IEREK PRESS
Academic Research Community
CrossMark
http://www.press.ierek.com
ESSD
ISSN (Print: 2357-0849, online: 2357-0857)
International Journal on:
Environmental Science and Sustainable Development

DOI: 10.21625/essd.v4i1.486

Facades for Achieving Visual Comfort: High Performance Computing

Fatima Belok[1], Mostafa Rabea[2], Mohamed Hanafi[3], Ibtihal El Bastawissi[4]

[1] *PhD candidate and teaching assistant, Faculty of Architecture-Design & Built Environment, Beirut Arab University*

[2] *Assistant professor, Faculty of Architecture-Design & Built Environment, Beirut Arab University*

[3] *Professor, Faculty of Architecture-Design & Built Environment, Beirut Arab University*

[4] *Professor and Dean of Faculty of Architecture-Design &Built Environment, Beirut Arab University*

Abstract

Within the last few decades, many digital technologies have been integrated to the field of architecture. This in turn has developed a number of architectural trends based on these revolutionary changes. Kinetic skin is one of these trends that is directly related to visual performance and comfort, an important aspect. The feeling of comfort is related to the sense organs network; i.e. the eyes, ears, nose, tactile sensors, heat sensors and brain. Visual sensation is the most dominant one in human perception since the eye contains two thirds of the nerve fibers within human central nervous system.

The use of kinetic facades for achieving visual comfort in spaces has been recently the subject of many researches, where various aspects have been explored. However, this paper will attempt to review these researches while identifying gaps and potential for future research.

Keywords

Visual comfort; kinetic Facades; optimization; digital tools

1. Introduction

1.1. Visual Comfort and Daylight

The Illumination Engineering Society of North America (IES) noticed that activity and perception could be reinforced through the lighting. Most of human perceptions are influenced by light (natural or artificial), which is a source of enjoyment and aesthetic pleasure. It also affects mental health. Also, daylight factor should be considered for having more comfortable spaces (Jenkins & Newborough, 2007).

Daylight could affect mainly three categories, which are functional efficiency, energy efficiency and human health (El-Dbaa, 2016).

a) Functional efficiency: adequate lighting allows for better functional efficiency, not only in terms of direct use, such as reading and writing, but in exposing features of color, texture, and form that increases spatial and functional efficiency of space (El-Dbaa, 2016).

b) Energy efficiency: by reducing the amount of artificial light, and by improving the amount of daylight in a space, the energy consumption will automatically be reduced. This reduction is not only related to the electricity, but also will reduce the cooling and heating load (El-Dbaa, 2016).

c) Human productivity and health: the importance of daylight does not only on the energy efficiency, it is also related to its advantages on user's productivity and health. Studies show that people working at night have a considerable increased negative mood than others working in daylight, since psychological well-being, mood, body temperature and brain activity, are influenced by the light in a specific architectural environment (Tomassoni, Galetta & Treglia, 2015). The nervous system could be disturbed if their amount of daylight is unsatisfied, which will motivate the feeling of fatigue (El Sheikh, 2011). Working or studying for long time in a space illuminated only by artificial light will cause discomfort and stress, while daylight helps to give a healthy space. Thus, controlling the amount of daylight in spaces, will improve the user productivity and mood. (Tomassoni et al., 2015).

1.2. Kinetic Facades Definition and Importance

Building envelope improves human comfort, because it is the layer between the outside and the inside of a building (Kim, 2013). The shading devices or the building envelope could be static or dynamic. Those that are non-stationary are generally described by words such as convertible, kinematic retractable, kinetic, or simply adaptive. In architecture, adaptive and dynamic building envelops are the current trends (Fouad, 2012; Barozzi, Lienhard, Zanelli & Monticelli, 2016).

Kinetic is the movement, while architecture is the style of the building (Fouad, 2012). Thus, Kinetic architecture is the design of buildings that are produced by movement. Several technologies responding to changing needs have been developed, where kinetic Architecture is one of the most important technologies, which is considered as an evolution from static to dynamic form in architecture (Al horr et al., 2016).

Many researchers have discussed kinetic architecture from 1970 till now, such as Zuc and Clark in 1970, Michael A.Fox in 2003, Chuck Hberman, Sanchez-del-Valle in 2005, Robert Kronenburg in 2007, Kostas Terzidis in 2008, etc. (Barozzi et al., 2016). Sanchez-del-Valle explains that usages of adaptive kinetic structure are due to economy of means, and responsibility toward the natural environment and human need satisfaction. In addition, in 2005 Sanchez-del-Valle said, "Adaptive kinetic architecture creates an ecological system as its components have shifting interdependencies when responding to changing environment". In addition, Kostas Terzidis in 2008 has argued that adding motion to a building will be important, since it will affect the design, aesthetic and performance of the building. Consequently, kinetic architecture is not just about moving a building, but it is also making a link between nature and built environment, regarding the environmental variations.

Furthermore, kinetic architecture could be applied in different ways based on the purpose of the system (Rossi, Nagy, & Schlueter, 2012). For instance, it could be applied on building facades, on building structure, in the landscape and others. This paper focuses on kinetic shadings. Kinetic and adaptive shadings could serve as a good treatment more than the fixed ones, since adaptive systems can be modified in relation to external environmental changes such as solar radiation, to achieve the optimum daylight and shade during the day. This mechanical system could be added on external or internal facades (Fouad, 2012 & Barozzi et al., 2016). In addition, many interactive ideas and concepts have been recently invented and could adjust and interact with environmental factors such as daylight heat, wind, or even people (Al horr et al., 2016).

