University of Salford

School Of Build Environment

MSc Digital Architectural Design

Design strategy for adaptive kinetic patterns: creating a generative design for dynamic solar shading systems

This Dissertation is submitted in partial fulfilment of the requirements for the degree of Master of Science in Digital Architectural Design from the University of Salford.

By

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Abstract

This dissertation discusses the role of designing adaptive kinetic patterns in architecture, architectural surfaces have been covered by patterns long time ago, and the problem is how kinetic adaptive patterns will be designed for improving the sustainability of buildings by providing a proper daylighting, there is no clear strategy for designing these kinetic patterns as it is still new to the field of architecture. This research aims to create a framework that provides strategy for designing adaptive kinetic patterns within the digital modelling phase that implemented by parametric and generative design tools, for making changes in the spatial quality response of the building, in order to enhance environmental performance through daylighting passive design. Creating design strategy will be done by analysing theories for designing this kind of patterns, extracting outcomes and design strategies from case studies, reinforcing the creation of the design strategy by design implementation. This research results indicated that the process of designing adaptive kinetic patterns has five phases: Design generation, Technology, Rationalization, Mechanism, and Materialization. Starting by design approach and specifications of the formal aspects of the designer, and how the designed pattern has been represented for following stages. Transforming the free-form and conceptual sketches into rational adaptive kinetic pattern joined with a supporting structure. Then selection of the technical machines aspects, processes, tools, systems and strategies. And finally taking decisions regarding the formal and interactive attributes of the structural system, the elements, and selecting materials.

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First of all, I am thankful to The Almighty God for guiding me in writing this dissertation. This work is dedicated to my parents, to my father who has always guided me through his clarity of view, his sharp mind and his uncompromising honesty. To my mother, who always prays for me, and has that generous kindness with whatever I pass through life.

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Jamil

Author's declaration

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1.0 Chapter one: Introduction

1.1 Overview and historical background

Architectural surfaces have been covered by patterns long time ago, after that, they have been expanded all over human artefacts. Probably, the first covered surface was a human skin that applied designed patterns. Patterns have an expansive and deep lineage. Due to the fact that their application has been developed, they earned new functions and missed their seniority functions, or different functions have imposed onto outdated functions. Patterns can improve the decoration, highlight features, camouflage elements in facades, or combining any of those (Schumacher, 2009).

Figure (1.1) human skin patterns: Papua facemask decoration and Chinese opera masks

Geometric patterns have fascinated human along history, designers had a fine knowledge about generating patterns' essentials for a long period before mathematicians devoted massive researches to this field, a distinguished paradigm has decorated by Moorish architectural style. All of the fundamental various kinds of patterns which could be shaped by identical tiles were found in the thirteenth century at Alhambra Palace in Granada, Andalusia, Spain, the mathematical categorizing has been actually done in the twentieth century. Present-day architecture produces a fabulous variation of new designs and three-dimensional patterns, however, architects probably will not always obtain the suitable tools at their disposal to recognize this kind of structures, this is a difficult and fascinating activity for mathematicians to fill the disparity between design and construction and innovate brand-new fabrication aware design tools for architectural software. Patterns are a tremendous field, even in architecture they are presented in many different software programs (Hoberman and Schwitter, 2008).

Collaboration has been made by architects with specialists for an early example of adaptive patterns in an architectural environment which is Garden of Eden Geodesic dome (1955), which was designed by Richard Buckminster Fuller who was a visionary thinker, the designer used two revolving domes inside each other, they were opining to the outside (Bonnemaison and Macy, 2007).

The opportunities for practical applications of kinetic architecture raised dramatically in the late-twentieth century as a result of improvements in technicians' skills, electronic devices, and robotics (Moloney, 2011).

Within present-day architecture there is a rising concern in kinetics. As verified by smart facades, the potentials are for a responsive skin that adapts to varying environment situations and user residence (Wigginton and Harris, 2002).

Figure (1.2) FLARE: Kinetic Membrane Facade

The term 'kinetic' in this context stands for having the capacity to be affected by reversible geometrical changes in whole or in part without losing the integrity of the system. When a kinetic structure is also adaptive, it gains the ability to respond to changing conditions, such as the weather, the time of the day, and the location of the sun.

Adaptive kinetic structures react to a changing environment, as well as generate their own. These conditions make them appropriate subjects through which the design and implementation of tools for 'digital prototyping' may be explored. Digital prototyping serves performance and simulation-based design. In general terms, it is an interdisciplinary integrated approach for modelling, predicting, and analysing the behaviour of a system, it is at the core of virtual engineering (Sanchez-del-Valle, 2005).

When an adaptable kinetic architecture responds by adjusting itself to a changing environment, it forms an ecological system. It is ecological because the system components have shifting interdependencies. Currently in architecture there is no single modelling and simulation environment that allows designing these structures in an integrated manner. There is also limited data about the actual behaviour of the systems and its consequences. The lessons afforded by the excellent examples built by many over time await full compilation and ongoing analysis for future use. This means that at the heart of any model or simulation is empirical research (Lee, 1999).

1.2 Aims and objectives

This research aims to create a framework that provides strategy for designing adaptive kinetic patterns within the digital modelling phase that implemented by parametric and generative design tools, for making changes in the spatial quality response of the building, in order to enhance environmental performance through daylighting passive design.

The framework will provide the strategy that can be followed for designing adaptive kinetic pattern within digital modelling phase.

Objectives

For achieving the research aim, the following objectives are required to be done:

1. To analyse theories in general that is related to adaptive kinetic pattern design, parametric generative design tools in architecture, and daylighting performance parameters.
2. To analyse contemporary adaptive kinetic patterns' projects that are related to the research aim, in order to extract design strategies from them.
3. To create a design implementation regarding the findings of the first and second objectives using a parametric generative digital design tool, for reinforcing the creation of the design framework.
4. To establish a design framework that provides a design strategy for adaptive kinetic pattern systems.

1.3 Study area and exclusions

Study area is focusing on theories for kinetic pattern design and its movement using parametric and generative tools. Usually, theory and practice have involved with kinetic design in terms of:

1. Designing kinetic patterns and patterns transformations within a virtual simulation environment (Tschumi, 1994).
2. Generative and Parametric design as a digital architectural design tools for designing kinetic elements (Leach, 2009).
3. Adaptive buildings configuration for reacting to environmental changes and specifically daylight (Holl et al. 2006).

Due to scope of research; this research had to narrow its focus in environmental performance, which was in research proposal 'creating an adaptive pattern that will be able to manage the problem of environmental changes; by controlling light levels, thermal performance, shading control, solar gain, ventilation and airflow control'. The focus on environmental changes has been narrowed to daylighting only, owing to lack of time and research capacity.

1.4 Dissertation Structure

Chapter one: Introduction

In the first part of this dissertation, a historical background is presented with aims, objectives, dissertation study area and exclusions, research problem and justification.

Chapter two: Literature Review

A literature review has relevant information and theories around kinetic patterns, parametric design, generative design, designing adaptive patterns, and daylighting attributes.

Chapter three: Research method and Implementation

Research method and implementation will discuss the way for approaching information, analysing the data, and applying the design implementation.

Chapter four: Literature-based case Studies

A number of designs that has been investigated and explored for their daylighting systems in order to get a valued principles from them.

Chapter five: Analysis and evaluation for case studies

Case studies analysed according to theories that based on extracted principles from the literature review, and the results of case studies' analysis will guide creating the design strategy.

Chapter six: Design Implementation and framework

Design implementation is an application for research finding to show examples for the created design strategy. A framework that can act like a map which can give coherence strategy for designing adaptive kinetic patterns.

Chapter seven: Conclusion and recommendation

Conclusions and recommendations made to involve in further investigation and research in the area of adaptive kinetic patterns, parametric and generative design tools.

Figure (1.3) Research process diagram

1.5 Justification and Rationale

The world of Patterns is one of the latest and fastest growing fields in architecture nowadays; many designers are creating a combination between patterns with software, sensors, and robotics, whether their focus are visual appearance or sustainability terms. Therefore, the justification for adaptive kinetic patterns is founded in the following reasons: economy of means, responsive towards the natural environment, and the satisfaction of human needs and desires (Sanchez-del-Valle, 2005). Developing daylighting usage decreases the requirement for artificial lighting and cooling, and has the ability for reducing energy costs by thirty to seventy percent. It also grants buildings more gorgeous, and increases occupants' healthiness and productivity (Kellum and Olson, 2003).

Adaptive kinetic patterns can enhance modulate efficiencies, broaden the contemporary aesthetic, and give it more relevant meaning. The declaration that architecture needs adaptive kinetic patterns responds to the profession's continuous search for adaptive design that supremely serves changing human needs as an interactive architecture (Sanchez-del-Valle, 2005).

Adaptive kinetic patterns design is still new in architecture and three-dimensional modelling field, an appropriate strategy for design these pattern is needed, in order to help designers improving their design skills and learn about this new field (Delagrange, 2006).

Kinetic structures needed to be modelled by a parametric generative modelling software, because they do not have a single form, but a continuous revolving shapes (Dino, 2012).

Research problem

The issue to be addressed in this research shall be how kinetic adaptive patterns will be designed using parametric tools for improving the sustainability of buildings by providing a proper daylighting, because there is no clear strategy for designing these kinetic patterns as it is still new to the field of architecture.

Pattern-based architecture elements spread from flexible skeletons and meshwork surfaces to structures that have the ability to change and respond according to design requirements, there is no clear criteria yet about designing this kind of responsive components (Akin, 1990).

Architecture has generally stood up against kinetics, up till now there is a few of movements rising at the field Present-day architecture produces a fabulous variation of new designs and three-dimensional patterns, however; architects probably will not always obtain the suitable tools at their disposal to recognize this kind of structures. This is a difficult and fascinating activity for mathematicians to fill the inequality between design and construction and innovate brand-new fabrication aware design tools for architectural software (Wolfard, 2006).

Patterns are a tremendous field, even in architecture they are presented in many different software programs. Lately, design tools and systems have been used for designing adaptive architectural applications, in order to enhance building performance, therefore, developing the usage of design tools is needed (Hoberman and Schwitter, 2008).

Development of generative design systems will certainly occupy the schema of the computational design in pursuit and theory; but architects do not always have the proper design tools for designing adaptive buildings, the capacity of parametric generative systems are still in exploring phase (Akin, 1990).

Designing through parametric generative tool is one of the main steps that should be considered when proposing and designing a kinetic element. The Potential of designing kinetic building elements using a parametric generative design tool is not explored in detail so far, and it is needed; in order to have a creative efficient adaptive design (Akin, 1990).

2.0 Chapter two: Literature review

Literature review have been divided into four parts for understanding theories of kinetic patterns design, parametric tools, generative tools, and daylighting features for achieving the main aim of this research.

The first part explains adaptive kinetic patterns, starting by underpinning this research with defining adaptive patterns, morphology, and kinetic architecture. Then, summarising kinetic architecture advantages, mechanisms and technologies, explaining timing, and transitions in place.

The second part is about parametric and generative design, it contains explanations for parametric and generative design, their software, how they work, and shape grammars, summarising reasons of selecting parametric design instead of computer aided design software (CAD), and last issue is design representation in parametric modelling.

Third part clarifying kinetic design influences through previous designs with variant of application places, and explanations for visualising pattern.

Fourth part describing the climate reacting of patterns, with a scope of studies on daylighting attributes which will be the main environmental concern in this research.

2.1 Adaptive kinetic patterns

2.1.1 Introduction to kinetic patterns

Kinetic architecture is a technique whereby structures are designed to enable elements of the building to move and revolve, without decreasing general structural stability. A building's capabilities for movement could be applied simply to improve its own aesthetic aspects, react to environmental issues, and operate features that might be unobtainable for a fixed structures. Architecture has generally stood up against kinetics, until now there are a few movements rising in the field. (Wolfard, 2006).

"Kinetic pattern is a transitory clusters, thickenings and gradients of motion" (Focillon, 1989).

The design of movement structures is commonly situated outside architecture sector, even though; there is a lot of fascinating technology prototypes and kinetic installation. Kinetic design strategy should be analysing the design of kinetics from the core, to identify the several specifications that have an effect on kinetic form and function (Moloney, 2011).

Figure (2.1) Kinetic pattern clusters

2.1.2 Morphology

Architectural morphology has been introduced by Philip Steadman in his book, the focus is on discovering the achievable range of designed shapes within geometric limitations, it is mainly engaged with restricts, which structure and their designs usually take. The usage of the phrase 'Morphology' refers to Goethe's root Term - Goethe refers to Johann von Goethe; a German poet and novelist – which means a common science of potential shapes, covering not only natural forms, but also forms in art, as well as the forms of architecture (Steadman, 1983).

Throughout abstract representations and combination of standard aspects of kinetics, the aim is to discover the theoretical area of kinetic form, having inferences that would go beyond present and past experiences. An obvious variation is required to be done between kinetics and further tactics to create a design for motion and time. Basically, architectural theory and practice have involved with mobility in terms of:

- Physical motion of the occupant.
- A sensation of motion as a result of the visual effects of changes in lighting or even the existence of humidity.
- The weathering of materials and also problems of corrosion.
- The representation of movements by form and surfaces that shows up animated.
- Design strategies which use geometric transformations or different motion methods.

Every one of these modes is outlined below, with the declaration that the majority are basic features of architecture, or comprise design approaches which have been misused along history. This part concludes a description of kinetics, which concentrates the range of this research to destinations outside these standard approaches to make a rise in architecture. The concepts here are designed outside the field of topic, to give an abstract reason for reference of the designers' concern about the poetry of movement.

The first aspect of mobility is important, due to the fact that architecture is experienced by the body in movement and by vision that is continuously changing focus.

The second manner happens where perception of motionless surface, form and space is changed by altering environmental situations. In this case, buildings may be designed to emphasise visual transformation in reaction to various light intensity and direction, the existence of humidity, and wind conditions (Marks 1993).

Regarding the third issue, at a totally different sequence of time the materials getting older, there is an extensive agreement for the advantage of materials attributes in creating deformation over time (Mostafavi and Leatherbarrow, 1993).

The representation of movement through animated form has relations to Italian Futurism and German Expressionism, buildings like Einstein Tower by Mendelsohn seem as if they are in motion, with a simplification for outlines and smooth continuous surfaces (Whiteley, 2003).

An advanced digital researches describe motion and time in architecture have been developed around strategies of geometric transformation, since they applied in design operation. Terzidis discusses that the digital tools expands this agenda by smoothing the simplicity of geometry (Terzidis, 2003).

The kinetic design result is moving patterns of geometry in stable condition of variation. While recognizing the continuous connection of the previous strategies for architectural theory and mobility, the concentrate in this case is on the impacts on design in cases where kinetics are in spatial conditions.

As illustrated in figure (2.2), motion has four geometric transitions in space: move, rotate, scale, and motion through material deformation. Move explains motion of an aspect in a vector direction, rotation enables movements of an object around all axis, whilst scaling represents expansion or contraction in size.

The geometric transitions in place: move, rotate, and scale, are the three basic kinetic types. Combinations of these, like move and rotation will create a rolling movement.

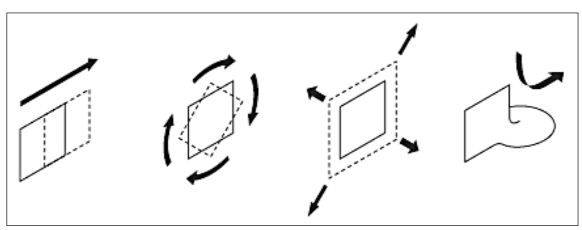

Figure (2.2) (Moloney, 2011) four geometric transitions in space

Material deformation

The definition of kinetics considered that material deformation is an additional category of complex motion, therefore, the objectives of studying morphology reflects pattern at a basic level and does not go through complex physics scale, the deformation of materials can be considered as combinations of geometric transitions, for example, melting wax can be considered as it is a complexes of moving and scaling. Due to the determinations of these experiments, kinetic types will be limited to the three simple geometric transformations and their combinations, this can results from the mixture of the similar base movement, such as rotate around the Z axis with an instantaneous rotation in the X axis, which results a combined twist. Otherwise, different base actions can be united, like moving along the Y axis and rotate around the Z axis that produces a fluctuate motion (Elbert, Musgrave, Peachey, Perlin, and Worley, 2003).

These are the primary establishing elements of kinetics, which are merged to generate more complicated movements, like a direction-based twist and roll. The last part of the explanation concerns the geometric transitions, wherever manipulation of materials' attributes, for example mass or flexibility enables additional deformation, this concentrating on transformation and deformation in spatial aspects allocates a difference between kinetics and what exactly have become generally known as media facades. The integration of motion graphics through projection monitors, LEDs or visual effects created by illuminating an exterior, are not included in the domain of this research (Cologne, 2006).

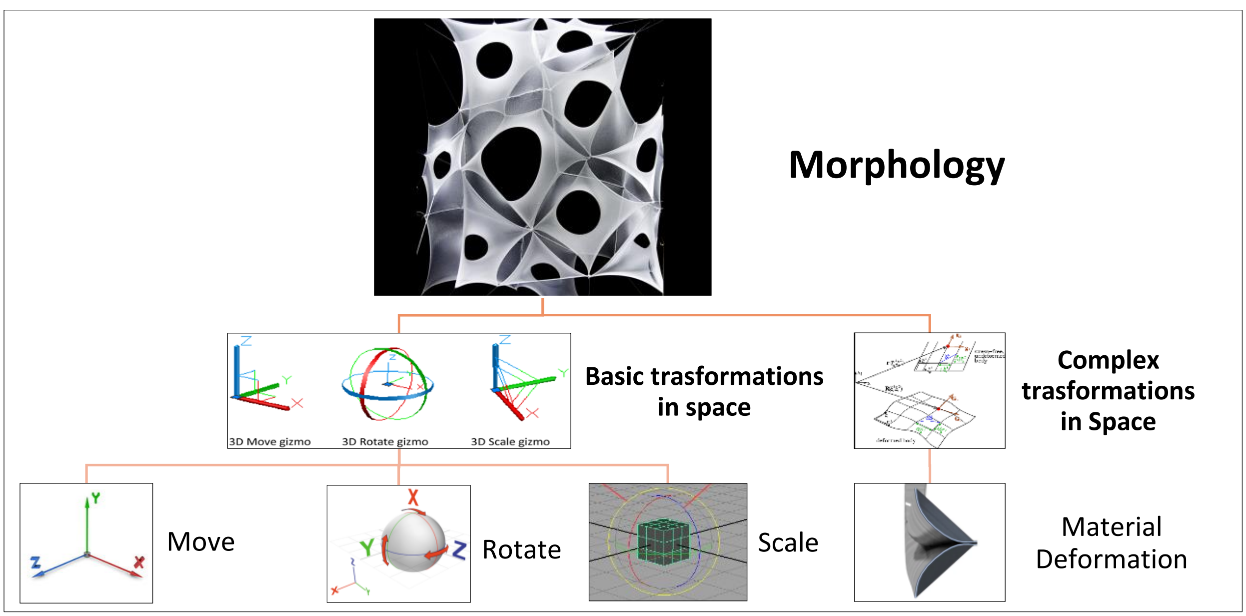

Figure (2.3) Morphology and geometric transformations in space

2.1.3 The prospect of kinetics

It is expected that by performing a detailed analysis of kinetic diagrams, certain development can be created for recognizing the possibility of kinetic stimulation for public surfaces in architecture. There are two types of architectural facades: smart and media facades, smart facades are interactive skins that adjusted for changing regarding environmental circumstances and user activities, while maintaining the same building efficiency.

