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ACHIEVING VISUAL COMFORT IN UNIVERSITY EDUCATIONAL SPACES:A DESIGN FRAMEWORK FOR RESPONSIVE KINETIC SKIN

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Abstract

Achieving human comfort in a space is an architectural necessity. Feeling comfort is related to the sense organs network, such as the eyes, ears, nose, tactile sensors, heat sensors and brain. In fact, last few decades has witnessed the integration of many technologies and trends into the field of responsive architecture; among which kinetic architecture has been significant. Thus, the aim of this thesis is to achieve visual comfort in educational spaces in universities, while arguing that a responsive kinetic skin is to be an effective mean for achievement. That should help refreshing student and enhancing their educational spaces visually, by considering various factors, such as the light transmitted through the kinetic system and the colors of kinetic units. Consequently, student health will be enhanced mentally and psychologically. In the thesis, several kinetic skin alternatives will be simulated digitally, to choose one of them that will be applied and tested as a physical model (scale1/1) in one of the universities spaces. The outcome of this thesis is giving a framework for designers and architects to design responsive kinetic skin in universities respecting visual comfort of students. This framework will be presented through a graphical user interface (GUI) that can be easily used by architects.

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A DESIGN FRAMEWORK FOR RESPONSIVE KINETIC SKIN

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ABSTRACT

Achieving human comfort in a space is an architectural necessity. Feeling comfort is related to the sense organs network, such as the eyes, ears, nose, tactile sensors, heat sensors and brain. In fact, last few decades has witnessed the integration of many technologies and trends into the field of responsive architecture; among which kinetic architecture has been significant. Thus, the aim of this thesis is to achieve visual comfort in educational spaces in universities, while arguing that a responsive kinetic skin is to be an effective mean for achievement. That should help refreshing student and enhancing their educational spaces visually, by considering various factors, such as the light transmitted through the kinetic system and the colors of kinetic units. Consequently, student health will be enhanced mentally and psychologically. In the thesis, several kinetic skin alternatives will be simulated digitally, to choose one of them that will be applied and tested as a physical model (scale1/1) in one of the universities spaces. The outcome of this thesis is giving a framework for designers and architects to design responsive kinetic skin in universities respecting visual comfort of students. This framework will be presented through a graphical user interface (GUI) that can be easily used by architects.

KEYWORDS

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1. INTRODUCTION

The definition of human comfort could be viewed from several domains such as architecture, physiology, psychology, social science and others. Comfort is not related only to physical environment; it is influenced by mood, personality and many social factors of individuals (Kamholz & Storer, 2009).

In the internal built environment, many factors affects human comfort such as thermal factors, olfactory factors, hygienic factors audio/sound factors, and visual/lighting factors. In addition, recently many interactive ideas and concepts are invented that could adjust and interact with many environmental factors such as heat, wind, or even people. This adjustment does not requisite human intervention. Also 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. This architectural evolution introduced many modulation vocabulary and terms (Al horr et al., 2016).

Two of the first academics who describe kinetic architecture as "one of that has the capability of adapting to change through kinetics" were Roger Clark and William Zuk, since 1970. Architects began to widely discuss kinetic systems in the second half of 20th. Kinetic systems could enhance climate conditions in internal spaces, in response to external environmental changes (Stevenson 2011).

Similar to the human comfort, Kinetic Architecture could be affected by many factors such as light, sound, wind, noise, human motion and others. Thus, I will achieve human comfort for students, using kinetic system in university's spaces. The hypothesis of the thesis is that the visual comfort of students and the educational environment could be enhanced and improved by applying kinetic skin on university's spaces façade (studios/classroom)

The research problem is that recent studies showed various problems related to indoor human comfort, especially within educational spaces; among which visual discomfort was one of those problems.

The aim of this thesis is achieving visual comfort in educational spaces in universities, through designing a responsive kinetic skin.

In order to achieve the mentioned aim, the objectives of this thesis are:

- Establishing a framework that connects all parameters related to visual comfort
- Present the framework to a mathematical logic (algorithm), that will be illustrated through a GUI (graphical user interface), which will be easily used by architects. Evaluating (measuring, testing) student comfort visually, by respecting light and colors factors.
- Developing and applying responsive kinetic skin system in university's spaces (design studio) to improve student comfort visually.