2. Aim

The aim of this paper is to explore possible roles for architects in developing kinetic facades for achieving visual comfort.

3. Objectives

The paper objectives are:

- Exploring the current state of art in kinetic facades and visual comfort.
- Exploring possible future applications and studies.

4. Methodology

This paper will start by a literature review on different recent researches and studies that focuses on how to reach visual comfort using kinetic facades, then an evaluation and a comparative analysis for the recent researches followed by a discussion. Finally, it will end by conclusions and recommendations.

5. Previous Work

Optimizing visual comfort and enhancing the daylight performance in different spaces, has been the aim and target of many researchers in several studies. Based on some readings in this field, it has been noted that architects and designers usually follow a certain process; i.e. starting with designing the kinetic skin and specifying its mechanism, then testing different alternatives using environmental simulation programs and software, and finally linking all of them to reach optimum solutions. Based on this process, and based on the responsive kinetic skin design framework (explained later), the examined researches in this field are classified in three categories, as shown in Fig.1, which are: form and mechanism, computational analysis and simulation, and design framework category.

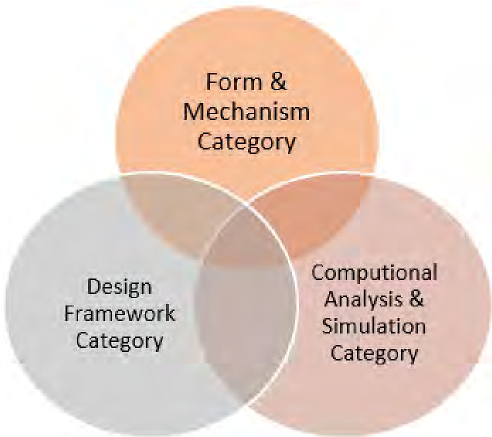

Figure 1. Categorization of different researches examining the daylight performance using kinetic systems (source: author)

5.1. Form and Mechanism Category

This category mainly focuses on researches examining the form and mechanism of kinetic systems for enhancing daylight performance in a space. It includes the scale, the composition, the aesthetic, and the motion of kinetic shadings. Several researchers discussed in their studies the performance of fixed and movable shadings in different architectural spaces. Some of them examined the effect of fixed screens on enhancing the daylight distribution with modification of one shading parameters, such as the shape of cells of the screens, rotation angles, and screen opening proportion (horizontal: vertical) from 1:1 to 18:1 (Sabry, Sherif, Gad Elhak, & Rakha, 2012). However, recently most of the researches are focusing on dynamic shadings in response to external environmental factors, such as the daylight, wind factor and others. As dynamic systems have several advantages in comparison to the static one, for instance increasing occupancy comfort, increasing energetic performance and giving chance for aesthetics opportunities. In addition, adaptive architecture allows changing the building behavior responding to real world events (Rossi et al., 2012), Nowadays, new technologies allow designing dynamic systems, which are related to internal and external conditions.

(Meyboom, Johnson & Wojtowicz, 2011) focused on the different shapes and organizations of kinetic facades, which affect human comfort inside the space as shown in Fig.2. Facades, which are the link between outside and inside of a building, should be responsive to adapt these environmental changes and satisfy the human comfort. This is where the amount of light (artificial or natural) and the shadings devices especially the kinetic one, could be controlled based on the illuminance standards, are all serving and targeting the occupants' and the users' comfort, as shown in Fig.3 (Rossi et al., 2012).

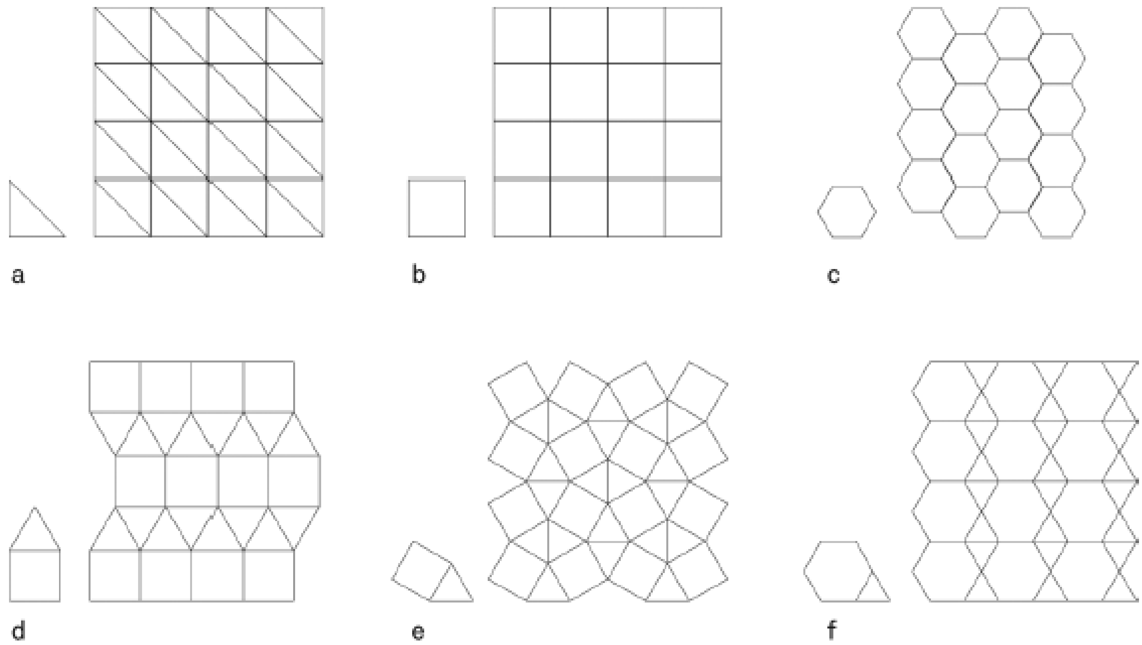

Figure 2. Examples of different shapes and organizations that could be presented on kinetic facades (Source: Rossi, Nagy & Schlueter, 2012).

