedback of the implementation is interpreted as contributions, deficiencies, and complexities of the tool.

5.1 Testing the Tool for Possible Scenarios

The tool is tested for five different scenarios having various environmental and spatial conditions.

5.1.1 Scenarios

Istanbul, Ankara, Antalya, Gaziantep, Erzurum are chosen as the cities for the scenarios. These cities represent different climate types of Turkey: temperate-humid, temperate-arid, hot-humid, hot-arid, and cold climates. Details of the scenarios are given in Table 5.1. Scenarios are defined in order to constitute a variety within the tool's capacity.

It is paid attention to test as many conditions as possible with these five cases. Apart from the climatic conditions, the tool is implemented for different building typologies and space functions. As it is seen in Table 5.1, there is also variety in terms of noise sources and surrounding obstacles. Similarly, building height varies, and the spaces are assumed to be on different floors of the buildings.

Table 5.1 : Scenarios.

Conditions		Scenarios				
Location	City	Istanbul	Ankara	Antalya	Gaziantep	Erzurum
	Hemisphere	Northern				
Earthquake	Latitude	Middle (30-60)				
	Criticality	High	Low	Low	High	High
Climate	Temperature	Temperate	Temperate	Hot	Hot	Cold
	Rainfall	Humid >600mm	Arid <400mm	Humid >600mm	Arid <400mm	600mm> Semi-Arid >400mm
Wind (predominant)	Diurnal Temp. Variation	Low	Low	Low	High	High
	Direction	Northeast	North	West	Northwest	West
Noise	Speed	Low <20km/h	Low <20km/h	Low <20km/h	Low <20km/h	High ≥20km/h
	Period Availability	Heating Traffic	Heating Traffic	Heating Traffic	Cooling Traffic	Heating None
Surrounding	Level	High >55dBA	High >55dBA	High >55dBA	Low ≤55dBA	-
	Direction	East	North	North	South	-
Building	Context	Urban	Urban	Urban	Urban	Rural
	Surfaces	Pavement	Buildings	Pavement	Pavement	Landscape
Space	Direction	-	West	-	-	-
	Color	-	Light (50-100%)	-	-	-
Space-interior	Typology	Commercial	Residential	Commercial	Educational	Commercial
	Height	High-rise >7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors
Space	Function	Office	Living Room	Shop/ Store	Classroom	Hotel Room
	Occupation Period	All year-all day	All year-all day	All year-all day	All year-all day	Winter-all day
Space-interior	Location (floor)	Upper	Lower (first 2 floors)	Lower (first 2 floors)	Upper	Upper
	Proportions	Uniform	Uniform	Deep	Uniform	Uniform
Space-interior	Surface Properties	Light (50-100%)	Light (50-100%)	Dark (0-49%)	Light (50-100%)	Light (50-100%)

5.1.2 Tool process

All the defined (made-up) conditions are processed in the input page of the tool for each scenario, respectively. Then, step by step, decisions are given for each facade parameter. For each case, random selections are done among the tool's design options. In the meanwhile, the tool runs to give (highlight) the most advantageous and disadvantageous options. To give an example, rating results and selected options for each facade parameter in the order of decision-making (defined by the tool) are presented in Figures 5.1-5.7 for the Istanbul case.

OUTPUT PAGE - ORIENTATION										
relationship coefficient:		5	3	5	5	5	5	5	5	
1st design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
ORIENTATION	North	0	0	0	0	-5	0	-5	0	-10
	South	0	0	0	0	5	0	5	0	10
	East	0	0	0	0	0	0	0	-10	-10
	West	0	0	0	0	0	0	0	10	10
	NorthEast	-10	-3	-10	-10	-5	-10	-5	0	most disadvantageous -53
	NorthWest	10	0	0	0	-5	0	-5	0	0
	SouthEast	10	0	0	0	5	0	5	0	20
	SouthWest	-10	3	10	10	5	10	5	0	most advantageous 33
	East	0	0	0	0	0	0	0	-10	selection -10

Figure 5.1 : Rating results of orientation options for Istanbul.

OUTPUT PAGE - TRANSPARENCY RATIO										
relationship coefficient:		5	3	0	0	5	0	5	5	
2nd design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
TRANSPARENCY RATIO	0%	10	6			0		-5	10	most advantageous 21
	25%	10	6			5		0	0	most advantageous 21
	50%	0	-6			-5		5	0	-6
	75%	-10	-6			-5		5	-10	most disadvantageous -26
	100%	-10	-6			-5		5	-10	most disadvantageous -26
	75%	-10	-6			-5		5	-10	selection -26

Figure 5.2 : Rating results of transparency ratio options for Istanbul.

OUTPUT PAGE - FACADE TYPE										
relationship coefficient:		5	3	3	3	5	5	0	3	
3rd design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
FACADE TYPE	Single-Skin Infill Masonry	-10	0	NA	NA	0	NA		6	-4
	Single-Skin Infill Frame	0	0	NA	NA	0	NA		0	0
	Single-Skin Infill Monolithic	-10	0	NA	NA	0	NA		6	-4
	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6	most advantageous
	Single-Skin Curtain Wall	10	0	NA	NA	0	NA		-6	most advantageous
	Single-Skin Cladding	-10	0	NA	NA	0	NA		6	-4
	Double-Skin Infill Masonry	-10	-6	NA	NA	-5	NA		6	most disadvantageous
	Double-Skin Infill Frame	-10	-6	NA	NA	5	NA		6	-5
	Double-Skin Infill Monolithic	-10	-6	NA	NA	-5	NA		6	most disadvantageous
	Double-Skin Infill Window	-10	-6	NA	NA	5	NA		6	-5
	Double-Skin Curtain Wall	-10	-6	NA	NA	5	NA		6	-5
	Double-Skin Cladding	-10	-6	NA	NA	-5	NA		6	most disadvantageous
	Double-Skin Infill Window	-10	-6	NA	NA	5	NA		6	selection

Figure 5.3 : Rating results of facade type options for Istanbul.

OUTPUT PAGE - WINDOW TYPE										
relationship coefficient:		0	3	1	0	5	5	5	1	
4th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
WINDOW TYPE	Fixed Full Height Flush		0	0		-5	-10	5	0	-10
	Fixed Full Height Recessed		3	2		-5	-10	5	0	-5
	Fixed Vision Level Flush		0	0		-5	-10	5	0	-10
	Fixed Vision Level Recessed		3	2		-5	-10	0	0	-10
	Fixed Upper Level Flush		0	0		-5	-10	-5	0	most disadvantageous
	Fixed Upper Level Recessed		3	2		-5	-10	-5	0	-15
	Operable Full Height Flush		0	0		5	10	5	-1	19
	Operable Full Height Recessed		3	2		5	10	5	-1	most advantageous
	Operable Vision Level Flush		0	0		5	10	5	-1	19
	Operable Vision Level Recessed		3	2		5	10	0	-1	19
	Operable Upper Level Flush		0	0		5	10	-5	-1	9
	Operable Upper Level Recessed		3	2		5	10	-5	-1	14
	Operable Vision Level Flush		0	0		5	10	5	-1	selection

Figure 5.4 : Rating results of window type options for Istanbul.

OUTPUT PAGE - GLAZING										
relationship coefficient		1	0	0	0	5	3	5	5	
5th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
GLAZING	single glazing, clear 4mm	2				-10	-6	-5	-10	-29
	single glazing, clear 6mm	2				-10	-6	-5	-10	-29
	single glazing, clear 8mm	0				-10	-6	-5	-10	most disadvantageous -31
	single glazing, green tinted 4mm	2				-10	-6	0	-10	-24
	single glazing, green tinted 6mm	2				-10	-6	0	-10	-24
	single glazing, green tinted 8mm	0				-10	-6	0	-10	-26
	double glazing, clear, with air 4-8-4mm	0				-10	-6	-5	-10	most disadvantageous -31
	double glazing, clear, with air 6-12-6mm	0				0	0	-5	0	-5
	double glazing, clear, with air 8-16-8mm	-2				10	6	-5	10	19
	double glazing, clear, with air 4-12-8mm	0				0	0	-5	10	5
	double glazing, green tinted, with air 4-8-4mm	0				-10	-6	0	-10	-26
	double glazing, green tinted, with air 6-12-6mm	0				0	0	0	0	0
	double glazing, green tinted, with air 8-16-8mm	-2				10	6	0	10	24
	double glazing, green tinted, with air 4-12-8mm	0				0	0	0	10	10
	double glazing, low-e coated, with air 4-8-4mm	0				0	0	0	-10	-10
	double glazing, low-e coated, with air 6-12-6mm	0				10	0	0	0	10
	double glazing, low-e coated, with air 8-16-8mm	-2				10	6	0	10	24
	double glazing, low-e coated, with air 4-12-8mm	0				10	0	0	10	20
	double glazing, clear, with argon 4-8-4mm	0				0	0	-5	0	-5
	double glazing, clear, with argon 6-12-6mm	0				10	6	-5	10	21
	double glazing, clear, with argon 8-16-8mm	-2				10	6	-5	10	19
	double glazing, clear, with argon 4-12-8mm	0				10	6	-5	10	21
	double glazing, green tinted, with argon 4-8-4mm	0				0	0	0	0	0
	double glazing, green tinted, with argon 6-12-6mm	0				10	6	0	10	most advantageous 26
	double glazing, green tinted, with argon 8-16-8mm	-2				10	6	0	10	24
	double glazing, green tinted, with argon 4-12-8mm	0				10	6	0	10	most advantageous 26
	double glazing, low-e coated, with argon 4-8-4mm	0				0	0	0	0	0
	double glazing, low-e coated, with argon 6-12-6mm	0				10	6	0	10	most advantageous 26
	double glazing, low-e coated, with argon 8-16-8mm	-2				10	6	0	10	24
	double glazing, low-e coated, with argon 4-12-8mm	0				10	6	0	10	most advantageous 26
	triple glazing, clear, with air 4-8-4-8-4mm	-2				10	6	-5	10	19
	triple glazing, clear, with air 6-12-6-12-6mm	-2				10	6	-5	10	19
	triple glazing, clear, with air 4-8-6-12-8mm	-2				10	6	-5	10	19
	double glazing, low-e coated, with argon 4-12-8mm	0				10	6	0	10	selection 26

Figure 5.5 : Rating results of glazing options for Istanbul.

OUTPUT PAGE - WALL CONFIGURATION										
relationship coefficient		0	5	5	0	5	5	0	5	
6th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
WALL CONFIGURATION	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool)		10	NA		5	5		10	30
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (XPS)		-10	NA		5	5		0	0
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (EPS)		-10	NA		5	5		0	0
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (Rockwool)		10	NA		0	0		10	20
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (XPS)		-10	NA		0	0		0	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (EPS)		-10	NA		0	0		0	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (Rockwool)		10	NA		-5	-5		10	10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (XPS)		-10	NA		-5	-5		0	most disadvantageous -20
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (EPS)		-10	NA		-5	-5		0	most disadvantageous -20
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool)		0	NA		10	10		20	most advantageous 40
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (XPS)		-20	NA		10	10		10	10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (EPS)		-20	NA		10	10		10	10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (Rockwool)		0	NA		0	0		20	20
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (XPS)		-20	NA		0	0		10	-10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (EPS)		-20	NA		0	0		10	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool)		10	NA		5	5		10	selection 30

Figure 5.6 : Rating results of wall configuration options for Istanbul.

OUTPUT PAGE - SHADING										
relationship coefficient		1	5	5	0	5	0	5	1	
7th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
SHADING	not available	2	-10	0		-10		-10	-1	most disadvantageous -29
	Overhang > 60cm (Exposed Concrete, Metal)	0	10	5		-10		-10	0	-5
	Lightshelf (50+50, 100+50cm) (Metal, Plastic)	0	10	5		-10		-10	0	-5
	Horizontal Louver <30cm, every 20-30cms from floor to vision level	0	0	5		-10		-10	0	-15
	Vertical Louver <30cm, every 20-30cms from space edges to vision area	0	-10	0		10		10	0	most advantageous 10
	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-2	10	5		-10		-10	0	-7
	Horizontal Louver <30cm, every 20-30cms from floor to vision level	0	0	5		-10		-10	0	selection -15

Figure 5.7 : Rating results of shading options for Istanbul.

5.1.3 Decision-making

Design decisions given for each case are provided in Tables 5.2-5.6. The decisions given for the cases are compared with the decisions of the tool's ideals. These are significant to recheck the decisions after the tool's performance evaluation. As seen from the Tables, in all the cases, the tool defines the 25% transparency ratio as the ideal (optimum) design decision. However, the ideal facade type changes. In all cases, southern orientations are considered as optimum options. The ideal orientation is south for Ankara, Antalya, and İzmir while southwest and southeast are the ideals for Istanbul and Gaziantep, respectively. In all cases, semi-permeable wall configurations having rockwool as thermal insulation are defined as the ideal decisions. Since the tool starts with the ideal orientations (southern), shading options are defined as the ideal. Glazing options with krypton infill gas are considered as the ideal in all of the cases.

Table 5.2 : Comparison of design decisions for Istanbul.

Decision Subjects	Tool's Ideal	Facade Design
Orientation	SouthWest	East
Transparency Ratio	25%	75%
Facade Type	Single-Skin Curtain Wall	Double-Skin Infill Window
Window Type	Operable Full Height Recessed	Operable Vision Level Flush
Glazing	Double glazing, clear, with krypton 4-12-8mm	Double glazing, low-e coated, with krypton 4-12-8mm
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	Horizontal Louver <30cm, every 20-30cms from floortop to vision level

Table 5.3 : Comparison of design decisions for Ankara.

Decision Subjects	Tool's Ideal	Facade Design
Orientation	South	East
Transparency Ratio	25%	75%
Facade Type	Double-skin Infill Frame	Double-Skin Infill Window
Window Type	Operable Full Height Flush	Operable Vision Level Flush
Glazing	Double glazing, clear, with krypton 8-16-8mm	Double glazing, low-e coated, with krypton 4-12-8mm
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding
Shading	Overhang > 60cm	Horizontal Louver <30cm, every 20-30cms from floortop to vision level

Table 5.4 : Comparison of design decisions for Antalya.

Decision Subjects	Tool's Ideal	Facade Design
Orientation	South	North
Transparency Ratio	25%	100%
Facade Type	Double-Skin Infill Window	Single-Skin Infill Window
Window Type	Operable Full Height Recessed	Fixed Full Height Recessed
Glazing	Double glazing, clear, with krypton 8-16-8mm	Double glazing, clear, with air 6-12-6mm
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding
Shading	Lightshelf (50+50, 100+50cm) (Metal, Plastic)	Not available

Table 5.5 : Comparison of design decisions for Gaziantep.

Decision Subjects	Tool's Ideal	Facade Design
Orientation	SouthEast	SouthEast
Transparency Ratio	25%	25%
Facade Type	Single-Skin Infill Masonry	Single-Skin Infill Masonry
Window Type	Operable Full Height Recessed	Operable Vision Level Recessed
Glazing	Double-glazing, clear, with krypton 6-12-6mm	Double glazing, clear, with air 6-12-6mm
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (EPS), Interior Cladding
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	Horizontal Louver <30cm, every 20-30cms from floortop to vision level

Table 5.6 : Comparison of design decisions for Erzurum.

Decision Subjects	Tool's Ideal	Facade Design
Orientation	South	SouthEast
Transparency Ratio	25%	50%
Facade Type	Single-Skin Infill Masonry	Double-Skin Infill Masonry
Window Type	Operable Vision Level Flush	Operable Vision Level Flush
Glazing	Triple glazing, clear, with air 6-12-6-12-6mm	Double glazing, clear, with krypton 6-12-6mm
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (XPS), Interior Cladding
Shading	Overhang > 60cm	Overhang > 60cm

5.1.4 Evaluation

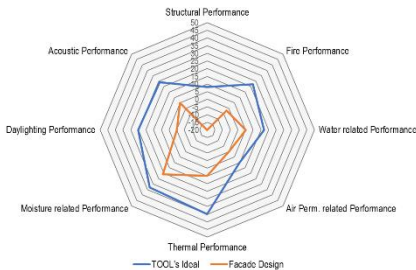
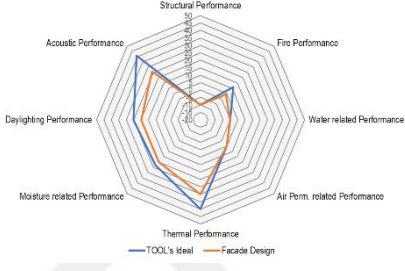
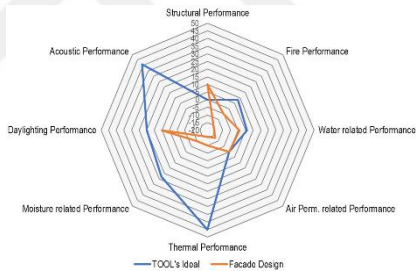
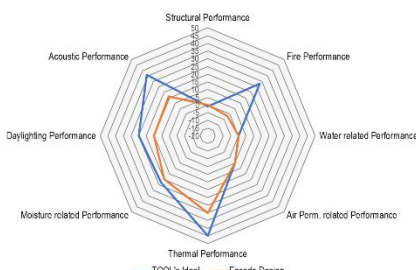
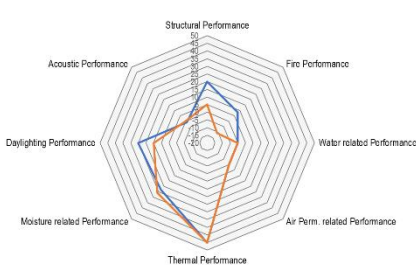
Overall performance evaluations for all scenarios are presented in Table 5.7 with rating scores and comparison charts. Ankara and Erzurum are the cases (facade designs of random decisions) that demonstrate the closest performance to the ideal designs proposed by the tool for each scenario separately. The case of Istanbul shows lower performance levels in all aspects when compared to the tool's ideal design proposed for that scenario. Antalya and Gaziantep cases seem to achieve the ideal performance graphics in air permeability, water-related, and structural aspects. However, they mostly fail for the rest of the performances.