There are five types of human comfort as mentioned before, which are thermal comfort, olfactory comfort (odors), auditory comfort (acoustics), hygienic comfort and visual comfort.

This thesis focuses mainly on the visual comfort, since Light and colors factors, which are included in the visual human comfort, have high impact on human psychology comfort.

Also it focuses on applying kinetic skin (building envelope), on university's spaces such as design studios/classrooms, for achieving the visual comfort for students, which will improve their performance.

Reviewing literature related to human comfort (especially visual comfort), also related to kinetic architecture applications. Then, collecting data about different psychological factors, and finding the related factors between human psychology and human comfort factors. Collecting data on kinetic parameters and selecting some of them to be studied. The next step is selecting one of the university's space for applying kinetic skin such as design studio/ classroom.

Later on, in further studies a case study in north Lebanon will be chosen for applying the kinetic skin system (BAU University and other universities). Then, designing the initial framework, and illustrating it through a graphical user interface, and designing digital prototype (on computer).

In addition to testing and simulating many alternatives digitally to select a responsive kinetic skin, which will be physically applied on the real field. Then designing physical prototype (real model) to prove the initial framework, and planning a final framework for designing responsive kinetic skin in educational spaces considering visual comfort. Measuring the visual human comfort and psychological comfort before and after applying the real model. Then, Comparing between the results (conforming or rejecting the hypothesis).

2. HUMAN COMFORT AND CATEGORIZATION

Building's characteristics have impact on the range of comfort and health. In addition, problems with indoor environmental quality (IEQ) of buildings, such as acoustic, thermal, visual and air quality have impact on comfort, occupant productivity and occupant performance in the space (Stevenson 2011). It is very important to understand the need of building's occupant, which could make some adaptation and adjustment to themselves or to the surrounding for decreasing discomfort (Hoque & Weil, 2016)

For measuring the level of comfort, several organizations have state the ranges for reaching the human comfort, which could be used as references, such as Air-Conditioning Engineers (ASHRAE), and International Organization for Standardization (ISO) (Boduch & Fincher, 2009).

One of the studies discussed and analyzed the relation between inhabitant health and well-being, and indoor environment quality, but this study focused only on office building, and suggested further studies in retails, residential building and school (Al horr et al., 2016).

Human senses: sight, touch, hearing, taste and smell, could lead for having better or worse human comfort. The best classification of human comfort types is the one including five categories, which are mostly related to human senses. The five categories are thermal comfort, visual comfort, auditory comfort, olfactory comfort and hygienic comfort (Boduch & Fincher, 2009). My research focuses mainly on the visual comfort in educational spaces. Since Light and colors factors, which are included in the visual human comfort, have high impact on human psychology comfort.

2.1. Visual Comfort

Visible light that could be perceived by human is just a small part of the total electromagnetic spectrum. Light has a frequency and wave properties. When the energy of light attacks a surface, it is transmitted, reflected or absorbed. The visual comfort focus mainly on light level, glare, contrast and color. A black surface absorbs most of the energy, while a white surface reflects back equally most of the spectrum. Contrast of color is an essential factor in visual comfort, there is a relation between the contrast and the comprehension, which is easier, when the contrast is greater. Also the glare makes the object difficult to be seen, and it is undesirable. The level of the light, the illuminance level and the brightness are related to the function inside the space as illustrated. Visual sensation is the most dominant one in human perception since the eye contains two third of nerve fiber that enter human central nervous system. But, also spaces could be perceived by other sensations such as sound, touch and smell (Boduch & Fincher, 2009).

This paper focuses on one of these five human comfort categories, which is the visual comfort based on its relation with human psychology and based on literature review, which will be discussed in the following paragraph.

2.2. Psychological Factors (Color and light in human psychology)

Studying human behavior and nature is a science called human psychology, which includes mind and body. There is a relation between architecture and human psychology. Here are some architectural components that could affect human psychology: open spaces, building form, lighting acoustics, positive and negative spaces (Human psychology, 2011).