Media facades, by contrast, employ technologies to consider facades as information monitors or even artworks at an urban scale. Facades are being adjusted as a space of interactive features, with the possibility to involve users with animated information screens or simply to establish abstract artworks. In any case of the design purpose, the developing scope of kinetic facades presents the challenge of developing advanced tactics for the design of motion. As proved by late experiments, when there is a technical development there is certainly a existence of the design of 'movement itself', this expression, which has its actual roots in the 1920, has made an improvement of kinetic artwork, emphasized the prospect and challenge for architecture. There is a capability to create new complex methods based on the design of motion (Miyake and Ishihara, 2006).

Figure (2.4) Media Façade

2.2 Parametric and Generative Design

2.2.1 Generative Design Systems in Architecture

Generative design systems grant formulation of complicated compositions, whether if it is formal or conceptual, through an application for simple series of equations and parameters. This new definition marks the development for innovative methods of design thinking. At this point, the main problem lies in the enlightenment of computation as a tool that supports the designer's capabilities in the perception and productivity of design artefacts in the contemporary architectural agenda. Parametric design is a computational process that can work as a generative or as an analytical method during design realization, and it has lately achieved great approval from scholars, professionals and researchers. However, this swift concern resulted to an excessive and shallow application of parametric essentials (Ahlquist and Menges, 2011).

According to Leach, there are two meanings for design: it means the process of designing an object (The design in this situation is an activity), and the design object as an outcome of the design process (The design here is an artifact), this difference is great when creating a design by generative design systems. A generative system is a production system that does not make the design artifact, but rather specifies a higher-grade specification that determines the creation of the artifact, or the design procedures. Therefore, generative systems made to outstrip formularization over form, which point out an essential change from the modelling of a designed object to the modelling of the design's logic. As such, generative systems need authorization for some design intelligence and actions from the user, thereby, assume the degree of automation. However, the generative system does not means to be the designer, but some of its working intelligence has been considered and encoded into the generating system by the user, to progress a specific design tasks or solve design problems. These specifications can be rules or constraints. (Leach, 2009).

2.2.2 Generative design dialectics in architectural design

According to Hanna and Barber, an analogue generative tactic simulated by Jean Nicolas Lous Durand, he has applied a various series of building elements in order to create a Neo Classical architecture (Hanna and Barber, 2001).

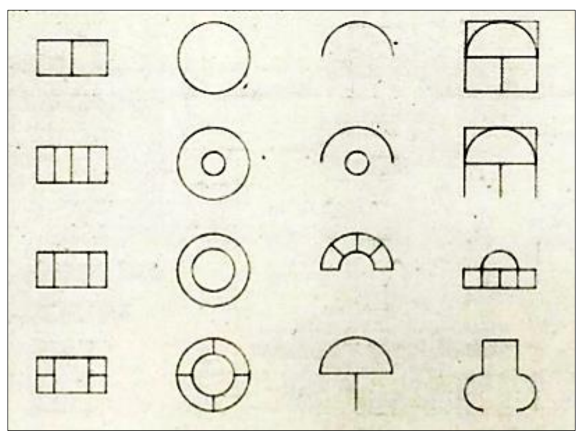

Figure (2.5) Jean Nicolas analogue generative technique

Before using computation in architecture, Le Corbusier's Five Points of Architecture (which constituted his style) have been counted as examples of analogue generative systems. (El-Khaldi, 2007). Another contemporary example, Peter Eisenman's usage of analogue transformational principles has been used in architectural design configurations. Eisenman's design concept works on a system that allows creative actions, generates unlimited number of dialogs, and makes unlimited use of words, Eisenman reflected this exercise on the design of a set of residences (Hays, 2000).

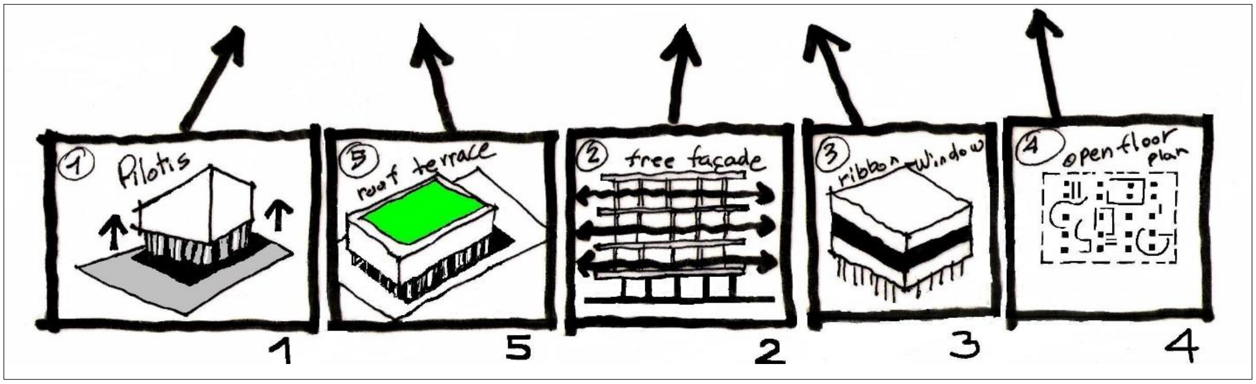

Figure (2.6) L e Corbusier's five points of architecture

Four elements are required to form the generative design process: input is first phase, starting by setting parameters and conditions, the second phase is generation technique using algorithms and set of rules, the third phase is output, it is the action of generating design alternatives, and the last phase is selecting the most efficient design, the design artifact cannot be achieved until the fourth phase, thus, a generative system is a production system or actually a representational simulator (Kolarevic, 2003).

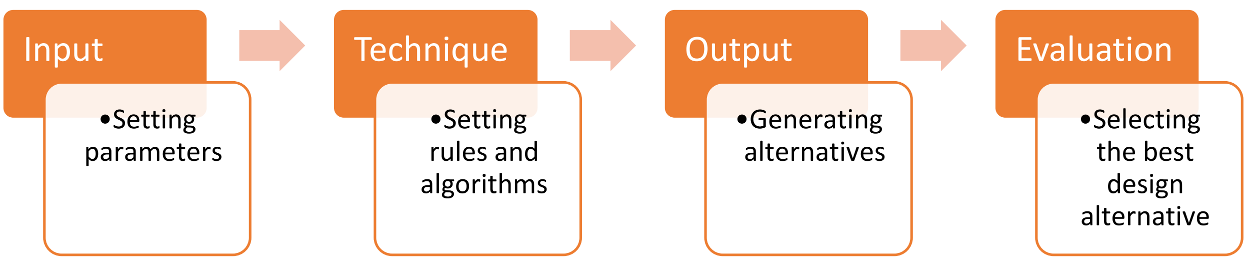

Figure (2.7) Generative design process

Generative systems can be generally identified into two classifications: linguistic and biological (Shea, 2004; Oxman, 2006; Arida, 2004). A linguistic system is a grammar-based formalism where a number of compositional principles (syntax) control and form the design (semantics). The computational application of linguistic generative systems mainly displays itself in shape grammars. Shape grammars determine and apply a collection of essentials on an original shape to be able to generate new complex shapes and geometrics out of it. According to Knight, shape grammars are descriptive and generative rules that have modification basis which can formalize the required shapes out of the original generated design, and generate alternative designs (Knight, 2000).

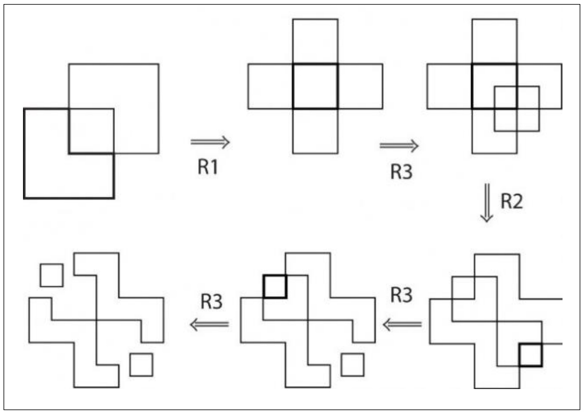

Figure (2.8) Shape Grammars

Biological generative design systems, otherwise, embrace an alternative generative approach, which consider nature and complicated living creatures as a model and applies its rules in the interpretation and transformation of architectural form (Hensel et al., 2010). Furthermore, Vincent emphasized that the main focus should be on generative design form transformation instead of the result shape itself (Vincent, 2009).

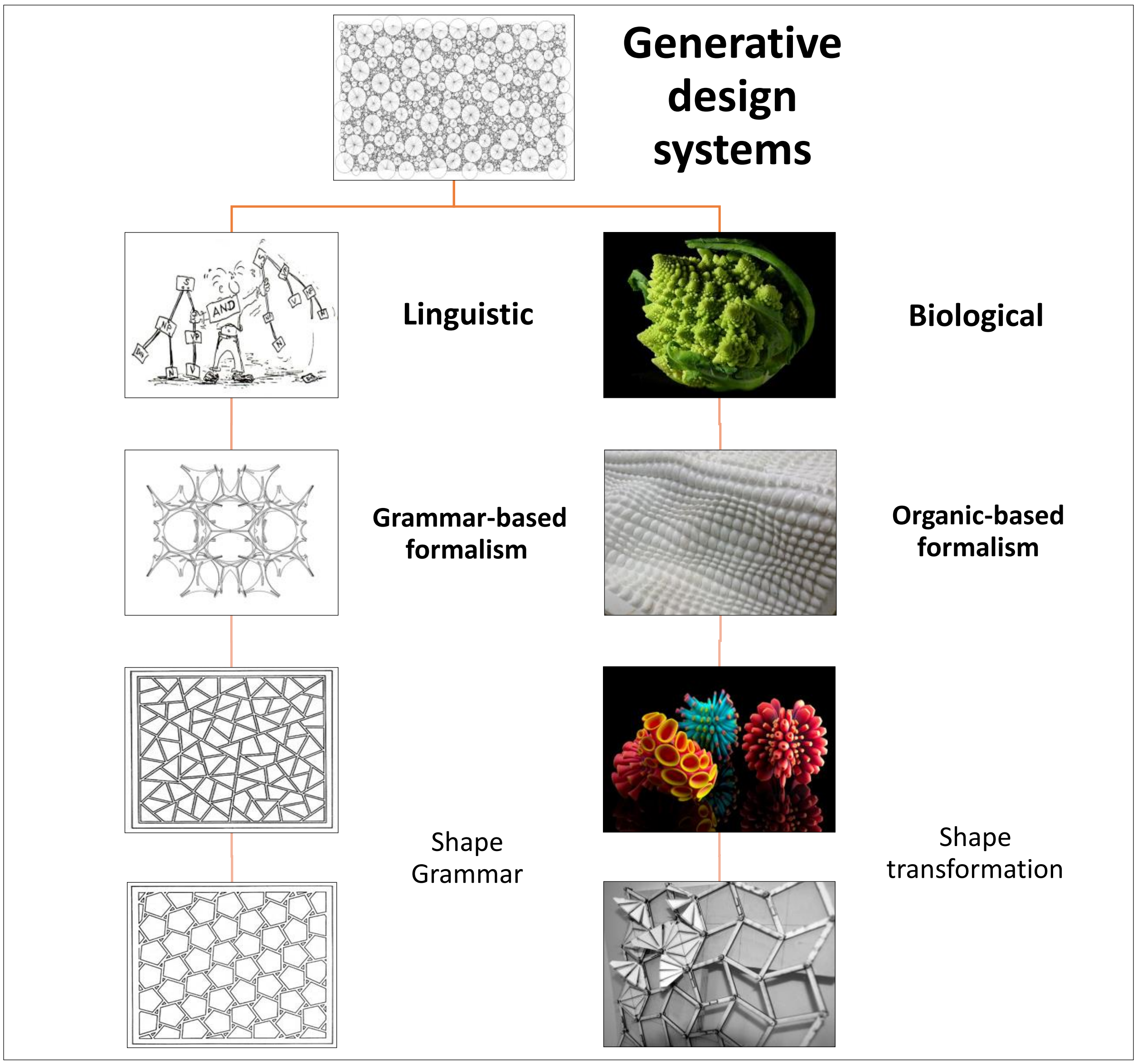

Figure (2.9) Generative design systems

2.2.3 Parametric Design Systems

Parametric systems are fundamentally based on algorithmic basics, subsequently, it is necessary to discuss the role of algorithms and algorithmic rational in design. An algorithm is a defined series of instructions that seek to achieve a particularly defined objective in a restricted number of phases. It takes one value or a set of values as an input, performs a set of computational calculations that convert the input, and lastly produces one value or a series of values as output (Cormen, 2001).

Algorithmic intelligent and algorithmic design have much relevance to the concept of generative design. Terzidis discusses that the strategy of algorithms can seeks generative processes or can emulate complicated phenomena. Algorithms can be considered as add-ons to the individual perception, and may simplify exploring the areas of unexpected potential (Terzidis, 2011). Burry proposes two reasons for using scripting in design: enhancing output to duplicate faster, and earning control over design to unleash the designer from the constraints of black box modelling software. Design structure can be generated and manipulated computationally by Algorithms, like data synthesis that consists of statistics or geometrics. This level of domination over the design in a three-dimensional modelling platform grants the extensive functionality, or classify particular conditions and respond properly, thus, an algorithm can efficiently deal with series of design with accuracy, and interpret these into architectural attributes. Parametric design is a part of algorithmic design, and is precisely based on algorithmic structure, there is no variance between algorithmic and parametric systems, because algorithmic process operates on parameters, and essential configurations of a parametric system are the algorithms, they are called program or definition. This little distinction between algorithmic and parametric design appears itself only during design operation, when the designer changes the parameter values to manipulate the design form, in order to have the most suitable design solution (Burry, 2011).

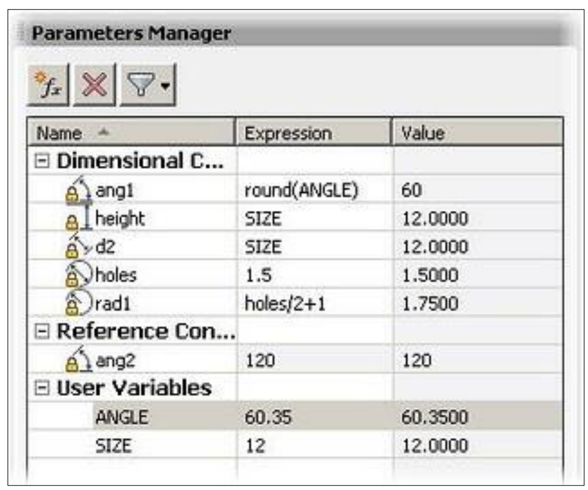

Figure (2.10) Design parameters manager in parametric design software

2.2.4 Exploring parametric logic-based design

The main purpose of traditional computer aided design tools is the representation of the final design result, and they depend on single-case design. Furthermore, parametric modelling as a design tool allows changing in the design space for the sake of exploring more alternatives for the same parametric model. The design standard expression in parametric design grants the designer exploring the variation of design preferences over time, revisit prior design alternatives, and improving the design process throughout the design process (Aish and Woodbury, 2005).

Parametric modelling enable simplicity to explore designs by assigning the automatic generation for a category of substitutional design solutions. A change in an input parameter stimulates a synchronized modification in the form, generating alternatives on the form while preserving the tacit consistency of the design (Vanucci, 2008). Parametric modelling converts this feature of kinetic pattern design into a new and strong expression (Schumacher, 2009).

Similarly, Oxman indicated that "associative geometry may support a design approach in which a geometrically, or tectonically defined series of dependency relationships is the basis for a generative, evolutionary design process. One can manipulate a particular shape or form and study many alternatives by changing the variables, or parameters, defining the geometry of an object or composition" (Oxman and Oxman, 2010).

Parametric modelling deliveries exceptional opportunity in handling performative aspects in architecture, in the form of a tool that enables the navigation of the parametric browsing environment with regards to measurable implementation specifications. Computational tools particularly parametric design can assist refined and dynamic co-ordination of cross-disciplinary intelligence that has been handed out across variety of analytical tools and techniques (Kocatürk and Medjdoub, 2011).

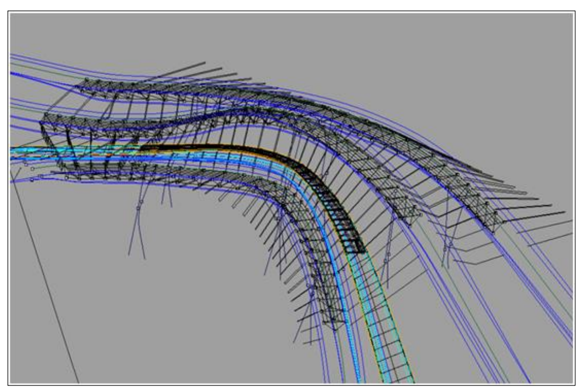

Figure (2.11) parametric modelling using cad software

2.2.5 Design representation in parametric modelling

Design representation has constantly been treated as a critical factor in improving design knowledge and exploration, Akin indicates that architecture is a representational field that filled with problems, declaring two different types of representation in design: analogue and symbolic (Akin, 2001).

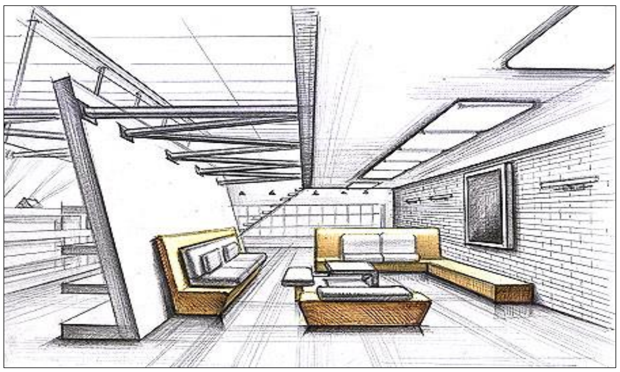

Figure (2.12) Analogue representational design

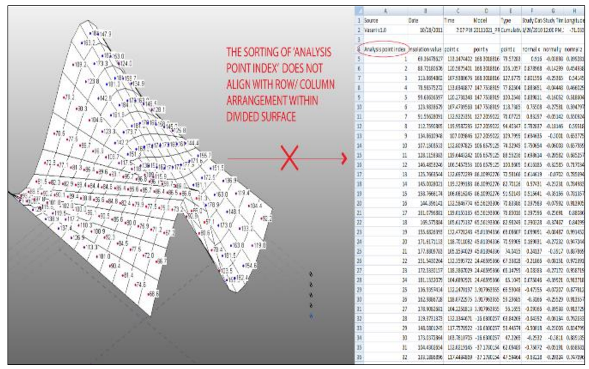

Figure (2.13) symbolic representational design

Analogue representations are illustrations, sketches, physical and digital models, which have a strong conformity to reality, they provide facilitating the valuation of significant design efficiency matters such as structure, context harmony, and constructability. On the other hand, Symbolic representations are physical or mathematical explanations related to the explanation of performance, for example heat transference, light and sound distribution etc. A parametric system can be considered as a tool to intermediate among the content of both analogue and symbolic representations, taking the practical information about form, graphical knowledge on formation, and performance in the introduction of algorithms and parameters. Consequently, parametric design tools specify several views of the design space.

On the first side of modelling program, there is a three-dimensional model view that shows the geometric (analogic) representation, on the second side there is always an editor that enables the designer to encode the algorithm, specifically the strategy, and this editor is possibly textual or visual. Visual editors like Grasshopper 3D (Grasshopper 3D is an add-on for Rhinoceros by McNeil and Generative Components by Bentley) have a common usage as a result of the low standard of technological knowledge needed on programming languages. At this point, the scheme depends on a focused graph data structure, where the graph nodes are geometric elements or parameters, so the edges are the approaches of the one-directional data transformation.