The aggregation of design decisions constitutes a total score for each performance aspect. Comparison charts provide overall performance evaluation for facade designs. The total score of a facade for a performance aspect is calculated by accumulating the scores coming from design decisions having an impact on that performance aspect. The sum of (+) and (-) is (0). One advantage scored due to a decision plus one disadvantage scored due to another decision make the facade design neutral (having no superiority) for that performance aspect. (0) has no effect on the graphic.

As a sample, detailed rating results of the facade design and the tool's ideal design for the Istanbul case are presented in Fig. 5.8. The rating results of the other cases are provided in Appendix B.1.

Table 5.7 : Overall performance evaluations for all scenarios - rating scores and comparison charts.

Overall Performance Evaluation – Scores And Comparison Charts

Performance Aspect	Tool's Ideal	Facade Design	Comparison Charts
Istanbul			
Structural Performance	3	-15	
Fire Performance	22	-2	
Water-related Performance	17	5	
Air Permeability-rel.	10	0	
Thermal Performance	35	10	
Moisture-rel. Performance	33	21	
Daylighting Performance	25	0	
Acoustic Performance	24	5	
Ankara			
Structural Performance	-10	-10	
Fire Performance	11	4	
Water-related Performance	0	0	
Air Permeability-rel.	5	5	
Thermal Performance	40	30	
Moisture-rel. Performance	23	20	
Daylighting Performance	25	20	
Acoustic Performance	41	26	
Antalya			
Structural Performance	0	10	
Fire Performance	8	-5	
Water-related Performance	6	1	
Air Permeability-rel.	0	0	
Thermal Performance	45	-10	
Moisture-rel. Performance	23	-10	
Daylighting Performance	20	10	
Acoustic Performance	41	-27	
Gaziantep			
Structural Performance	-1	0	
Fire Performance	28	-2	
Water-related Performance	0	0	
Air Permeability-rel.	5	5	
Thermal Performance	45	25	
Moisture-rel. Performance	23	15	
Daylighting Performance	25	15	
Acoustic Performance	36	16	
Erzurum			
Structural Performance	20	5	
Fire Performance	8	-11	
Water-related Performance	0	0	
Air Permeability-rel.	0	0	
Thermal Performance	45	45	
Moisture-rel. Performance	23	26	
Daylighting Performance	25	15	
Acoustic Performance	-1	0	

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-10	3	10	10	5	10	5	0	
Transparency Ratio	25%	5	6			5		0	0	
Facade Type	Single-Skin Curtain Wall	10	0	NA	NA	0	NA		-6	
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA	
Glazing	double glazing, clear, with argon 4-12-8mm	NA				5	3	10	10	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-2	10	5		5		5	0	
SCORE		3	22	17	10	35	33	25	24	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	East	0	0	0	0	0	0	0	-10	
Transparency Ratio	75%	-5	-6			-5		5	-10	
Facade Type	Double-Skin Infill Window	-10	-6	NA	NA	5	NA		6	
Window Type	Operable Vision Level Flush		0	0		5	10	5	-1	
Glazing	double glazing, low-e coated, with argon 4-12-8mm	0				10	6	0	10	
Wall Configuration	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding		10	NA		5	5		10	
Shading	Horizontal Louver <30cm, every 20-30cms from floortop to vision level	0	0	5		-10		-10	0	
SCORE		-15	-2	5	0	10	21	0	5	

Figure 5.8 : Rating results of the ideal design (proposed by the tool) and the facade design for Istanbul.

As seen in Fig. 5.8, a single decision may increase the score in one aspect while decreasing it in another aspect or vice versa. To exemplify, to select southwest instead of east decreases the structural performance while increases the performance for all the other aspects.

5.2 Sensitivity Analysis

To understand the sensitivity of facade performance to each facade parameter (decision), a sensitivity analysis is conducted. It is performed by changing one parameter while keeping all others fixed. Thus, the solely effect of each parameter on the overall performance can be obtained. A result in any step may not lead to a

meaningful result, but the analysis will give an idea about the amplitudes of each parameter, as it is intended.

The sensitivity analysis is conducted for the Istanbul case, which is a made-up scenario. The decision-making process and the detailed rating results of the case were presented in the previous Sections. Input data were given, the tool process was utilized; thus the ideal design was achieved.

5.2.1 Constants and Variables

The ideal design obtained based on the selections is kept the same at each analysis step and illustrated with the red line on every graph whereas each grey line refers to the effect of just one parameter change. Therefore, a priority between the parameters (based on their effect amplitude) can be compared, and the position of the ideal design can be seen among other options.

5.2.2 Results

The sensitivity analysis results are presented in Appendix B.1. The results demonstrate that all the aspects of facade performance are highly sensitive to the orientation parameter. The facade performance shows the least sensitivity to the facade type except for the structural and acoustic aspects. Besides, daylighting and acoustic performances of the facade are highly sensitive to the glazing parameter.

Moreover, instead of seeking an answer for the dilemma of 'should the facade orientation be an input parameter for the tool?' or 'should it be selected by the designer?'; the analysis is implemented for the orientation. This step asks the question of how the facade performance changes just by changing its orientation for the same case (Istanbul) and by running the tool starting from the transparency ratio. The results show how important the orientation is on the overall design/ performance. The tool's ideals for different orientations for the Istanbul case are illustrated in Fig. 5.9.

The wind direction plays a key role in the performance of the facade. As it is stated on the tool algorithm, for the structural performance; since the predominant wind direction is on the northeast-southwest line; these two orientation options are scored negatively while the options perpendicular to the predominant wind direction get positive scores and others get (0). From this point, since the building is a high-rise, the score is multiplied by (2), then the gap between southwest and northwest becomes

higher. Northwest gets three times higher score. If the tool does not aim a holistic evaluation, northwest and southeast can be selected easily. Building height is as important as the predominant wind direction since it multiplies the score. Besides, wind speed has a similar effect on structural performance.

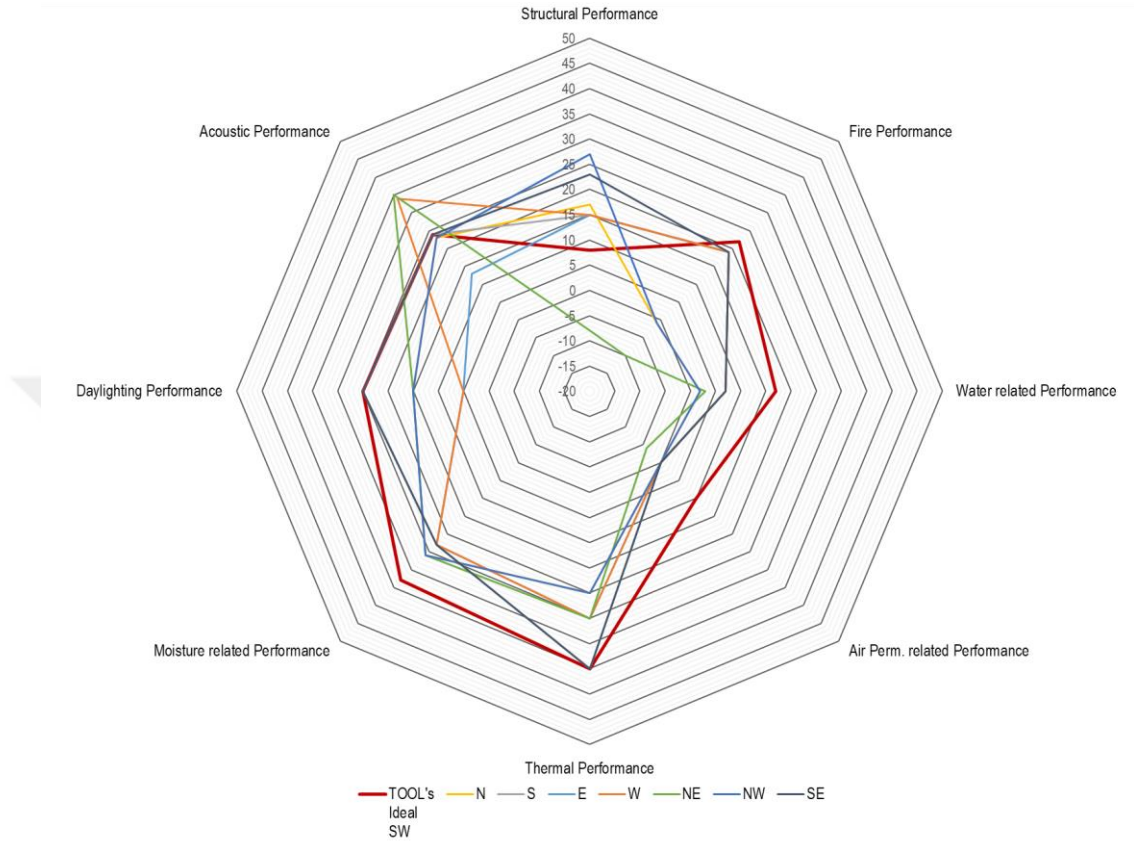


Figure 5.9 : Tool's ideals for different orientations for Istanbul case.

5.3 Testing the Tool with Real Projects

To evaluate the practicability of the tool and to come to a better conclusion, the tool is tested for seven different projects of the same institution (educational). A classroom facade from each project is tested by the tool. The evaluation results are presented in Table 5.15.

5.3.1 Tool Users

The main project team of the institution is the users of the tool. These are client- owner, architects, and engineers (structural and mechanical). They are the main stakeholders of building design who generally have an influence on the decision-making of facade design, especially in the early stages of the process.

5.3.2 Projects

The projects chosen for testing are school buildings. 5 of the projects are constructed, and 2 of them are on-going projects. The tool is implemented for classroom facades.

The classrooms are located on the second floor of the schools except for the classroom in Dragos, Istanbul College. It is located on the first floor. Three of them are in Istanbul, in different locations, while the rest of them are in different cities in Turkey. All the cases have specific environmental conditions in terms of climate, wind, and noise. On the other hand, the spatial conditions of the cases are similar. Classrooms have uniform room proportions, having light-colored interior surfaces. All the cases have single-skin, infill type facade with aerated concrete masonry units and a window. All of them have a 50% transparency ratio and operable windows. The facades differ from each other with orientation, window position (flush or recessed), glazing type, and shading.

The environmental and spatial conditions of the projects are given in Table 5.8. As mentioned, the spatial conditions are the same for all the projects whereas the environmental conditions are specific to their locations. As can be seen in the Table, since Turkey is an earthquake-prone country, the criticality is high in terms of earthquake for all the cities chosen. There are hot-humid and temperate-humid climate types for these real project cases. Besides, diurnal temperature difference is low for all the cases. Although the direction of the predominant wind changes for each case, their speed is the same as low $<20\text{km/h}$. In hot climates, the period of the predominant wind is cooling seasons, while in temperate climates, heating seasons are the period of the predominant wind. The availability of traffic noise changes with the location. The level and the direction of the noise change, as well. Surrounding conditions are also specific to the locations. However, there are not close buildings that can obstruct sunlight and daylight for the facades in question.

The proposed tool does not describe a method for the definition of environmental and spatial conditions. For this reason, some of the conditions are defined by assuming the worst possible options for conditions. It is especially done for defining the noise levels.

Table 5.8 : Conditions of the projects.

Conditions		Project Conditions							
Environmental	Location	City	İzmir Bornova	Istanbul Çamlıca	Istanbul Dragos	Istanbul Ümraniye	Muğla	Yalova	Çanakkale
	Earthquake	Hemisphere Latitude Criticality Temperature	Northern Middle (30-60) High Hot	High Temperate	High Temperate	High Temperate	High Hot	High Temperate	High Temperate
	Climate	Rainfall	Humid >600mm	Humid >600mm	Humid >600mm	Humid >600mm	Humid >600mm	Humid >600mm	Humid >600mm
	Wind (predominant)	Diurnal Temp. Variation	Low	Low	Low	Low	Low	Low	Low
		Direction	Southeast	Northeast	Northeast	Northeast	West	Northwest	Northeast
		Speed	Low <20km/h	Low <20km/h	Low <20km/h	Low <20km/h	Low <20km/h	Low <20km/h	Low <20km/h
	Noise	Period Availability	Cooling Traffic	Heating Traffic	Heating None	Heating Traffic	Cooling None	Heating Traffic	Cooling None
		Level	Low ≤55dBA	High >55dBA	-	High >55dBA	-	Low ≤55dBA	-
	Surrounding	Direction Context	North Urban	South Urban	- Urban	Northwest Urban	- Rural	North Urban	- Rural
		Surfaces	Pavement	Pavement	Pavement	Pavement	Pavement	Trees as obstruction	Landscape
		Direction	-	-	-	-	-	East	-
		Color	-	-	-	-	-	Light (50-100%)	-

Table 5.8 (continued) : Conditions of the projects.

Conditions		Project Conditions							
Spatial	Location	City	İzmir Bornova	Istanbul Çamlıca	Istanbul Dragos	Istanbul Ümraniye	Muğla	Yalova	Çanakkale
	Building	Typology	Educational	Educational	Educational	Educational	Educational	Educational	Educational
		Height	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors	Low-rise ≤7 floors
	Space	Function	Classroom	Classroom	Classroom	Classroom	Classroom	Classroom	Classroom
		Occupation Period	All year-all day	All year-all day	All year-all day	All year-all day	All year-all day	All year-all day	All year-all day
		Location (floor)	Upper	Upper	Lower (first 2 floors)	Upper	Upper	Upper	Upper
	Space-interior	Proportions	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform
		Surface Properties	Light (50-100%)	Light (50-100%)	Light (50-100%)	Light (50-100%)	Light (50-100%)	Light (50-100%)	Light (50-100%)

5.3.3 Decisions

Rating results and selected options for each facade parameter (design decision subject) for İzmir, Bornova case are given in Figures 5.10-5.16.

OUTPUT PAGE - ORIENTATION										
relationship coefficient:		5	3	5	5	5	5	5	5	
1st design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
ORIENTATION	North	0	0	0	0	0	0	-5	-10	-15
	South	0	0	0	0	5	0	5	10	most advantageous 20
	East	0	0	0	0	-5	0	0	0	-5
	West	0	0	0	0	-5	0	0	0	-5
	NorthEast	5	0	0	0	0	0	-5	0	0
	NorthWest	-5	6	5	5	0	5	-5	0	11
	SouthEast	-5	-6	-5	-5	5	-5	5	0	most disadvantageous -16
	SouthWest	5	0	0	0	0	0	5	0	10
	East	0	0	0	0	-5	0	0	0	selection -5

Figure 5.10 : Rating results of orientation options for İzmir, Bornova.

OUTPUT PAGE - TRANSPARENCY RATIO										
relationship coefficient:		5	3	0	0	5	0	5	5	
2nd design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
TRANSPARENCY RATIO	0%	5	6			5		-5	10	most advantageous 21
	25%	5	6			-5		0	0	6
	50%	0	-6			-5		5	0	-6
	75%	-5	-6			-5		5	-10	most disadvantageous -21
	100%	-5	-6			-5		5	-10	most disadvantageous -21
	50%	0	-6			-5		5	0	selection -6

Figure 5.11 : Rating results of transparency ratio options for İzmir, Bornova.

OUTPUT PAGE - FACADE TYPE										
relationship coefficient:		5	3	3	3	5	5	0	3	
3rd design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
FACADE TYPE	Single-Skin Infill Masonry	-5	0	NA	NA	-5	NA		6	most advantageous -4
	Single-Skin Infill Frame	0	0	NA	NA	-5	NA		0	-5
	Single-Skin Infill Monolithic	-5	0	NA	NA	-5	NA		6	most advantageous -4
	Single-Skin Infill Window	5	0	NA	NA	-5	NA		-6	-6
	Single-Skin Curtain Wall	5	0	NA	NA	-5	NA		-6	-6
	Single-Skin Cladding	-5	0	NA	NA	-5	NA		6	most advantageous -4
	Double-Skin Infill Masonry	-5	-6	NA	NA	-5	NA		6	most disadvantageous -10
	Double-Skin Infill Frame	-5	-6	NA	NA	0	NA		6	-5
	Double-Skin Infill Monolithic	-5	-6	NA	NA	-5	NA		6	most disadvantageous -10
	Double-Skin Infill Window	-5	-6	NA	NA	0	NA		6	-5
	Double-Skin Curtain Wall	-5	-6	NA	NA	0	NA		6	-5
	Double-Skin Cladding	-5	-6	NA	NA	-5	NA		6	most disadvantageous -10
	Single-Skin Infill Frame	0	0	NA	NA	-5	NA		0	selection -5

Figure 5.12 : Rating results of facade type options for Izmir, Bornova.