Many factors could have impact on human emotion and psychological state. Light and color are two of the most important factors that have effect on user performance. Colors could be classified as primary colors (red, yellow and blue), secondary colors (green, orange and purple), and Tertiary colors, which are created by mixing primary and secondary colors. Each color could have a meaning and affect human feelings (Cerrato, 2012), as shown in Table 1.

The intensity of light also is related to the mood in a space. Heart rate and skin conductance could be used for measuring physiological state (Abas, 2017).

Lighting influences the mood of individuals such adding suspense during theater performance or creating an environment of calm in a space. In addition, psychological well-being, mood, body temperature and brain activity, are influenced by the light in a specific architectural environment. Low lighting is used in public spaces, such as hospitals and airport, to give sense of protection and relaxation, while high lighting is used in production environment such as working space, to increase the level of productivity.

The light of a space is connected to human environmental experience. There is a correlation between light colors and lighting levels. Both of them influence human biological cycle, by reducing or rising the secretions of hormone (Tomassoni, Galetta, & Treglia, 2015).

Table 1: Shows Different Colors and Its Meanings (source after Eiseman, 2006 & Cerrato, 2012)

Color	Meaning
Red	• Physiologically, red calls the adrenaline glands to get the body and senses activated

	• Red is associated with danger, power, energy and courage • It is a good color to make people excited
Blue	• It is the color of sea and sky. it reduces appetite tension and fear • It symbolizes stability, trust and confidence (could be used in bank and financial companies) • It relates to one - to one communication rather than a mass communication
Yellow	• It is unstable color, avoid using it to express safety and stability (when there is a lot of yellow, many people could not stay for long) • It could be used for children's product and entertainment business
Orange	• It is one of the favorite colors to children especially from three to six years old age group • It is associated with joy, it represents happiness and enthusiasm • It is used in resorts and hotels
Green	• It is the color of nature, also it is associated with healing and health • It means safety (oppose to red)
Purple	• Psychologically it increases people creativity • It could be in academic institutions (inspire intellectual thoughts and achievement)
White	• It symbolizes purity, perfection and safety • It represents creativity and new beginnings. It helps to create order
Black	• It symbolizes power, mystery and death • It gives self-confidence, but using too much black make depression (unfriendly)

Referring to table 1, if the target place is an educational one (design studio), many colors could be avoid it, such as the blue one since it is frequently used in hospitals, because it is a calm color and used in one to one communication spaces rather than mass communication spaces. In addition, the yellow color is not preferable, because it is used for entertainment activities rather than education one.

2.3. Pilot Study and Analysis

This part contains pilot study (questionnaire), targeting students (52), assistants and staff at different universities in Lebanon. It aims to detect the problems faced by students that are related to human comfort, in the educational spaces such as classrooms, design studios, libraries and others.

The 86% of responses are from Beirut Arab University, in Tripoli campus. 10 % of response are from LU (Lebanese University), 2% from Azem University and 2% from Al Manar University.

The majority of universities' users (90%) are facing problems related to human comfort, as shown in Figure 1. This big percentage was one of the main motivation to detect and solve problems in universities' spaces to enhance the educational environment for students.

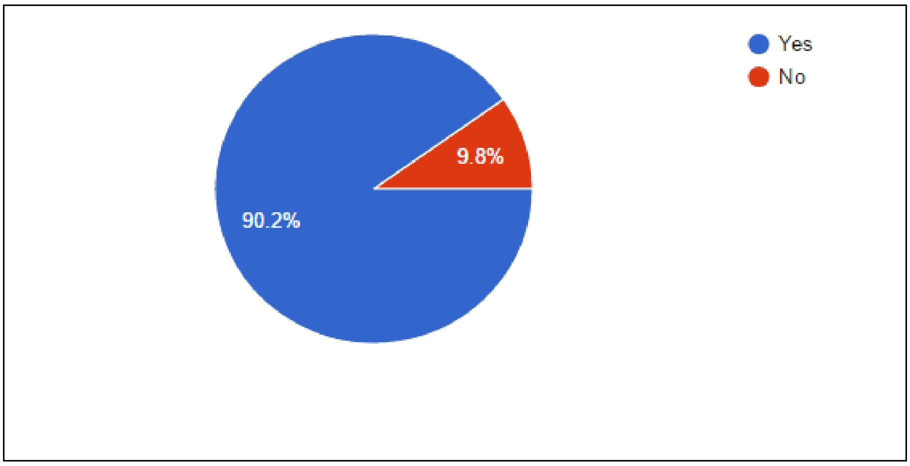

Fig. 1: Percentage of Universities 'users facing problems related to human comfort (source: authors)

