J. Appl. Environ. Biol. Sci., 6(7)61-68, 2016
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ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

The Study of Effective Components in Façade Engineering Towards Developing a Conceptual Framework

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Received: September 24, 2015
Accepted: April 3, 2016

ABSTRACT

Building as a live organism, which can range from simplicity to complexity in itself, creates a controllable micro-ecosystem in an ecosystem that is beyond human being control and provides the required conditions for residence. This metabolism consists of different parts; each plays a role to satisfy housing needs. One of them is the façade. Although façade design was born with creation of the first architectural property by men; "Façade Engineering" is considered to be a new discipline in science. It has found a special position among other building construction disciplines following the growing concern about buildings sustainability especially considering the fact of climate change and the necessity for integrated building design. Façade engineering can be reviewed from different aspects. This paper used qualitative approach and content analysis strategy to categorize and recognize the effective components of façade engineering in eight main groups of: Structure, Sociability, Material, Security, Physics, Management, Integrity, and Aesthetics. So, by elaborating these effective components, it paves the way for developing a conceptual framework.

KEYWORDS: Façade engineering, Effective Components, Conceptual Framework, Building Envelope, Design.

1. INTRODUCTION

"The façade separates the useable interior space from the outside world"[1]. This general definition for façade refers to its basic function; however, as Klein notes: "the functions of building envelope are extending in current façade concepts [2].The new concepts regarding façade have led to the formation of a new interdisciplinary scientific discipline called "façade engineering", consisting of various fields and wide horizons to encompass. Perino and Serra [3] suggested that "the building envelope more than a construction component, will have to be seen as a place, a spatial location". Lowings believed that "the future is unpredictable. We think that the envelope will evolve in a number of different ways" [4]. It seems that the variety of these ways will find more complex aspects with new developments in the field of building technology. These technologies have assisted the modern buildings not to be a 'static and neutral' entity toward environmental changes, but a 'dynamic and active' kind, able to react to environmental changes and provided a broader aspects of environmental comfort. However, the science of façade engineering does not suffice and seeks to plan, design and implement buildings which are like a live organism and able to breath, be fed, molt based on seasons, and react toward activities and behaviors occurring in environment. Therefore, the building can be more in tune with 'the demands and needs of users' and can shift from its static state to a responsive and changeable one in order to meet the user's various demands. The importance of addressing façade engineering concept can be considered from different perspectives such as: the importance of energy saving due to the shortage of fossil fuel resources, the importance of considering façade design in the process of architectural education, training and design, the importance of reducing visual pollution in urban landscape, the importance of sustainability in particular its environmental aspect, the economic importance to reduce the costs of construction, operation and maintenance of the building, and also the importance of facilitating the implementation process and reducing the time of implementation. Despite all these necessities, the theoretical and practical studies show the lack of an integrated approach toward façade that can simultaneously consider its different aspects.

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Therefore, the studies and experiences in façade engineering, despite their contribution in advancing this field, are not capable of achieving all the goals of façade engineering and only realize some of its diverse aspects. Having understood the necessity for an integrated approach toward façade engineering, this paper raises this question that which components should be considered in façade engineering. So by answering this question the way for achieving an integrated approach toward façade engineering would be paved. However, in order to realize such important issue, there is still a long way ahead and lots of questions must be answered.

2. MATERIALS AND METHODS

Based on research question, the qualitative research methodology is chosen and with applying logical reasoning strategy as well as 'content analysis' and 'logical inference'; this paper aims to analyze the content by recognizing and categorizing international documents and theories. So, by determining the components of façade engineering; the context for developing a conceptual framework for effective components in façade engineering is provided. Moreover, reading and evidential observation based on books, papers and authentic documents are used as research tools.

2.1. Façade Engineering

An architectural design not only includes the concept, the composition of space and the organization of the building's functions but also should realize its structure. The structure is composed of the whole and details. So details are parts of the architectural concept that are conceived as elements of a certain scale and the architect need to exercise creative control of these elements [1]. Some of these details are within the building façade. Although most of the viewpoints on façade design address aesthetic issues; in recent approaches of architectural technology it is believed that "no other building system combines as significant as impact on both building's performance and aesthetic" [5].These approaches indicate façade as a part of building that not only covers the building, but also can play various functions such as active and passive control of the living environment. Addressing the issue of façade design that is consistent with the new technologies in buildings is very important today. For these reasons, Klein (2008) highlighted that "The number of projects being realized with technologies that are not standardized according to the façade industry is relatively low"[2].