OUTPUT PAGE - WINDOW TYPE										
relationship coefficient:		0	3	1	0	5	5	5	1	
4th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
WINDOW TYPE	Fixed Full Height Flush		0	0		-5	-10	5	NA	-10
	Fixed Full Height Recessed		6	1		-5	-10	5	NA	-3
	Fixed Vision Level Flush		0	0		-5	-10	5	NA	-10
	Fixed Vision Level Recessed		6	1		-5	-10	0	NA	-8
	Fixed Upper Level Flush		0	0		-5	-10	-5	NA	most disadvantageous -20
	Fixed Upper Level Recessed		6	1		-5	-10	-5	NA	-13
	Operable Full Height Flush		0	0		5	10	5	NA	20
	Operable Full Height Recessed		6	1		5	10	5	NA	most advantageous 27
	Operable Vision Level Flush		0	0		5	10	5	NA	20
	Operable Vision Level Recessed		6	1		5	10	0	NA	22
	Operable Upper Level Flush		0	0		5	10	-5	NA	10
	Operable Upper Level Recessed		6	1		5	10	-5	NA	17
	Operable Vision Level Flush		0	0		5	10	5	NA	selection 20

Figure 5.13 : Rating results of window type options for Izmir, Bornova.

OUTPUT PAGE - G L A Z I N G										
relationship coefficient:		1	0	0	0	5	3	5	5	
5th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
GLAZING	single glazing, clear 4mm	2				-10	-6	0	-10	-24
	single glazing, clear 6mm	2				-10	-6	0	-10	-24
	single glazing, clear 8mm	0				-10	-6	0	-10	-26
	single glazing, green tinted 4mm	2				-10	-6	-5	-10	-29
	single glazing, green tinted 6mm	2				-10	-6	-5	-10	-29
	single glazing, green tinted 8mm	0				-10	-6	-5	-10	most disadvantageous -31
	double glazing, clear, with air 4-8-4mm	0				-10	-6	0	-10	-26
	double glazing, clear, with air 6-12-6mm	0				0	0	0	0	0
	double glazing, clear, with air 8-16-8mm	-2				10	6	0	10	24
	double glazing, clear, with air 4-12-8mm	0				0	0	0	10	10
	double glazing, green tinted, with air 4-8-4mm	0				-10	-6	-5	-10	most disadvantageous -31
	double glazing, green tinted, with air 6-12-6mm	0				0	0	-5	0	-5
	double glazing, green tinted, with air 8-16-8mm	-2				10	6	-5	10	19
	double glazing, green tinted, with air 4-12-8mm	0				0	0	-5	10	5
	double glazing, low-e coated, with air 4-8-4mm	0				0	0	5	-10	-5
	double glazing, low-e coated, with air 6-12-6mm	0				10	0	5	0	15
	double glazing, low-e coated, with air 8-16-8mm	-2				10	6	5	10	29
	double glazing, low-e coated, with air 4-12-8mm	0				10	0	5	10	25
	double glazing, clear, with argon 4-8-4mm	0				0	0	0	0	0
	double glazing, clear, with argon 6-12-6mm	0				10	6	0	10	26
	double glazing, clear, with argon 8-16-8mm	-2				10	6	0	10	24
	double glazing, clear, with argon 4-12-8mm	0				10	6	0	10	26
	double glazing, green tinted, with argon 4-8-4mm	0				0	0	-5	0	-5
	double glazing, green tinted, with argon 6-12-6mm	0				10	6	-5	10	21
	double glazing, green tinted, with argon 8-16-8mm	-2				10	6	-5	10	19
	double glazing, green tinted, with argon 4-12-8mm	0				10	6	-5	10	21
	double glazing, low-e coated, with argon 4-8-4mm	0				0	0	5	0	5
	double glazing, low-e coated, with argon 6-12-6mm	0				10	6	5	10	most advantageous 31
	double glazing, low-e coated, with argon 8-16-8mm	-2				10	6	5	10	29
	double glazing, low-e coated, with argon 4-12-8mm	0				10	6	5	10	most advantageous 31
	triple glazing, clear, with air 4-8-4-8-4mm	-2				10	6	0	10	24
	triple glazing, clear, with air 6-12-6-12-6mm	-2				10	6	0	10	24
	triple glazing, clear, with air 4-8-6-12-8mm	-2				10	6	0	10	24
	double glazing, low-e coated, with argon 6-12-6mm	0				10	6	5	10	selection 31

Figure 5.14 : Rating results of glazing options for Izmir, Bornova.

OUTPUT PAGE - WALL CONFIGURATION										
relationship coefficient:		0	5	5	0	5	5	0	5	
6th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
WALL CONFIGURATION	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool)		10	NA		5	5		10	30
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (XPS)		-10	NA		5	5		0	0
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (EPS)		-10	NA		5	5		0	0
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (Rockwool)		10	NA		0	0		10	20
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (XPS)		-10	NA		0	0		0	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation in the middle (EPS)		-10	NA		0	0		0	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (Rockwool)		10	NA		-5	-5		10	10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (XPS)		-10	NA		-5	-5		0	most disadvantageous
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the inner side (EPS)		-10	NA		-5	-5		0	most disadvantageous
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool)		0	NA		10	10		20	most advantageous
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (XPS)		-20	NA		10	10		10	10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation in the middle (EPS)		-20	NA		10	10		10	10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (Rockwool)		0	NA		0	0		20	20
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (XPS)		-20	NA		0	0		10	-10
	Semi-permeable Cladding with ventilated Air Cavity, Thermal Insulation at the inner side (EPS)		-20	NA		0	0		10	-10
	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (XPS)		-10	NA		5	5		0	selection
										0

Figure 5.15 : Rating results of wall configuration options for Izmir, Bornova.

OUTPUT PAGE - SHADING										
relationship coefficient:		1	5	5	0	5	0	5	1	
7th design decision	Options	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	EVALUATION
SHADING	not available	1	-10	0		-10		-5	-1	most disadvantageous
	Overhang > 60cm	0	10	5		-10		-5	0	0
	Lightshelf (50+50, 100+50cm)	0	10	5		-10		-5	0	0
	Horizontal Louver <30cm, every 20-30cms from floor to vision level	0	0	5		-10		-5	0	-10
	Vertical Louver <30cm, every 20-30cms from space edges to vision area	0	-10	0		10		5	0	most advantageous
	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-1	10	5		-10		-5	0	-1
	not available	1	-10	0		-10		-5	-1	selection
										-25

Figure 5.16 : Rating results of shading options for Izmir, Bornova.

Table 5.9 : Performance evaluation results of the classroom facades.

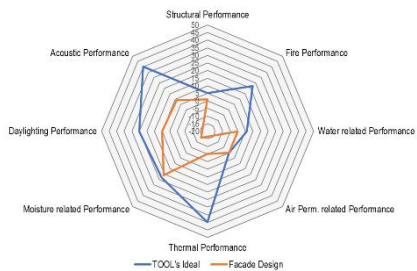
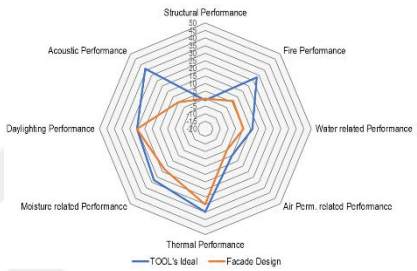
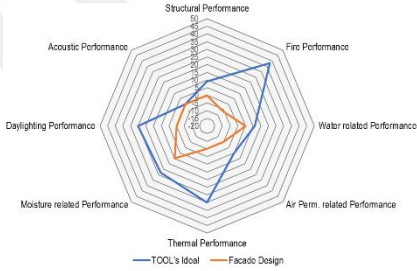
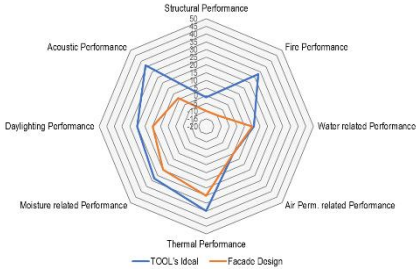
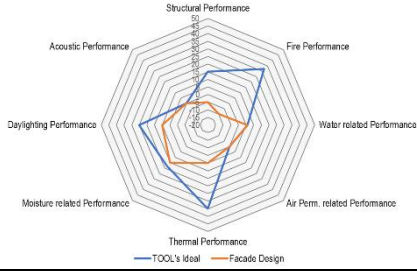
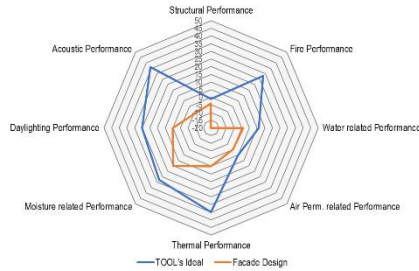
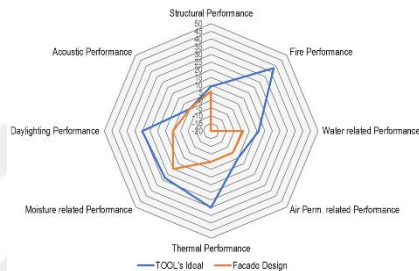
Photos	Tool's Evaluation
A classroom facade oriented towards the east in Izmir Bornova College	
	
A classroom facade oriented towards the south in Istanbul Çamlıca College	
	
A classroom facade oriented towards the northeast in Istanbul Dragos College	
	
A classroom facade oriented towards the southwest in Istanbul Ümraniye College	
	
A classroom facade oriented towards the southwest in Muğla College	
	

Table 5.9 (continued) : Performance evaluation results of the classroom facades.

Overall Performance Evaluation Comparison Charts	Photos	Tool's Evaluation
	A classroom facade oriented towards the north in Yalova Uğur College	
		
	A classroom facade oriented towards the northwest in Çanakkale College	
		
		

5.3.4 Results

As a sample, detailed rating results of the facade design and the tool's ideal design for İzmir, Bornova case are presented in Fig. 5.17. The rating results of the other cases are provided in Appendix B.1. The results demonstrate that none of the cases demonstrate the same performance with the tool's ideal. From a holistic perspective, Istanbul Çamlıca project has the best performance, while Yalova project seems to have the worst performance. If İzmir Bornova case is examined in detail (see Fig. 5.17), the highest reduction in performance aspects is due to wall configuration and shading options.

In İzmir Bornova case, the predominant wind is towards the southeast, so in this orientation, there is a performance reduction due to wind and wind-driven rain loads. The tool considers the maximum performance with minimum effort. Needless to say, in this orientation, the required performance levels can be achieved. However, when compared to the other orientations, more measures need to be taken due to its more challenging conditions. İzmir has a hot climate, and east orientation is not the best since it is hard to control the sunlight in that direction. Although glazing selection compensates some of the reduction in thermal and acoustic performances, there is a substantial reduction in most of the performance aspects, especially in thermal performance due to the absence of shading.

RESULTS / TOOL'S IDEAL									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	South	0	0	0	0	5	0	5	10
Transparency Ratio	25%	5	6			5		0	0
Facade Type	Single-Skin Infill Frame	0	0	NA	NA	0	NA		0
Window Type	Operable Full Height Recessed		6	1		5	10	5	NA
Glazing	double glazing, clear, with air 8-16-8mm	NA				10	3	10	10
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	10	5		5		5	0
SCORE		5	22	6	0	40	23	25	40
RESULTS / FACADE DESIGN									
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	East	0	0	0	0	-5	0	0	0
Transparency Ratio	50%	0	-6			-5		5	0
Facade Type	Single-Skin Infill Frame	0	0	NA	NA	-5	NA		0
Window Type	Operable Vision Level Flush		0	0		5	10	5	NA
Glazing	double glazing, low-e coated, with argon 6-12-6mm	0				10	6	5	10
Wall Configuration	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding		-10	NA		5	5		0
Shading	not available	1	-10	0		-10		-5	-1
SCORE		1	-26	0	0	-5	21	10	9

Figure 5.17 : Rating results of the ideal design (proposed by the tool) and the facade design for Izmir, Bornova.

In Fig. 5.17, it can be seen that all decisions are linked to each other from the first decision (facade parameter). The tool's ideal orientation for the İzmir Bornova case is south, so the rest of the decisions are proposed correspondingly by the tool. This final comparison of the design decisions does not work for the tool user, and it is better to check the rating charts that give the advantageous and disadvantageous options for each facade parameter. To exemplify, as seen in Fig. 5.17, the tool's ideal shading is an overhang, which is in accordance with the south orientation and is not an ideal option for the east orientation. The tool's ideal facade design that is composed of the most advantageous facade parameter options needs to be considered as a package of decisions; in other words, needs to be evaluated holistically.

Similarly, decision-makers can use the tool by selecting the options which are not under their control and allowing the tool to present the most proper (ideal) options for the remaining design decisions which are under their control. For example, in the Izmir Bornova case, if the decision-maker needs to orientate the facade towards the east, and in order to have a highly transparent facade such as 75%, then the tool recommends an infill masonry facade type which used to be an infill frame facade type (offering a lighter structure for the wall) to compensate for the potential heat loss or loss in sound insulation with the wall part. Furthermore, the tool proposes heavier infill gases with low-e coating for the glazing and a vertical louver for the shading, which are totally different from the ones proposed for the south-oriented facade with 25% transparency ratio. Therefore, with the tool's recommendations, it is possible to get closer to the performance scores of the ideal design proposed by the tool, no matter what the initial decisions are (orientation and transparency ratio in this case).

5.4 Interviews with the Tool Users

A series of interviews are conducted with the stakeholders of the projects after letting them use the tool or see the outcomes of the tool. Interviews are done for the classroom facades evaluated by the tool in the previous Sections. The interviews are conducted with the main project team of the institution. Prior to the interviews, the tool is used by architects for some projects while the tool's outcomes (comparison of design decisions and performance evaluation charts) are provided to rest of the stakeholders for the other projects. Client-owner, architects, engineers (structural and mechanical) are the professionals who are asked for their opinions through semi-structured, open-ended questions.

The full version of the interview records is presented in Appendix B.2.

5.4.1 Questions

A few questions are addressed to the interviewees. Questions are preferred to be half-structured and open-ended. There are minor differences between the questions addressed to different stakeholders. A sample for the interview questions (these are for architects) for getting feedback from the tool users is given below. There are two parts in the interview questions. The first part is the information about the interviewee while the second part is for their opinions about the tool.

Information about interviewee:

1. What is your occupation?
2. What is your experience in your occupation? Both in years and the content.
3. What is your role in the facade design process?

Information about the project:

4. Which project(s) you tried the Tool for?

Opinions about the Tool:

5. Did you have any difficulties in defining the input data specific to your project(s)?
6. How did you access/ obtain the information you are asked to define the input data?
7. Do you think you have any more options for the design decisions within the Tool? If any, can you exemplify it?
8. While you were making decisions in view of the Tool's rating matrices and holistic evaluation, did you have any difficulties?
9. Did the Tool contribute to the design process about comparing the possible options? Such as to be faster, to think holistically, etc.
10. Do you think the Tool has aspects restricting/ limiting the flexibility in design?
11. Do you prefer a more detailed scale for rating like 1, 2, 3, 4, 5 or ++, +, 0, -, -- ? Why?
12. What sort of a path, did you follow for the options and conditions that you could not find within the Tool?
13. Is the last graphic supporting the design process?
14. Is that graphic clear/ expressive enough?
15. Is the Tool user-friendly?
16. What are your recommendations? If you have any comments about the Tool, please share.

17. Do you think the Tool reminds you of the issues that you sometimes can overlook/ ignore/ omit during the design process? In other words, does it help you think differently?

18. Do you think the Tool leads you to different design decisions than your cliché solutions?

19. Do you prefer to use the Tool in your projects?

20. How do you rate your level of satisfaction with the Tool from 0 to 5 ? (0 represents the lowest satisfaction level).

21. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you, or are they the issues that you know by intuition?

5.4.2 Answers

The answers for the questions are given in Appendix B.2. It can be easily said that the tool is generally approved by the stakeholders.

5.4.3 Interpretation

The general opinion of the stakeholders is itemized below.

- The tool outcomes are easily comprehensible.
- The tool is mainly for architects.
- It is good to know the reasoning process behind the design decisions.
- It is good to see the compromises in design in the early stages.
- It is good to see the potential gains in performance by changing decisions.
- The tool can contribute to the communication between architects and stakeholders in technical aspects.
- It is new to see/ evaluate the different facade performance aspects altogether.
- The tool is preferred to be used.
- The tool is found beneficial for providing a transparent decision-making process.

5.5 Feedback of the Implementation

The tool is implemented for made-up scenarios and real projects. Then, sensitivity analysis for a single scenario and interviews for the projects are conducted. The feedback is the interpretation of the testing results and the interviews.