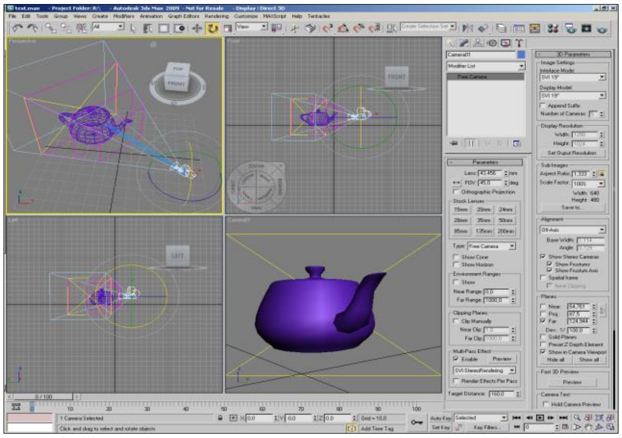

Figure (2.14) modelling program platform for 3DS Max software

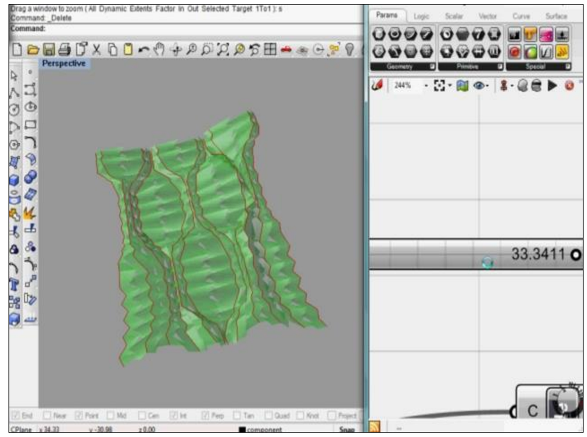

Figure (2.15) Grasshopper 3D modelling platform

Therefore, parametric systems simplify a multiple interaction between the geometry that is the primary design representation, and the symbolic design requirements (Dino, 2012).

Parametric design tools highlight a collection of design approaches, instead of supplying the designer with a thorough framework of technologies or rigid tactics. It also provide the possibility to transform the technique of design by computational design, instead of to just expand or change designers' applications for parametric generative systems (Akin, 1990).

2.3 Designing Adaptive Patterns

2.3.1 Motivations

Kinetic design appeared from the path of contemporary architecture, strategies are discovered to connect digital desirability with present-day parametric design, provided by current experimentations of the free facade in movement, this recent design space has discovered from the definition of morphology. By concentrating on the primary parameters, they are connected together in order to create moving forces of kinetic pattern, and performing the transformation which is essential when designing patterns.

The product of kinetic design is not a single result, but a strategy from which a series of results reveal over time. This requires designers to consider the design of control system and data input, and the design of the physical elements. It can be expected that the conceptual model has established in phases which can support designers and academics to discover the several factors that have impact on kinetic configuration. By using systematic indexing and axiomatic exploration; an example of these aspects is employed here to form design implementations, these implementations produce abstract patterns, visualized orthogonally by the abstraction of animation software, intentionally presented in the form of images that create a variety of design patterns to organise a starting group of visual references. The animations obviously do not record the phenomenology of architectural knowledge (Rickey, 1963).

2.3.2 Operable structure

When the most important parametric parts are found, the variables are consequently advanced in more detail, adjusted to recognise algorithmic tactics for generating pattern. This simplifies a systematic approach to the creation of animations that are generated to visualize the resulting pattern. The transforming nature of kinetics gives a challenge to visualize these experiments, method here is used to develop the traditional study drawings of a pattern, and this technique of design study has been broadly used to rise complex methods for static architectural designs. Classically, drawings outline has substantial related relationships when specifying window fenestration and sectional shapes, with fast shading systems engaged to propose three-dimensional satisfaction (Vesely, 2004).

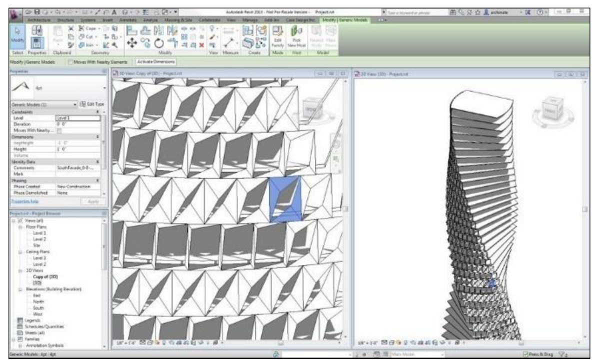

Figure (2.16) generating animations for design by Autodesk Revit software

They are not proposed to represent the involvement of the constructed pattern, but work as abstractions, diagrams of relationships between parts, profiles, and surface effects. In a similar manner to such drawings, the planned animations that result from these experimentations are illustrative, as compared to a more effective tactic to digital visualization. The deliberate implementation of a non-realistic style is meant to emphasis attention on kinetic pattern, independent of physical scale, materiality or metaphorical relations, which is included in the structure of the experimentations (Herbert, 1993).

2.3.3 Present-day experiments

While Veinel Korkmaz discovers the potentials of umbrella-like structures (Korkmaz, 2005), the kinetic of such works is typically a monolithic translation or rotating motion, as sections slide or fold back within the main construction, while they deliver a decent analysis of the several kinetic processes, this emphasis on the mechanism reflects typical design exploration in this arena. In most cases, dynamic structures are regarded and assumed as engineering solutions, and the compositional features of the design are less important (Ban, Ambasz, Bell, and Wood, 2005).

Figure (2.17) Umbrella-like structures in Al-Madina Al-Monawara Mosque

Another sun-shading pattern in Madrid, which was done by Foster and Partners consultant, proposes another compositional tactics to a remarkable movement characteristically related with these dynamic structures. As visualized in Figure (2.1) and (2.2), each hexagonal sunscreen contracts autonomously into a complete triangulated grid, while the simulation displays a steady centre-to-edge configuration, the various direction of the hexagonal forms add a further complexity that is not gladly probable. The systematic centre-to-edge transitive motion is improved by the contrasting direction of the separated portions, additionally, the self-directed movement of each part possibly permits a series of non-uniform arrangements from centre to edge (Craig, 2006).

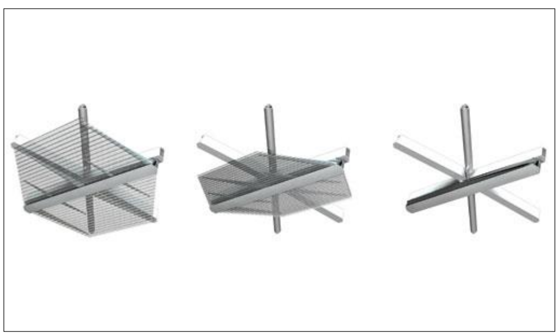

Figure (2.18) (Moloney, 2011) Analytical drawing of adaptive shading for the Ciudad de Justicia, Madrid, by Hobermann Associates

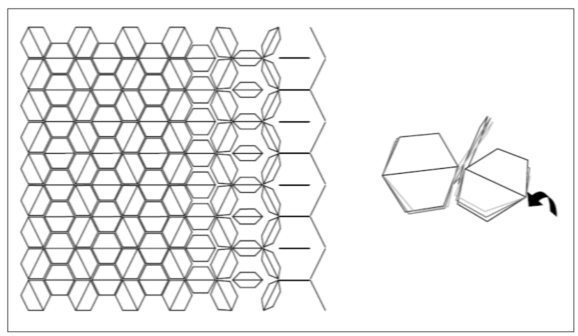

Figure (2.19) (Moloney, 2011) Analytical drawing of adaptive shading for the Ciudad de Justicia, Madrid, by Hobermann Associates

Design variables

Determination of animation experimentations is to generate patterns at the level of abstracted morphology, these issues can be generated algorithmically and parametrically, even though, it could be probable to connect real data sources like temperature, pedestrian movement or economic orientation. For kinetic patterns, animation is the relation between arrangements of kinetic parts, gathering or spreading of pattern along a facade, which is expected to be the main impact on pattern forming (Barratt, 1980).

It has been planned that the significant variables for pattern at an architectural scale would have the most impact on the spatial gathering or spreading of related kinetics, in conclusion, it is suggested that the determinations of generating pattern variety, and the type of kinetics requires to be considered, while bearing in mind that pattern has non-specific scale relationships between parts. The control level was expected to have the highest impact on pattern morphology, furthermore, these control variables established the full range of cyclic structures, it was debated that transient scale is fewer important in aspects of the pattern structure forming (Gibson, 1950).

Visualizing pattern using generative design

The aim of experimentations is to algorithmically generate an extensive series of movement patterns for kinetic facades. These will be visualized as computer animations in a purposely non-photorealistic style of representation. Undoubtedly, there are several small differences that would limit understanding of a facade when constructed, however, while recent tools enables photorealism, this method is not considered suitable in software viewports. The main focus should be on the important features of patterns instead of the small differences of surface details. In conclusion, the tactic is related to old-fashioned techniques used for the design of static patterns, where normally there is a collection of sketches that discover complex concepts. They are regularly line drawings undertaken by hand or formed on a drawing board, occasionally they are incompletely rendered to propose three-dimensional satisfaction (Gibson, 1950).

2.4 Adaptive patterns and daylighting

Adaptive buildings change their configuration in real time by reacting to environmental changes, while adaptive applications can be efficiently applied to an extensive scope of building systems, by controlling levels of light, solar energy gathering, and thermal performance. Adaptive systems decrease energy usage, enhancing comfort, and increasing built environment sustainability. Adaptation manage the issue of climate changes, to cover this rising challenge; manufacturers create products, systems, and tools that can reach higher standards of sustainable performance. Systems can make visual effectiveness while they providing performance advantages that would be appropriate for any building form, climate or context adaption can be customized by pattern for particular building designs and needs. As an example for adaptive patterns, constantly evolving patterns that contain surfaces with translucent framed screen that can shift and evolve will create a dynamic element that adjusts light, ventilation, airflow, and privacy. Patters usually consist of a combination of packed panels that can be constructed by several metals or plastics. Patterns can form a kaleidoscopic visual presenting aligning, and then spacing into a smooth, swift, and spreading mesh (Hoberman and Schwitter, 2008).

Daylighting performance parameters

Performance parameters represent a daylighting technique which are surrounded by the environment of a particular structure, which enable the designer to decide if a system needs to be employed in order to attain the design aims. Parameters comprise visual performance, convenience, construction energy usage, economy, and also systems integral. The most important energy-concerning design purposes of a daylighting technique are to deliver useful daylight for a specific weather or structure kind for an essential period of the year that permits artificial lighting to be neutralized by natural daylight, air conditioning and heating systems loads to be decreased (IEA, 2000).

2.4.1 Visual performance

Visual performance parameters are employed to decide if the provided lighting situation enables view or visibility and are directly linked to the physiology of the eye. Usually, decent vision is described by a sufficient amount of light for the predictable visual process, steady illuminance, luminance distribution, appropriate directionality to model three-dimensional series of faces and masses (direction of case light from the sides or from above), the non-existence of glare, and suitable comfort to render colours precisely when needed (IEA, 2000).

Illuminance
Illuminance is the whole illuminating influx fallen on surfaces per unit area, it is actually a measurement mode for the amount of the fallen lighting that illuminate the surfaces, wave-length measured by the brightness purpose to interact with epidermal illumination perception (IEA, 2000).

Distribution
Illuminance and luminance distribution is a quantity of in what manner lighting differs from spot to another towards planes or surfaces. For good field of view, it is suitable to have a few amount of consistency towards the action planes. Bad visibility and visual harassing possibly will consequence eye enforcement to adjust itself very rapidly for an extensive domain of light levels (IEA, 2000).

Glare
Inappropriate glare is actually occurred whenever intraocular light (Intraocular is the fluid pressure inside the eye) spread takes place inside the eye, the difference in the retinal picture is decreased (usually at a lower light levels), and eyesight is partially or even completely obstructed, for example, once the eye faces front lights of approaching vehicles) (IEA, 2000).

Distress glare is an experience of irritation due to large or non-uniform distributions of radiance in the range of sight. The physical system of inconvenience glare usually are certainly not properly recognized, an evaluation of inconvenience glare is depend on volume, luminosity, and quantity of glare sources (IEA, 2000).

Directivity

For many tasks, sufficient directivity is needed to model and assess three-dimensional masses and faces, the higher the quantity of diffused light, the lesser amount of shadowing takes place, decreasing ability for an occupant to assess the depth, form, and texture of a surface. A balance between scattered and directional light allows an occupant to determine the surface softness, glossiness, and other attributes (IEA, 2000).

2.4.2 Visual comfort

Visual comfort involves person reactions into a lighted atmosphere which has real vision standards, such as psychosomatic factors, light has impacts on individuals' particular feelings towards atmosphere. Small studies have been carried out to allow limitations of the visual comfort supplied by progressive daylighting techniques, intellectual aspects like consideration, expectation, and adjustment may impact on individual's capability to understand objects and detect surfaces (IEA, 2000).

Outdoors view

Windows are extremely appreciated for their sights of the natural atmosphere and for their link to outside, motion and modifications in light amounts during the day may be rationally relaxing or refreshing, and views of attractions or sights can enhance feeling the place (IEA, 2000).

Appearance

Patterns of daylight can impact an individuals' aesthetic judgments of the surrounding's consistency, clearness, mystery, and locative complexity. Designers have used sunlight in order to have an excellent artistic effects to emphasize space or to produce spiritual effects, daylighting do not often generates haphazard patterns, which may regularly created by electrical illumination solutions. Nevertheless, pattern of lights and shadows can make disruption and difference in the field of view, daylighting systems that make regions of extremely deformed or symmetrical patterns must be applied cautiously (IEA, 2000).

Linguistic generative design systems can provide a good pattern appearance by creating a geometrical or a kaleidoscopic visual representation especially when using shape grammar (Knight, 2000).

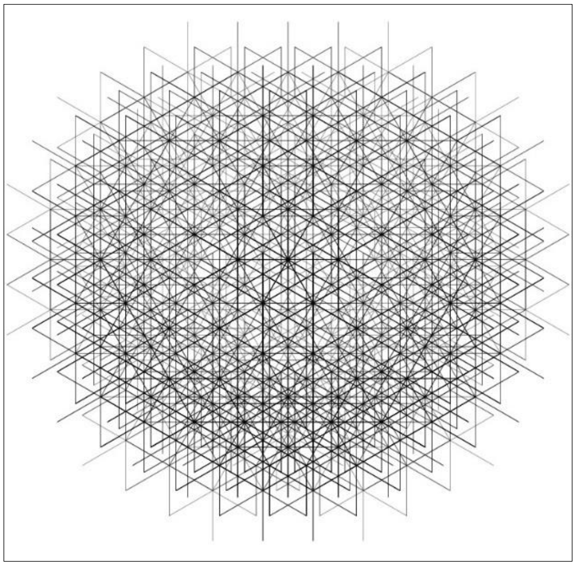

Figure (2.20) Geometric pattern that creates an aesthetic appearance for daylight shadows

Colour
Real colour rendering is significant for projects that include colour corresponding, quality regulation, and precise colour insight. Commonly, fewer changes in daylighting system colours will be more desirable technique (IEA, 2000).

Privacy
The level of privacy provided by daylighting system may be hard to measure, because privacy relies upon the related illumination of indoor in comparison to outdoor and understanding occupants' privacy (IEA, 2000).

Social performance
Daylight atmosphere stimulates an emotional reaction that has impacts on the temper and social performance of an occupant, direct sunlight can be refreshing as a result of its non-uniform luminance spreading, directionality, flexibility, and radiant variability (IEA, 2000).

Health
Daylight can has health benefits on body and temper, its temporary variance can be utilized to struggle jet lag and sick building syndrome. In certain weathers, daylight systems that deliver more illuminance throughout the wintertime and fewer through the summertime (in opposite quantity to daylight convenience) are assumed more desired, to counter the impacts of periodic affective defect (IEA, 2000).

2.4.3 Energy saving

Lighting energy
From the energy efficiency point of view, daylight balances the requirement for electrical illumination by delivering sufficient amounts of activity or ambient illuminance. At the most basic standards of analysis at assumed depths for the wall that contains windows activity conditions, solar situations, and illuminance enhance the energy efficiency for daylighting systems (IEA, 2000).

Thermal comfort
Daylighting systems can impact on thermal comfort in a many conditions, windows temperature has effects on thermal comfort, low temperature can decrease thermal comfort in wintertime because of long-weave radiative swapping, and the same for high temperature at summertime. In certain situations, direct sunlight may maintain a better thermal comfort through the

wintertime, in general, the thermal comfort of daylighting systems can be examined by basic methods, and moreover, features that manage direct sunlight must be accessible. Insulated openings increase inner windows surfaces' temperature ranges and enhance comfort, regional specifications and rules that determine suitable surfaces temperatures, direct sunlight adjustment, etc. must be adopted (IEA, 2000).

2.5 Literature review main consequences

Main essential aspects can be extracted from the literature review in theories of designing adaptive kinetic patterns:

Morphology discovering the achievable range of planned shapes within geometric limitations, it defines the pattern spatial transformations which are the principles of creating a kinetic element. Spatial transformation has three basic geometric transitions in place: move, rotate, and scale which are merged to generate more complicated movements, like twist or roll. Motion through material deformation is considered to be a complex geometric transformation.

There are two types of architectural facades: smart and media facades, media façade do not create a real kinetic patterns as it does not create any spatial movement.

Generative design process has four phases, input is first phase, by starting setting parameters and conditions in designing patterns. The second phase is generation technique, using algorithms and set of rules, like algorithms that is related to sun path. The third phase is output, it is the action of generating variants, which is creating the movement of adaptive pattern over time and parameters change in this design case. The last phase is selecting the most efficient variant, this phase is excluded from designing adaptive kinetic pattern; due to the fact that there is no choosing a single parametric design outcome, whole generated designs will be considered as a design outcome. When designing adaptive kinetic patterns, four phases are required to be done in order to create a complete design process.

Generative design systems divided into two types; linguistic and biological. Linguistic has a grammar-based shape formalism like shape grammar, on the other hand, biological has organic-based shape formalism and it is has its own shape transformations. Shape grammar determines and applies a collection of adjustment essentials on a starter shape to be able to generate new advanced design that will give the designed pattern forms more complexity. Both systems can be used to form a kinetic pattern shape.

Representational design has two types: analogue and symbolic, both of them are used in designing adaptive kinetic patterns, analogue as an initial phase of design, and symbolic as a main phase. Kinetic mechanism and technology are linked with the theme of mobility to create the representation of movement through animated form.

Timing is a main aspect in designing kinetic patterns, for adaption, the design has to create a relation between sun and pattern movement, that will be done by tracking sun and consider it as an attraction point that influence pattern motion, or by creating a timer based on space occupants' comfort.

Controlling the illuminance, distribution, glare, and light directivity by adaptive patterns depends on the spaces between pattern surfaces which can be adjusted by pattern movement, pattern material like perforations density, and windows' glass kind. In a parametric or a generative software, controlling visual performance should be customized to make to deliver the suitable lighting properties for any location in the world.

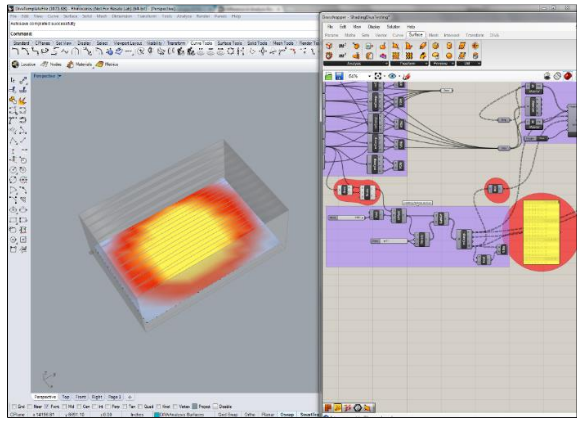

Figure (2.21) Visual performance parameters controlling parametric design software

Illuminance unit is (Lux) or (lx), suitable daylight illuminance is more than 100 lux and less than 2000 lux. Studies indicated that the illuminance that comes from windows is about 450 lux/m² and above, every space has its own illuminance standards, for example indoor offices need about 850 lux/m² (IESNA, 2000).