Buildings are like organisms, sucking in resources and emitting wastes [6]. The direction of this organism forward moving, despite all ups and downs, has been toward being more self-sufficient and sustainable. The significance of this self-sufficiency and sustainability is more perceived particularly in large-scale buildings due to their greater demands for energy to provide the users comforts. Restricted comfort zone of the 21st century people due to being used to mechanical lives, has led to increasing demand for energy on one side as well as energy crisis and environmental change on the other side. This imbalance in energy demand and the Earth's capacity has raised the alarms. To balance the scale, considering the façade design which simultaneously separates and links the inside and outside, can be helpful. To achieve this goal, it is required to have a holistic view toward façade. The 'Façade Engineering', as a new branch of architectural related studies, has emerged to achieve these goals. In this field of study, building f façade is not considered as a separate element; but it is seen as a multi-dimensional element [1]. Kragh [7]introduced façade engineering as "a relatively new discipline, which is gaining importance in a time where recession and climate change are factors leading to increasing focus on the need for an integrated approach to the design and procurement of buildings. Technological developments and the way buildings are procured means that success often depends on specialist input across abroad spectrum, which some twenty years ago led to the creation of the first façade engineering practices" [7].Façade Engineering offers a set of design solutions to create building envelops that can contribute to energy saving as well as optimizing material, construction and maintenance time, and costs during construction, usage and maintenance.

The move to the use of engineered walls has created a need for specialists, façade engineers, designers and analysts, who can understand the new technical complexities of envelope design and performance. Although façade design used to be a part of architect responsibility; façade engineering with its multi-dimensional view toward façade, as a smart envelope of an organism, has necessitated the use of different specifications in order to achieve its ideal goal. However, among all inter-disciplinary specialists required for engineered façade design, the architect plays her/his role like an administrator [8]. Some factors leading to development of complex building envelopes and consequently the need for specialists in the design and construction process are: "today's modern and demanding architecture, complex geometry of façades, new material and techniques, increased statutory requirements and standards regarding energy efficiency (CO_2 emission), different demands and requirements in various regions and counties, various climatic conditions (maritime, snow, ice, high winds, earthquake, high humidity and temperatures)" [9]. It is important to note that, besides detailed knowledge and high experience of the façade engineers group, some other requirements need to be fulfilled, including special software (3D, simulations) to meet the architect's requirements, continues development in façade technology, design and systems, research on new material and manufacturing/installation process, and knowledge of local statutory requirements [9]. From scrutiny of façade engineering concept, it is concluded that façade engineering as an interdisciplinary knowledge can be reviewed from different perspectives and considering its new development, the necessity for research on this topic becomes more obvious. This paper, by focusing on effective components in façade engineering, recognizes these components to achieve the research goal.

2.2. Recognition of Effective Components in Façade Engineering based on Experts' Opinions

In the past, what is expected from a simple wall[1] is simply to provide security against nature; however, today "more and more it is expected to act as a skin[2] the same way as human skin acts: as a vital part of our body, responsible for keeping the temperature of the body itself within comfortable limits, but also harvesting water, electricity, clean air and treating or emitting waste sustainability. Depending on the location, nature of the building, architect and client, additional requirements such as solar control or acoustic damping can become part of a façade[3]" [6].