5.5.1 Contributions of the tool

The tool contributes to the facade design process in many aspects such as; it provides technical knowledge about different aspects simultaneously, or it enables a fast evaluation, thus fast decision-making for the users. The users are faced with conflicting issues and compromises in design from the very beginning of the process. It is better when compared to a process with revisions and repetitions.

It is evident in the interviews that the tool has the potential to eliminate the barriers for the stakeholders other than the architect to get involved in the process more than the current situation. On the other hand, it can support the architects in technical aspects for better communications with the rest of the stakeholders.

5.5.2 Deficiencies of the tool

The tool proposes an approach for decision-making in the facade design process. It is kept as simple as possible, and the options are not increased in number; instead, only the common options are included to see if the idea works. However, the number of options need to be increased to cover most of the facade parameter options available in the construction industry. It can be possible with the inclusion of a database. Thus, it can be widely used by professionals.

In the current version of the tool, the conditions need to be defined by the users from drop-down lists. However, it would be better in the later versions to integrate the methodology for the users on how to determine the environmental and spatial conditions such as the level of the road traffic noise.

Although the tool does not address local conditions, it is kept limited within the tool to cover the climates of Turkey. This is because these conditions need to be included in testing the tool for real projects.

The tool assumptions can evolve as the tool is used by the stakeholders. The relationships between conditions and functions and the coefficients of the relationships

can be refined. Moreover, orientation can be defined as a condition rather than a decision, since the final results or the subsequent decisions totally change with this parameter.

5.5.3 Complexities in the usage of the tool

Possible complexities were tried to be removed as much as possible. In the first trial of the tool, the users were expected to rate the options according to the prescriptions provided by the tool. However, it was seen that this method takes a lot of time which conflicts with the objective of the thesis. It may not have that much contribution to the process, whereas, in this version, the users are expected to process the input data (environmental and spatial conditions of their cases) and just give decisions.

Moreover, in the first trials, there was not a visual document for the design options. It is available in the final tool, which is believed to assist the decision-makers in understanding the options written in the tool rating charts.

5.6 Summary of the Chapter

In this Chapter, for validation purposes, the tool is tested with made-up scenarios and real projects. Besides, for one of the made-up scenarios, a sensitivity analysis is conducted. Then, the tool is opened for use by architects and some other stakeholders (owner, engineers) of the facade design process for real (on-going and constructed) projects. Opinions of the tool users (the stakeholders of the process) after they used the tool for the real projects are recorded through interviews. The testing results and the interviews are interpreted to discuss the contributions and the deficiencies of the tool, and the complexities in the usage of the tool.

6. DISCUSSIONS AND CONCLUSION

Facade design, which has always been a complex task, is getting more complicated with today's increasing requirements. The constraints are getting harsher such as shortage of energy and material sources, while the comfort expectations are rising. Facades may need to respond to today's trends like sustainability or ecological design. Moreover, design options increase in number, become almost limitless, consequently make decision-making harder more than ever. The present speed age forces the design of facades in a very limited time. In addition to these, decision-makers of facade design can be technically incapable, and there can be conflicting aspects in design.

The proposed design decision support tool draws a framework to maintain the holism all through the decision-making in facade design. It provides the notion of interrelations among performance aspects, design decisions, and conditions at the early stages of the facade design process.

Outcomes of the thesis support a more transparent design process when compared to the existing ones, which will, in turn, lead to better designs in a shorter time period. The usage of the tool during the facade design process will be time-saving, which is highly important in the age of fast decisions. The tool usage may prevent negative iterations in design and reduce the time reserved for the simulations of numerous alternatives. Each stakeholder may benefit from a different side of the tool while perceiving the whole facade design. With these attributes, the tool may make the process easier.

It is believed that the tool will guide the decision-makers of facade design to give special emphasis on the interactions of performance aspects among each other and with facade parameters. This will lead to holistic design.

The tool tries to gather the variables and the consequences in one equation and aims to support especially the inexperienced decision-makers by indicating the performance tendency of the facade after each decision made. It is a kind of advice tool for use during the early stages of facade design. The tool does not aim to take the place of

simulation or testing tools. On the contrary, it aims at decreasing the design alternatives to contribute to the simulation and testing processes.

The tool gives the performance tendency of the decisions based on the information available in the literature. Its originality comes from its holistic approach. It compares the possible options by taking into account environmental and spatial conditions and other variables instead of providing real values of a specific option in certain conditions.

The tool is just a template/ guideline that facade design stakeholders can use during the early stages of the process. It does not dictate a specific design solution. So, the selected option can be different from the most advantageous one (the tool's ideal). Nevertheless, if the selected option has disadvantages in terms of some performances, the tool also gives the opportunity to compare the decision with the most advantageous option.

The aim is to reduce the number of design options to support the later comprehensive assessments and to provide a rough impression regarding the entire performance. The decisions are planned to be given in order by taking into account the design stages/scales they are decided for. To assess the effect of the combinations of design decisions given for different facade parameters, basic/ fundamental equations from the literature are utilized.

The results of the tool do not give real performance values or have a meaning that a facade design fails or passes. In the light of the tool's objective functions, it says, there can be more proper design options that can balance the relations among the performance aspects in line with conditions. The common ground of the objective functions embedded in the tool is to have maximum performance with minimum effort.

The ideal option changes according to the conditions. Here, the tool's responsibility is to give the most proper options in terms of overall facade performance. Even though some significant factors such as budget, feasibility, etc. are kept out of scope, the tool gives the opportunity to compare the options for their cost/ 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 tool enables to follow the compromises in design and their reasons in a transparent way.

As the testing results are examined, it can be seen that the tool's ideal design decisions change with varying conditions. As soon as the most advantageous option is chosen for the first decision subject (orientation), ratings, so the most advantageous and disadvantageous options change for the consecutive decision subjects. The decision-making is defined as a dynamic and highly interactive process. Moreover, it can be noticed in the results that the tool's ideal can have lower scores for some performance aspects. This is because the tool considers the decision-making in a holistic way, taking all the aspects into account for each design decision (facade parameter).

Project conditions may vary, so the importance factors (relationship coefficient) of the performance aspects. In that case, design decisions can be given accordingly, which makes the tool flexible to changing priorities/ conditions. All the relevant adjustments can be made as long as they are grounded on the developed tool. The weights of the relationships between performance aspects and facade parameters can be refined as well. It can be a matter of another research.

The design options provided within the tool are very limited in number. So, the tool provides the best option among the options available in the tool, as an ideal option. If the options were sufficient in variety, the ideal options proposed by the tool would be more reasonable. It would also be better if the tool described how to define the conditions in accordance with the tool's options. Moreover, one of the most important things the implementation of the tool demonstrates is that the orientation parameter needs to be considered as a condition rather than a design variable.

In conclusion, it is considered as a start-up tool that needs to be refined in further studies. In future studies, design options within the scope of the tool can be expanded and rated by following a similar logic. Furthermore, the tool can be customized for specific climatic conditions or building/ facade types. It may evolve in the future, as new knowledge is incorporated into the tool.



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APPENDICES

APPENDIX A : Tool options and rating charts

APPENDIX B.1 : Tool testing and sensitivity analysis results

APPENDIX B.2 : Interview questions and answers





APPENDIX A

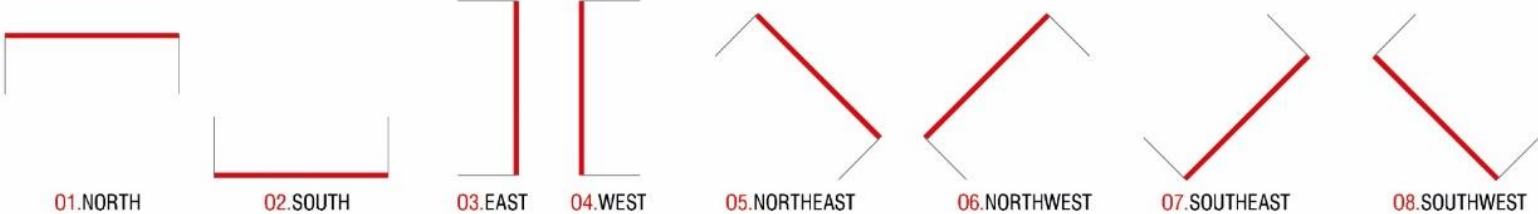
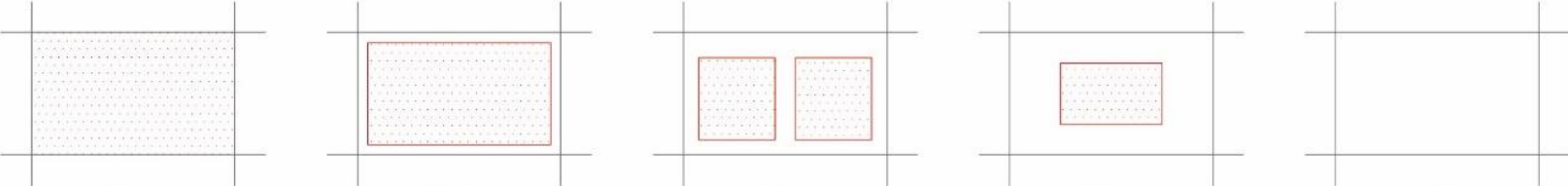
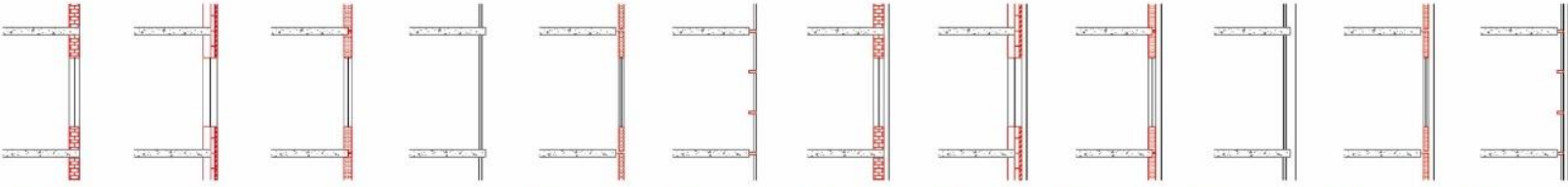
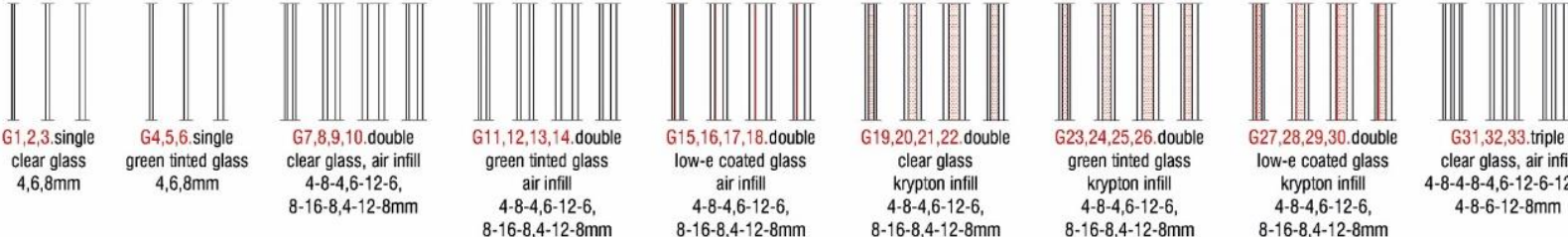
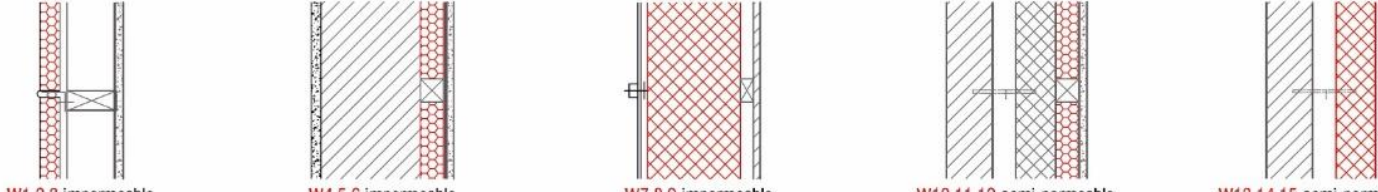
DESIGN DECISIONS & OPTIONS											
ORIENTATION	 01.NORTH02.SOUTH03.EAST04.WEST05.NORTHEAST06.NORTHWEST07.SOUTHEAST08.SOUTHWEST										
TRANSPARENCY RATIO	 TR1.100%TR2.75%TR3.50%TR4.25%TR5.0%										
FACADE TYPE	 FT1.single-skin infill masonryFT2.single-skin infill frameFT3.single-skin infill monolithicFT4.single-skin infill windowFT5.single-skin cladding panelFT6.single-skin curtain wallFT7.double-skin infill masonryFT8.double-skin infill frameFT9.double-skin infill monolithicFT10.double-skin infill masonryFT11.double-skin cladding panelFT12.double-skin curtain wall										
WINDOW TYPE	 WT1.vision level flush-fixedWT2.upper level flush-fixedWT3.full height flush-fixedWT4.vision level recessed-fixedWT5.upper level recessed-fixedWT6.full height recessed-fixedWT7.vision level flush-operableWT8.upper level flush-operableWT9.full height flush-operableWT10.vision level recessed-operableWT11.upper level recessed-operableWT12.full height recessed-operable										
GLAZING	 G1,2,3.single clear glass 4,6,8mmG4,5,6.single green tinted glass 4,6,8mmG7,8,9,10.double clear glass, air infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG11,12,13,14.double green tinted glass air infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG15,16,17,18.double low-e coated glass air infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG19,20,21,22.double clear glass krypton infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG23,24,25,26.double green tinted glass krypton infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG27,28,29,30.double low-e coated glass krypton infill 4-8-4,6-12-6, 8-16-8,4-12-8mmG31,32,33.triple clear glass, air infill 4-8-4-8-4,6-12-6-12-6, 4-8-6-12-8mm										
WALL CONFIGURATION	 W1,2,3.impermeable thermal insulation at the outer side rockwool, XPS, EPSW4,5,6.impermeable thermal insulation at the inner side rockwool, XPS, EPSW7,8,9.impermeable thermal insulation in the middle rockwool, XPS, EPSW10,11,12.semi-permeable thermal insulation at the inner side rockwool, XPS, EPSW13,14,15.semi-permeable thermal insulation in the middle rockwool, XPS, EPS										
SHADING	 S1.noneS2.overhangS3.horizontal louverS4.lightshelfS5.vertical finS6.overhang + vertical fin										

Figure A.1 : Design decisions and options.



Table A.1 : Rating chart for orientation.

Orientation & Performance	Objective Functions	Condition-1	Function-1	Condition-2	Function-2	Condition-3	Function-3
O-P1	Lower Wind Loads	if there is dominance among winds	give (-) for the options in the predominant wind directions give (+) for the perpendicular directions give (0) for the rest	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)		
O-P2	Lower Fire Loads (Protection from the Wind)	if there is dominance among winds	give (-) for the options exposed to predominant wind directions give (+) for the most protected ones give (0) for the rest	if it has high-safety requirements or if the wind speed is high	multiply the ratings (function - 1) by (2)		
O-P3	Lower Wind-Driven Rain Loads	if there is dominance among winds and if annual rainfall is higher than 400mm	give (-) for the options in the predominant wind directions give (+) for the most protected ones give (0) for the rest	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)		
O-P4	Lower Wind Loads	if there is dominance among winds and/ or if it has a climate different than the cold climate	give (-) for the options in the predominant wind directions give (+) for the most protected ones give (0) for the rest	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)		
O-P5	Higher Solar Radiation Lower Wind Exposure	in Northern Hemisphere, if it has cold climate	give (+) for South, SouthEast, SouthWest give (0) for East, West give (-) for North, NorthEast, NorthWest	if there is the predominant wind in that direction	give (0) for that direction give (-) for that direction	if the major space occupation is Winter seasons or if it has predominant winds in the Northern directions	multiply the ratings (function - 2) by (2)
	Higher Solar Radiation Lower Wind Exposure	in Northern Hemisphere, if it has temperate-arid climate	give (+) for South, SouthEast, SouthWest give (0) for East, West give (-) for North, NorthEast, NorthWest	if there is the predominant wind in that direction	give (0) for that direction give (-) for that direction multiply by (2)		
	Higher Solar Radiation Wind Exposure (in Summer Seasons)	in Northern Hemisphere, if it has temperate-humid climate	give (+) for South, SouthEast, SouthWest give (0) for East, West give (-) for North, NorthEast, NorthWest	if there is the predominant wind in that direction in Summer seasons (cooling periods)	multiply by (2) give (+) for that direction give (0) for that direction		
	Optimum Solar Radiation (Overheating Prevention) Lower Wind Exposure	in Northern Hemisphere, if it has hot-arid climate	give (+) for South give (0) for North, NorthEast, NorthWest, SouthEast, SouthWest give (-) for East, West	if there is the predominant wind in that direction	give (0) for South give (-) for North, NorthEast, NorthWest, SouthEast, SouthWest multiply by (2)		
	Optimum Solar Radiation (Overheating Prevention) Higher Wind Exposure	in Northern Hemisphere, if it has hot-humid climate	give (+) for South give (0) for North, NorthEast, NorthWest, SouthEast, SouthWest give (-) for East, West	if there is the predominant wind in that direction	multiply by (2) give (+) for that direction give (0) for that direction		
O-P6	Lower Wind-Driven Rain Loads	if there is dominance among winds and if annual rainfall is higher than 400mm	give (-) for the options in the predominant wind directions give (+) for the most protected ones give (0) for the rest	if it is high-rise building or if the wind speed is high	multiply by (2)		
O-P7	Higher Daylight Lower Glare Risk	in Northern Hemisphere	give (+) for South, SouthEast, SouthWest give (0) for East, West give (-) for North, NorthEast, NorthWest	if visible sky angle is low in that direction	give (0) for that direction give (-) for that direction multiply by (2)	if the space requires high illuminance levels (500 lux)	multiply the ratings (function - 2) by (2)
	Uniform Daylight Lower Glare Risk	in Northern Hemisphere, in middle and low latitudes	give (+) for North, NorthEast, NorthWest give (0) for South give (-) for East, West, SouthEast, SouthWest	if visible sky angle is low in that direction	give (0) for that direction give (-) for that direction multiply by (2)		
		in Northern Hemisphere, in high latitudes	give (+) for North, NorthEast, NorthWest give (-) for South give (-) for East, West, SouthEast, SouthWest	if visible sky angle is low in that direction	give (0) for that direction multiply by (2)		
O-P8	Lower Noise	if there is traffic noise	give (-) for the options in the direction of noise sources give (+) for the most noise protected directions give (0) for the rest	if the space is highly noise-sensitive or if the noise level is higher than 55dBA	multiply by (2)		



Table A.2 : Rating chart for transparency ratio.