The following chart illustrated in Figure 2, shows that the most common universities' facilities in which students face problems are consecutively, design studios, cafeteria, classrooms/lecture rooms , library, sport/recreational zones, followed by lounges, laboratory and theater having the lowest percentage (5.90%). It is deducted that design studios, cafeteria, classrooms, library and recreational zones have the highest percentages. However, this paper focuses mostly on educational spaces that affect directly educational environment, and also focuses on indoor facilities, which are more controllable thus, cafeteria and sport/ recreational zones are neglected (out of focus). Thus, this paper focuses on one of the following universities' facilities, which are studios, lecture rooms or library (study spaces) as shown in Figure 2.

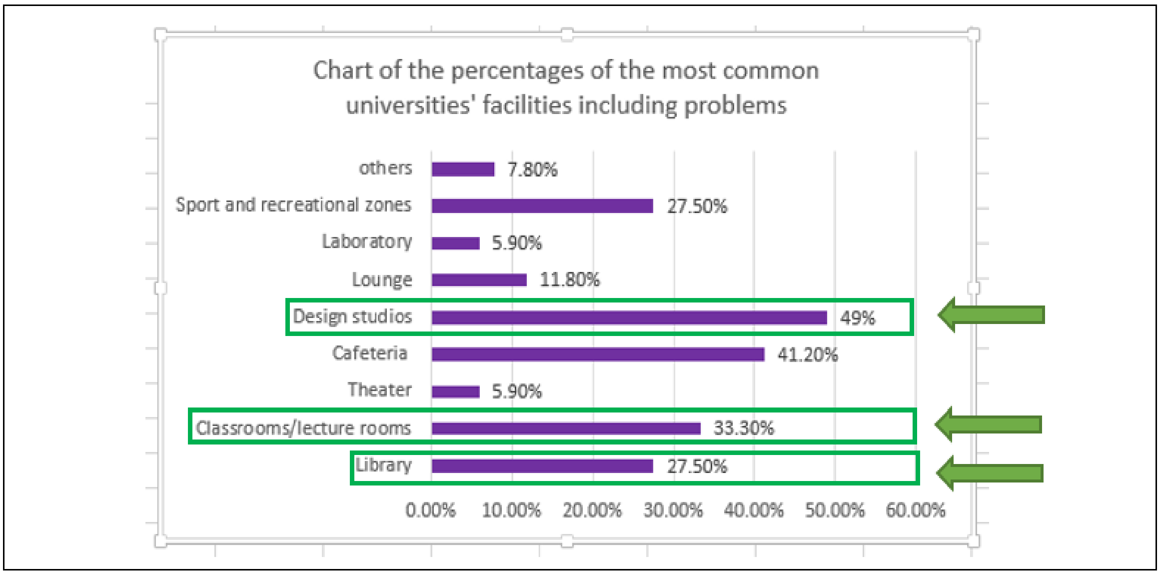

Fig. 2 Some Universities' facilities that could be studied (source: authors)

The main detected problems are related to acoustic and visual problems, consequently solutions should address to one or both of them, as shown in Figure 3.