In relation to what components should be considered in façade design, which is the main topic of the third section of this paper, it should be noted that there is a growing number of components for a well-designed façade, driven by issues like comfort and sustainability. Keiller et al. [8]categorized the performance required of the façade as follows: structure, integrity, physics and materials (Table 1). Knaack et al. [1]also introduced the different functions that building façade should serve. He indicated that architectural appearance of the building, provides views to the inside and outside. Building façade allows sunlight to penetrate into the building while usually providing protection from the sun at the same time. It also creates an insulating layer against cold, heat and noise that can be used during energy generation process (Table 1). Therefore, the role of façade in the energy generation process and utility systems can be mentioned. Auer [10] is among those who considered merging the façade together with mechanical tools highly beneficial. Auer considered them as interface between inside and outside that in this case can have one integrated control system for both systems (Table 1). Perino and Serra [3]also believed that the active technologies, mentioned in Table 1, are better to be functionally/structurally integrated rather than being incorporated as an 'addition' to the façade. Timmeren, besides all components (Table 1), quoted from Kennedy[4](1997) on the importance of aesthetics component in façade engineering as follows: "this aspect as part of spatial quality appears to be hard to define objectively. Nevertheless, it may be considered one of the criteria for lasting success of sustainability of a designed building and as far as visible for the systems" [6]. The US Energy Independence and Security Act of 2007 [11] defined high-performance building[5] and façade. This act introduces seven conditions for highly efficient façades that can be seen in Table 1 [12]. Wildlife can be mentioned as another effective component in façade design. "Mother Nature tries to reclaim its turf by various means. Pioneering plants, acrobatic rodents, ubiquitous insects, and nuisance birds feel welcome on modern façades lacking traditional means of protection. Their presence is undesirable because they present health hazards, cause a build-up of unappetizing deposits, make people feel uncomfortable, and physically deteriorate the building materials. This threat can be assessed by proper design analysis, and eliminated by minor modifications to the architectural design" [13].

Besides all the components that have been mentioned based on experts' opinion, there is additional component that can be said to be the most important one. This component refers to the sociability that a building envelope should contain. Tillmann [6]believed that "the building envelope is not a mere machine, an instrument to solely solve the issues of energy and comfort. It also serves a societal purpose. Architectural quality is a cultural value, and a climate oriented building skin must comply with the highest standards" [6]. Being accepted by society can guarantee an engineered façade to remain popular and effective in modern life. Respectively, besides mentioning some other components, Anshuma [14] discussed the importance of sociability component in façade engineering, due to the fact that the social environment around the building is less considered from the beginning of the construction of new buildings. At the end of this section, the most important international theories and documents in relation to effective components in façade engineering are presented in Table 1.

Table1- Introduction of effective components in façade engineering based on experts' opinions (Authors)

No.	Name of Expert	Year	Main Proposed Components for Engineered Façade
1	**Keiller et al.**	2003	Wind Loading, Dead Loads, Movement, Construction, Water Tightness, Air tightness, Safety, Heat transfer, Acoustics, Solar gain, Daylight, Compatibility, Durability, Forming, Connection.
2	**Anshuman**	2005	Sociability, Client, Facility Management, Energy Management, Building Automation Management & life Safety Management.
3	**Knaack et al.**	2007	Natural Light, Waterproofing, Protection against UV radiation, Energy generation, Push and Pull force from wind loads, Ventilation, Vapour diffusion, Noise, View in/out, Interior loads, Heat/cold isolation, Self-weight, Appearance in urban context.
4	**The US Energy Independence and Security Act of 2007 (EISA sec. 401-12, 13)**	2007	Energy Conservation, Environment, Safety, Security, Durability, Accessibility, Cost-benefit, Productivity, Sustainability, Functionality, Operational Considerations.
5	**Auer**	2008	Air tightness, Daylight transmission and distribution, Operable window for Natural Ventilation, Energy generation. Beneficailly merging the façade together with mechanical tools for the following reason: Glare and solar control, Natural Ventilation, Comfortable heating and cooling.
6	**Tillman**	2008	Providing Useable interior space, Rain and water Proofing, Thermal Separation, Sun protection, Security, Relationship to the overall structure, Interface with neighboring buildings, Specialized components integration, Sealing components, Energy savings, Active contribution to heating, cooling, ventilation, and Adaptability to changing user requirements, Upgradeability.
		2009	Adaptation, Conditioning exterior air, Minimizing the negative impact on environment, Maximum operating comfort for the user, Sociability.
7	**Timmeren**	2009	Act as a shelter against rain/wind/cold, Harvesting water, Electricity, Clean air and treating or emitting waste sustainably, Solar control, Acoustic damping, Thermal Insulation, Avoiding PM10 emissions to enter the building, Bounding and/or emission of harmful CO2 and ozone produced in the building, Natural Light Admittance, Structural soundness, Structural soundless, Social Safety, Physical Safety, Security of utilities & supply and consistency, Minimum or an optimum of added raw materials and low as possible use of chemicals for materials, A minimum of pollution of soil/Air/Ground area/Surface water, Using closing cycles as much as possible, A minimum of energy use or a maximum of renewable energy, Future value (flexibility, uniformity), Thermal and acoustical comfort, Ventilation, Lighting, Minimizing or Optimizing use of material, Adaptability and extendib ility, Screening off against incorrect use/sabotage/vandalism, Compactness and optimizing use of surface area, Accessibility of parties involved, Aesthetic quality, and Independence of specialized institutions (self-control by users).
8	**Patterson and Matusova**	2013	Energy performance, Environmental impacts, Safety and security, Durability, Economic Efficiency, Human comfort/health/productivity, Operational considerations, Daylight Optimization, View optimization, Minimize glare, Control solar heat gain, Minimizing heat loss, Natural Ventilation, Performance optimization, and Minimizing environmental impact.
9	**Perino and Serra**	2015	generation/conversion systems(as for example the technologies for the on-site exploitation of the solar radiation), ventilation (being used as air heat exchangers, air pre-heaters, ventilation outlets/inlets, ducts etc.), HVAC and artificial lighting systems.