Transparency Ratio & Performance	Function - 0 (previous decision effect)	Objective Functions	Condition-1	Function-1	Condition-2	Function-2
TR-P1	just take the selected orientation option into account	Higher Stability	in earthquake zones	give (-) for 75% and 100% transparency ratios (it is harder to give (0) for 50% option give (+) for 25% and 0% ratios	if it is oriented in the predominant wind direction	multiply the ratings (function - 1) by (2)
TR-P2	just take the selected orientation option into account	Higher Protection	in multi-storey buildings	give (+) for 25% and 0% ratios give (-) for 50%, 75%, 100%	if it has high safety requirements or if it is a high-rise building	multiply the ratings (function - 1) by (2)
TR-P3						
TR-P4						
			in Northern Hemisphere in cold and temperate climates if it is oriented towards Northern orientations	give (+) for 0% option give (0) for 25% option give (-) for 50%, 75%, and 100% options		
		Higher Solar Radiation	in Northern Hemisphere in cold and temperate climates if it is oriented towards Southern orientations	give (+) for 25% and 50% give (0) for 75% and 100% (due to potential overheating in Summers) give (-) for 0% (for not providing solar radiation indoors)		
		Lower Overheating Risk		give (-) for 50%, 75%, and 100% options		
			in Northern Hemisphere in cold and temperate climates if it is oriented towards East or West orientations	give (+) for 25% option give (0) for 0% (not providing solar radiation indoors but protecting them from solar radiation which is hard to control)		
TR-P5	just take the selected orientation option into account					
			in Northern Hemisphere, in hot climates, if it is oriented towards Southern orientations	give (+) for 25% option give (0) for 0% option give (-) for 50%, 75%, and 100% options		
		Optimum Solar Radiation	in Northern Hemisphere, in hot climates, if it is oriented towards East or West orientations	give (-) for 25%, 50%, 75%, and 100% options give (+) for 0% option		
		Lower Overheating Risk				
			in Northern Hemisphere, in hot climates, if it is oriented towards Northern orientations	give (+) for 25% and 50% option give (0) for 0% option give (-) for 75% and 100%		
TR-P6						
			for surroundings (urban, dark-colored buildings or trees in that direction or rural, trees in that direction)	give (+) for 75%, and 100% options give (0) for 50% option give (-) for 0% and 25% options		
				give (+) for 50%, 75%, and 100% options		
TR-P7	just take the selected orientation option into account	Higher Daylight Factor	for surroundings (urban, light colored buildings in that direction)	give (0) for 25% option give (-) for 0% option		
				give (+) for 50%, 75%, and 100% options		
			for surroundings (urban, no obstruction, pavement or rural, no obstruction, landscape)	give (0) for 25% option give (-) for 0% option		
				give (+) for 0%	if the space is highly noise-sensitive or	
TR-P8	just take the selected orientation option into account	Higher Noise Protection	if there is traffic noise	give (0) for 25% and 50% options give (-) for 75% and 100% options	if it is in the direction of the noise source or if the noise level is higher than 55dBA	multiply the ratings (function - 1) by (2)



Table A.3 : Rating chart for facade type.

Facade Type & Performance	Function - 0 (previous decision effect)	Objective Functions	Condition-1	Function-1	Condition-2	Function-2
FT-P1	limit the options based on the transparency ratio if 0%, do not take into account the window facade and the curtain wall, if 100%, just take into account the window facade and the curtain wall	Lighter Systems	unless it is exposed to high-speed wind conditions	give (-) for double-skin facades, infill masonry facades, infill monolithic facades, and cladding facades	if earthquake criticality is high or if it is a high-rise building	multiply the ratings (function - 1) by (2)
				give (+) for window facades, curtain walls		
		Heavier Systems	if it is exposed to high-speed wind conditions	give (0) for the rest	if earthquake criticality is high or if it is a high-rise building	give (0) for double-skin facades, infill masonry facades, infill monolithic facades
				give (+) for double-skin facades, infill masonry facades, infill monolithic facades		
FT-P2	limit the options based on the transparency ratio	Higher Protection	any condition (assuming that double-skin facade is second-skin type, not box-window, corridor and shaft type)	give (-) for double-skin facades	if it has high safety requirements or if it is a high-rise building	multiply the ratings (function - 1) by (2)
				give (0) for single-skin facades		
FT-P3	limit the options based on the transparency ratio if 0%, do not take into account the window facade and the curtain wall, if 100%, just take into account the window facade and the curtain wall	Higher Protection (Water Check, Water Barrier)	if it is oriented towards predominant wind directions and if annual rainfall is higher than 400mm	give (+) for double-skin facades	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)
				give (0) for single-skin facades		
FT-P4	limit the options based on the transparency ratio if 0%, do not take into account the window facade and the curtain wall, if 100%, just take into account the window facade and the curtain wall	Higher Protection	if it is oriented towards predominant wind directions	give (+) for double-skin facades	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)
				give (0) for single-skin facades		
		Lower Thermal Conductivity	in hot and humid climates	give (+) for double-skin infill frame systems, window facades, curtain walls	if transparency ratio is 50%, 75% or 100%	give (0) for double-skin infill frame systems, window facades, curtain walls
				give (0) for single-skin infill frame, window facades, curtain walls		
FT-P5	limit the options based on the transparency ratio if 0%, do not take into account the window facade and the curtain wall, if 100%, just take into account the window facade and the curtain wall	Optimum Thermal Conductivity	in temperate climates	give (-) for single and double-skin infill masonry, infill monolithic, cladding facades	if diurnal temperature variation is high	multiply the ratings (function - 1) by (2)
				give (+) for double-skin infill frame, window facades, curtain walls		
		Optimum Thermal Storage	in temperate climates	give (0) for infill masonry, infill monolithic, cladding facades, infill frame, window facades, curtain walls		
				give (-) for double-skin infill masonry, infill monolithic, cladding facades		
		Lower Thermal Conductivity	in hot and arid climates	give (+) for single and double-skin infill masonry, infill monolithic, cladding facades		
				give (0) for infill frame systems		
FT-P6		Higher Thermal Storage	in cold climates	give (-) for window facades, curtain walls	if diurnal temperature variation is high	multiply the ratings (function - 1) by (2)
				give (+) for double-skin facades		
FT-P7		Higher Protection (Water Check, Water Barrier)	if it is oriented towards predominant wind directions and if annual rainfall is higher than 400mm	give (0) for single-skin facades	if it is high-rise building or if the wind speed is high	multiply the ratings (function - 1) by (2)
				give (+) for double-skin facades, infill masonry facades, infill concrete facades, cladding facades		
FT-P8	limit the options based on the transparency ratio	Heavier Systems	if there is traffic noise	give (-) for window facades, curtain walls	if the space is highly noise-sensitive or if it is in the direction of the noise source or if the noise level is higher than 55dBA	multiply the ratings (function - 1) by (2)
				give (0) for the rest		



Window Type & Performance	Function - 0 (previous decision effect)	Objective Functions	Condition-1	Function-1	Condition-2	Function-2
WT-P1						
WT-P2	if the transparency ratio is different than 0%, rate window type options	Higher Protection	unless it is a single-storey building and for spaces on the first 2 floors	give (+) for recessed and operable windows give (0) for the rest	if it has high safety requirements	multiply the ratings (function - 1) by (2)
			unless it is a single-storey building and for spaces on the upper floors (assuming that window lintels are concrete)	give (+) for recessed windows give (0) for the rest give (+) for operable windows		
		Higher Accessibility	if it is a single-storey building	give (0) for the rest		
WT-P3	if the transparency ratio is different than 0%, rate window type options	Higher Protection	if annual rainfall is higher than 400mm	give (+) for recessed windows give (0) for the rest	if it is a high-rise building	multiply the ratings (function - 1) by (2)
WT-P4						
WT-P5	if the transparency ratio is different than 0%, rate window type options	Lower Overheating Risk	in hot and temperate climates if it is oriented towards Southern directions	give (+) for recessed and operable options give (-) for the rest	if transparency ratio is among 50%, 75% or 100% options or if the major space occupation is Summer seasons	multiply the ratings (function - 1) by (2)
			in hot and temperate climates if it is oriented towards orientations other than Southern directions	give (+) for operable windows give (-) for the rest		
		Higher Solar Radiation	in cold climates if it is oriented towards Southern directions	give (-) for recessed options give (0) for the rest		
WT-P6	if the transparency ratio is different than 0%, rate window type options	Higher Ventilation	in cold and hot arid, temperate arid climates	give (+) for operable windows give (-) for the rest	if the space is occupied all throughout the day	multiply the ratings (function - 1) by (2)
			in humid climates unless it is a highly moisture-generating space	give (+) for operable windows give (-) for the rest		
		Homogeneous Daylight	if the space has uniform plan proportions	give (+) for full-height windows, flush vision level windows give (0) for recessed vision level windows give (-) for upper-level windows		
WT-P7	if the transparency ratio is different than 0%, rate window type options	Much Daylight Deep Interiors	if the space has deep plan proportions	give (+) for upper level and full-height windows give (0) for vision level windows		
				give (-) for operable windows		
WT-P8	if the transparency ratio is different than 0%, rate window type options	Less Exposure to Noise	if it is oriented towards the direction of the noise sources	give (-) for operable windows give (0) for the rest	if the transparency ratio is 25%	give (+) for fixed upper-level windows



Table A.5 : Rating chart for glazing.

Glazing & Performance	Function - 0 (previous decision effect)	Objective Functions	Condition -1	Function - 1	Condition -2	Function - 2
G-P1	limit the options based on the transparency ratio	Lighter Systems	if transparency ratio is among 50%, 75%, and 100% options	give (+) for single glazing except for 8mm option (give (0) for it) give (0) for double glazing except for 8-16-8mm option (give (-) for it) give (-) for triple glazing	in earthquake zones	multiply the ratings (function - 1) by (2)
G-P2						
G-P3						
G-P4						
		Higher Insulation		give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)	if it is oriented towards northern directions or if transparency ratio is among 50%, 75% or 100% options	multiply the ratings (function - 1) by (2)
		Optimum Solar Heat Gain	in Northern hemisphere in cold climates	give (0) for double glazing (4-12-8 or 6-12-6mm, clear or green-tinted with air infill) (4-8-4mm, low-e coated, with air or argon infill) (4-8-4mm, clear or green-tinted, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)		
G-P5	if the transparency ratio is different than 0%, rate window type options	Optimum Insulation	in Northern hemisphere in temperate climates	give (0) for double glazing (4-12-8 or 6-12-6mm, clear or green-tinted with air infill) (4-8-4mm, low-e coated, with air or argon infill) (4-8-4mm, clear or green-tinted, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)	if it is oriented towards east or west directions or if transparency ratio is among 50%, 75% or 100% options	multiply the ratings (function - 1) by (2)
		Lower Solar Heat Gain		give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)	if it is oriented towards southern, east or west directions or if transparency ratio is among 50%, 75% or 100% options	multiply the ratings (function - 1) by (2)
		Higher Insulation	in Northern hemisphere in hot climates	give (0) for double glazing (4-12-8 or 6-12-6mm, clear or green-tinted with air infill) (4-8-4mm, low-e coated, with air or argon infill) (4-8-4mm, clear or green-tinted, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)		
G-P6		Lower Solar Heat Gain		give (0) for double glazing (4-12-8 or 6-12-6mm, clear or green-tinted with air infill) (4-8-4mm, low-e coated, with air or argon infill) (4-8-4mm, clear or green-tinted, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)	if it is oriented towards northern directions or if transparency ratio is among 50%, 75% or 100% options	multiply the ratings (function - 1) by (2)
		Higher Insulation	in Northern hemisphere	give (0) for double glazing (4-12-8 or 6-12-6mm, clear or green-tinted with air infill) (4-8-4mm, low-e coated, with air or argon infill) (4-8-4mm, clear or green-tinted, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted) give (+) for triple glazing give (+) for double glazing (8-16-8mm, clear or green-tinted or low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm, low-e coated, with air or argon infill) (6-12-6 or 4-12-8mm clear or green-tinted, with argon infill)		
G-P7	if the transparency ratio is different than 0%, rate window type options	Optimum Effective Aperture	if the transp. ratio is 75% or 100%	give (-) for options having a clear glass give (0) for the rest give (+) for options having low-e coated glass give (0) for options having a clear glass give (-) for options having a green-tinted glass	if it is south, southeast, southwest oriented or if it is east oriented and the major occupation is in the mornings or if it is west oriented and the major occupation is in the afternoons	multiply the ratings (function - 1) by (2)
			if the transparency ratio is 50%	give (+) for options having a clear glass give (0) for options having low-e coated glass give (-) for options having a green-tinted glass give (+) for triple glazing give (+) for double glazing (8-16-8mm, 4-12-8mm, with air or argon infill) (6-12-6mm, with argon infill)		
			If the transparency ratio is 25%	give (0) for options having a clear glass give (0) for options having low-e coated glass give (-) for options having a green-tinted glass give (+) for triple glazing give (+) for double glazing (8-16-8mm, 4-12-8mm, with air or argon infill) (6-12-6mm, with argon infill)	if transparency ratio is among 50%, 75% or 100% options or if it is in the direction of the noise source or if the space is highly noise-sensitive	multiply the ratings (function - 1) by (2)
G-P8		Higher Protection	if there is traffic noise	give (0) for double glazing (6-12-6mm, clear or green-tinted or low-e coated, with air infill) (4-8-4mm, clear or green-tinted or low-e coated, with argon infill) give (-) for double glazing (4-8-4mm, clear or green-tinted or low-e coated, with air infill) give (-) for single glazing, (4 or 6 or 8mm, clear or green-tinted)		



Table A.6 : Rating chart for wall configuration.

Wall Configuration & Performance	Function - 0 (Previous Decision Effect)	Objective Functions	Condition - 1	Function - 1	Condition - 2	Function - 2
W-P1						
W-P2	if the transparency ratio is different than 100%, rate wall config. options	Higher Fire Resistance Lower Fire Spread Risk	in any condition	give (-) for impermeable options having XPS and EPS for thermal insulation give (-2) for semi-permeable options having XPS and EPS for thermal insulation give (+) for impermeable options having rockwool for thermal insulation give (0) for semi-permeable options having rockwool for thermal insulation give (+) for semi-permeable cladding options	if it has high safety requirements or if it is a high-rise building	multiply the ratings (function - 1) by (2)
W-P3	if the transparency ratio is different than 100%, rate wall config. options	Higher Protection	if it is oriented towards predominant wind directions and if annual rainfall is higher than 400mm	give (0) for the rest	if the wind speed is high	multiply the ratings (function - 1) by (2)
W-P4						
W-P5	if the transparency ratio is different than 100%, rate wall config. options	Higher Insulation	in any condition	give (+) for semi-permeable options having thermal insulation in the middle give (+) for impermeable options having thermal insulation at the outer side give (0) for impermeable options having thermal insulation in the middle give (0) for semi-permeable options having thermal insulation at the inner side give (-) for options having thermal insulation at the inner side give (+) for semi-permeable options having thermal insulation in the middle give (+) for impermeable options having thermal insulation at the outer side give (0) for impermeable options having thermal insulation in the middle give (0) for semi-permeable options having thermal insulation at the inner side give (-) for impermeable options having thermal insulation at the inner side		
W-P6	if the transparency ratio is different than 100%, rate wall config. options	Higher Insulation	in any condition	give (+) for semi-permeable options having thermal insulation in the middle give (+) for impermeable options having thermal insulation at the outer side give (0) for impermeable options having thermal insulation in the middle give (0) for semi-permeable options having thermal insulation at the inner side give (-) for impermeable options having thermal insulation at the inner side		
W-P7						
W-P8	if the transparency ratio is different than 100%, rate wall config. options	Higher Protection	if there is traffic noise	give (+2) for semi-permeable options having rockwool for thermal insulation give (+) for semi-permeable options having XPS or EPS for thermal insulation give (+) for impermeable options having rockwool for thermal insulation give (0) for impermeable options having XPS or EPS for thermal insulation	if the space is highly noise-sensitive or if it is in the direction of the noise source or if the noise level is higher than 55dBA	multiply the ratings (function - 1) by (2)



Table A.7 : Rating chart for shading.