Designer should calculate the glare by daylight analysis software parametrically, glare should not exceed 45 percent, and it is preferable to not be below 30%.

Figure (2.22) daylight glare probability analysis by parametric software

Privacy can be customized according to the required function, adjusting the spaces between pattern surfaces will change the privacy level. Appearance and colour can be controlled by parameters that vitiate according to the design concept. Outdoor view can be maximised and minimised regarding the spaces between pattern surfaces.

Social performance, health, and energy saving are controlled indirectly, they will be changed as a result of varying previous parameters. 24 °C (75 °F) is declared as the most comfortable room temperature (Olesen, 2004).

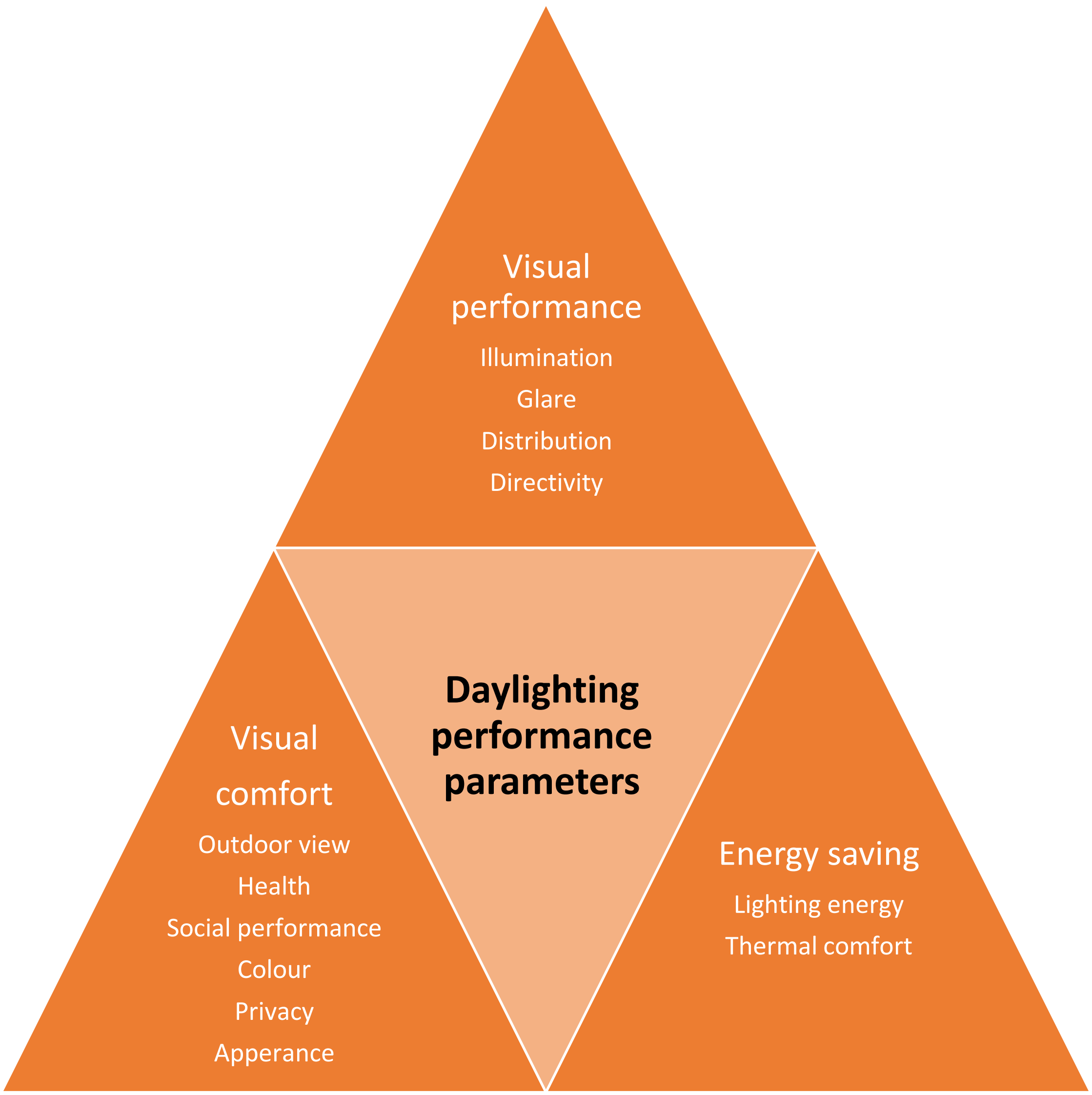

Figure (2.23) Daylighting performance parameters

In conclusion, kinetic adaptive patterns have a theoretical design strategy allocated by generative design process, pattern morphology is defined by generative design system, if the system is linguistic; morphology will be based on grammar formalism that generates complex geometries, on the other hand, if it is biological, it will has a nature shape formalism.

Daylighting parameters and rules will be defined in the generative design process within input and technique phases. The representation of the design process has an analogue and symbolic types that presented by parametric design software.

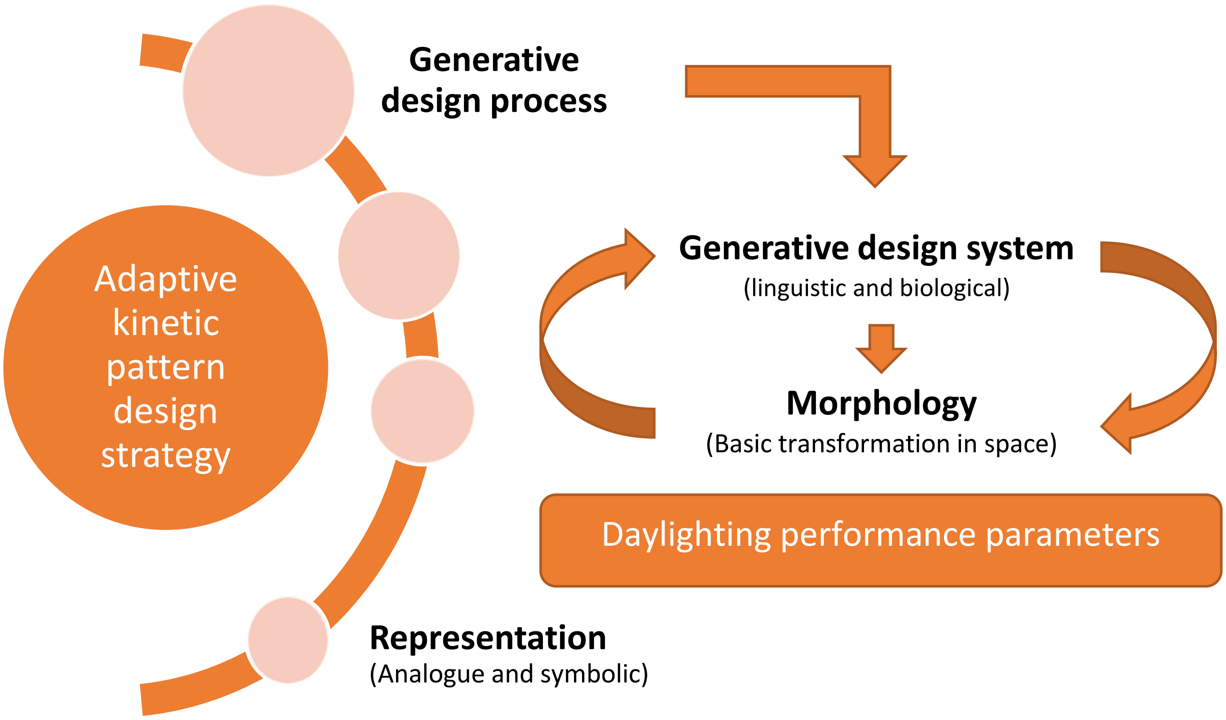

Figure (2.24) Adaptive kinetic pattern design theoretical strategy mind map

3.0 Research method and implementation

3.1 Introduction

Research methods and implementation chapter will present the selected research methods for this research that are suitable for approaching the main aim and objectives of this research, including justification for them.

Research method

There are several methods for research which can be assumed to achieve the preferred facts, it is essential for the researcher to dominate these methods in order to assist him to employ the finest methods consciously. In general cases, limitations and obstacles permanently happen in finding resources for the research, therefore, regularly only single method will be taken (Fellows & Liu, 2008). The following are the planned methodology and research methods to be used in order to achieve the research aim:

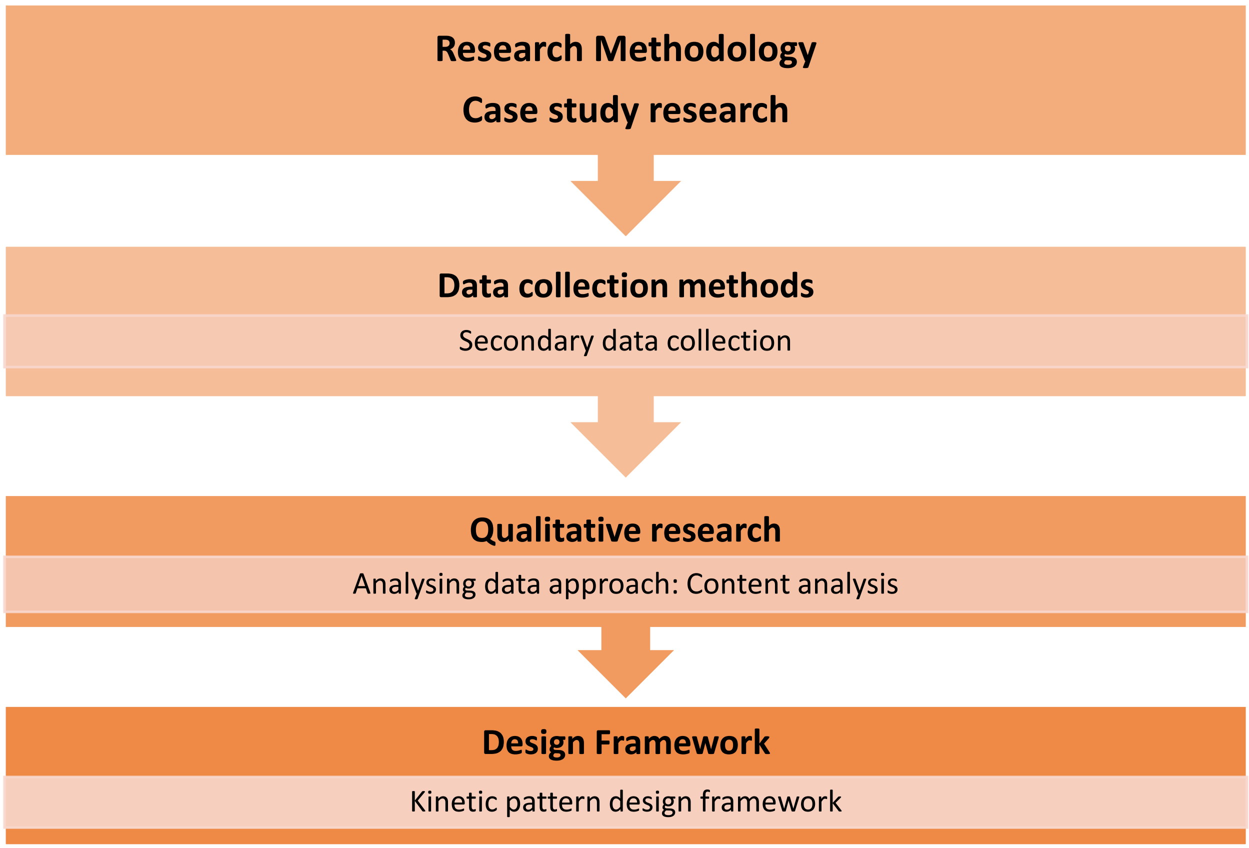

Figure (3.1) research methodology and used method

3.2 Research approach

The author discovered that inductive method is the appropriate approach to be used in order to achieve research aims and objectives. Inductive method diagnoses a situation, showing other choices, and discovering new concepts especially with a subject that still needs to explore. By working on the basis of inductive research method, researcher will be able to achieve wide and deep understanding onto the research area which is still properly unclear, to discover new information and find durable logical strategies to add on to the contemporary studies and future researches (Gray, 2004).

Briefly, according to the selected research subject and objectives this research is considered and developed to be done logically with the inductive research method.

3.3 Case study research

Case study method can be adopted for a lot of topics, as well as common subjects, projects design, and implementations. According to Stake, a case study can considered as a precious research method in adding to understanding, spreading experience and rising faith about a topic (Stake 2000). A case study explores topics and subjects where relations may be unclear or inexact, so a case study is more regularly used qualitatively (Yin, 1994).

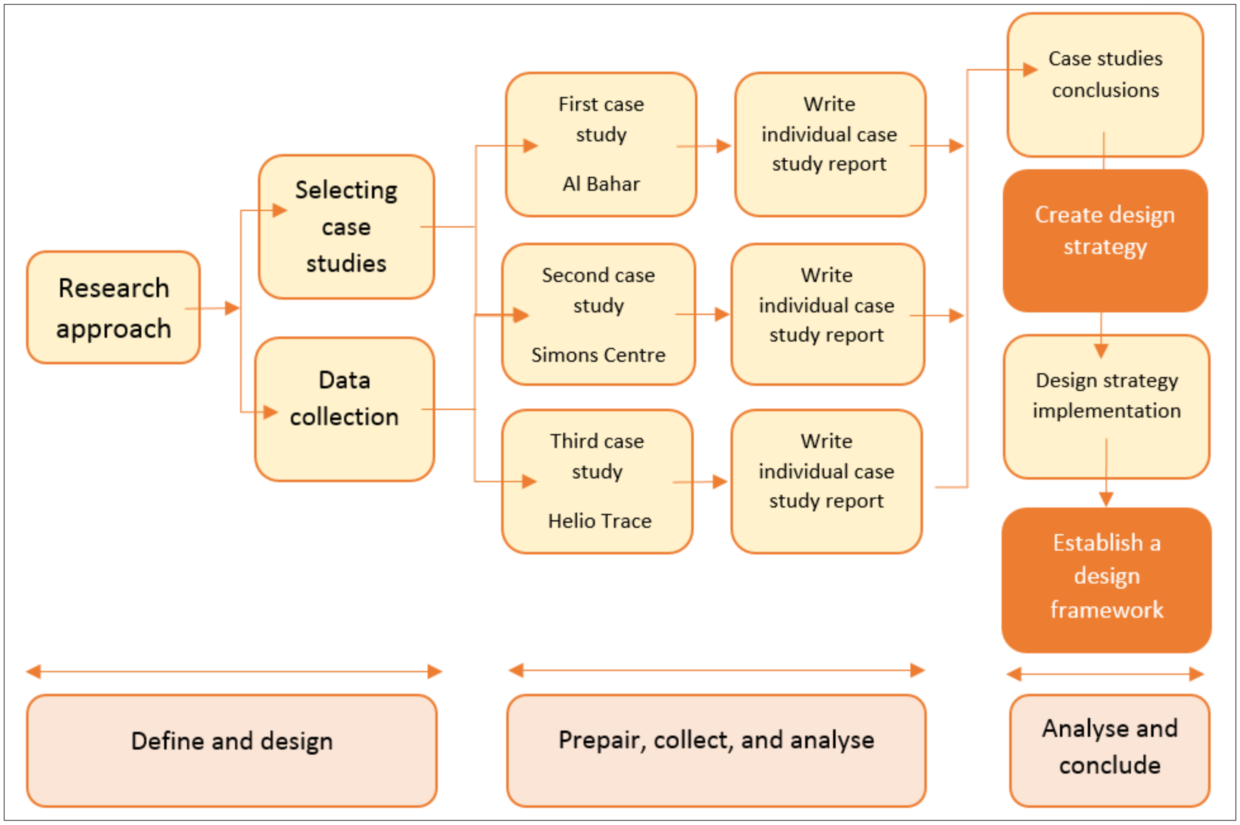

Figure (3.2) used multiple case study method

To maintain the precision, using the inductive approach, this research will take several case studies instead of basing conclusions on a single case, when a single case study been studied, it might not be appropriate to make a decent argument for covering the entire research. Inductive approach does not confirm or disprove a theory, but using a procedure of collecting data, it seeks to create outlines and definitions (Gray, 2004).

Case studies shall be carried out at various conditions and locations in order to compare and contrast information. In order to gather facts for this research work, case studies will be intend to carry out at a selected case studies for certain reasons that explained below:

- They are relevant cases to the research subject.
- They are new designs that meets contemporary architectural design standards.
- Their efficiency were tested by manufacturers and users.
- They are rich in works of adaptive patterns and architecture and can be designed by a parametric generative tool.

- Case studies in this field are very limited, only a few number of cases are exist.

It is expected to find the required data that will lead to the research aim from selected case studies.

3.4 Data collection

Yin proposes that "there are generally six main sources of case study data: documentation, archival records, interviews, direct observation, participant observation, and physical artefacts". Documentation and archival records sources -which are considered as secondary data collection methods- will be adopted as main sources for data collection in this research, because they have particular details for designing adaptive patterns, they can be reviewed frequently, and they have extensive coverage for this research subject. On the other hand, Interviews, direct observation, participant observation, and physical artefacts are considered to be primary data collection methods, it will be hard to apply any of these methods because they need a site visit for each case study, reflexivity as it depends on what the observer or the interviewer wants to identify or hear, time-consuming, and some of the case studies are not exist yet as they are still in a conceptual stage (Yin, 1994).

Primary data collection

There is no adopted primary data collection method in this research.

Secondary data collection

For this research, Secondary data collecting is considered as decent research method for this specific study because it saves time despite the fact that it still providing the required information. This information can grant a good solution to the research problem and create a better quality results in contrast with primary data collecting methods. Based on this research, secondary data can be gained through books, journals, magazines, publications, websites and multimedia files like videos and audios. These resources have been chosen to enhance the literature compositions and main theoretical arguments for this research. Consequently, cautious in selecting secondary sources is required (Gray, 2004).

3.5 Qualitative research

Qualitative research method has been used to illustrate cases, problems, phenomenons or events (Kumar, 2005), it is connected to comprehensive exploratory studies, where the prospect for quality outcomes exist (Denzin and Lincoln 1994). Comparing qualitative with quantitative research method, the quantitative method detects and determines the objective significances by using statistics and digits (Patel, 2009), but in this case, research problem needs to be solved by giving factual evidences and concluding a design framework. Collected materials using qualitative method are naturally abstracts and non-numerical, unorganized or raw, but more detailed and comprehensive. It qualifies keen and obvious contemporary arguments to be designed and to confirm and support creating design framework (Fellows and Liu, 2008).

For this research, qualitative method has been chosen to explore specialist's perception, ideas, views, experiences, and beliefs in the direction of creating a design framework for adaptive kinetic patterns with the usage of parametric and generative design tools. There is a difficulty to interpret these facts in numerical values for the quantitative approach (Bandolier, 2007, Naoum, 2007).

Briefly, this research will use the qualitative research method instead of quantitative, to figure out the fundamental theoretic concepts, carry out data analysis and implementations to support concluding the final results.