Based on Table 1, each expert in façade engineering has considered some effective components related to this issue; introducing a comprehensive viewpoint including all these effective components is the main goal of this paper which is investigated in the result section.

3. RESULTS: Developing the Conceptual Framework

In Section 3, the effective components in façade engineering form various experts' viewpoints were discussed. So as it is indicated, there are many factors involved in this matter that have been referred by many experts. Although it is obvious that some of the components are considered more important in design process; there is the possibility that some of the components are neglected in practical field due to their plurality and dispersion. So, in order to organize the suggested components, the following eight components are recognized as main ones: 'Structure', 'Sociability', 'Material', 'Security', 'Physics, Management', 'Integrity', and 'Aesthetics'. It seems that the other components can be categorized as a subset of the principal components and thereby reducing the number of them. As the main concepts of some of the components and their subsets were previously referred by different titles, it becomes necessary to use the best title that can include all the aspect of each component from the various viewpoints of experts. Thus, in this paper, the eight principal components and their subsets are put into a coherent category as follows:

Component 1- Structure: Wind Load, Earthquake Load, Extendibility, Constructability, Self-weight, Movement, and Joint;

Component 2-Sociability: Media, Urban Context, Outdoor interaction, Automation System, Ease of Operation for User, Accessibility, and Indoor Interaction;

Component 3- Material: Compatibility, Optimization of Surface Area, Durability, Forming, Compactness, and Connection;

Component 4- Security: Wildlife Protection, Noise Protection, Resist Impact and Blast, Social Safety, Installation Safety, Physical Safety, Fire Safety, and Acoustical Privacy;

Component 5- Physics: Bounding CO2/Ozone Emission, Natural Ventilation, UV Protection, Sunlight Protection, Sunlight Penetration, Sound Protection, Energy Efficiency, Energy Operation, Night Lighting, Ease of Implementation, Luminous Comfort, Acoustical Comfort, Thermal Comfort, and Minimize Light Pollution;
Component 6- Management: Client, Facility Management, Energy Management, Economy Recourse Management, Maintainability, Optimize Construction Time, Life Safety Management, and Building Automation Management;
Component 7- Integrity: Harvesting Water, Water Tightness, Air Tightness, and Vapour Diffuser; and
Component 8- Aesthetics: Exterior Aspects, Aesthetic Aspects in Urban Context, Optimize Contract with Neighbors Buildings, and Interior Aesthetic Aspects.

In order to approach the conceptual framework, it is required to examine the eight components and their subcomponents in detail. The first component to be reviewed is “Structure”. Considering the structure in designing building envelopes especially tall buildings, for which the wind and earthquake loads are significant factors, has great importance. The building envelope structure specifies how to transfer those loads to the main structure of the building or the independent structure of the envelope. The building envelope should be designed in a way that their deviation and deformation, caused by the forces of wind and earthquake, are not exceeded over their acceptable limit. These features should also be taken into account in designing building envelope joints and details; so they can show suitable reactions against displacements causing by those forces. Another feature that a building façade can have is the ability to extend that provides the possibility for adding extra parts in future or replace the defective parts. In addition to the mentioned items and regardless of the type of structure designed for the building envelope, the building envelope and its intended structure must be able to withstand their own weight. Moreover, the constructability of building façades should be considered in design process according to material, economic and time resources.