Shading & Performance	Function - 0 (previous decision effect)	Objective Functions	Condition - 1	Function - 1	Condition - 2	Function - 2	
S-P1	if the transparency ratio is different than 0%, rate window type options	Lighter Systems	in earthquake zones	give (+) for none option give (-) for vertical louver + overhang options give (0) for the rest	if it is a high-rise building	multiply the ratings (function - 1) by (2)	
S-P2		Higher Protection	unless it is a single-storey building (assuming that all shading elements are from fire-resistant materials)	give (+) for overhangs, lightshelves, and vertical louvers + overhangs give (0) horizontal louvers give (-) for the rest	if it has high safety requirements or if it is a high-rise building	multiply the ratings (function - 1) by (2)	
S-P3		Higher Protection	if annual rainfall is higher than 400mm	give (+) for overhangs, horizontal louvers, lightshelves, and vertical louvers + overhangs give (0) for the rest	if it is oriented towards predominant wind directions	multiply the ratings (function - 1) by (2)	
S-P4							
S-P5	if the transparency ratio is different than 0%, rate window type options	Higher Solar Radiation	in Northern Hemisphere if facade orientation is North	give (+) for none option give (-) for the rest	if transparency ratio is among 50%, 75%, and 100% options	give (0) for the rest give (0) for none option give (+) for vertical louvers	
			in Northern Hemisphere if facade orientation is NorthEast or NorthWest	give (+) for none option give (0) for vertical louvers			
		Optimum Solar Radiation	in Northern Hemisphere if facade orientation is South	give (+) for overhangs, horizontal louvers, lightshelves give (-) for the rest	if transparency ratio is among 50%, 75%, and 100% options	multiply the ratings (function - 1) by (2)	
			in Northern Hemisphere if facade orientation is East or West	give (+) for vertical louvers give (-) for the rest			
S-P6			in Northern Hemisphere if facade orientation is SouthEast or SouthWest	give (+) for vertical louvers + overhangs give (-) for none option give (0) for the rest			
S-P7	if the transparency ratio is different than 0%, rate window type options	Higher Daylight	in Northern Hemisphere if facade orientation is North, NorthEast or NorthWest (uniform plans)	give (+) for none option give (-) for the rest	if the effective aperture is lower than 0.25 or if visible sky angle is low in that direction	multiply the ratings (function - 1) by (2)	
		Optimum Daylight	in Northern Hemisphere if facade orientation is South (uniform plans)	give (+) for overhangs, horizontal louvers, lightshelves give (-) for the rest	if the effective aperture is higher than 0.35	multiply the ratings (function - 1) by (2)	
			in Northern Hemisphere if facade orientation is East or West (uniform plans)	give (+) for vertical louvers give (-) for the rest			
		S-P8	if the transparency ratio is different than 0%, rate window type options	Higher Glare Control	in Northern Hemisphere if facade orientation is SouthEast or SouthWest (uniform plans)	give (+) for vertical louvers + overhangs give (-) for none option give (0) for the rest	
Much Daylight Deep Interiors				give (+) for lightshelves give (0) for none option give (-) for the rest			
	Higher Protection			(assuming that the shading elements are of sound-absorbing materials)	if there is traffic noise	give (-) for none option give (+) for the rest	



APPENDIX B.1

TEST NO 2 - ANKARA PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Arid < 400mm	Low	Define	North	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	Low		Define	Traffic	High > 55dBA	North	Define	Urban	Buildings as obstruction	West	Light (50-100%)
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Residential	Low-rise (≤7 floors)			Define	Living Room	All Year-All Day	Lower (first 2 floor)	Define	Uniform	Light (50-100%)



Figure B.1 : Testing results for Ankara-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	South	-5	3	NA	5	5	NA	5	10	
Transparency Ratio	25%	NA	3			5		0	0	
Facade Type	Double-Skin Infill Frame	-5	-3	NA	NA	5	NA		6	
Window Type	Operable Full Height Flush		3	NA		5	10	5	NA	
Glazing	double glazing, clear, with argon 8-16-8mm	NA				5	3	10	5	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20	
Shading	Overhang > 60cm (Exposed Concrete, Metal)	NA	5	NA		5		5	0	
SCORE		-10	11	0	5	40	23	25	41	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	East	-5	3	NA	5	5	NA	5	10	
Transparency Ratio	75%	NA	3			5		0	0	
Facade Type	Double-Skin Infill Window	-5	0	NA	NA	0	NA		6	
Window Type	Operable Vision Level Flush		3	NA		5	10	0	NA	
Glazing	double glazing, low-e coated, with argon 4-12-8mm	NA				0	0	10	0	
Wall Configuration	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding		-10	NA		10	10		10	
Shading	Horizontal Louver <30cm, every 20-30cms from floortop to vision level	NA	5	NA		5		5	0	
SCORE		-10	4	0	5	30	20	20	26	

Figure B.2 : Testing results for Ankara-2.

TEST NO 3 - ANTALYA PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Hot	Humid > 600mm	Low	Define	West	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	Low		Define	Traffic	High > 55dBA	North	Define	Urban	Pavement		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Commercial	Low-rise (≤7 floors)			Define	Shop / Store	All Year-All Day	Lower (first 2 floor)	Define	Deep	Dark (0-49%)



Figure B.3 : Testing results for Antalya-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	South	5	0	0	0	5	0	0	10	
Transparency Ratio	25%	NA	3			5		0	0	
Facade Type	Double-Skin Infill Window	-5	-3	NA	NA	5	NA		6	
Window Type	Operable Full Height Recessed		3	1		5	10	5	NA	
Glazing	double glazing, clear, with argon 8-16-8mm	NA				10	3	10	5	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20	
Shading	Lightshelf (50+50, 100+50cm) (Metal, Plastic)	NA	5	5		5		5	0	
SCORE		0	8	6	0	45	23	20	41	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	North	5	0	0	0	0	0	5	-10	
Transparency Ratio	100%	NA	-3			-5		5	-10	
Facade Type	Single-Skin Infill Window	5	0	NA	NA	-5	NA		-6	
Window Type	Fixed Full Height Recessed		3	1		-5	-10	5	0	
Glazing	double glazing, clear, with air 6-12-6mm	0				0	0	-5	0	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		NA	NA		NA	NA		NA	
Shading	not available	NA	-5	0		5		0	-1	
SCORE		10	-5	1	0	-10	-10	10	-27	

Figure B.4 : Testing results for Antalya-2.

TEST NO 4 - GAZIANTEP PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Hot	Arid < 400mm	High	Define	NorthWest	Low < 20km/h	Cooling Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	Traffic	Low ≤ 55dBA	South	Define	Urban	Pavement		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Upper	Define	Uniform	Light (50-100%)



Figure B.5 : Testing results for Gaziantep-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthEast	-5	6	NA	5	0	NA	5	0	
Transparency Ratio	25%	5	6			5		0	0	
Facade Type	Single-Skin Infill Masonry	-5	0	NA	NA	10	NA		6	
Window Type	Operable Full Height Recessed		6	NA		5	10	5	NA	
Glazing	double glazing, clear, with argon 6-12-6mm	NA				10	3	10	10	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-1	10	NA		5		5	0	
SCORE		-6	28	0	5	45	23	25	36	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthEast	-5	6	NA	5	0	NA	5	0	
Transparency Ratio	25%	5	6			5		0	0	
Facade Type	Single-Skin Infill Masonry	-5	0	NA	NA	10	NA		6	
Window Type	Operable Vision Level Recessed		6	NA		5	10	0	NA	
Glazing	double glazing, clear, with air 6-12-6mm	NA				0	0	10	0	
Wall Configuration	Semi-permeable Cladding, with ventilated air Air Cavity, Thermal Insulation in the middle (EPS), Interior Cladding		-20	NA		5	5		10	
Shading	Horizontal Louver <30cm, every 20-30cms from floortop to vision level	0	0	NA		0		0	0	
SCORE		-5	-2	0	5	25	15	15	16	

Figure B.6 : Testing results for Gaziantep-2.

TEST NO 5- ERZURUM PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Cold		High	Define	West	High $\geq 20\text{km/h}$	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	None			Define	Rural	Landscape		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Commercial	Low-rise (≤ 7 floors)			Define	Hotel Room	Winter-All Day	Upper	Define	Uniform	Light (50-100%)



Figure B.7 : Testing results for Erzurum-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	South	10	0	NA	NA	10	NA	5	NA	
Transparency Ratio	25%	5	3			5		0	NA	
Facade Type	Single-Skin Infill Masonry	5	0	NA	NA	10	NA		NA	
Window Type	Operable Vision Level Flush		0	NA		0	10	5	-1	
Glazing	triple glazing, clear, with air 6-12-6-12-6mm	NA				5	3	10	NA	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		NA	
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	5	NA		5		5	NA	
SCORE		20	8	0	0	45	23	25	-1	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthEast	0	0	NA	NA	10	NA	5	NA	
Transparency Ratio	50%	0	-3			5		5	NA	
Facade Type	Double-Skin Infill Masonry	5	-3	NA	NA	10	NA		NA	
Window Type	Operable Vision Level Flush		0	NA		0	10	5	NA	
Glazing	double glazing, clear, with argon 6-12-6mm	0				10	6	0	NA	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (XPS), Interior Cladding		-10	NA		10	10		NA	
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	5	NA		0		0	NA	
SCORE		5	-11	0	0	45	26	15	0	

Figure B.8 : Testing results for Erzurum-2.

TEST NO 6 - CANAKKALE PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Humid > 600mm	Low	Define	NorthEast	Low < 20km/h	Cooling Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	None			Define	Rural	Landscape		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Lower (first 2 floor)	Define	Uniform	Light (50-100%)



Figure B.9 : Testing results for Çanakkale-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-5	6	5	5	5	5	5	NA	
Transparency Ratio	25%	5	6			5		0	NA	
Facade Type	Single-Skin Infill Window	5	0	NA	NA	0	NA		NA	
Window Type	Operable Full Height Recessed		6	1		5	10	5	NA	
Glazing	double glazing, clear, with argon 6-12-6mm	NA				5	3	10	NA	
Wall Configuration	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding		10	NA		5	5		NA	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-1	10	5		5		5	NA	
SCORE		4	38	11	5	30	23	25	0	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	NorthWest	5	0	0	0	-5	0	-5	NA	
Transparency Ratio	50%	0	-6			-5		5	NA	
Facade Type	Single-Skin Infill Frame	0	0	NA	NA	0	NA		NA	
Window Type	Operable Vision Level Recessed		6	1		5	10	0	NA	
Glazing	double glazing, green tinted, with air 6-12-6mm	0				0	0	-5	NA	
Wall Configuration	Impermeable Cladding, No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding		-10	NA		5	5		NA	
Shading	not available	1	-10	0		0		10	NA	
SCORE		6	-20	1	0	0	15	5	0	

Figure B.10 : Testing results for Çanakkale-2.

TEST NO 7 - ISTANBUL CAMLICA PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Humid > 600mm	Low	Define	NorthEast	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	Traffic	High > 55dBA	South	Define	Urban	Pavement		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Upper	Define	Uniform	Light (50-100%)

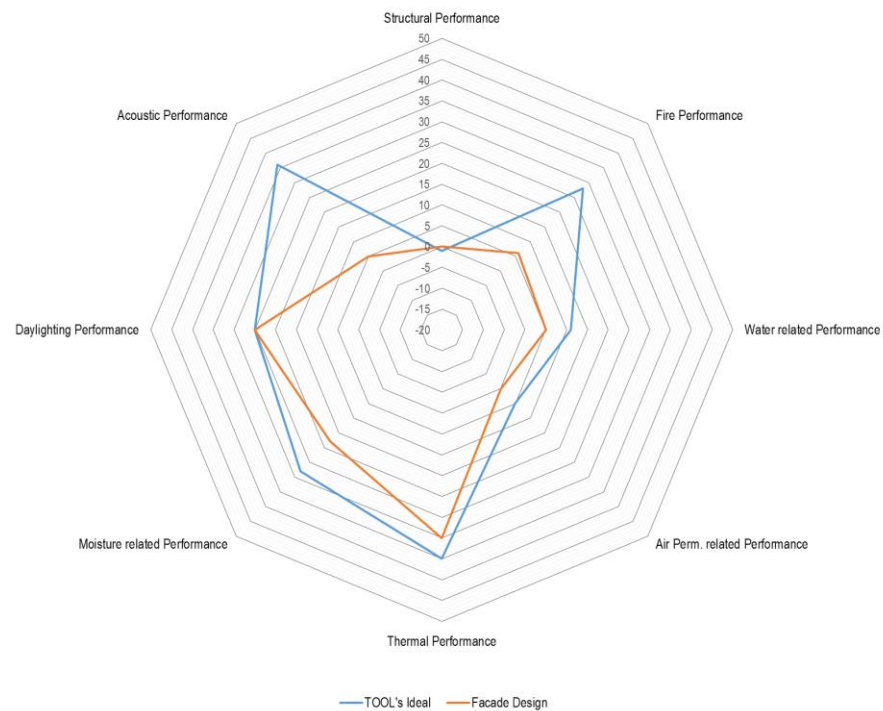


Figure B.11 : Testing results for Çamlıca-1.

RESULTS / TOOL'S IDEAL												
TOOL'S IDEAL	SELECTION			Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest			-5	6	5	5	5	5	5	0	
Transparency Ratio	25%			10	6			5		0	0	
Facade Type	Single-Skin Infill Masonry			-5	0	NA	NA	0	NA		6	
Window Type	Operable Full Height Recessed				6	1			5	10	5	NA
Glazing	double glazing, clear, with air 8-16-8mm			NA				5	3	10	10	
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding (Timber, Gypsum)				0	NA			10	10		20
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)			-1	10	5			5		5	0
SCORE				-1	28	11	5	35	28	25	36	
RESULTS / FACADE DESIGN												
FACADE DESIGN	SELECTION			Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	South			0	0	0	0	5	0	5	-10	
Transparency Ratio	25%			5	6			5		0	0	
Facade Type	Single-Skin Infill Masonry			-5	0	NA	NA	0	NA		6	
Window Type	Operable Vision Level Flush				0	0			5	10	5	-1
Glazing	double glazing, clear, with air 8-16-8mm			NA				5	3	10	10	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding (Timber, Gypsum)				-10	NA			5	5		0
Shading	Overhang > 60cm (Exposed Concrete, Metal)			0	10	5			5		5	0
SCORE				0	6	5	0	30	18	25	5	

Figure B.12 : Testing results for Çamlıca-2.

TEST NO 9 - MUĞLA PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Hot	Humid > 600mm	Low	Define	West	Low < 20km/h	Cooling Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	None			Define	Rural	Landscape		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Upper	Define	Uniform	Light (50-100%)

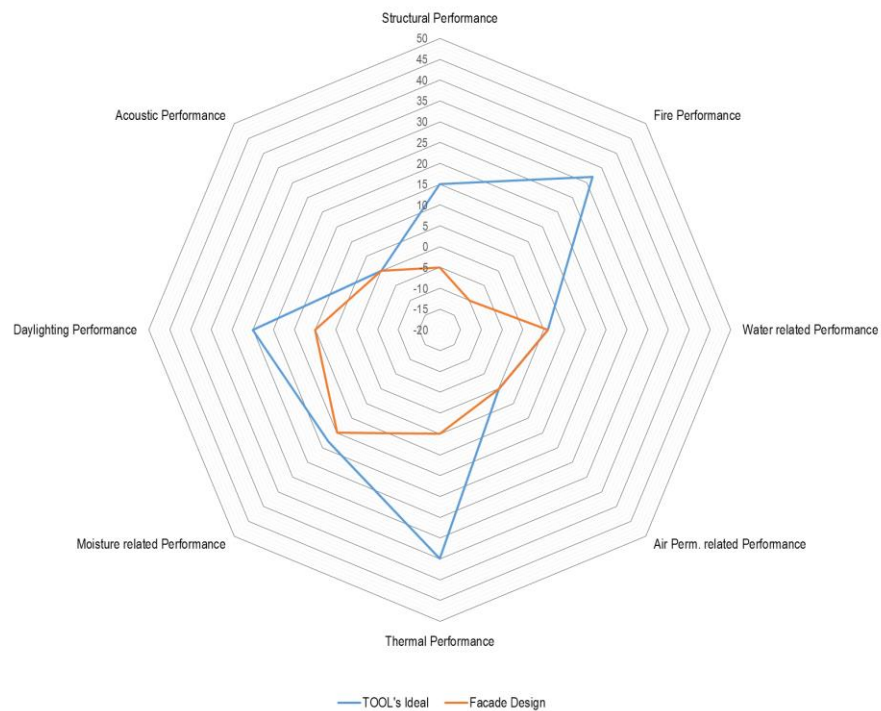


Figure B.13 : Testing results for Muğla-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	South	5	0	0	0	5	0	5	NA	
Transparency Ratio	25%	5	6			5		0	NA	
Facade Type	Single-Skin Curtain Wall	5	0	NA	NA	0	NA		NA	
Window Type	Operable Full Height Recessed		6	1		5	10	5	NA	
Glazing	double glazing, clear, with argon 8-16-8mm	NA				10	3	10	NA	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding (Timber, Gypsum)		10	NA		5	5		NA	
Shading	Lightshelf (50+50, 100+50cm) (Metal, Plastic)	0	10	5		5		5	NA	
SCORE		15	32	6	0	35	18	25	0	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	0	0	0	0	0	0	5	NA	
Transparency Ratio	50%	0	-6			-5		5	NA	
Facade Type	Single-Skin Infill Masonry	-5	0	NA	NA	-5	NA		NA	
Window Type	Operable Vision Level Recessed		6	1		10	10	0	NA	
Glazing	double glazing, clear, with air 6-12-6mm	0				0	0	0	NA	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding (Timber, Gypsum)		-10	NA		5	5		NA	
Shading	Horizontal Louver <30cm, every 20-30cms from floortop to vision level	0	0	5		0		0	NA	
SCORE		-5	-10	6	0	5	15	10	0	

Figure B.14 : Testing results for Muğla-2.