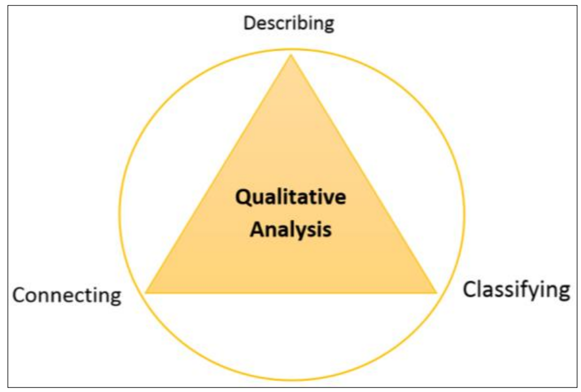

Figure (3.3) Qualitative analysis process (Dey, 1993)

Analysing data: Content analysis

Content analysis is a significant approach for analysing qualitative data. Basically, this comprises the creation of conclusions about data by methodically and objectively classifying exceptional features within them. In content analysis data must be broken into a small parts and interpreted in order to understand the research by using analysis, after that connections were made between research parts, providing the basis for new definitions, all of that will be following content analysis classes which are: summarizing, explicating, and structuring (DEY, 1993)

Data in this research have been disaggregated into small units, relations between categories have been recognized, and finally integration of categories made for producing a design strategy and framework.

3.6 Design Implementation

The standard processes for applying a research is to start with a obviously defined research concentration, extract from Literature Review what other researchers have said about research problem, implement own practical experiment, discuss the results, and reach to a conclusion (Glaser and Strauss, 1967).

Content analysis boosts the researcher to pursue where the research takes, establishing strategies as researcher goes on. Then, depending on literature review and case studies information, researcher will apply additional practical effort; etcetera, keep shifting between practical work and review of related literature, until developing a durable design strategy (Biggam, 2007).

Design implementation is needed to be an application for research finding in order to absorb more information from personal experiments, and to show examples for the created design strategy, that will enhance establishing a decent design framework.

3.7 Conceptual framework

A conceptual framework (also called theoretical framework) is a kind of median theory which seek to link the features of an enquiry or a problem. This framework can be like a guide map that would give rationality to experimental enquiry or condition. A theoretical framework is used to provide an ideal approach to an idea or thought. In general, researchers uses a conceptual framework at the beginning because it supports the researcher to make strong research problem and aims (Kakutani, 2009).

Producing a theoretical framework imposes the designer or researcher to specify what it is going to be studied and abandoned, it also provides assumed relations between key variables (Gray, 2004).

Creating a framework for adaptive kinetic patterns will help designers to improve their skills in designing these elements, it will help architects and designers who would like to improve the environmental performance of buildings.

3.8 Ethical considerations

All collected data have been accurately referenced, interpreted, and analysed, the conclusions and results are completely genuine.

Confidential data have been requested from Adaptive Building Company and Aedas Architects, due to the need of additional information, Adaptive Building Company has supplied the author with a document that contains confidential data regarding the second case study which is Simons Centre at Stony Brook University kinetic façade. Furthermore, Aedas Architects has provided the author with documents and videos regarding Al Bahar Towers – External Automated Shading case study that also contain confidential data, all electronic data will be stored securely, there will be a password on them, and saved on a protected computer, accessed only by the researcher.

4.0 Chapter four: Literature-based case studies

In this chapter a number of designs has been investigated, analysis has been made for patterns and daylighting systems in order to get a valuation criteria from them. However; It is needed to mention that Parametric Patterns by Zaha Hadid Architects, The Arab World Institute, Aldar Central Market have been removed from the case studies which was mentioned in the research proposal because the lack and deficiency of project information.

4.1 First Case Study: Al Bahar Towers – External Automated Shading System (2012)

Figure (4.1) Al Bahar Towers

Country: Abu Dhabi, United Arab Emirates

Climate: Hot Arid climate

Designer: Aedas Architects

Building Function: Office Building

Pattern system: triangular automated shading system

Pattern features: Shading oriented strategy, filtering light.

Facade construction system: Steel structural frame, glass curtain wall

Urban context: Eastern Ring Road, in the heart of Abu Dhabi

Application in project: External facades

Other possible applications: Exterior facades

Introduction

Abu Dhabi has a lot of new high-rise buildings, because it is a desert and it has hot arid climate; some design teams started to find an exclusive ways for reducing their carbon footprint as a concern for sustainability and environmental influence.

The project has twin 29-story towers to produce a gorgeous landmark that would reproduce the emirate's architectural culture while providing a fashionable sustainable building by the usage of recent technology (Arup, 2012).

Concept

Al Bahar Towers inspired by "Mashrabia" which is a traditional Islamic and Arabic motif of wooden lattice screen that was considered as a vernacular architecture, it was made for creating an interesting façade, an efficient shading system, reducing solar gain, reducing glare, and providing privacy. Al Bahar Towers has made a modern interpretation for "Mashrabia".

The "Mashrabia" at Al Bahar Towers consist of a series of transparent umbrella-like modules that open and close in response to the sun's path. Every one of the two towers contains more than one thousand individual shading devices. Another element inspired Al Bahar pattern, Mangrove flower which founded where the towers are located (Arup, 2012).

Figure (4.2) a sample of Mashrabiya in United Arab Emirates

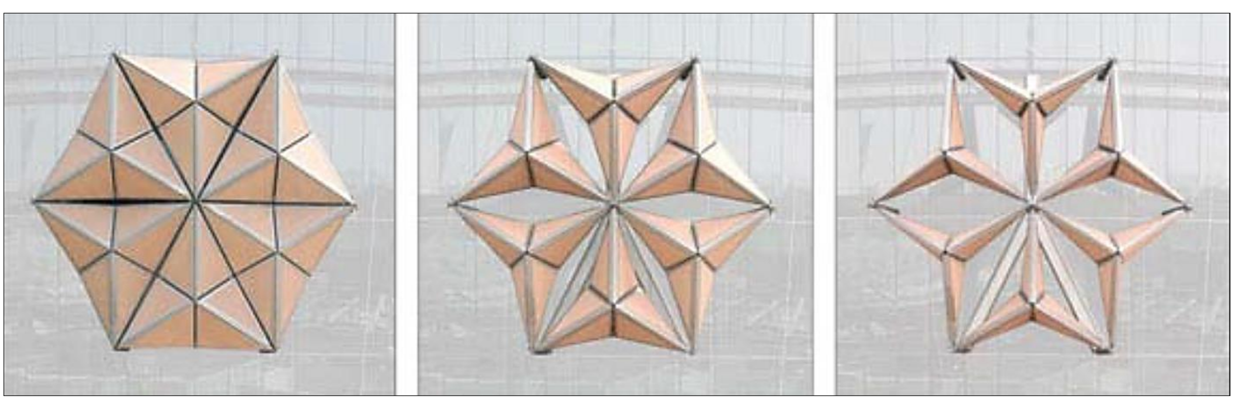

Figure (4.3) Comparison of shading units fully closed (left) and fully open (right) for Al Bahar Towers

Pattern Technology

Each unit comprises a series of stretched PTFE (polytetrafluoroethylene) panels and is driven by a linear actuator that will progressively open and close once per day in response to a pre-programmed sequence that has been calculated to prevent direct sunlight from striking the façade and to limit direct solar gain to a maximum of 400 watts per linear meter. The entire installation is protected by a variety of sensors that will open the units in the event of overcast conditions or high winds. The effects of this system are comprehensive: reduced glare, improved daylight penetration, less reliance on artificial lighting, and over 50% reduction in solar gain, which results in a reduction of CO_2 emissions by 1,750 tonnes per year. PTFE Panels is a material that can stand against wind, dust, sand, and ultraviolet radiation, it also considered as a self-cleaning material and can handle about 150 years. The material has a pattern of perforations with a suitable density that enables light and air to go through it (Arup, 2012).

Figure (4.4) Façade close-up view showing shading panels

Figure (4.5) PTFE (polytetrafluoroethylene) panels

Pattern design

Aedas team applied innovative computational design skills in supporting the project which was parametric design for the kinetic façade. Here are the steps that have been taken in designing this pattern:

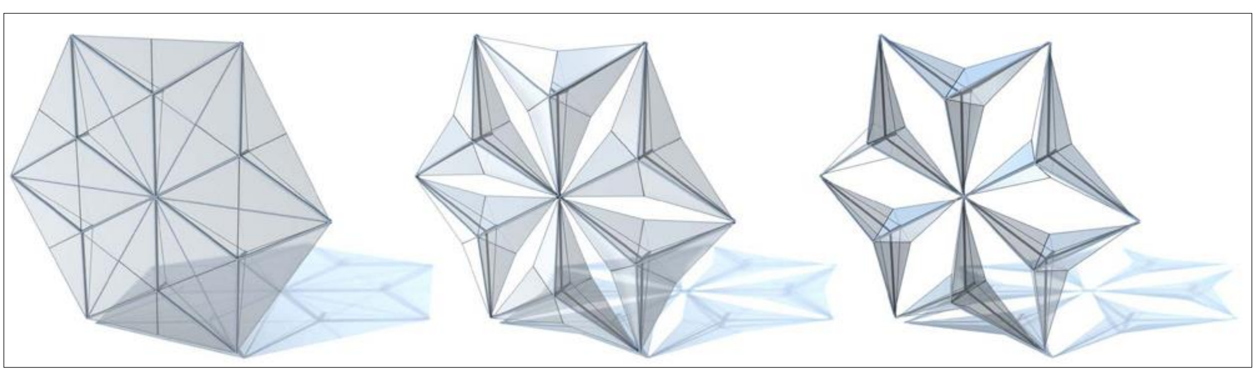

Figure (4.6) Al Bahar kinetic pattern unit CAD drawings

1- Movable Joinery

Following the cosine relationship imposed by the spine and rotational angle of the wing further trigonometric relationship are also found based on this movement. Thus, rather than writing in fixed measurements, parametric equations are written as a formulae which slots in to satisfy those relations, making all lengths become scalable elements. The following figures are a series of elements that have been nested into the movable joinery (Chen, 2011).

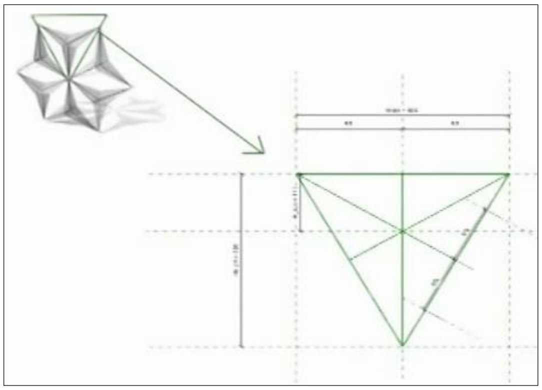

Figure (4.7) movable joinery which is a part of the pattern

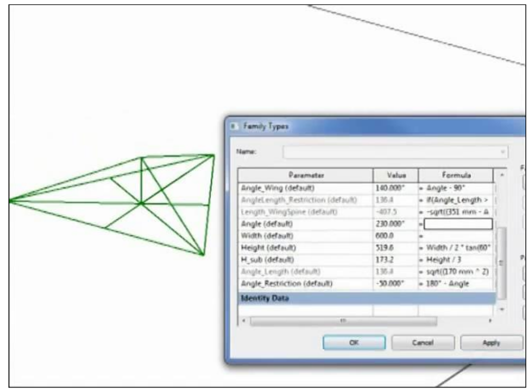

Figure (4.8) parameters for movable joinery

2- Individual Components

These components are then nested into the family of main joinery where the spine movement is driven by the rotation angle of the wings (Chen, 2011).

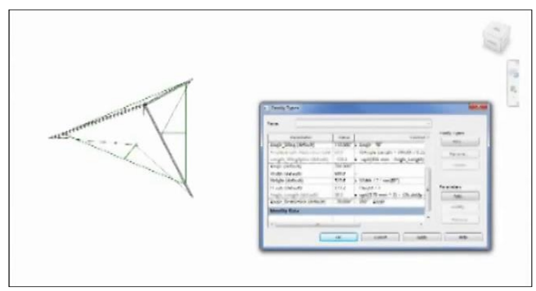

Figure (4.9) nested components into the family of main joinery

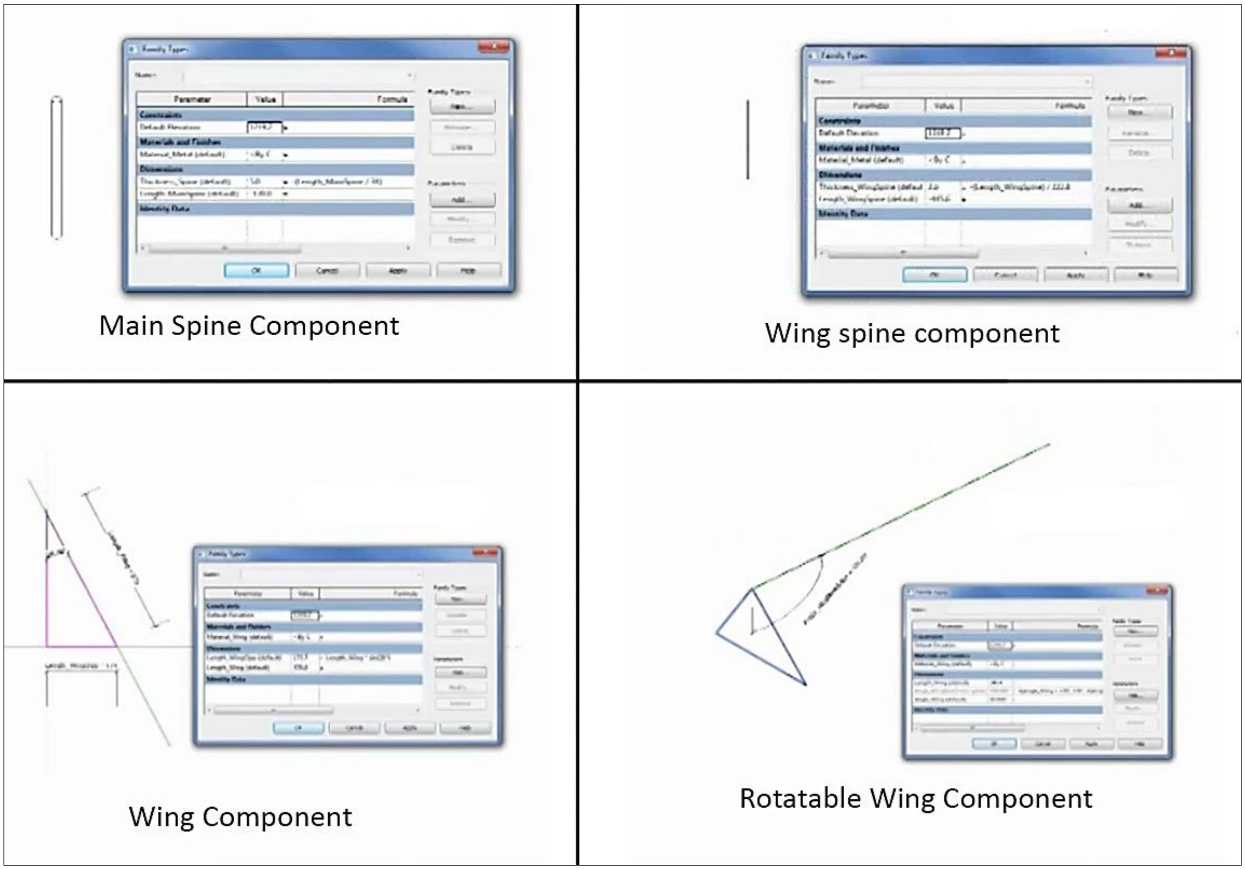

Figure (4.10) Al Bahar Tower joinery components

3- Extension joint

The extension joinery under the main joinery acts as a supporting part on the glass curtain wall on the façade of the building. This part is fixed with no angular rotation, however it must be scalable in relation to the main joinery.

In order to make the relation; a triangle of the same size and same parameter as the main joinery was made.

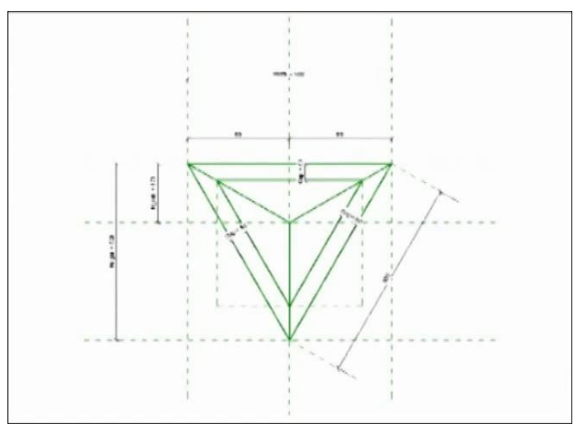

Figure (4.11) triangle of extension joint

The smaller triangle is a scaled down version of the main triangle forming the base of the extension joinery (Chen, 2011).

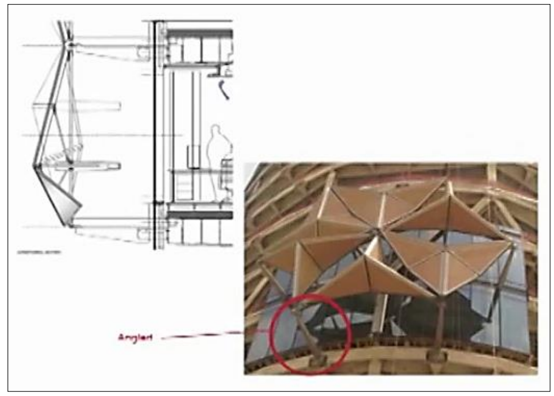

Figure (4.12) the small triangle

4- Extension components and component combination

The main joinery then nested into this extension joinery along with the other extension components. Their parameters coexists within one another and formed inter, relating chain effects whilst a variable is changed (Chen, 2011).

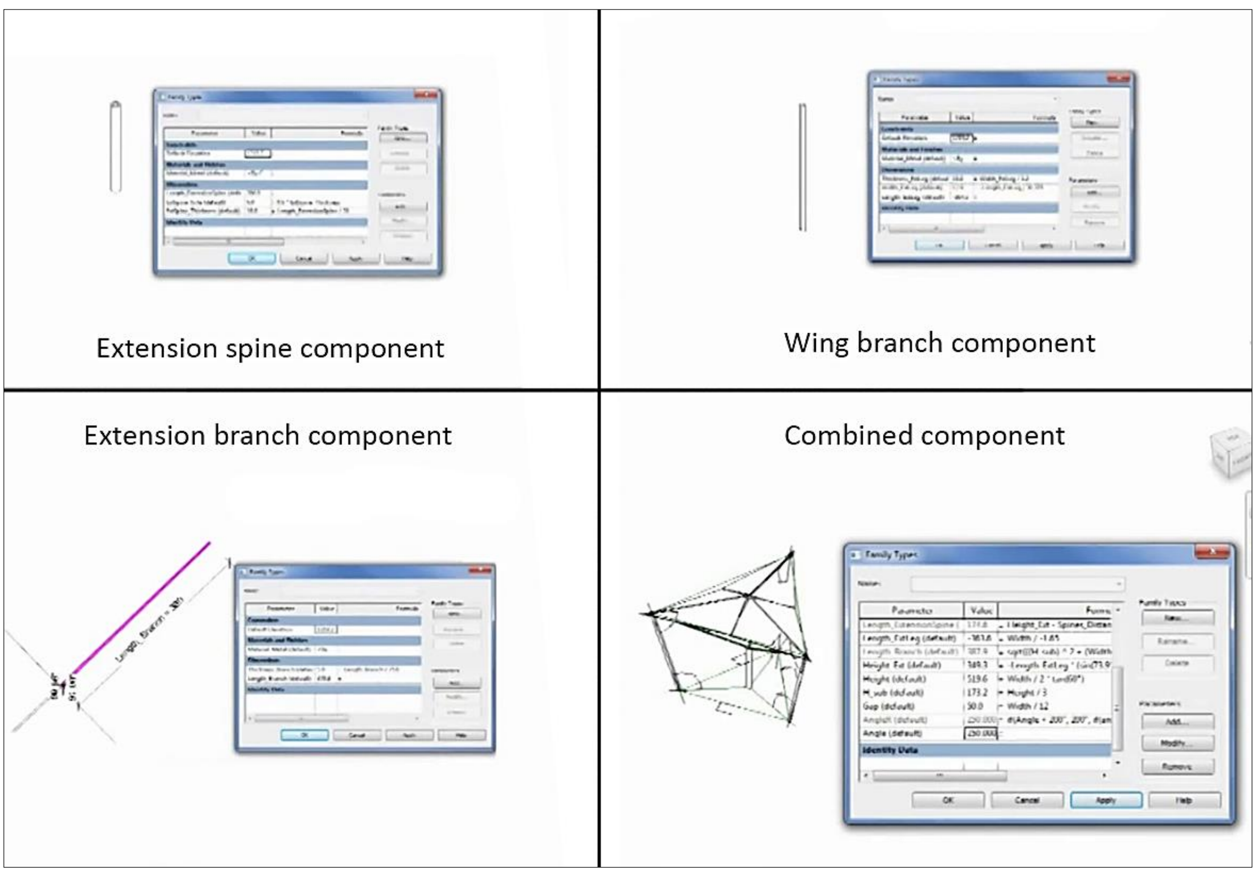

Figure (4.13) Extension components and combined component

5- Curtain Panel Pattern

The component then nested into a triangular curtain panel pattern family, with joined parameters, and locked edge.