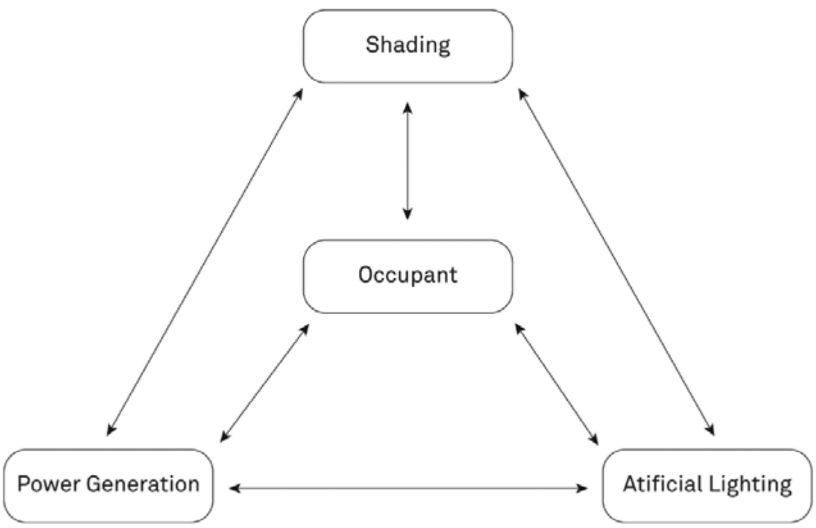

Figure 3. The importance of the occupant in each factor (source: Rossi, Nagy and Schlueter, 2012).

(Varendorff & Garcia-Hansen, 2012) have done a comparison for many shapes of kinetic systems on a specific building facade to identifying the best daylight distribution in relation to daylight glare probability and the amount of exterior unobstructed view. In a similar approach, (Elghazi & Mahmoud, 2016), have tested several origami techniques, which are one of the designs approaches that could provide kinetic shadings for better daylight performance based on several parameters, such as the motion and the module size. In addition, they have also examined the optimum number of folds and divisions for the origami geometries, as shown in Fig.4.

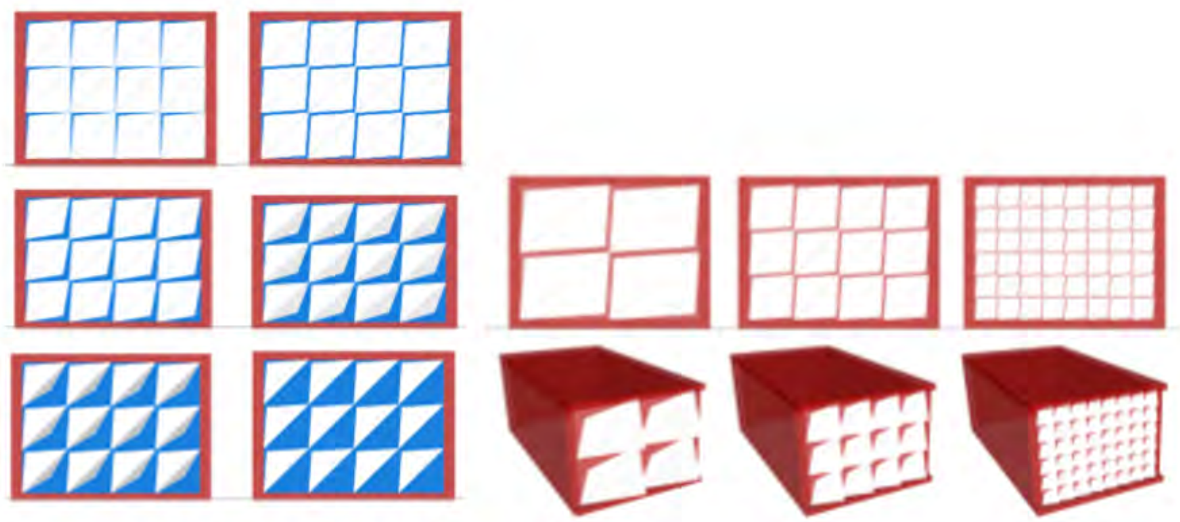

Figure 4. Different scale, composition and mechanism for a kinetic façade for optimizing daylight performance (source: Elghazi & Mahmoud, 2016)

(El-Dbaa, 2016) has studied the effect of the kinetic facades in an office building on improving the daylight performance through specifying the best louvers movement using simulations. It has determined the best movement of two types of kinetic louvers, rotation and vertical movement. In addition, it has given many examples concerning the kinetic façade's motion and mechanism, as shown in Fig.5.