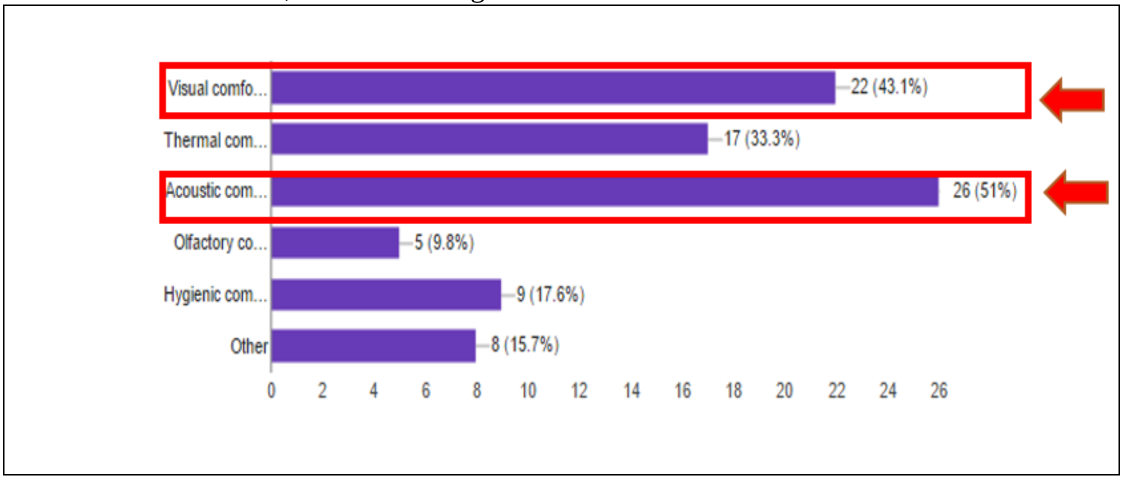

Fig. 3 Percentage of the most common Human Comfort problems faced in universities' spaces (Source: authors)

3. UNIVERSITY FACILITIES' FOCUSES

This paper focuses on university's spaces that are considered as main educational spaces and, which are interacted with the natural lighting, as an outdoor environmental factor, because this paper concentrates mainly on the visual comfort (including lighting factor),as mentioned before. Thus, the administration facilities, the commercial facilities (including cafeteria), the residential facilities, the student services (including recreational areas) and health care facilities are rejected (out of focus), because these facilities are not considered as main educational spaces, which affect educational level directly. In addition laboratory facilities and centrally timetabled teaching space facilities (including theater) are also not considered in the study, because they are not interacted with an outdoor environmental factor (natural light) related to visual comfort. Consequently, this paper should focus only on study or classrooms facilities, which include design studios, as shown in Figure 4.