At this point, user only needs to adjust one angle to be able to control the entire system. The width is for scaling purposes of the façade (Chen, 2011).

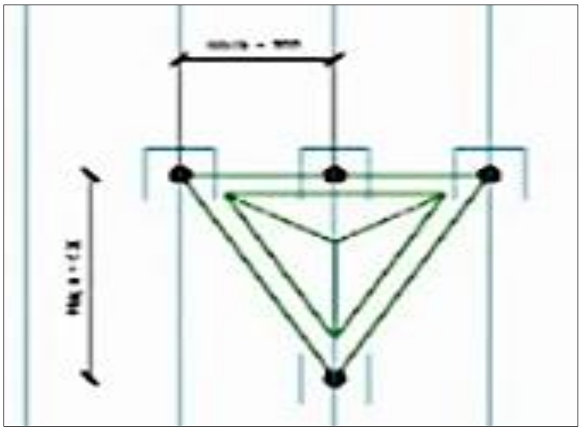

Figure (4.14) nested component into a triangular curtain pattern

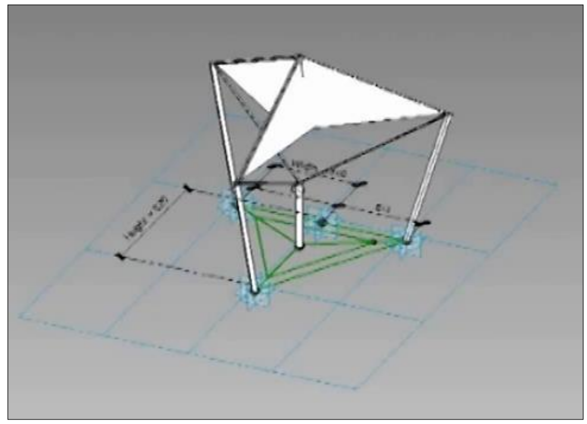

Figure (4.15) simulation for a complete Al Bahar kinetic pattern unit system

6- Façade Skin and Pattern Import

After designing the kinetic pattern by the parametric software, the designer has imported the original building to compact the kinetic pattern on it. Then, the designer has loaded the building and the kinetic pattern into project environment to make the final model ready for rendering (Chen, 2011).

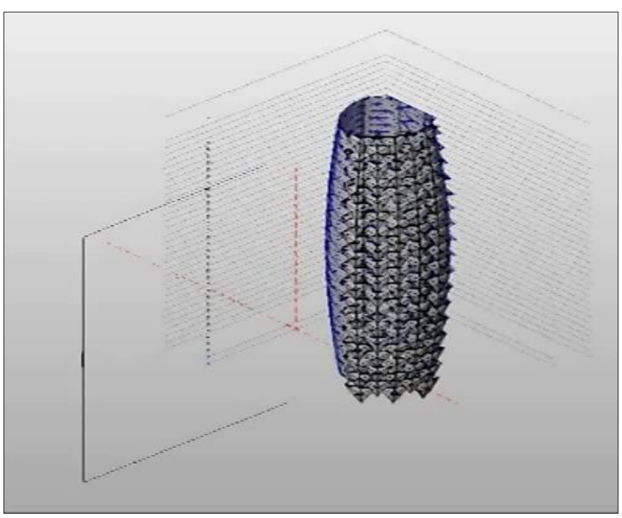

Figure (4.16) kinetic pattern combined with the main building

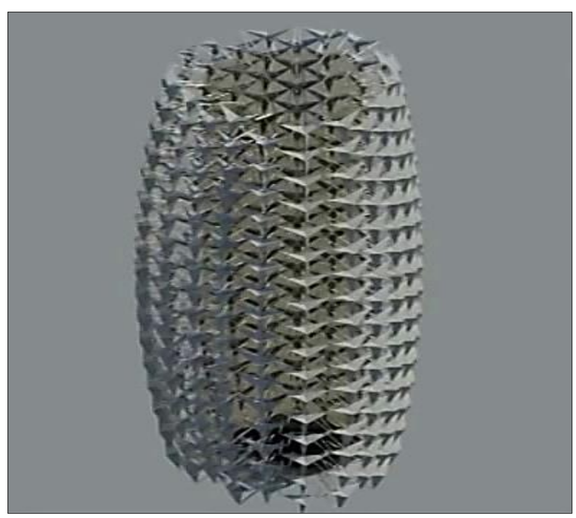

Figure (4.17) a rendered shot for Al Bahar tower model

Shading system

Al Bahar Towers façade is controlled by a computer for responding to ideal solar and light situations.

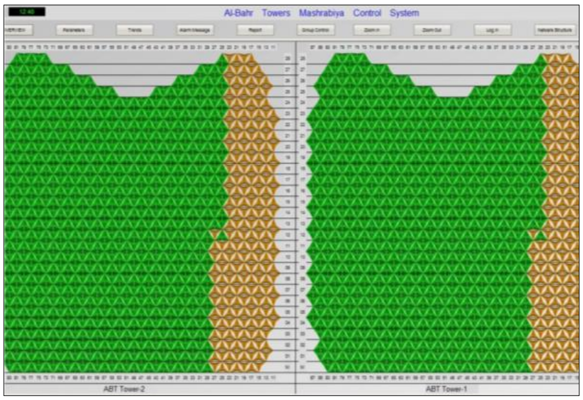

Figure (4.18) Al Bahar Pattern control system

Design team developed modified applications to simulate facade movement in response to the sun's path like java script. Grasshopper and Rhinoceros software were the main applications that the group used in designing and simulating the kinetic pattern (Arup, 2012).

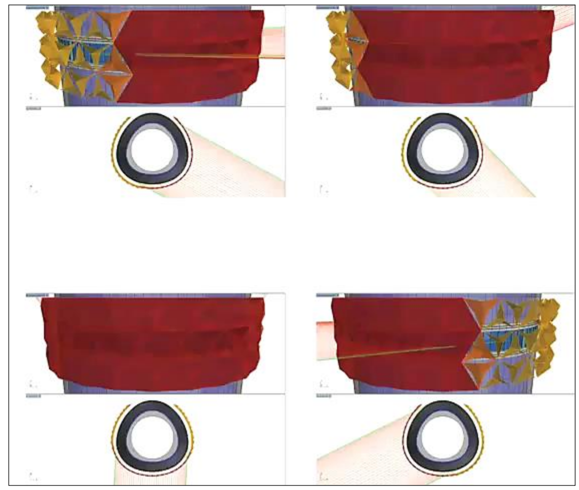

Figure (4.19) Solar analysis of Al Bahar towers – Grasshopper software

The entire installation is protected by a variety of sensors that will open the units in the event oh this system are comprehensive: reduced glare, improved daylight penetration, less reliance on artificial lighting, and over 50% reduction in solar gain which results in a reduction of CO_2 emissions by 1,750 tons per year (Arup, 2012).

4.2 Second Case Study: Simons Centre at Stony Brook University (2010)

Figure (4.20) (Hoberman and Schwitter 2008) Simons Centre Tessellate pattern

Country: New York, United States of America

Climate: Humid subtropical climate

Designer: Perkins Eastman

Building Function: State University of New York

Pattern system: Tessellate; constantly evolving surfaces.

Pattern features: Completely mutable shading control, Controlling solar gain, glare, ventilation, airflow and privacy

Facade construction system: Adaptive patterns coverage of stainless steel manufactured by Water jet cutting, glass curtain wall

Urban context: University campus, Geometry and Physics centre

Application in project: Southern façade

Other possible applications: Exterior facades, Interiors, roofs, canopies. , Integrated into glazing

Introduction

Dynamic installations has been made for the new Centre for Geometry and Physics by Adaptive Building Initiative. The first application of Adaptive Building Initiative Tessellate system has served art and function, it is a masterpiece that has a sections of geometric pattern reflecting occupant scientists' science and mathematics, it also achieving the requirements of the building plan. As these sections align and splay; the visual effects are of scattered geometrical patterns, Tessellate forms a combination of geometric shapes like hexagon, circle, square, and triangle that shapes into an opaque mesh. The outcome is a kinetic pattern that spreads 124 square meters and provides the building with the functional capability to a dynamic opacity transformation (Hoberman and Schwitter 2008).

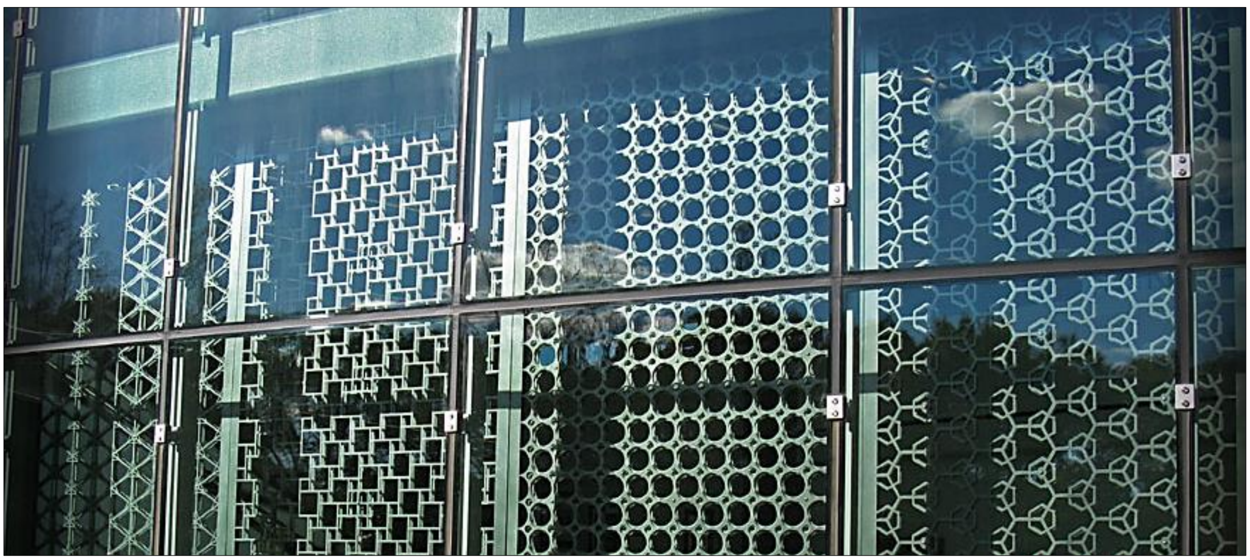

Figure (4.21) Tessellate system facade

Concept

Pattern shifts like flower which blooms each morning, it is known as the "Morning Glory". Every night the petals on the flower withdraw, and the flower closes itself to preserve energy, and opens at morning. Tessellate cane with these organic philosophies to architecture.

Figure (4.22) Morning Glory flower

Tessellate pattern modules are independent, framed curtains with cribriform patterns that can constantly move and evolve; creating a dynamicity for an architectural element that adjusts light and heliacal gain, ventilation and airflow, privacy, and sights. Tessellate consists of an arranged panel sets of that can be built of several metals or plastics. Overlapping of these layers gives the kaleidoscopic visual representation of patterns aligning and then diverging into a fine, light-diffusing mesh (Hoberman and Schwitter 2008).

Pattern Technology

Aligning and diverging sparse a visual effect for geometric patterns, the result is a kinetic surface that provides the building with the functional capability to dynamically adjusts its opacity. Each one of Tessellate modules runs only on one motor. A module is controlled by a computer processor, which could be programmed for several objectives (Hoberman and Schwitter 2008).

Pattern Design

The pattern has an overlapping Arabic motifs, Crafts fabrics, and optical art illusions. Simple geometrical shapes forming the diffused mesh, they are: hexagons, circles, squares, or triangles. Other shapes like rectangles are available, but the pattern will become more complex.

Figure (4.23) triangular and rectangular Tessellate pattern

Pattern has a central axis that ties its units together structurally, it also considered to be a pivot point regarding pattern machinery, and it is a reference for defining the movement of other layers, each one of petals has a pin, and the pattern changes as the pin moves (Hoberman and Schwitter 2008).

Shading system

Tessellate has a location-based sensor that responses to light and weather conditions For example, when detecting high levels of direct daylight, the steel sheets change, and their patterns totally interlock, to block sun rays. The sensors are programmed in many ways to take full advantage of energy efficiency and savings.

According to ABI, patterns opacity can varies from ten to eighty five percent, also Its speed can be adjusted to track the sun or responding to environmental aspects like energy usage, solar gain, and daylight levels. In real buildings, a BMS would monitor these parameters for adjusting the system's sheets so they can directly decrease solar gain or balance light levels (Hoberman and Schwitter 2008).

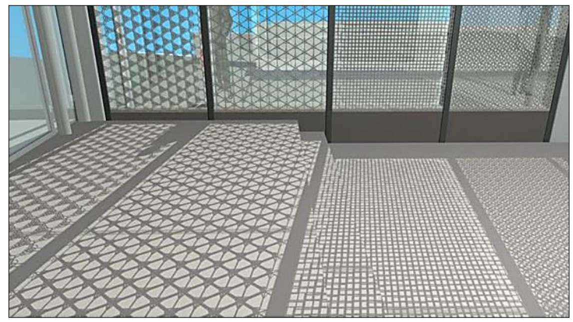

Figure (4.24) Perforated shades for Tessellate by "The Adaptive Building Initiative"

4.3 Third Case Study: Helio Trace Centre of Architecture (2010)

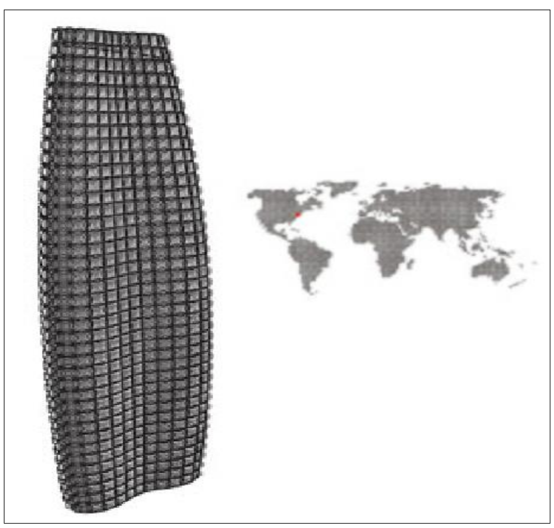

Figure (4.25) (Hoberman and Schwitter 2008) Helio Trace Centre of Architecture

Country: New York, United States of America

Climate: Humid subtropical climate

Designer: Skidmore, Owings and Merrill LLP

Building Function: Office building

Pattern system: Strata

Pattern features: Decreasing of solar gain, accurate equation between shade and sun guarantee, Decrease the daytime use of artificial lights with daylight, and air conditioning with natural airflow, react to ecosystem, form and function

Facade construction system: Kinetic curtain wall system that keeps track of the sun's path

Urban context: Exterior wall

Application in project: Southern facade

Other possible applications: Exterior facades, roofs, canopies, integrated into glazing

Introduction

Helio Trace Centre of Architecture facade concept has been done in a competition by a team of Adaptive Building Initiative, Merrill, Owings, Skidmore and the Permasteelisa Group. The aim of this collaboration was to develop a sophisticated building surrounding pattern that could influence contextual and environmental contributions informing a responsive kinetic curtain wall system. Architects and field specialists of this team envisioned a configuration that enhances the curtain wall performance regarding daylight and glare, and that decreases solar heat gain by 81%. Adaptive Building Initiative developed the kinetic shading system for the whole facade, applying its pattern-based Strata system.

Sustainable Engineering Studio presented environmental analysis that strengthen experimental data in order to rise the position and production of the kinetic shading system. Permasteelisa Group is a curtain wall artificer, worked with the team for engineering the scheme, resolving constructability and implementation issues. The final design presents an adaptive kinetic pattern; responding to ecological, formal, and functional requirements (Hoberman and Schwitter, 2008).

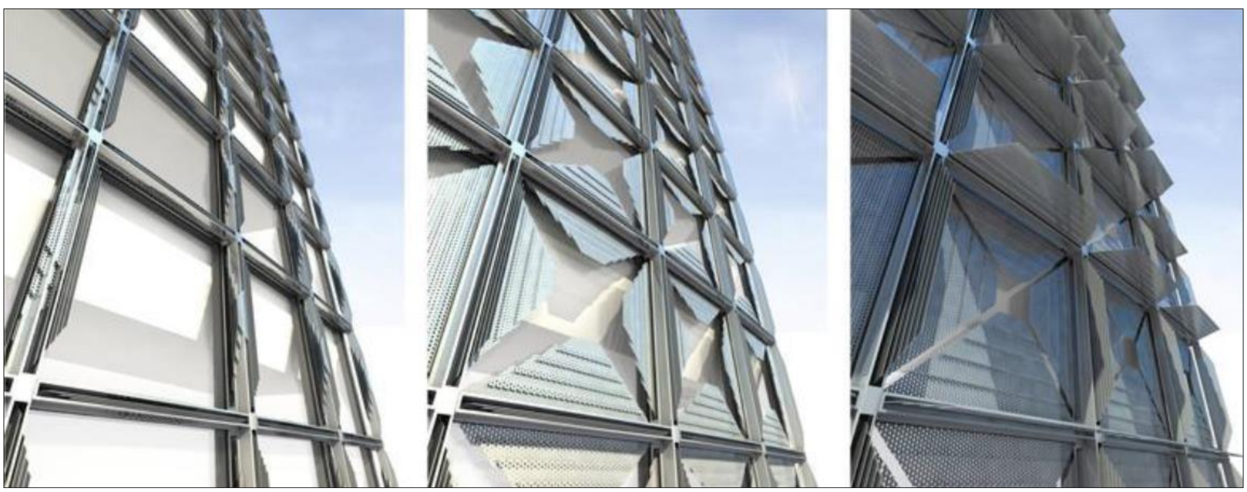

Figure (4.26) (Hoberman and Schwitter 2008) Helio Trace Centre of Architecture adaptive pattern

Concept

Helio Trace Centre of Architecture concept achieved citation of merit from the 2010 R+D (Research + Development) Awards and the Centre for Architecture, and was distinguished in the Contemporary Fine Arts exhibition.

Helio Trace kinetic curtain wall system can factually keep track of the sun path over the course of a day and a year. In contrast with other system mechanisms; this kinetic pattern will expressively develop daylight whereas decreasing solar heat gain impacts on building residents.

The system preserves excellent daylighting at the surrounding area while it eliminates glare, decreases peak solar heat gain by 81% on a yearly basis (Hoberman and Schwitter, 2008).