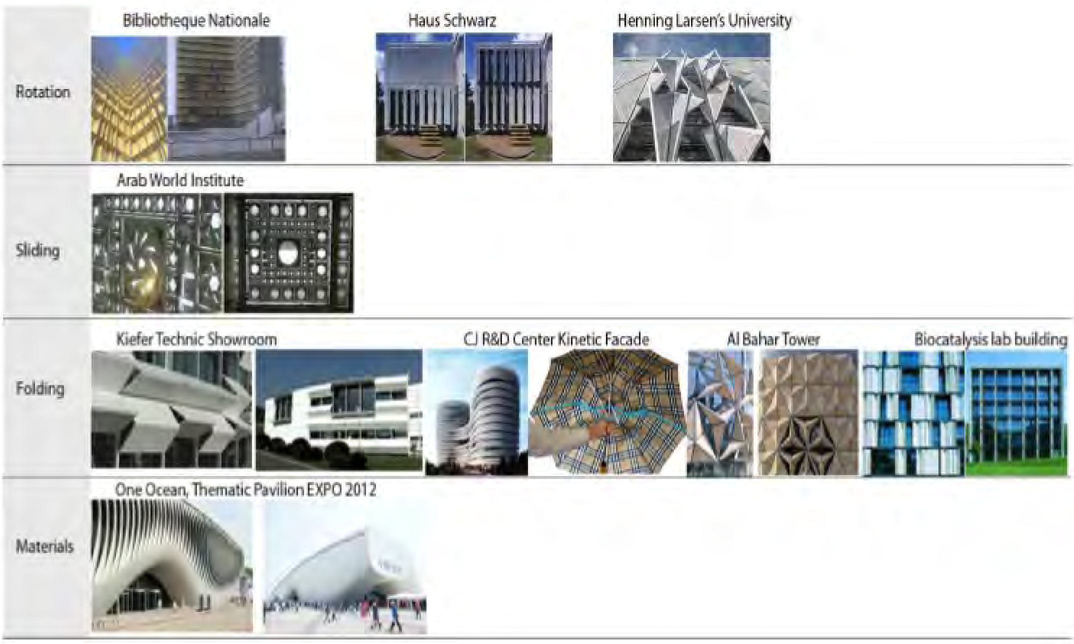

Figure 5. Examples of different kinetic facades' motion and mechanism (source: El-Dbaa, 2016)

Thus, based on these studies, it is noted that designing the form, geometry and mechanism of a kinetic system should be done through using different modeling software and programs such as Grasshopper, Rhino and others for inserting many inputs. Architects and designers therefore face some problems in the process of modeling of kinetic system, since it consumes lots of time and efforts.

5.2. Computational analysis and simulation category

The computational analysis and simulation category reviews researches focusing mainly on environmental simulation for daylight; it also involves small description and presentation of the existing digital application and plug-in used by architects to do this type of simulation. Several papers have examined and compared different types, methods and plug-ins for daylight and glare simulation.

(Yoo & Manz, 2011) has argued that visual comfort increases and glare decreases by installing fixed shading devices. In a similar approach, (Sabry et al., 2012) has studied the daylight performance through using several solar screens shape. In addition, the effect of using shading devices on daylight performance was investigated by many researchers in several climates and locations, since the negative effect of solar radiation and direct sunlight could be reduced by using shading devices (Wageh & Gadehlak, 2017). In 2016, Tzempelokps and Hiong have developed a strategy for controlling the glare using roller blind. (Eltaweel & Su, 2017) developed a reflective blind strategy that could be used parametrically through Grasshopper for Rhinoceros. (Katsifaraki, Bueno, & Kuhn, 2017) have developed a new shading controller, in office buildings that also controls the glare and maximizes the daylight level through doing a prototype in Freiburg, Germany.

Nowadays simulation tools are very important, since many architects want to test internal spaces before the construction phase (Evangelos & David, 2005). Several digital tools, such as Diva, honeybee, Rayfront, Relux 2004 Vision and Lightscape are used by architects to evaluate the performance of a building facade quantitatively and qualitatively in correspondence to the daylight transmittance of this façade (Kim, 2013). Many inputs should be introduced to those tools, such as the space materials, the materials transmittance, the grid of measurement, the weather file and others, while the outputs are graphs and tables. Diva is a plug-in inserted to Rhino software. It allows evaluating the environmental performance on urban landscape and buildings, as shown in Fig.6. In Harvard University, the Graduate School of Design developed Diva initially, but now Solemma LLC. is developing Diva (He, Schnabel, Chen & Wang, 2017). Also, the glare and illuminance level could be calculated in different software, such as Diva and Energy Plus, which is a program for energy simulation used by architects, engineers and researchers ("Energy Plus", 2018).

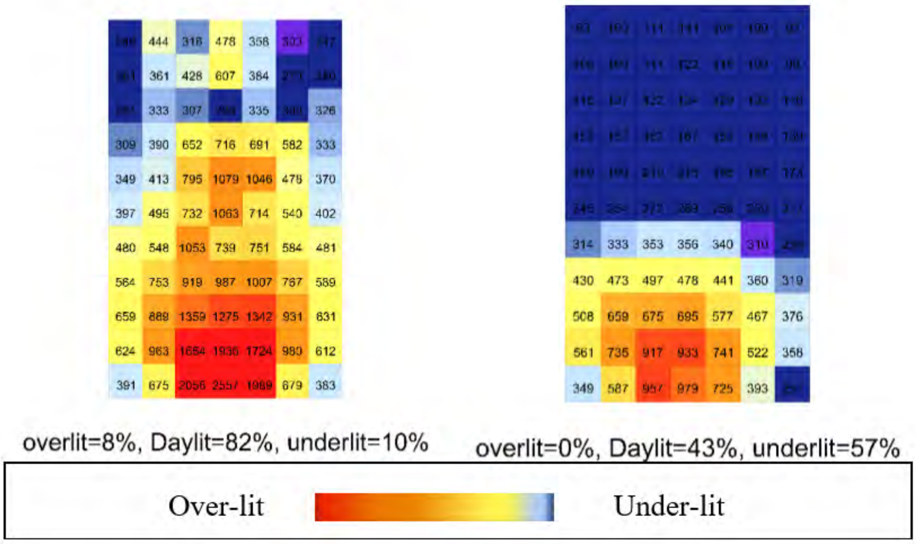

Figure 6. A daylight simulation using DIVA plug-in (source: El-Dbaa, 2016)