TEST NO 10 - ISTANBUL UMRANIYE PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Humid > 600mm	Low	Define	NorthEast	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	Traffic	High > 55dBA	NorthWest	Define	Urban	Pavement		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Upper	Define	Uniform	Light (50-100%)



Figure B.15 : Testing results for Istanbul, Ümraniye-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-5	6	5	5	5	5	5	0	
Transparency Ratio	25%	10	6			5		0	0	
Facade Type	Single-Skin Cladding	-5	0	NA	NA	0	NA		6	
Window Type	Operable Full Height Recessed		6	1		5	10	5	NA	
Glazing	double glazing, clear, with argon 6-12-6mm	NA				5	3	10	10	
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-1	10	5		5		5	0	
SCORE		-1	28	11	5	35	28	25	36	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-5	6	5	5	5	5	5	0	
Transparency Ratio	50%	0	-6			5		5	0	
Facade Type	Single-Skin Infill Masonry	-5	0	NA	NA	0	NA		6	
Window Type	Operable Vision Level Flush		0	0		10	10	5	NA	
Glazing	double glazing, clear, with air 6-12-6mm	0				0	0	0	0	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding (Timber, Gypsum)		-10	NA		5	5		0	
Shading	Horizontal Louver <30cm, every 20-30cms from floortop to vision level	0	0	5		0		0	0	
SCORE		-10	-10	10	5	25	20	15	6	

Figure B.16 : Testing results for Istanbul, Ümraniye-2.

TEST NO 11 - ISTANBUL DRAGOS PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Humid > 600mm	Low	Define	NorthEast	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	None			Define	Urban	Pavement		
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Lower (first 2 floor)	Define	Uniform	Light (50-100%)



Figure B.17 : Testing results for Istanbul, Dragos-1.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-5	6	5	5	5	5	5	NA	
Transparency Ratio	25%	10	6			5		0	NA	
Facade Type	Single-Skin Infill Window	5	0	NA	NA	0	NA		NA	
Window Type	Operable Full Height Recessed		6	1		5	10	5	NA	
Glazing	double glazing, clear, with argon 4-12-8mm	NA				5	3	10	NA	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding (Timber, Gypsum)		10	NA		5	5		NA	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-1	10	5		5		5	NA	
SCORE		9	38	11	5	30	23	25	0	
RESULTS / FACADE DESIGN										
FACADE DESIGN	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	NorthEast	-5	-6	-5	-5	-5	-5	-5	NA	
Transparency Ratio	50%	0	-6			-5		5	NA	
Facade Type	Single-Skin Infill Window	5	0	0	0	0	0		NA	
Window Type	Operable Vision Level Flush		6	0		5	10	5	NA	
Glazing	double glazing, clear, with air 6-12-6mm	0				0	0	0	NA	
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding (Timber, Gypsum)		-10	0		5	5		NA	
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	10	10		-5		-5	NA	
SCORE		0	-6	5	-5	-5	10	0	0	

Figure B.18 : Testing results for Istanbul, Dragos-2.

TEST NO 12 - YALOVA PROJECT / INPUT											
LOCATION	Hemisphere	Latitude		CLIMATE (general)	Temperature (annual)	Rainfall (annual)	Diurnal Temperature Range	WIND (predominant)	Direction	Speed	Period
Define	Northern	Middle (30-60)		Define	Temperate	Humid > 600mm	Low	Define	NorthWest	Low < 20km/h	Heating Period
EARTHQUAKE	Criticality		NOISE	Availability	Level	Direction	SURROUNDING	Context	Surfaces	Direction	Color (reflectivity)
Define	High		Define	Traffic	Low ≤ 55dBA	North	Define	Urban	Trees as obstruction	East	Light (50-100%)
BUILDING	Typology	Height			SPACE	Function	Occupation Period (major)	Location (floor)	SPACE-interior	Proportions	Surface Properties (color reflectivity)
Define	Educational	Low-rise (≤7 floors)			Define	Classroom	All Year-All Day	Upper	Define	Uniform	Light (50-100%)



Figure B.19 : Testing results for Yalova-1.

RESULTS / TOOL'S IDEAL											
TOOL'S IDEAL	SELECTION			Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	SouthEast			-5	6	5	5	5	5	5	0
Transparency Ratio	25%			10	6			5		0	0
Facade Type	Single-Skin Infill Masonry			-5	0	NA	NA	0	NA		6
Window Type	Operable Full Height Recessed				6	1		5	10	5	NA
Glazing	double glazing, clear, with argon 6-12-6mm			NA				5	3	10	10
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (Rockwool), Interior Cladding (Timber, Gypsum)				10	NA		5	5		10
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)			-1	10	5		5		5	0
SCORE				-1	38	11	5	30	23	25	26
RESULTS / FACADE DESIGN											
FACADE DESIGN	SELECTION			Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	North			0	0	0	0	-5	0	-5	-10
Transparency Ratio	50%			0	-6			-5		5	0
Facade Type	Single-Skin Infill Masonry			-5	0	NA	NA	0	NA		6
Window Type	Operable Vision Level Recessed				6	1		5	10	0	-1
Glazing	double glazing, green tinted, with air 6-12-6mm			0				0	0	-5	0
Wall Configuration	Impermeable Cladding (Cement, Metal, Plastic, Composite, Glass), No Air Cavity, Thermal Insulation at the outer side (XPS), Interior Cladding (Timber, Gypsum)				-10	NA		5	5		0
Shading	not available			1	-10	0		5		10	-1
SCORE				-4	-20	1	0	5	15	5	-6

Figure B.20 : Testing results for Yalova-2.

RESULTS / TOOL'S IDEAL										
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance	
Orientation	SouthWest	-10	3	10	10	5	10	5	0	
Transparency Ratio	25%	5	6			5		0	0	
Facade Type	Single-Skin Curtain Wall	10	0	NA	NA	0	NA		-6	
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA	
Glazing	double glazing, clear, with argon 4-12-8mm	NA				5	3	10	10	
Wall Configuration	Semi-permeable Cladding, with ventilated Air Cavity, Thermal Insulation in the middle (Rockwool), Interior Cladding		0	NA		10	10		20	
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-2	10	5		5		5	0	
SCORE		3	22	17	10	35	33	25	24	

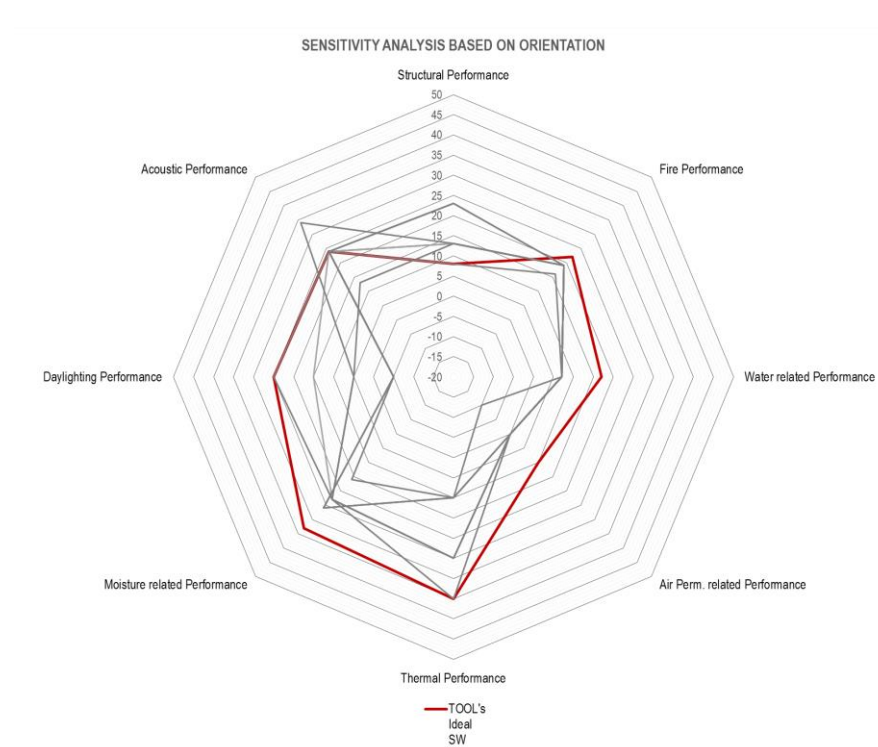


Figure B.21 : Sensitivity analysis based on orientation.

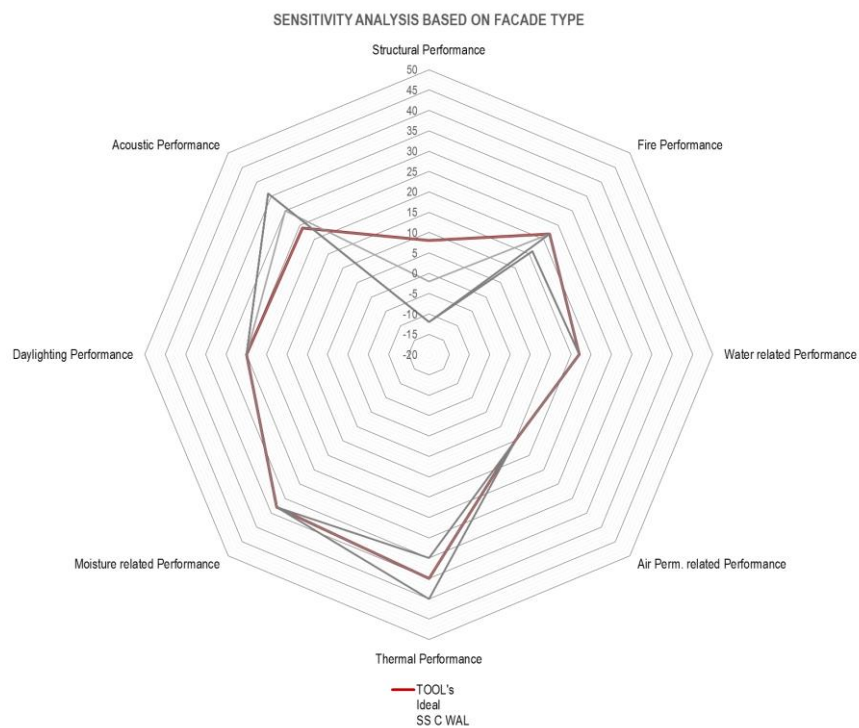


Figure B.22 : Sensitivity analysis based on transparency ratio and facade type.



Figure B.23 : Sensitivity analysis based on window type and glazing.



Figure B.24 : Sensitivity analysis based on wall configuration and shading.

ISTANBUL - NORTH											
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance		
Orientation	North	0	0	0	0	-5	0	-5	0		
Transparency Ratio	25%	5	6			0		0	0		
Facade Type	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6		
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA		
Glazing	double glazing, clear, with air 8-16-8mm	NA				5	6	5	10		
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20		
Shading	not available	2	-10	0		5		10	-1		
SCORE		17	-1	2	0	20	26	15	23		
ISTANBUL - SOUTH											
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance		
Orientation	South	0	0	0	0	5	0	5	0		
Transparency Ratio	25%	5	6			5		0	0		
Facade Type	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6		
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA		
Glazing	double glazing, clear, with argon 8-16-8mm	NA				5	3	10	10		
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20		
Shading	Lightsheif (50+50, 100+50cm) (Metal, Plastic)	0	10	5		5		5	0		
SCORE		15	19	7	0	35	23	25	24		

Figure B.25 : Tool's ideal for different orientations for Istanbul-north and south.

ISTANBUL - EAST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	East	0	0	0	0	0	0	0	-10
Transparency Ratio	25%	5	6			5		0	0
Facade Type	Single-Skin Curtain Wall	10	0	NA	NA	0	NA		-6
Window Type	Operable Full Height Recessed		3	2		5	10	5	-1
Glazing	double glazing, clear, with argon 6-12-6mm	NA				10	3	5	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	10	5		-5		-5	0
SCORE		15	19	7	0	25	23	5	13
ISTANBUL - WEST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	West	0	0	0	0	0	0	0	10
Transparency Ratio	25%	5	6			5		0	0
Facade Type	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA
Glazing	double glazing, clear, with air 8-16-8mm	NA				10	3	5	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20
Shading	Overhang > 60cm (Exposed Concrete, Metal)	0	10	5		-5		-5	0
SCORE		15	19	7	0	25	23	5	34

Figure B.26 : Tool's ideal for different orientations for Istanbul-east and west.

ISTANBUL - NORTHEAST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	NorthEast	-10	-3	-10	-10	-5	-10	-5	0
Transparency Ratio	25%	10	6			0		0	0
Facade Type	Double-Skin Infill Window	-10	-6	6	6	5	10		6
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA
Glazing	triple glazing, clear, with air 4-8-4-8-4mm	NA				5	6	5	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	5		10	10		20
Shading	not available	2	-10	0		5		10	-1
SCORE		-8	-10	3	-4	25	26	15	35
ISTANBUL - NORTHWEST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	NorthWest	10	0	0	0	-5	0	-5	0
Transparency Ratio	25%	5	6			0		0	0
Facade Type	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA
Glazing	double glazing, clear, with air 8-16-8mm	NA				5	6	5	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20
Shading	not available	2	-10	0		5		10	-1
SCORE		27	-1	2	0	20	26	15	23

Figure B.27 : Tool's ideal for different orientations for Istanbul-northeast and northwest.

ISTANBUL - SOUTHEAST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	SouthEast	10	0	0	0	5	0	5	0
Transparency Ratio	25%	5	6			5		0	0
Facade Type	Single-Skin Infill Window	10	0	NA	NA	0	NA		-6
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA
Glazing	double glazing, clear, with air 8-16-8mm	NA				5	3	10	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-2	10	5		5		5	0
SCORE		23	19	7	0	35	23	25	24
ISTANBUL - SOUTHWEST									
TOOL'S IDEAL	SELECTION	Structural Performance	Fire Performance	Water related Performance	Air Perm. related Performance	Thermal Performance	Moisture related Performance	Daylighting Performance	Acoustic Performance
Orientation	SouthWest	-10	3	10	10	5	10	5	0
Transparency Ratio	25%	10	6			5		0	0
Facade Type	Single-Skin Curtain Wall	10	0	NA	NA	0	NA		-6
Window Type	Operable Full Height Recessed		3	2		5	10	5	NA
Glazing	double glazing, clear, with argon 4-12-8mm	NA				5	3	10	10
Wall Configuration	Semi-permeable Cladding (Brick, Timber), with ventilated Air Cavity, Thermal Insulation at the middle side (Rockwool), Interior Cladding (Timber, Gypsum)		0	NA		10	10		20
Shading	Vertical Louver <30cm, every 20-30cms from space edges to vision area + Overhang (same size with louver)	-2	10	5		5		5	0
SCORE		8	22	17	10	35	33	25	24

Figure B.28 : Tool's ideal for different orientations for Istanbul-southeast and southwest.

APPENDIX B.2

Interview Questions and Answers

1st interview w/ MD

1. What is your occupation?

MD: Architect/ Academician (Assoc. Prof. Dr.)

2. What is your experience in your occupation? Both in years and the content.

MD: 20-year experience in different sectors, owner of an architectural firm since 2011, and has experience on around 50 educational buildings in which most of them are more than 5000 m². Besides all these, teaching design at a university for 10 years.

3. What is your role in the facade design process?

MD: Active role in decision-making regarding facades, from brainstorming and sketches to material selection and details.