Pattern Technology

Facade technology of Helio Trace Centre developed a worldwide design which was programmed to be carried out any place in the world, by adapting to location attributes, orientation, and sun path. It can be utilized to any reasonable building geometry by adjusting different curtain wall panels. Three elements formalize the system:

Kinetic patterns shade on the building facade is linked to a pre-fabricated, thermally efficient building covering, which enable interior chilled ceiling plates usage that have a lower energy efficiency than other standard air conditioning solutions (Hoberman and Schwitter, 2008).

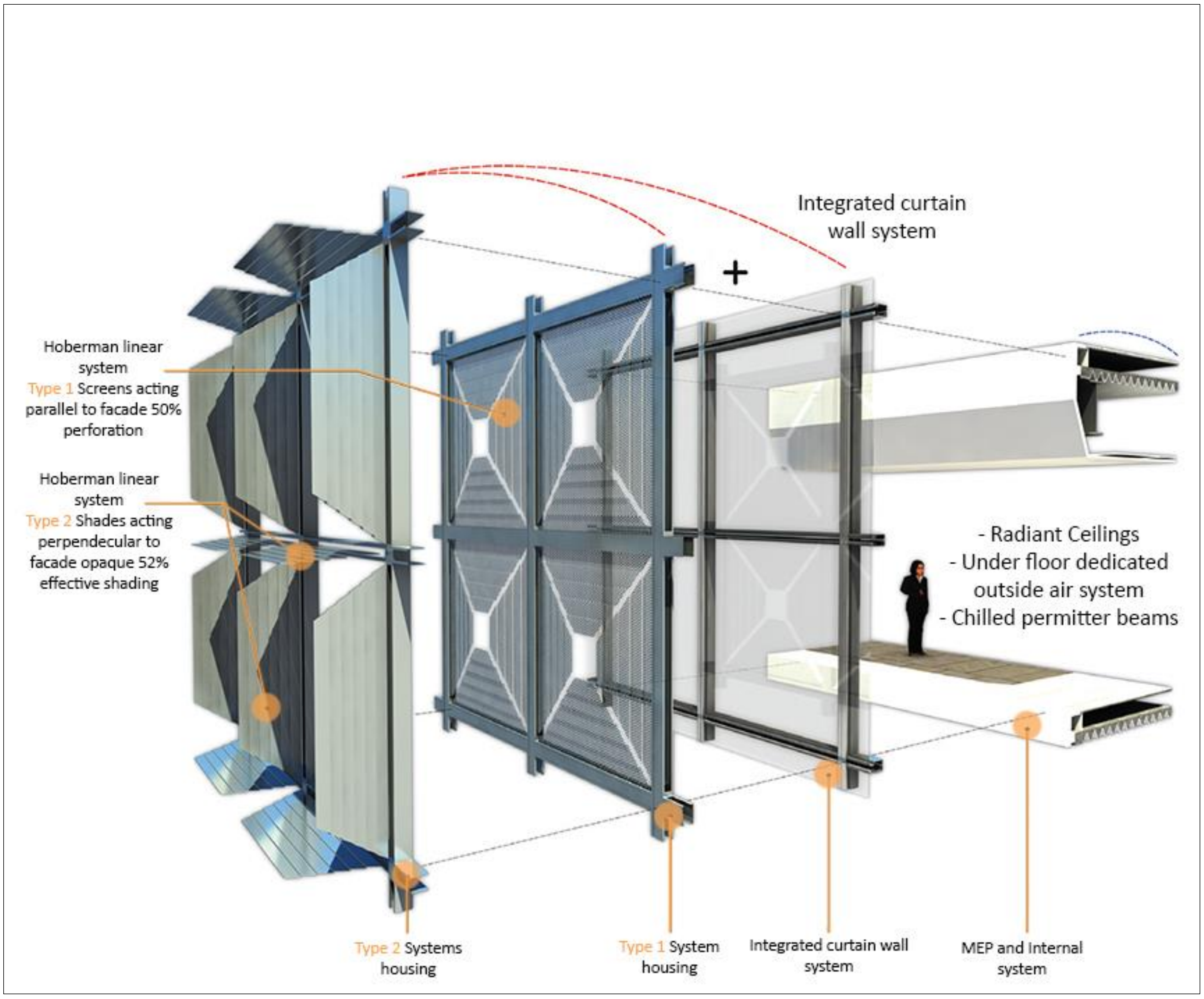

Figure (4.27) Exploded 3D section for Helio Trace Centre window unit

Shading system

Helio Trace maintains the precise balance between shade and sun. A mobile external sunshade blocks out the rays when required, architects can modify the system to climate, sun path and processes schedules.

Design team done wide solar analysis of Helio Trace system mechanisms with three objectives: to decrease glare, increase daylighting, and control solar heat gain. Glare studies (at the top), with baseline analysis at its left and enhanced analysis at its right. Daylight levels (at the middle) were adjusted to avoid extreme illumination (at middle left) which can be a reason of glare and to help increasing energy savings, also to provide user comfort. Finally, the problem of high solar gain (at bottom left) was analysed regarding the systems external shades, all of them together can cut the peak solar gain by an expected 81 percent.

The team's parametric analysis calculated the ideal deployment level of every shading system at particular times of day, for every season (Hoberman and Schwitter 2008).

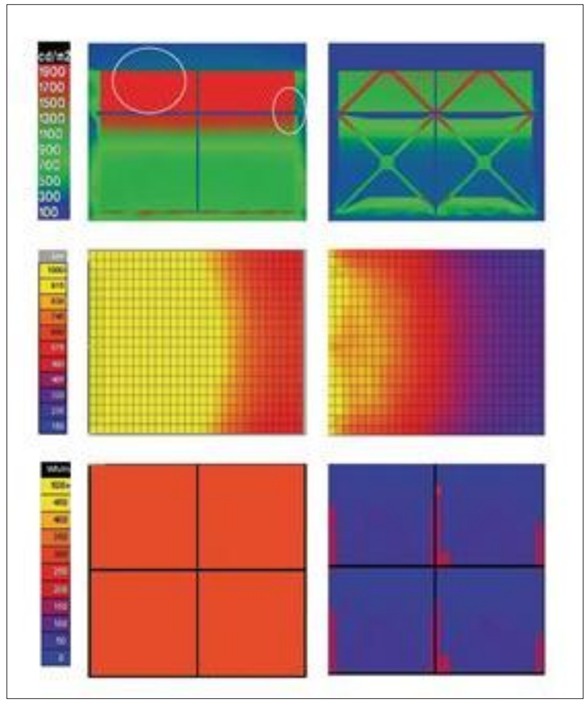

Figure (4.28) Glare, daylight levels, and solar gain analysis for Helio Trace

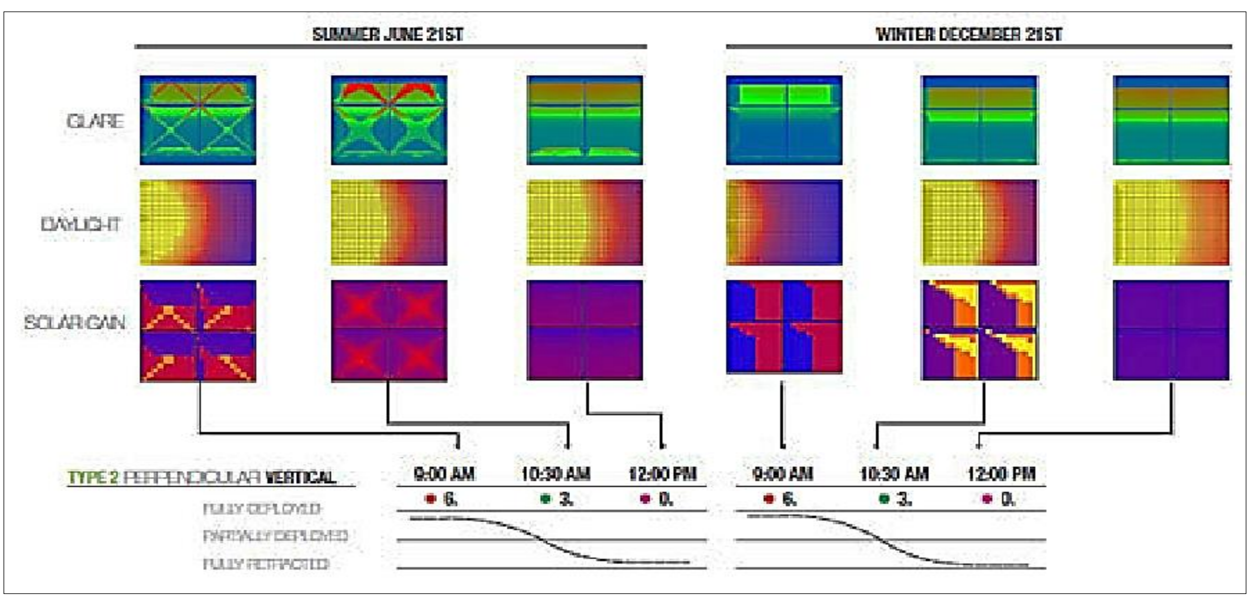

Figure (4.29) Glare, daylight levels, and solar gain analysis for Helio Trace during the daytime

5.0 Analysis and evaluation for case studies

After collecting and classifying of the all data and information about case studies, their adaptive pattern and daylighting shading systems were being analysed. This analysis can provide the required specifications for indicate of suitable daylighting system. This is achieved by creating a mind map using all features of the kinetic pattern which have been extracted from literature review.

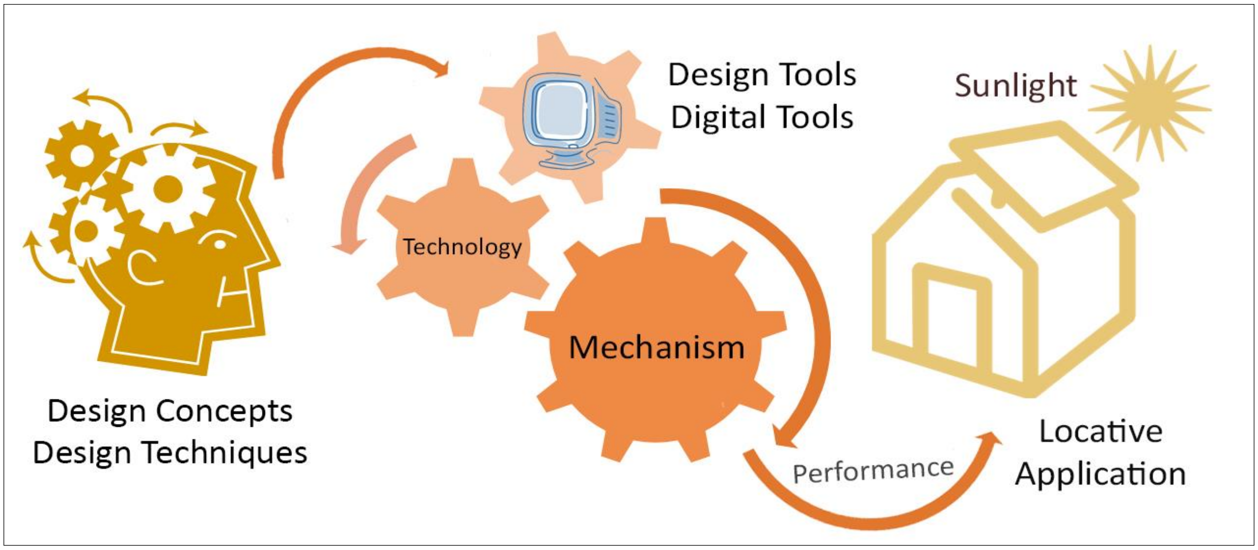

Figure (5.1) Kinetic adaptive patterns design mind map

5.1 Design concept:

Design concept is the way that the designer transformed an idea to a real concept and design.

Al Bahar Towers:

The designer succeeded to convert design concept with formally, functionally, and motional aspects to a real design, inspired by Mashrabia and Mangrove Flower.

Simons Centre:

Designer partially failed converting design concept to a real design, function and form were not done properly concerning Morning Glory flower. On the other hand, designer has put an additional concept which is Arabic design elements, and it was successful as a formal design inspirations.

Helio Trace Centre:

There were no formalisation or pattern transformation concept, only functional sun tracking.

Evaluation:

By analysing case studies' concepts, it can be noticed that Al Bahar Towers used design concept as an inspiration for form and function, Helio Trace centre as a function only, and Simons centre partially failed to be inspired formally and functionally by concept; as it was succeeded in interpreting flowers opening while sun tracking, and failed to establish a three-dimensional model and movement to morning glory flower.

It will be a more compatible and harmonious design if the design concept translated into a good form, function, and pattern transformation, by making a combination between them as an integrated concept, instead of making alternatives or other approaches that is far from the main concept.

5.2 Kinetic pattern design and technology

After that by categorizing and arranging case studies' characteristics, the following specifications were noticed:

Al Bahar Towers pattern analysis

The design was inspired by "Mashrabia" and fascinated by Mangrove flower movement at the same time, interpretation of Mashrabia was done by converting its perforations and privacy to kinetic elements material which is PTFE Panels and by the whole facade pattern.

Figure (5.2) Mangrove Flower

Regarding pattern animation, Mangrove flower forms the pattern element and joinery movement, form and movement were very similar to Mangrove opening and closing.

Al Bahar Towers has a biological generative system approach for pattern formalism, because it has been fascinated by Mangrove flower movement, while designing this pattern, the designer has set the pattern rules, parameters, and algorithms in order to form the required shape and transformations for this flower not for making a complex geometries. The designer has used both representation type symbolic and analogue in modelling design software after completing the combination of main component and extension components.

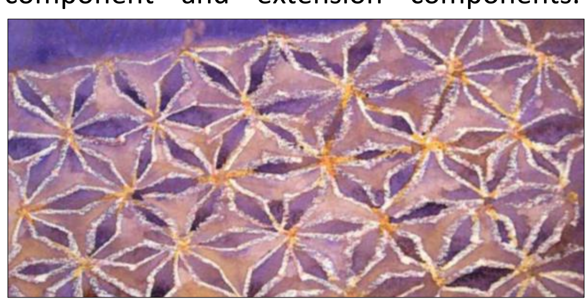

Figure (5.3) Al Bahar Towers Mangrove flower pattern

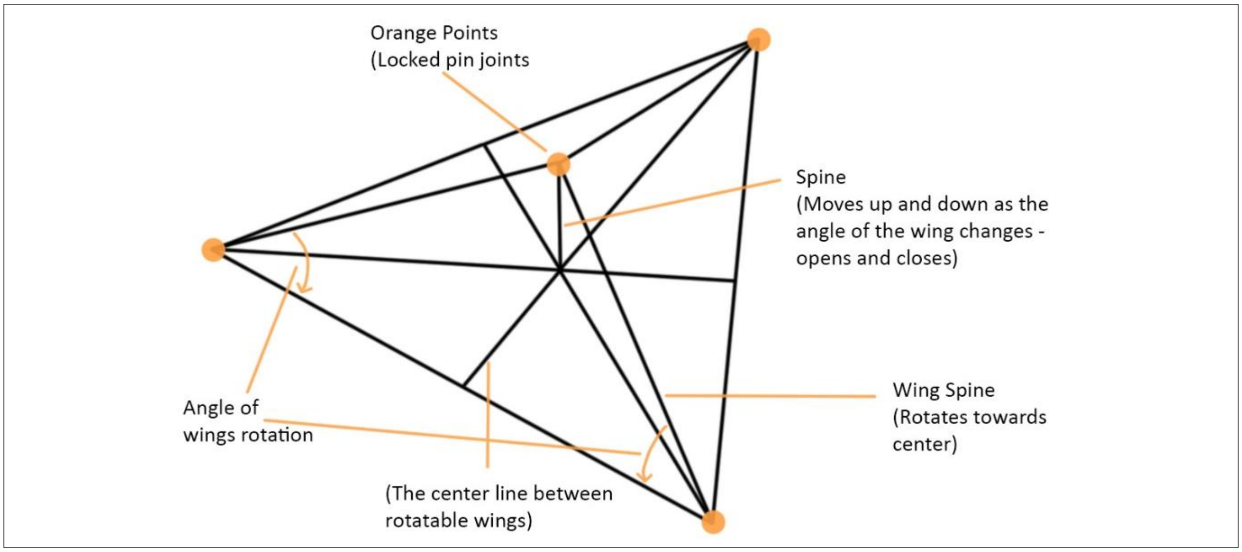

Figure (5.4) Analytical drawing for movable joinery

The designer used the cosine formula as an equation for keeping angles' relations between triangles that forms pattern morphology. Starting by setting the parameters for the main element of the pattern which is the movable joinery, it can be noticed that the pattern unit has three wing spines that rotate towards the centre performing the transformation. Pattern element has locked pin joints that combine wing spines together, the spine moves up and down as the angle of the wing changes. This kinetic pattern wing spines transform only in one dimension which is Z axis, by its movement, wing spines make a two-dimensional movement, X, Y, and Z directions.

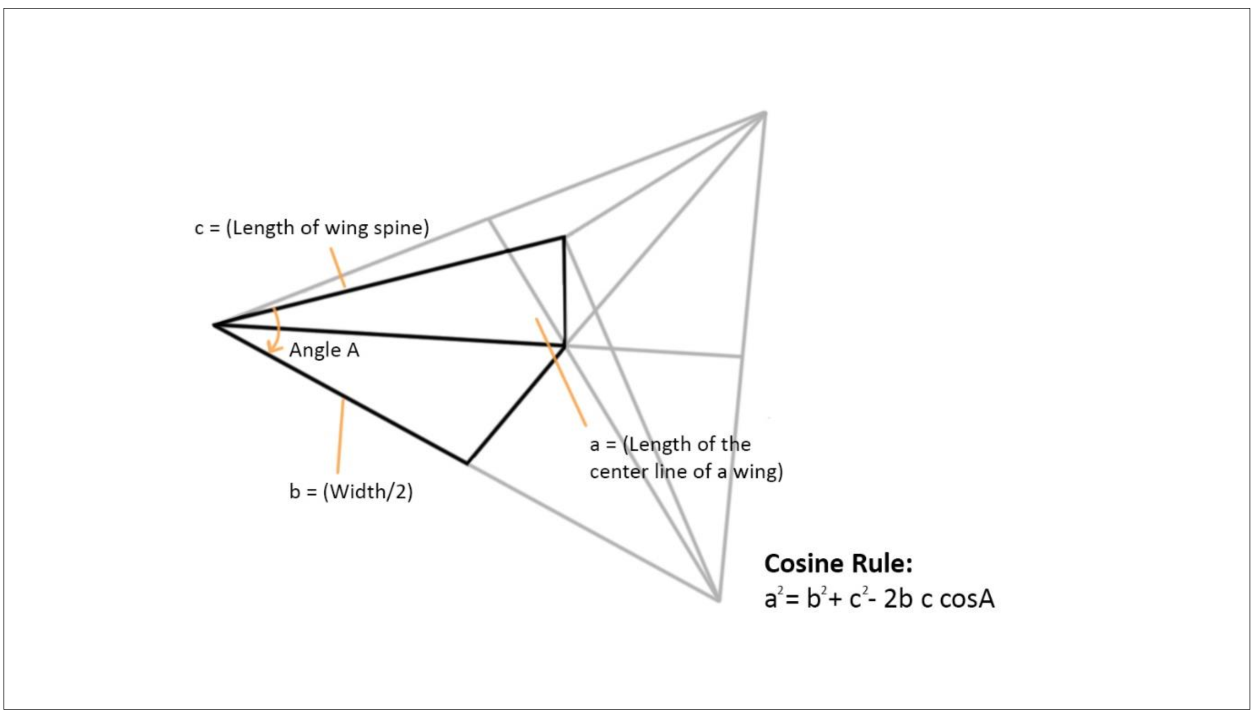

Figure (5.5) Analytical drawing for the mathematical relationship between joined elements

Pattern element contains component combination which is movable joinery and extension components, this element has three legs that holds pattern movable unit.