However, an extended and long workflow for optimization process and corresponding visualizations graphs are needed to be done by architects to reach the optimum kinetic shading for achieving visual comfort, which is considered as a problem for architects, since it will take lots of time to be accomplished, as shown in Fig 7. In addition, users should practice on all of these programs to reach the optimum solution which is also another problem faced by many architects.

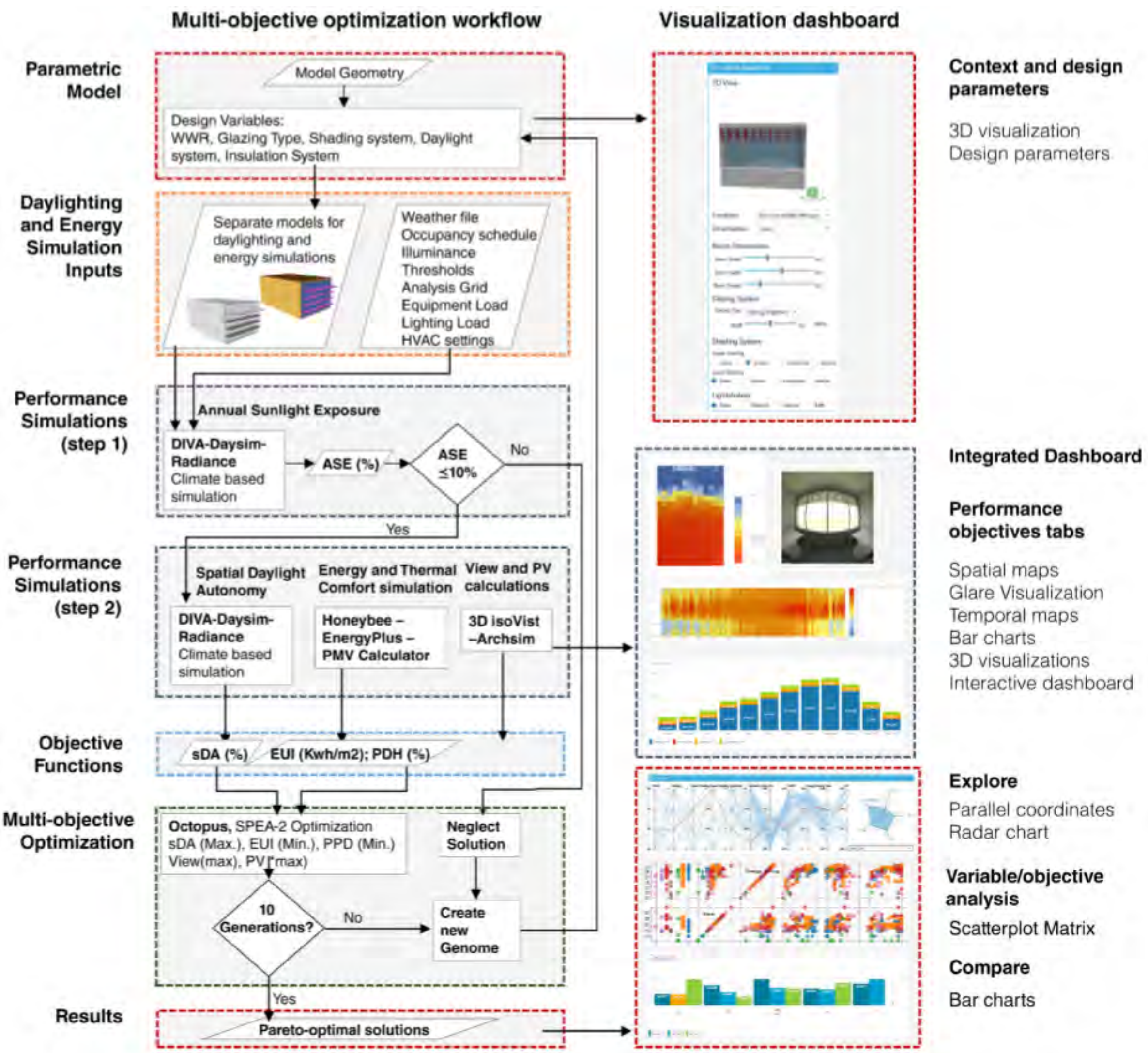

Figure 7. Optimization process workflow and the corresponding visualizations panels in some of the visualization tool (source: Gadelhak, Lang & Petzold, 2017)

5.3. Design Framework Category

Many researchers have proposed theoretical frameworks for supporting the design, as shown in Fig.8. For instance, in 1970 the waterfall model is a framework focusing on the early design stage, as shown in Fig.9a. In 2000, another framework was proposed, which is the pathfinder model (Horváth, 2000), as shown in Fig.9b, The most updated theoretical framework is the responsive kinetic skin design framework for supporting the design process of kinetic architecture in early design stages (Zboinska Cudzik, Juchnevic & Radziszewski.,2015), as illustrated in Fig.10.