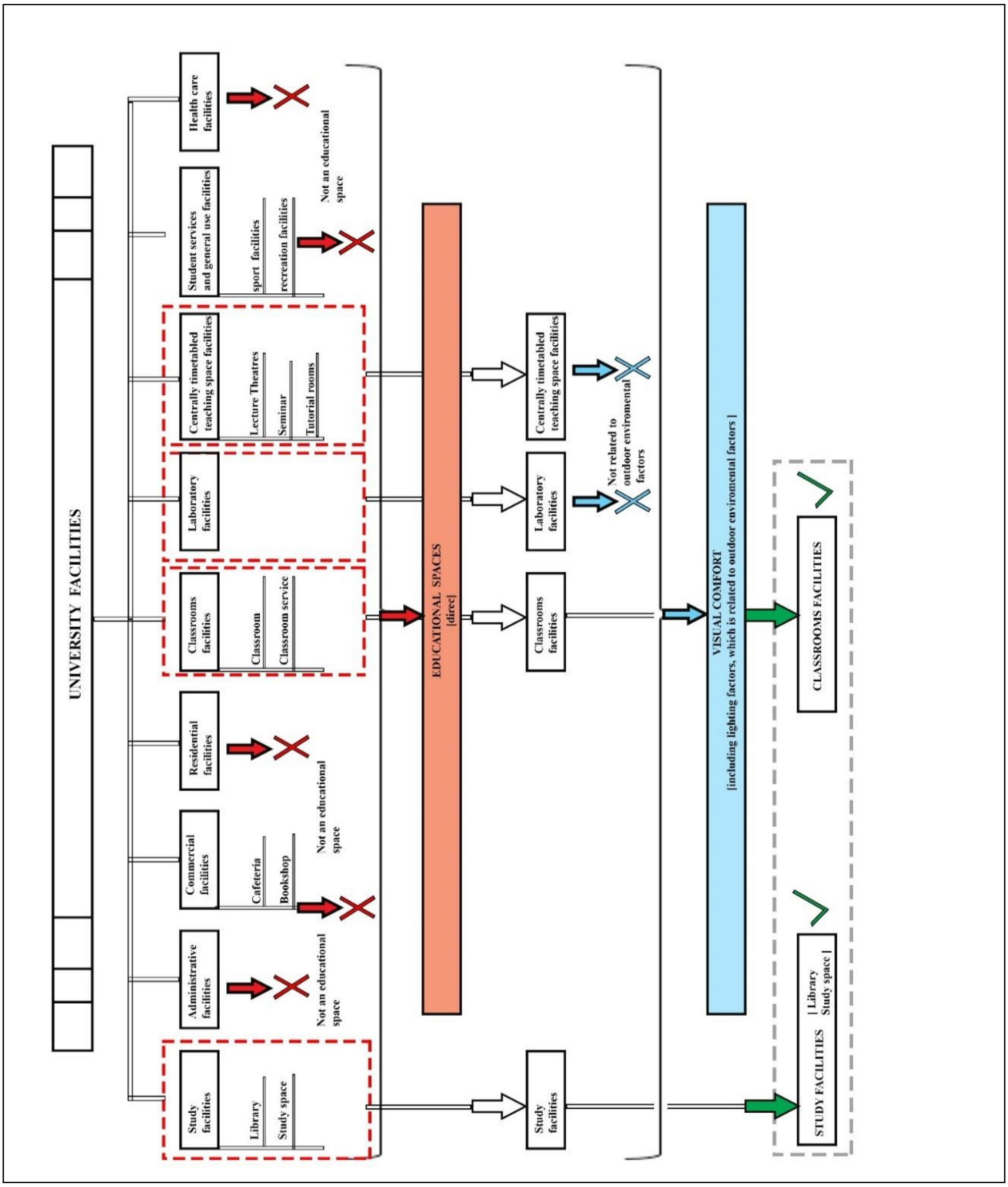

Fig. 4 Criteria of selecting universities' facilities that will be studied in this paper (source: authors)

4. KINETIC ARCHITECTURE

Kinetic is the movement, while architecture is the style of the building, thus Kinetic Architecture is the design of building that are produced by movement. Many people has 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, 2016).

Sanchez-del-valle explains that usages of adaptive kinetic structure due to economy of means, responsibility toward the natural environment and human need satisfaction. In architecture, dynamic and adaptive building envelops are the current trends. The term envelop is referring to the total enclosure of the building. The shading devices, which are non-stationary are generally described by words such as convertible, kinematic retractable, kinetic, or simply adaptive. In addition, shading systems that interact with the environments are described by many word like responsive, reformative and dynamic (Barozzi, 2016).

4.1. Examples of Adaptive Shading Systems

Since this paper is focusing on putting kinetic shading devices in educational spaces, thus the following examples show some adaptive shading systems and clarify its advantages and disadvantages.

An important example of external adaptive shading devices is Abu Dhabi Investment Council HD. This case study represent an office building (two towers) designed by the architect Aedas (Andia & Spiegelhalter, 2014). It is composed of 29 floors (150 meters). The architect uses diaphanous screen, which are responding to the environmental conditions, and enveloping the most exposed part of the building, inspired form of 'Mashrabiya' that reflect the traditional culture in a modern way, as shown in Figure 5. Each tower contains 1000 Mashrabiya units, which are PTEF fabric mesh panels (usage of recyclable materials). It is suggested that this screen solution has many positive points such as:

- Reducing 25 percent from the cooling load
- Reducing the carbon footprint of the towers (1,750 tons per year)
- Minimizing solar gain (50%), through the open and close operation that is responding to the sun movement
- Reducing the glass specification, which will contribute to economic solution (save money) (Walch, 2016)