4. Which project(s) you tried the Tool for?

MD: Çanakkale Bahçeşehir College and Çamlıca, Istanbul Bahçeşehir College

5. Did you have any difficulties for defining the input data specific to your project(s)?

MD: No, I did not.

6. How did you access/ obtain the information you are asked to define the input data?

MD: I obtained the relevant information via the internet.

7. Do you think you have any more options for the design decisions within the Tool?
If any, can you exemplify?

MD: Yes, I think it would be better if the Tool includes the reflective glass option.

8. While you were making decisions in view of the Tool's rating matrices and holistic evaluation, did you have any difficulties?

MD: No, I did not.

9. Did the Tool contribute to the design process about comparing the possible options?
Such as to be faster, to think holistically, etc.

MD: Definitely, yes. It is always an advantage to be aware of the possible consequences in advance.

10. Do you think the Tool has aspects restricting/ limiting the flexibility in design?

MD: I do not think so. Prior to design or in the early stages of design, to be informed about different aspects of facade design at once, and to evaluate alternative scenarios from scratch will save time, and money accordingly. I think this will contribute to the design process.

11. Do you prefer a more detailed scale for rating like 1, 2, 3, 4, 5 or ++, +, 0, -, -- ?
Why?

MD: I prefer this simpler scale since I think it gives a more correct impression to the Tool user. Tool's responsibility should be to reflect the performance tendency of design, rather than to give a numerical value.

12. What sort of a path, did you follow for the options and conditions that you could not find within the Tool?

MD: It did not happen.

13. Is the last graphic supporting the design process?

MD: Yes.

14. Is that graphic clear/ expressive enough?

MD: Yes.

15. Is the Tool user-friendly?

MD: Yes.

16. What are your recommendations? If you have any comment about the Tool, please share.

MD: The Tool should be supported by the visual representation of the design options.

17. Do you think the Tool reminds you of the issues that you sometimes can overlook/ ignore/ omit during the design process? In other words, does it help you think differently?

MD: Generally, in the design process, certain aspects are focused on, and some are overlooked. So, the design is not evaluated as a whole. We, as designers, assume that most of the technical aspects can be overcome through material selection and detailing, in other words, through the decisions made in later stages of design.

18. Do you think the Tool leads you to different design decisions than your cliché solutions?

MD: Yes, definitely.

19. Do you prefer to use the Tool in your projects?

MD: Yes.

20. How do you rate your level of satisfaction about the Tool from 0 to 5 ? (0 represents the lowest satisfaction level).

MD: 4

21. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you, or are they the issues that you know by intuition?

MD: Outcomes are valuable and original since they let us see the effects of our decisions on facade technical performance. None of them is new to me. As independent criteria, I can predict the consequences of design decisions with years of experience. But holistically, it is hard to establish these conditional relationships by intuition. The Tool provides us the big picture.

2nd Interview w/ HY

1. What is your occupation?

HY: Chief Executive Manager of Bahçeşehir-Uğur Educational Institutions

2. What is your experience in your occupation? Both in years and the content.

HY: Member of the administrative board of educational institutions since 2007.

3. What is your role in the facade design process?

HY: Client, Owner, User (leaseholder)

We mostly give franchise, and the franchise holders undertake the construction of the building and generally subcontracts the facade construction. I am not dealing with details. On behalf of me, architects, engineers who I work with are collaborating with the contractors. My concern is about the final product, image. I leave all the responsibility regarding details to my technical teams.

4. Which project(s) you tried the Tool for?

HY: İzmir Bornova Bahçeşehir College and Çamlıca, Istanbul Bahçeşehir College

5. What does this final performance evaluation graphic mean to you? Orange lines represent facade design of your project while blue lines belong to the ideal design decisions proposed by the Tool.

HY: I can see the performance of our project is close to the ideal but at some points less than the ideal. I want to learn why.

6. If you were able to see this graphic before, would you have any requests from the architect of your project?

HY: Yes, of course. I would ask for the reasons for this image.

7. Do you think this Tool can help you get involved in the facade design process more than the current situation? Do you prefer?

HY: It looks simple that I can easily understand. Assuming that the Tool's evaluation is reliable, yes. I think I can have a say in this field, comment on the design and the architect's decisions.

8. What are the barriers for you to get involved in the process more than the current situation?

HY: Technical issues. I am not so good at the technical and artistic aspects. I am dealing with economical issues.

9. What is the ideal facade design for you?

HY: It depends on the project, its strategic importance within our investments. If it is a prestigious project, then I expect an outstanding facade (glass facade, elegant claddings, high-quality windows, etc.) On the other hand, if it is not a project that we do not like to go to great expenses, then I would not prefer glass facades, it can cause heating and cooling energy costs plus maintenance costs in operation which we like to avoid.

10. In which circumstances do you think you can be convinced to change your decisions or to ask for changes in decisions? For instance; reduction in initial costs, reduction in operation costs, improving comfort conditions, increase in productivity, etc.

HY: All of them I can be convinced. But, since we are mostly the leaseholders of our projects, then I need to compare the reduction of operation costs with the increase in our rental fees that may come from changes (reflected on the fees) in design.

11. Do you think to see the consequences of design decisions at the early stages of design can change your expectations from the project?

HY: Yes, they can change my mind. We have to make fast decisions and make agreements accordingly. So, if it is at the very beginning of the project and if the consequences are to a considerable extent, in other words, if it is worth to waste time, then why not? I can change my expectations.

12. What if I say, by just changing the position of the window in relation to the wall (needs almost no additional costs), you can achieve higher comfort conditions, which in return will increase the success of the students, and your institution accordingly, what would you say? It does not directly make a gain in operational costs, but it can indirectly contribute to your institution's success.

HY: I would say my team: immediately make it done!.

13. Do you think the Tool can contribute to your communication with the architect?

HY: I think so. I can have consciousness of technical aspects.

14. Do you prefer this Tool to be used in your projects? Did you find it beneficial?

HY: I found it beneficial. I will talk with the architects about the usage of the Tool.

3rd Interview w/ SK

1. What is your occupation?

SK: Civil Engineer (MSc.)

2. What is your experience in your occupation? Both in years and the content.

SK: I have been working as a business development manager at NEST, which is a company with the scope of design, project management, fabrication, and erection of steel structures, since 2010.

3. What is your role in the facade design process?

SK: Our role is to provide stability against outdoor impacts (wind, earthquake). Since the facade constitutes the great part of the building envelope, the outdoor impacts have a significant role in the design process, so we do.

4. Which project(s) you tried the Tool for?

SK: İzmir Bornova Bahçeşehir College, Muğla Bahçeşehir College

5. What does this final performance evaluation graphic mean to you? Orange lines represent facade design of your project while blue lines belong to the ideal design decisions proposed by the Tool.

SK: It is good to see that structural performance criteria which are in our responsibility are taken into consideration in the design process together with the other aspects. It shows that at least up to the time that I get involved, the structural aspects are taken into account. Because in later stages, which I mostly participate in the process, it can be late to make changes in design decisions such as orientation which is one of the major decisions in terms of facade structure.

6. If you were able to see this graphic before, would you have any requests from the architect or the other stakeholders?

SK: I think there is no need to make a request. The Tool gives the opportunity to consider the structural performance issues at the early stages without me involving. It also provides me not to make assessments retrospectively.

7. Do you think this Tool can help you get involved in the facade design process more than the current situation? Do you prefer?

SK: The Tool does not change our roles within the process. We have the same responsibilities; in any case, we have to make the same calculations. The Tool just gives a rough approach and makes the architect think in the same way with the structural engineer at the early design stages. If the Tool is confirmed/ validated as it is used by engineers, coefficients can be readjusted, and the assessment of the Tool can become more reliable. The Tool does not change the roles but does decrease workloads of all the stakeholders.

The ideal design can be discovered in limitless time. I think this Tool seems like the easiest way of eliminating design options in a limited time. Assuming that it works well as intended, it is a very good way of decision-making. The Tool provides sound judgments and a good reason-result relationship.

8. What are the barriers for you to get involved in the process more than the current situation?

SK: At the very early stages, to have the structural performance criteria getting involved is much more important than me as structural engineer participated in the process. To have the criteria taken into account from the very beginning is like to have a representative of the structural engineer at the table. On the other hand, the barrier can be the lack of time, I guess.

9. What is the ideal facade design for you?

SK: A safe and durable one which sustains its insulating (heat, light, sound) functions for the intended service life. Also, preferably an inexpensive one.

10. Do you think you can convince the architect with the help of the Tool's evaluation at certain points in design?

SK: I think, it is not about convincing others. The Tool presents a strong relationship among different disciplines. It makes decision-making easy for all the parties.

11. Do you think you can be convinced with the performance evaluation proposed by the Tool, after seeing the rest of the performances?

SK: No, it is not just me, but the Tool's evaluation has many meanings for all the decision-makers.

12. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you, or are they the issues that you know by intuition?

SK: I just consider the benefits in terms of structural performance, but to see the effects of structurally advantageous decisions on the other aspects is new and beneficial for me.

13. Do you think the Tool can contribute to your communication with the architects?

SK: Of course.

14. Do you prefer this Tool to be used in your projects? Did you find it beneficial?

SK: Yes, I prefer.

4th Interview w/ MK

1. What is your occupation?

MK: Civil Engineer

2. What is your experience in your occupation? Both in years and the content.

Structural design of buildings since 1981. Owner of the firm Kültür Mühendislik Müşavirlik Müteahhitlik.

3. What is your role in the facade design process?

MK: My role is to consider the weight of the facade, wind loads, and the connection points of the facade structure with the primary structural system.

4. Which project(s) you tried the Tool for?

MK: Üsküdar, Istanbul Bahçeşehir College, Yalova Bahçeşehir College, Dragos, Istanbul Bahçeşehir College

5. What does this final performance evaluation graphic mean to you? Orange lines represent facade design of your project while blue lines belong to the ideal design decisions proposed by the Tool.

MK: As I understand, it can be possible to achieve the blue lines. However, some architectural concerns or project priorities/ constraints, such as effective usage of sites, make the architect give the decision in that way and make us continue from that decision.

6. If you were able to see this graphic before, would you have any requests from the architect or the other stakeholders?

MK: We have a place in the decision-making process, but our decisions do not affect the Tool's evaluation that much, compared to the others. But it is of main decision-makers' duties to find a solution satisfying the criteria of all these performance aspects. It is like the visual indicator of how the rule of thumbs is achieved by the architects.

7. Do you think this Tool can help you get involved in the facade design process more than the current situation? Do you prefer?

MK: As a structural engineer, I can say it is not in the first place for us. But it is much more important for other disciplines, such as acoustic or lighting consultants to get involved earlier in the process, so revisions/ repetitions in design can be prevented.

8. What are the barriers for you to get involved in the process more than the current situation?

MK: To be in a separate office than the architectural office, and lack of time. Sometimes, architects prefer to ignore the technical aspects in earlier stages and do not like to get you involved in.

9. What is the ideal facade design for you?

MK: Visually pleasing, in harmony with the region's silhouette, providing daylight and noise insulation. It should not be costly and overdesigned which have functionless details and parts.

10. Do you think you can convince the architect with the help of the Tool's evaluation at certain points in design?

MK: Yes, I think for deciding on the orientation, or the transparent parts.

11. Do you think you can be convinced with the performance evaluation proposed by the Tool, after seeing the rest of the performances?

MK: Yes, I can be convinced.

12. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you or are they the issues that you know by intuition?

MK: I can not see the whole by intuition.

13. Do you think the Tool can contribute to your communication with the architects?

MK: It can be considered as a roadmap. It provides a common language for the communication of all stakeholders.

14. Do you prefer this Tool to be used in your projects? Did you find it beneficial?

MK: Yes. I prefer to have architects considering structural performance from the start.

5th Interview w/ MB

1. What is your occupation?

MB: Architect

2. What is your experience in your occupation? Both in years and the content.

MB: Owner of Suem Mimarlık since 2015.

3. What is your role in the facade design process?

MB: After the completion of the conceptual design, we make contact with the company which the facade works are subcontracted to. They make decisions on the details such as the thickness of components, or glazing type, etc. Then we integrate their decisions into our design in later stages.

4. Which project(s) you tried the Tool for?

MB: Çamlıca, Istanbul Bahçeşehir College, Çanakkale Bahçeşehir College

5. Is the final performance evaluation graphic as the outcome of the Tool clear/ expressive enough?

MB: Yes, I think so. As I understand, this Tool works better for architects and investors.

6. Do you think the Tool reminds you of the issues that you sometimes can overlook/ ignore/ omit during the design process? In other words, does it help you think differently?

MB: I think so. We, as architects sometimes, can overlook some technical aspects at the early project stages while focusing on the aesthetic features of the facades.

7. What is the ideal facade design for you?

MB: My primary concern mostly is on the aesthetic features of the facade. Then, daylighting comes. When it has a noisy surrounding, then acoustic can be my concern in facade design, as well. I am not telling about the weather-resistant solutions; in any case we need to fulfill these issues. Fire performance is also important, and we are aware of the strict fire regulations, fire class of the materials.

8. Do you prefer to use the Tool in your projects?

MB: Yes, I prefer. Especially in challenging projects such as glass facades or curtain walls having aluminum claddings which can be costly. It will be better to evaluate their performance in advance.

9. Do you think the Tool can contribute to the facade design process, collaboration with the other stakeholders?

MB: I think it can help me to convince the investor in certain issues, system or material selection, etc. or to have the control mechanism while collaborating with the facade companies. I can check the graphic to see whether I am in the right direction.

10. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you or are they the issues that you know by intuition?

MB: It is good and new to see the different aspects altogether.

6th Interview w/ DÇ, MP, EE

1. What is your occupation?

DÇ: Civil Engineer

MP: Mechanical Engineer

EE: Electrical Engineer

2. What is your experience in your occupation?

DÇ, MP: Part of the projects in Suem Mimarlık.

3. What is your role in the facade design process?

DÇ: Civil Engineer

MP: Mechanical Engineer

EE: Electrical Engineer (not directly related-so did not continue to answer the questions)

4. Which project(s) you tried the Tool for?

DÇ, MP: Muğla Bahçeşehir College, Üsküdar, Istanbul Bahçeşehir College, Dragos, Istanbul, Bahçeşehir College, Yalova Bahçeşehir College

5. What does this final performance evaluation graphic mean to you? Orange lines represent facade design of your project while blue lines belong to the ideal design decisions proposed by the Tool.

DÇ, MP: Different performance aspects, it is clear enough.

6. If you were able to see this graphic before, would you have any requests from the architect or the other stakeholders? Do you prefer?

DÇ: I do not know right now what I can ask for, considering the structural performance.

MP: I can request some changes in decisions more easily.

7. Do you think this Tool can help you get involved in the facade design process more than the current situation? Do you prefer?

DÇ, MP: I think we prefer. It is always good to know the reasoning process behind the decisions.

8. Do you think you can convince the architect with the help of the Tool's evaluation at certain points in design?

MP: Yes, I think with the help of the Tool, we can better collaborate with the architect, such as insulation thickness or material selection.

9. Do you think you can be convinced with the performance evaluation proposed by the Tool, after seeing the rest of the performances?

MP: Yes, I think we can understand the architect's requests better.

DÇ: We can better understand the architect's decisions.

10. Based on your experiences, what do you think about the outcomes of the Tool? Are they new for you, or are they the issues that you know by intuition?

DÇ, MP: To see the issues as a whole is new for us.

11. Do you think the Tool can contribute to your communication with the architects?
DÇ, MP: Yes, when the architects see the weak points in design from the beginning, they communicate with the engineers or other stakeholders to reconsider the design.

12. Do you prefer this Tool to be used in your projects? Did you find it beneficial?
DÇ, MP: Yes. Firstly, it indicates how the architect values our works in design. This may motivate us. Secondly, the architect gives the message ‘be careful at your works, I am aware of the technical aspects’. This may provide more transparent and reliable collaboration among stakeholders.





CURRICULUM VITAE



Name Surname : Sinem Kltr

Place and Date of Birth : Balıkesir, 22 Eyll 1985

E-Mail : sinemkultur@gmail.com

EDUCATION :

- **B.Sc.** : 2007, Bahcesehir University, Faculty of Architecture, Department of Architecture, *full scholarship, 1st rank.*
- **M.Sc.** : 2010, Istanbul Technical University, Graduate School of Science Engineering and Technology, Architecture Department, *thesis funded by Scientific Research Projects Unit of ITU.*

PROFESSIONAL EXPERIENCE AND REWARDS:

- Since 2007, Research Assistant at Bahcesehir University, Faculty of Architecture and Design, Department of Architecture (*Teaching Assistant, iaSU Conferences Organizing Committee Member, Editor of iaSU Conference Publications, etc.*).
- Since 2011, Architect at Eđitim Mimarlık Architectural Office.
- 2014 Spring Semester, Guest Researcher at Delft University of Technology.
- Since 2009, Coordinator of ICSA (InterCultural Study of Architecture) Student and Faculty Exchange Program of Mukogawa Women's University, Japan and Bahesehir University, Turkey.
- 2008, Mention Prize at Architectural Competition, *Kayseri İ Kalesi'nin Korunarak Kltr ve Sanat Ortamına Dnřtrlmesi iin Ulusal Mimari Yarışması.*

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