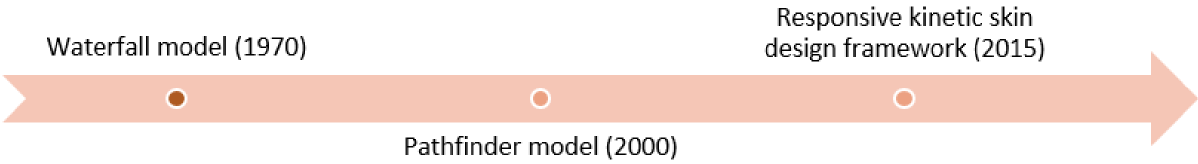

Figure 8. Chronological order of the theoretical framework (source: author)

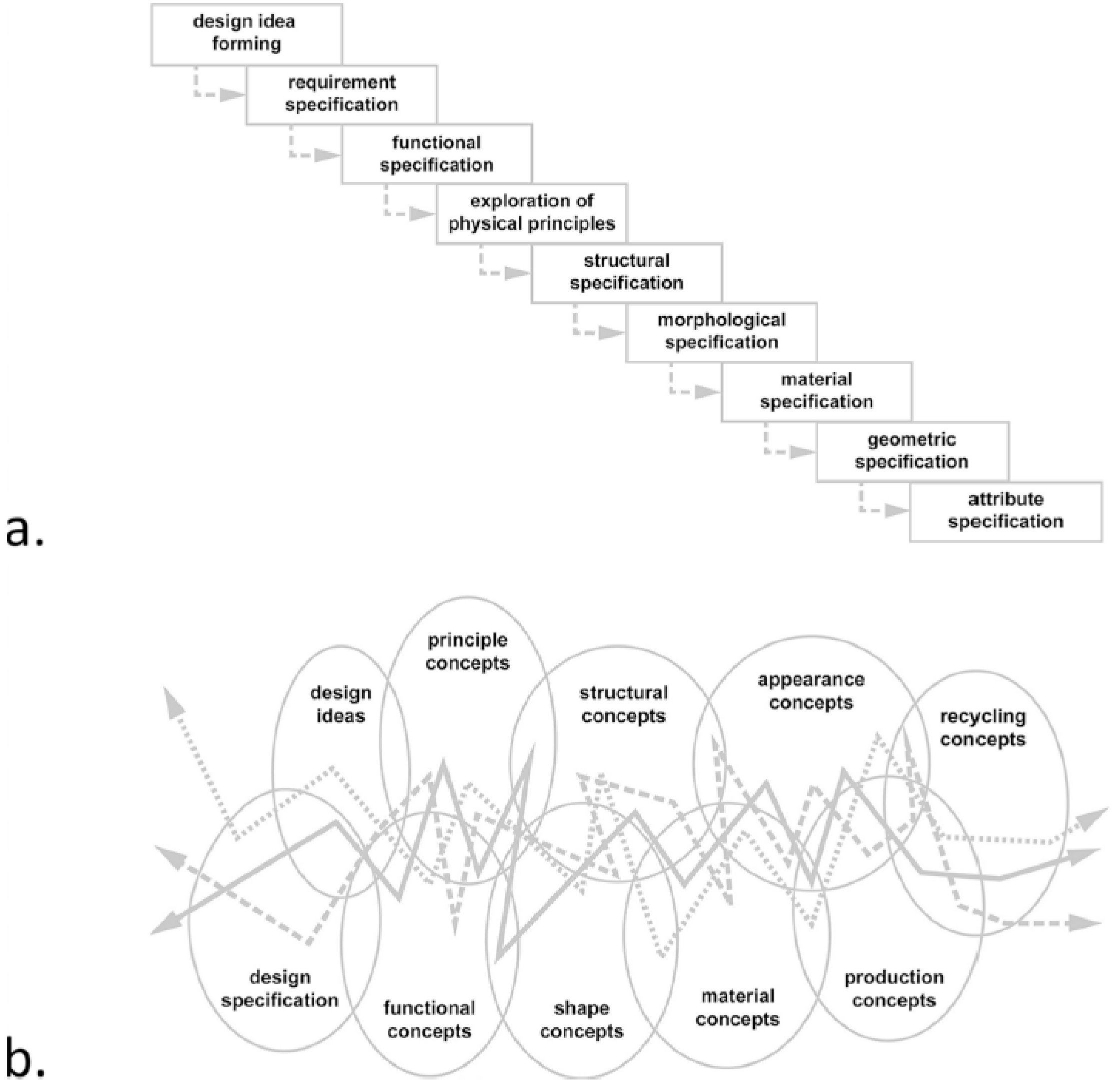

Figure 9. Shows the two existing structured frameworks for the conceptual design process before the appearance of the theoretical framework of kinetic architecture (source: Zboinska et al.,2015)

The responsive kinetic skin design framework was constructed and developed focusing on the construction of its foundation. Several experiments were prepared to specify the framework characteristics (Zboinska et al., 2015). This framework has explored six design aspects of adaptive architecture, as shown in Fig.10, which are:

- Functionality: selecting the best solution to have the optimum performance (using grasshopper and Galapagos).
- Form: defining the geometrical shape/composition, and exploring esthetically each part (using Rhinoceros and grasshopper).
- Kinetic behaviors: exploring the visual qualities of the movement, and simulating of the system dynamism (using Kangaroo)

– Performance: Analyzing and simulating computationally the system performance, such as environmental performance, structural performance and other (using Karamba and Diva).