The second component is “Sociability” meaning the ability to communicate with users and pedestrians; this component is the product of a new approach towards social life in contemporary cities. With application of control systems, the building facades can be changed according to the users’ needs. In this case, convenient access and being user-friendly must be taken into consideration. In addition to considering the urban context of design, building façades can be equipped to be capable of playing audios and videos; so broader and more effective interaction with users inside or outside the building are provided. In all these cases, providing integrated automation system to establish communication between the building façade and other members of the building such as building mechanical systems, lighting system and also user interface with facade should be of interest to designers.

The third effective component in developing the conceptual framework of façade engineering is “Material”. Materials used in the construction of the building façade must have the capacity to be compatible and integrated with other elements of the façade, the environmental conditions and the users. Also these materials and their connections need to have the capacity of being flexible, in order to offer the possibility of being applied in various construction forms. Obviously, the choice of materials and the design of components and connections must be in such a way that the use of materials in proportion to the shape and the surface of building is optimized. Besides all these items, durability and sustainability during construction and operation are considered as effective factors in the choices of materials.

“Security” is the fourth effective component in building façade design; Security encompasses many different aspects. One of the most important one is the sufficient strength of building envelope against unexpected events such as explosions and being severely crashed by objects from outside or inside the building. In addition, the façade must be equipped against fire; for example by having ducts to lead the smoke outside the building to increase safety and consequently social security. Security in the building façades also includes resistance against insects and creatures like birds. Resistance against internal and external sound pollutions that provides psychological security and acoustical privacy for the users should also be considered in façade design.

The fifth effective component in developing the conceptual framework of façade engineering is “Physics”; including a wide range of topics. For instance, the entire system of façade must be energy-efficient. There are several ways to achieve an energy-efficient façade; such as considerations for using natural air flow through ventilation system and also considerations for providing optimized thermal and acoustic comfort. In addition, the building envelope should have the lowest emissions of greenhouse gases such as carbon dioxide and ozone during its construction and operation. Another case in the field of physics that must be taken into account is providing the possibility of protection against UV and daylight nuisance while allowing the required sunlight to enter the building. The systems for contorting the amount of light reaching into the building should be user-friendly. Moreover, the internal and external lightings are better to be designed in a way that create the least possible light pollution.

“Management” is a critical component in the design of the building façade that besides considering the employer’s viewpoints and demands, provides an integrated automation system to control and manage facilities, energy, safety and maintenance as well as financial resources during the design, construction and operation of the building envelope. Through an integrated management system the optimal time of construction can be achieved. “Integrity” is the seventh effective component in the development of conceptual of façade engineering. The building façade must have a rainwater collection system to gather rain to re-use in the building. Also, the building envelope should show a strong resistance against unpredicted weather condition. Considerations for disposal of vapor on the surface of façade should be given during design and construction processes. Last but not the least is the “Aesthetic” component. Considering the different aspects of aesthetic of the both outside and inside the building is particularly important. In this regard, how the envelop is related to its context should be given priority.

Based on the eight principal components and their subcomponents, the conceptual framework of façade engineering components is presented in this section. The proposed framework, despite its comprehensiveness, simply considers all the components in an effective correlation and as an integrated totality (Figure 1).