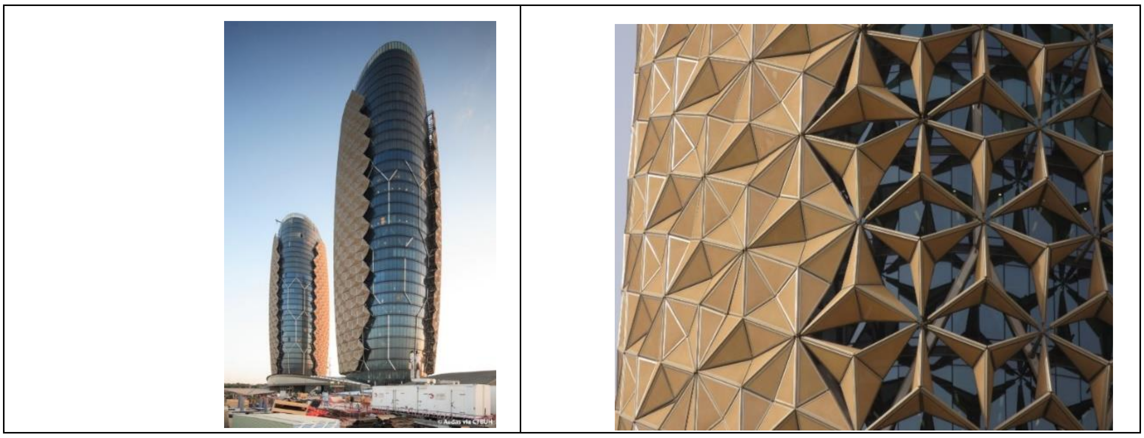

Fig.5 The two tower of Abu Dhabi Investment Council HD (Source: Andia & Spiegelhalter, 2014)

Another example is the Kiefer Technic Showroom, which is an office building completed in 2007, located in Austria, designed by Ersnt Giselbercht and partner architecture.

It consists of two layers a dynamic layer having white perforated aluminum panels as material (front layer) and a static one (back layer), having polygonal glass as material, as shown in Figure 6. There are 122 aluminum panels, having a vertical motion (Fouad, 2012).

Fig. 6 Aluminum panels operation of Kiefer Technic Showroom (source: fouad, 2012)

The University of Southern Denmark (ADU) is another example of a kinetic façade accomplished in 2014, as shown in figures 7 and 8. This building is designed by Henning Larsen. The kinetic façade serves as dynamic solar shading, which could be modified depending on the heat and daylight levels (Stephen, 2015).

 **Fig.7 shows the colored moving facade of ADU building (Source: Stephen, 2015)**	 **Fig. 8 shows the ADU building when its panels are open (Source: Stephen, 2015)**

The main target from this dynamism was:

- Creating a comfortable working environment for the student
- Decreasing the heat and cooling load of the building by becoming more open in the winter, and more closed in late spring.
- Reducing energy consumption by 50% in comparison to other similar buildings' type in the region

The aluminum panels are divided into two categories. The first one is the movable panels (from 0-90 degree, while the second one is the fixed panels at a 30,60 or 90 degree (Stephen, 2015).

As summary of this part , kinetic façade or 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, for having the optimum daylight and shading during the day.(Fouad, 2012 & Barozzi, 2016).

Consequently, kinetic architecture is not just about moving building, but it is also making a link between the natural and built environment, regarding the environmental variations.

4.2. Principle OF Movement

For designing good architectural environment, many design principles are considered. The following points represent parameters for having good design of movable architecture (El Khayat¸2014).

- **Time**
  Material and movement are accompanied by the time.
- **Physics and balance**
  Mechanics follows physics, and it is dealing with objects' movement. Complex motions are produced by combining the basic building blocks of kinetics, which are rotation and scaling that could be contraction or expansion in size (Moloney, 2011).
  Dynamic is a category of mechanics, which is related to statics study and forces (El Khayat¸2014). Objects movement could be divided into one dimensional motion in two dimensions, circular motion, periodic motion, vibration motion, and oscillatory motion.
- **Acceleration and speed**
  One of movement components is the speed. With no speed, there is no movement, because movement is the result of acceleration and deceleration changes, from a stationary condition to a new one. In addition, there is an indirect relation between acceleration and sensory perception. The appearance could be affected by the way, in which elements are coupled in series.
- **Weight and mass**
  Small masses are more easily set in motion. The mass should be considered in both design and construction phases. Weight is an important element that could affect movable designs (El Khayat¸2014)
- **Scale and complexity**
  Complexity is affected by the scale of movable element. High precision execution is required in large scale construction as well as in small scale construction. In kinematic chain, the individual movements raises the complexity of the movement.