– Responsive behavior: Studying the interaction between the environment and the architecture. Also analyzing the real time performance in the physical environment (using Arduino toolkit, firefly, sensors and actuators).

– System mechanism: Specifying the material and the mechanical design of the system. Also fabricating the prototype and testing its movement (using laser cutter and 3D printer).

Those six design aspects were also explored by various means (Zboinska et al.,2015), as shown in Fig.11.

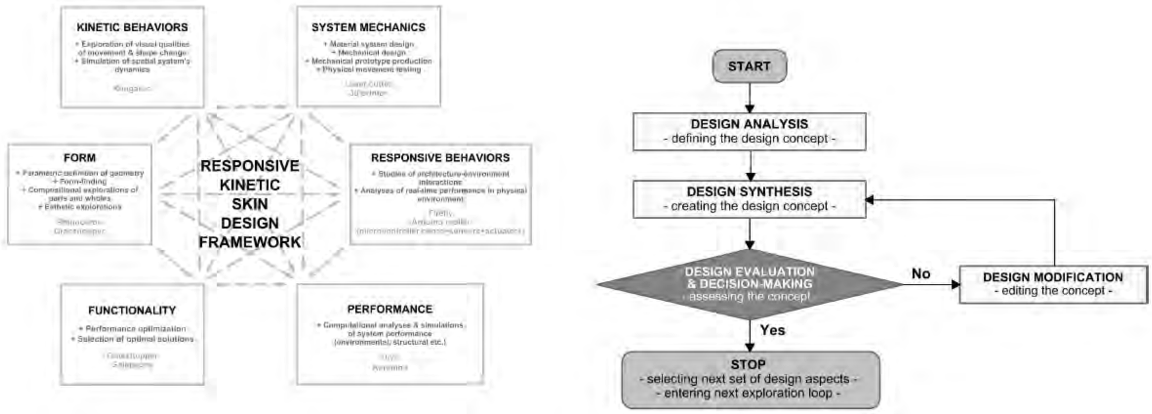

Figure 10. Responsive kinetic skin design framework and its cycle (source: Zboinska et al., 2015)

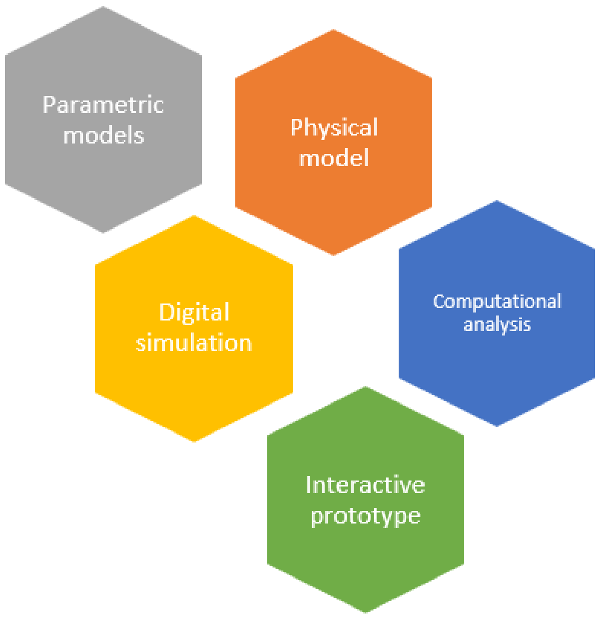

Figure 11. Various means that explore the six design aspects of the framework (source: author)

However, this framework is not yet digitalized to be easily used by architects and designers. It still also needs more empirical verification, more exploration for its advantages and limitations, and need more development in the future (Zboinska et al.,2015).

6. Conclusion and Recommendations

Based on the above review; the current researches in the field of kinetic facades for daylight optimization has been focused on the following lines:

- Kinetic facades' form and mechanism, in which researches have explored several shapes, scale, aesthetical compositions and motions of kinetic facades.
- Kinetic facades' form and mechanism, several researches have focused on developing and applying different environmental simulation programs and software related to optimizing daylight using kinetic systems.
- Kinetic design framework, in which several studies have examined theoretically different design frameworks, mainly the responsive kinetic skin design framework, as it is related to kinetic and responsive behavior.

Hence, it is recommended to discuss and explore more possible future researches in the topic concerning the enhancement of daylight performance by applying kinetic shadings. These recommendations to be categorized as follows:

- In the form and mechanism category: it is recommended to explore more on automatic optimization of the form and mechanism of kinetic shadings to improve the daylight performance in a space.
- In the computational analysis and simulation category: the processes of optimization and visualization present many challenges for architects, require extensive computer programing knowledge in different software, and involves many different specialists to reach optimum solution. Thus, for better functionality, it would be recommended to devise a single toolset that function automatically for facilitating architect's ability to realize more effective kinetic skins.
- In the design framework category: a theoretic framework needs to be validated through digital tools finding a mathematical relation between several environmental and kinetic parameters, to reduce its complexity. In addition, it is better to present it through an easy graphical user interface (GUI), to be easily used by all architects, not just by those who are professional in using digital tools and applications.

Finally, the consideration of these recommendations will help architects to overcome many problems, to save time, to reduce their efforts, and to efficiently design and control kinetic shadings for ultimately achieving visual comfort in different spaces.