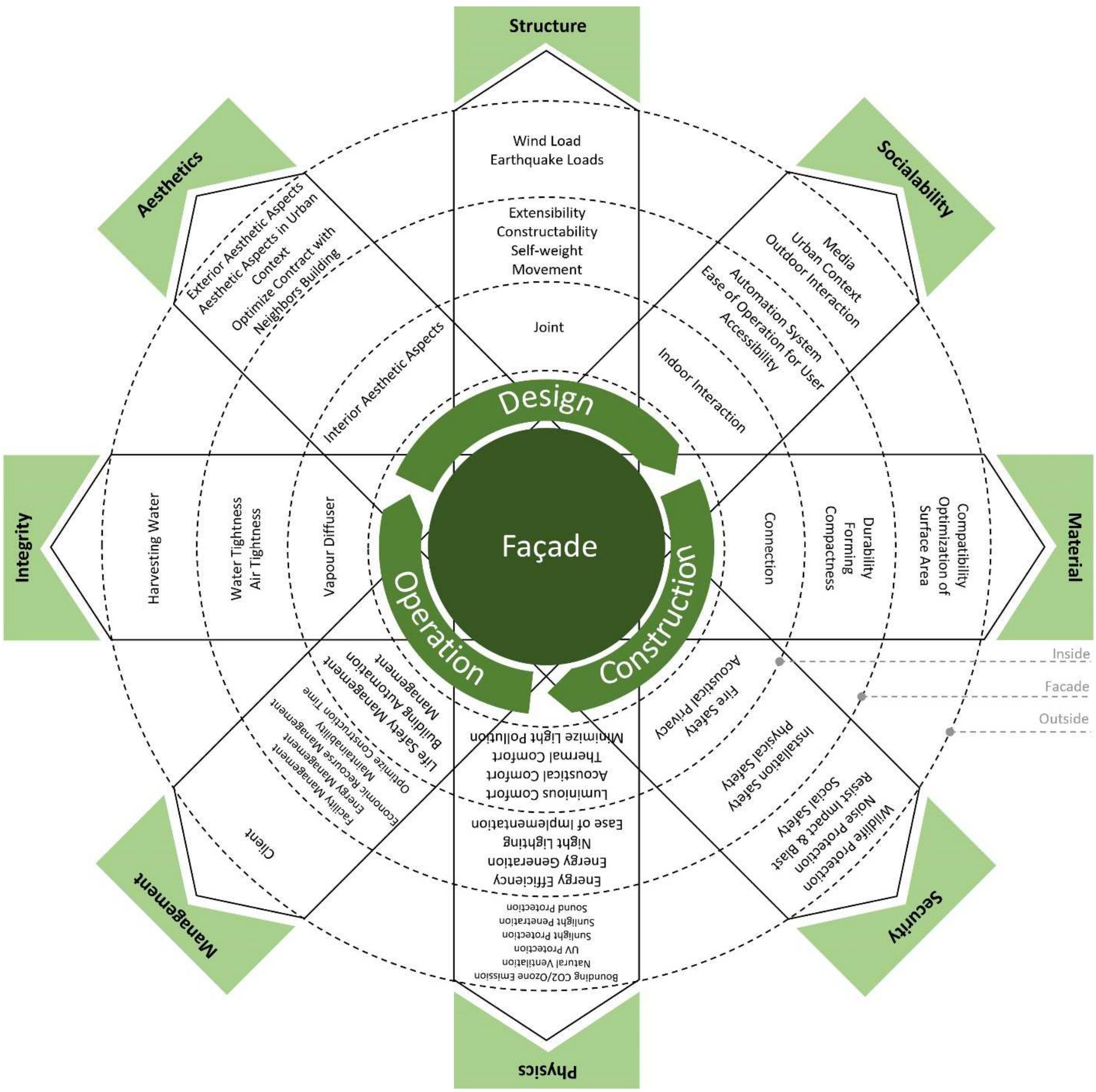

Figure 1- Façade engineering components conceptual Framework (Source: Authors)

The aim of this model is to present effective components in façade engineering in order to help design and management groups and building users in the processes of ‘design’, ‘construction’, and ‘operation’ to achieve the main goal of façade engineering of the project. The eight principal components and their explanatory subsets are introduced until the time this research conducted. Obviously, due to future advances in science and engineering; the number of them is likely to increase and therefor the components would be required to review in future.

4. CONCLUSION

In today's architecture, buildings have living and dynamic nature. One of the most outstanding features of contemporary buildings are their compatibility to diverse environmental and climatic changes. Façade, as one of the key elements of building, plays an undeniable role in this field. The science of façade engineering, as a new branch in construction industry, seeks to achieve sustainable development goals and to harmonize the building and the needs of users in different climates through integrated design. Given the urgency and importance of reviewing the related theories, having been raised by various experts, the effective components in façade engineering are presented in eight categories; the other components are recognized as subsets of the principal components. Conducted reviews have led to a comprehensive and holistic model with the aim of introducing effective factors in the field of façade engineering. Using this model can assist design and project management groups as well as users in the processes of design, implementation and operation. In future research, it is recommended to revisit the proposed model due to current progress in the new field of façade engineering and the possibility of new components addition. Future researches could take the advantage of using the proposed conceptual framework of this paper for analyzing the components of designed façades, by using quantitative research methodology such as Factor Analysis, in case studies of the diverse climatic contexts and different historical periods in order to evaluate and rank the components that mostly contribute to the efficiency of the façades of that place or time.

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