In this paper, some of these parameter should be fixed and others variable, such as the acceleration and speed vary is one of the parameters that varies for defining the better speed of the movable unit to have the best performance, but a suitable unit scale is specified and considered as fixed parameter.

5. CONCLUSION AND RECOMMENDATIONS

Architectural students spend most of their time in design studios, which have bigger spaces than the normal classroom, and need a larger opening, thus design studios are very related to visual comfort.

As a summary, based on questionnaire's responses and based on some mentioned criteria, design studios (included in classrooms category) is the selected universities' spaces to be tested for reaching the optimum visual comfort. Through applying kinetic systems on the façade for enhancing the educational environment of students.

In addition, based on the previous pilot study and literature review, this paper focuses on the following points, as shown in Figure 9:

- Regarding human comfort: it focuses on visual comfort, including lighting and colors
- Regarding universities' spaces: it emphasizes on classrooms facilities, especially design studios
- Regarding kinetic parameters: it focuses on scale and complexity; weight and mass (as fixed parameters); and it focuses on acceleration and speed; and motion (as variable parameters).

It is recommended in the following steps to test the kinetic shading in design studios, as a university space, to achieve visual comfort using some fixed and variable parameters. Which is important to design a framework for architect, to enhance the educational levels in universities (faculty of architecture).

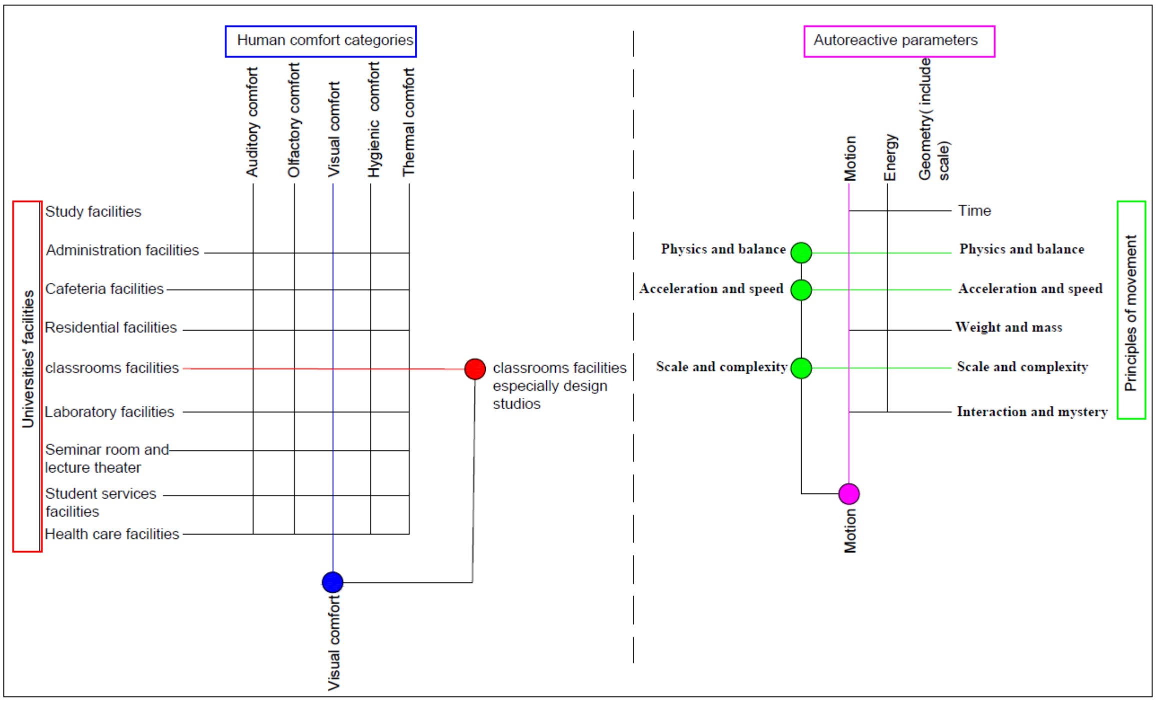

Fig. 9 Matrix diagrams for the paper focuses' factors (Source: authors)

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