In other words, architects' role should positively develop towards more efficient environmental performance of building through kinetic facades.

7. References

1. Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., & Elsarrag, E. (2016). Occupant productivity and office indoor environment quality: A review of the literature. *Building And Environment*, *105*, 369-389. doi: 10.1016/j.buildenv.2016.06.001
2. Barozzi, M., Lienhard, J., Zanelli, A., & Monticelli, C. (2016). The Sustainability of Adaptive Envelopes: Developments of Kinetic Architecture. *Procedia Engineering*, *155*, 275-284. doi: 10.1016/j.proeng.2016.08.029
3. El-Dbaa, R. (2016). *The Use of Kinetic Facades in Enhancing Daylight Performance for Office Buildings*. Master Degree. Arab Academy for Science, Technology and Maritime Transport.
4. Elghazi, Y., & Mahmoud, A. (2016). Origami Exploration: A Generative Parametric Technique For kinetic cellular façade to optimize Daylight Performance. *Shape, form and geometry, Applications*, *2*.
5. Eltaweel, A., & Su, Y. (2017). Controlling venetian blinds based on parametric design; via implementing Grasshopper's plugins: A case study of an office building in Cairo. *Energy and Buildings*, *139*, 31-43. doi: 10.1016/j.enbuild.2016.12.075
6. EnergyPlus. (2018). EnergyPlus. Retrieved from https://energyplus.net/

7. Evangelos, D. and David, C. (2005). Daylighting Simulation: Comparison of Softwares for Architect's Utilization. In: *Ninth International IBPSA Conference*. [online] Available at: http://www.ibpsa.org/proceedings/bs2005/bs05_0183_190.pdf [Accessed 23 Jun. 2018].

8. Fouad, S. (2012). *Design Methodology Kinetic Architecture* (Master of science). Alexandria University.

9. Gadelhak, M., Lang, W., & Petzold, F. (2017). A Visualization Dashboard and Decision Support Tool for Building Integrated Performance Optimization. In *ShoCK- Sharing Computational Knowledge*. Rome, Italy. Retrieved from https://www.researchgate.net/publication/320057576_A_Visualization_Dashboard_and_Decision_Support_Tool_for_Building_Integrated_Performance_Optimization

10. He, Y., Schnabel, M., Chen, R. and Wang, N. (2017). A Parametric Analysis Process For Daylight Illuminance. In: *22nd International Conference of the Association for Computer Aided Architectural Design Research in Asia (CAADRIA)*. Hong King, pp.417-425.

11. Horváth, I 2000 'Conceptual design: Inside and outside', *Proceedings of the 2nd International Seminar and Workshop on Engineering Design in Integrated Product Development*, pp. 63-72.

12. Jenkins, D., & Newborough, M. (2007). An approach for estimating the carbon emissions associated with office lighting with a daylight contribution. *Applied Energy*, *84*(6), 608-622. doi: 10.1016/j.apenergy.2007.02.002

13. Katsifaraki, A., Bueno, B., & Kuhn, T. (2017). A daylight optimized simulation-based shading controller for venetian blinds. *Building and Environment*, *126*, 207-220. doi: 10.1016/j.buildenv.2017.10.003

14. Kim, J. (2013). Adaptive façade design for the daylighting performance in an office building: the investigation of an opening design strategy with cellular automata. *International Journal of Low-Carbon Technologies*, *10*(3), pp.313-320. doi:10.1093/ijlct/ctt015

15. Liu, Y. (2012). A Study on Perception of Daylight Shadows and Visual Comfort in Library Reading Areas. In: *American Solar Energy Society*. Oregon.

16. Meyboom, A., Johnson, G., & Wojtowicz, J. (2011). Architectronics: Towards a Responsive Environment. *International Journal of Architectural Computing*, *9*(1), 77-98. doi: 10.1260/1478-0771.9.1.77

17. Rossi, D., Nagy, Z. and Schlueter, A. (2012). Adaptive Distributed Robotics for Environmental Performance, Occupant Comfort and Architectural Expression. *International Journal of Architectural Computing*,*10*(3), pp.341-359.

18. Sabry, H., Sherif, A., Gad Elhak, M., & Rakha, T. (2012). External Perforated Solar Screen Parameters and Configurations: Daylighting Performance of Screen Axial Rotation and Opening Proportion in Residential Desert Buildings. In *14th International Conference on Computing in Civil and Building Engineering*. Moscow,Russia.

19. Tomassoni, R., Galetta, G., & Treglia, E. (2015). Psychology of Light: How Light Influences the Health and Psyche. *Psychology*, *06*(10), 1216-1222. doi: 10.4236/psych.2015.610119

20. Varendorff, A., & Garcia-Hansen, V. (2012). Building Envelope: Performance optimization processes for a daylight responsive architecture. In *28th Conference, Opportunities, Limits & Needs Towards an Environmentally responsible architecture*. Peru.

21. Wageh, M., & Gadehlak, M. (2017). Optimization of Facade Design for Daylighting and View to-Outside: A case study in Lecco, Lombardy, Italy. *Draft*, 1-9.

22. Yoo, S. H. & Manz, H. (2011). Available remodeling simulation for a BIPV as a shading device. *Solar Energy,95*(1), pp. 394-397

23. Zboinska, M., Cudzik, J., Juchnevic, R., & Radziszewski, K. (2015). A Design Framework and a Digital Toolset Supporting the Early-Stage Explorations of Responsive Kinetic Building Skin Concepts. *Smart and responsive design*,*2*, pp.715-725.