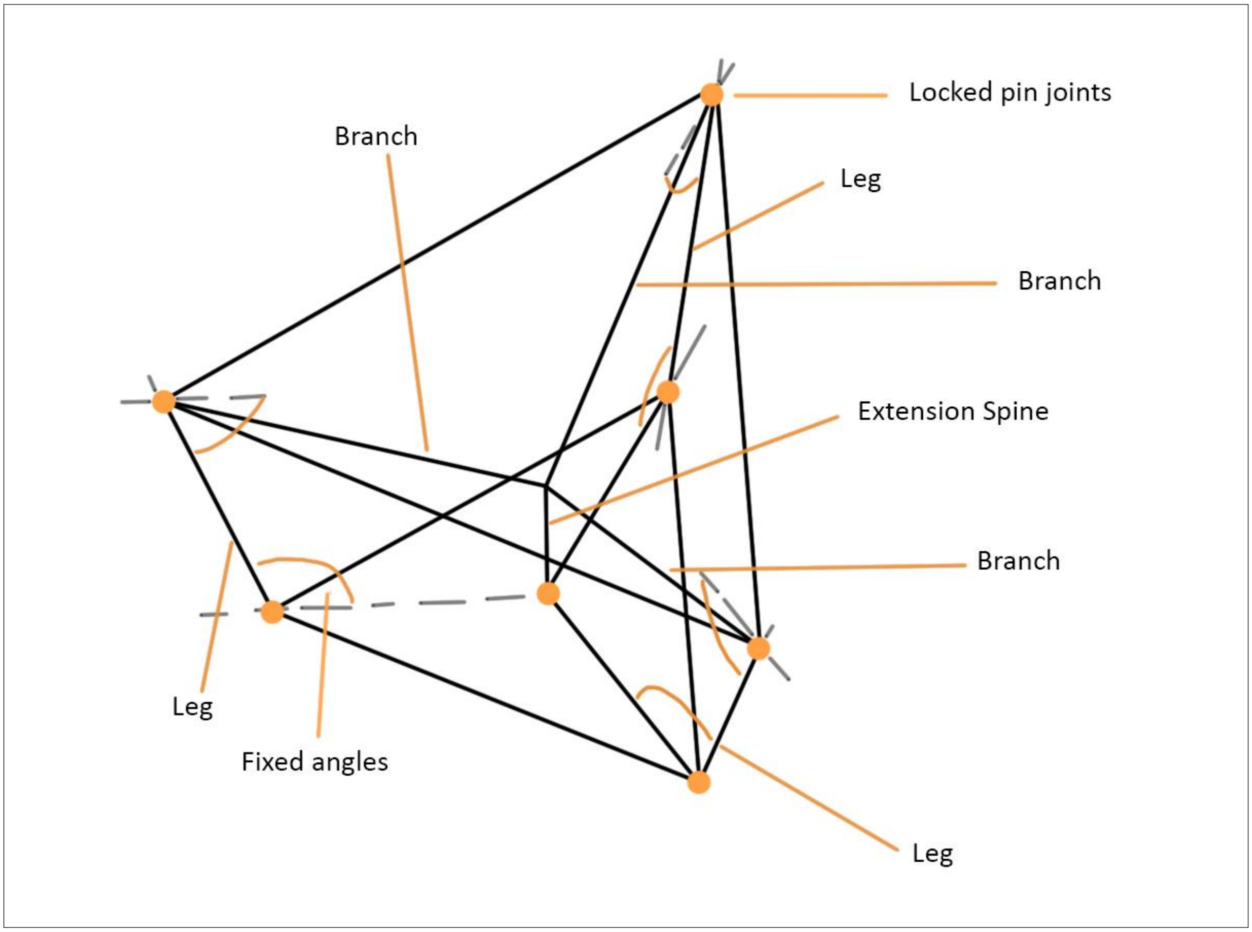

Figure (5.6) Analytical drawing for a whole joinery

Simons Centre pattern analysis

Design concept was inspired by "Morning Glory" flower blooming, but the concept interpretation and the formalisation were far from the original flower shape, because the flower pattern were abstracted into a two-dimensional pattern that keep shifting its place instead of making a three-dimensional movement. Another issue that Morning Glory flower retracts every night to save energy, but the pattern keeps revolving and make the flower openings to save energy, which is a conflict with the flower concept, on the other hand, the flowers open responding to light and also the pattern does.

Figure (5.7) Morning Glory Flower opening and closing

Arabic motifs, arts, crafts textiles, and optical art illusions were formalising patterns' meshes, those are more convenience as a formalisation elements than Morning glory flower. The pattern contains simple geometrical shapes that keeps revolving according to Arabic illusions.

Tessellate consists of three geometric pattern layers, the layers are moving according to a generative engine that is based on shape grammar rules which are linguistic-based system approach, the engine picks and processes these rules, shape rules defines transformation for a current shape., in this case it has a systematic triangular tessellation as a primary system. The pattern has four hexagonal grids, each one consists of big and small hexagons, the first main grid is fixed, the other grids move in a triangular direction away from the main grid performing a complex geometric patterns similar to kaleidoscopic patters.

This kinetic pattern is based on a two-dimensional movement, it moves only in X and Y direction.

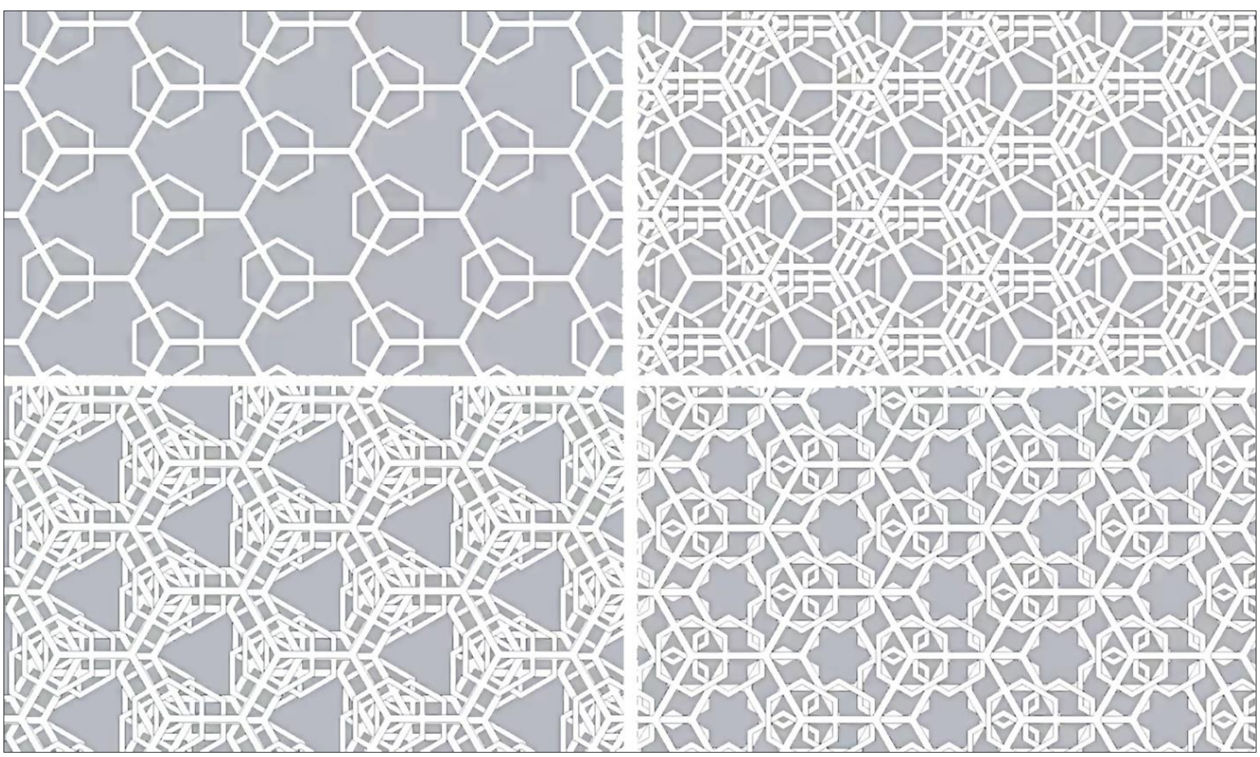

Figure (5.8) Analytical drawings for Tessellate pattern's behaviour

This Pattern can be designed by a parametric generative design tool by many ways, the easiest way is by setting a shape grammar rule to a pattern layers and make them moving in X and Y directions. Another way for creating this design by parametric software is by making an offset (a shape extracted from the original shape in equivalent distance and direction, parallel or perpendicular to the original shape) for any basic pattern. The designer has made an analouge and symbolic design representation for this design.

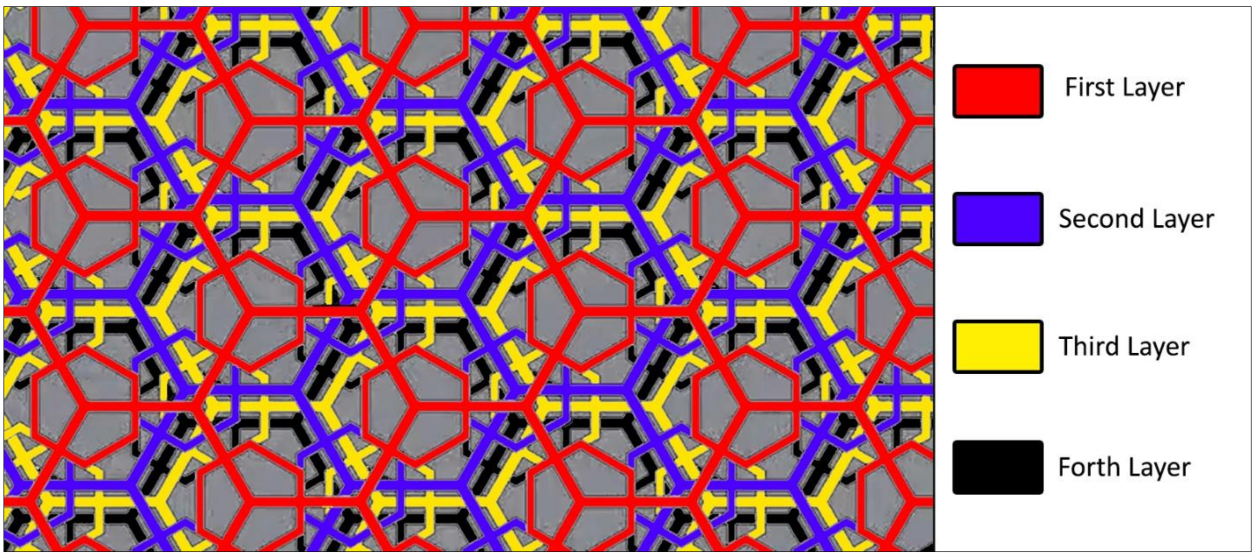

Figure (5.9) Analytical drawing for Tessellate pattern's layers

Helio Trace Centre pattern analysis

The main concept of Helio trace centre is keeping the track of the sun path over the course of a day and a year, so there is no formalisation concept for this pattern design, but a functional concept.

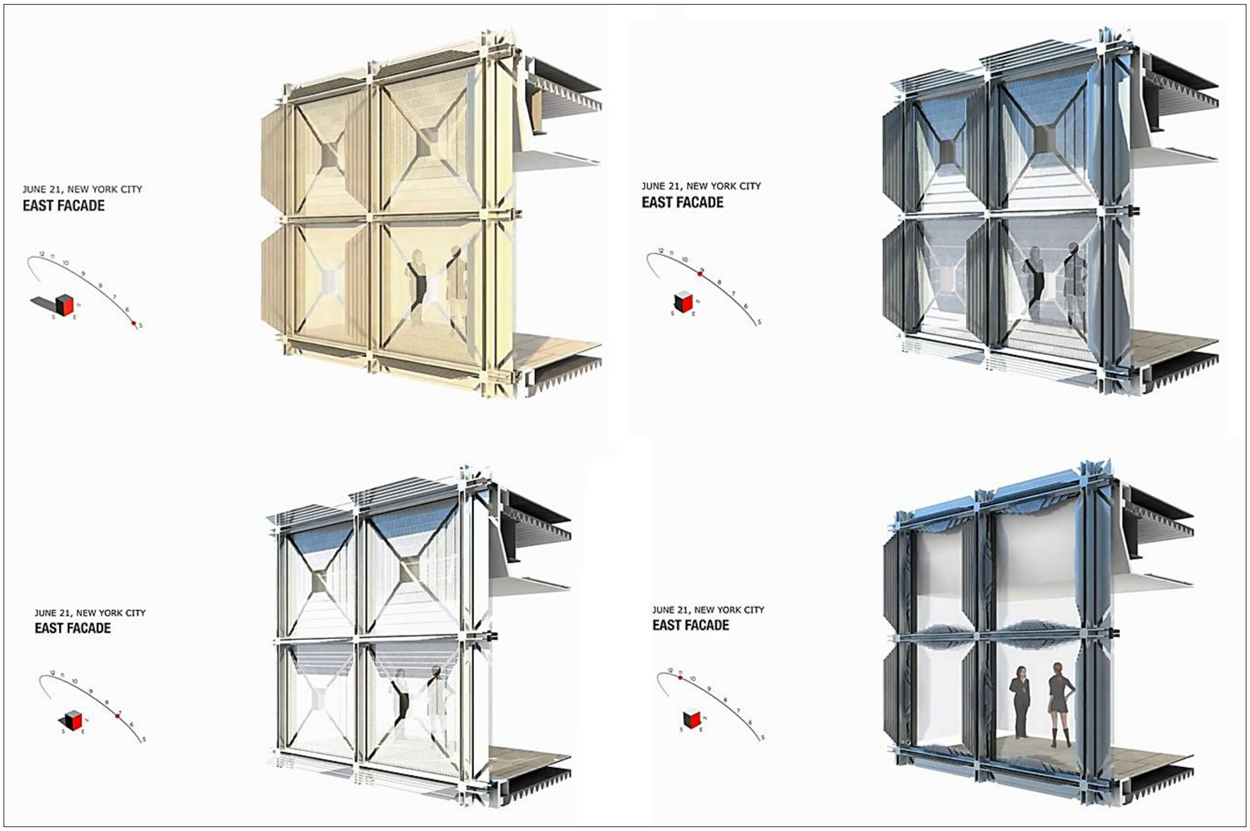

Figure (5.10) Changes in kinetic pattern during daytime

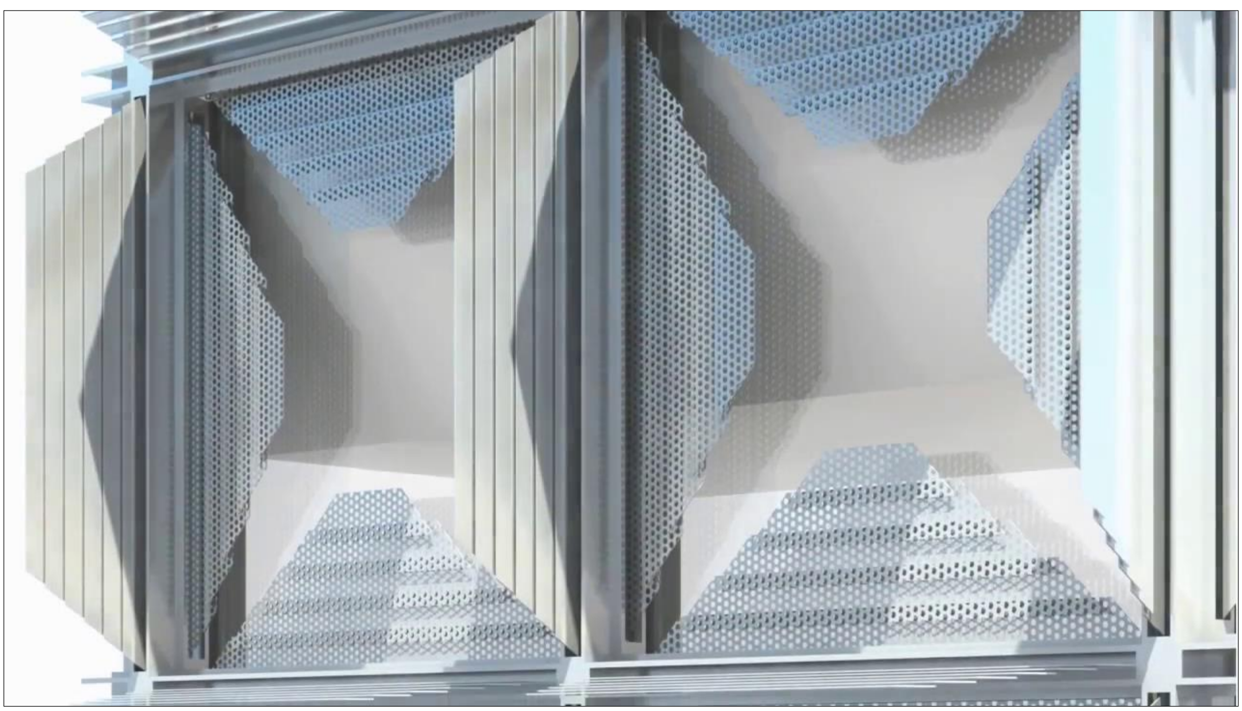

Figure (5.11) a window part of Helio Trace Centre kinetic window

This design has both linguistic and biological generative system approaches, because its morphology takes and organic transformation when expanding like shy plants, shy plant is a sensitive plant that shrinks or expanding itself when touched or shaken (Adams, 1972). Pattern movement is tranforming according to set of rules that maintains parallelity and perpendicularity of pattern surfaces, so it is lingiustic system also. The design has analouge and symbolic representation.

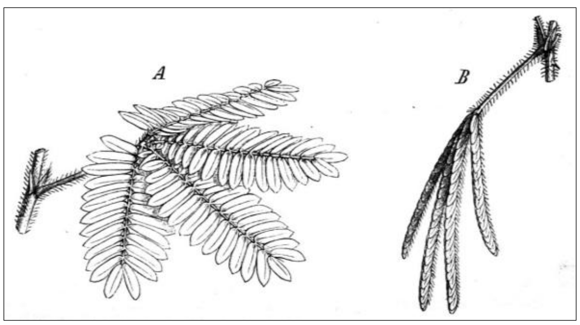

Figure (5.13) analytical sketches for shy plant movement

Every adaptive shading unit of the kinetic façade has a twelve pieces, four perpendicular and eight parallel units, each one has five metal sheets. The sheets expand and retract towards the centre performing a pyramid shape. A small beams are welded with the sheets in order to keep the unit stable structurally. The pattern material has perforations with a suitable density and diameter that enables light and air to go through with a suitable amount.

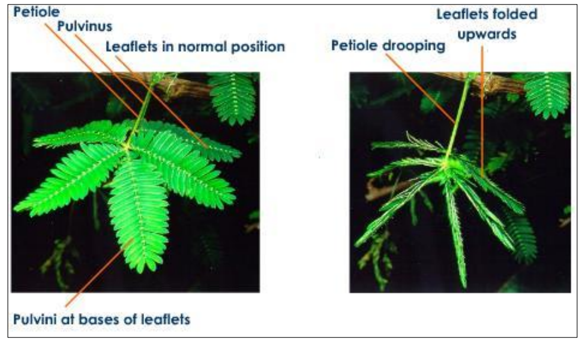

Figure (5.12) shy plant before and after getting touched

Sheets movement is based on a one-dimensional movement, it moves only in X or Y or Z direction, and all of the eight parallel sheets expand and retract together at the same time, however, perpendicular sheets can expanded separately, nevertheless, the four sheets move at the same time, making the adaptive shading from window sides.

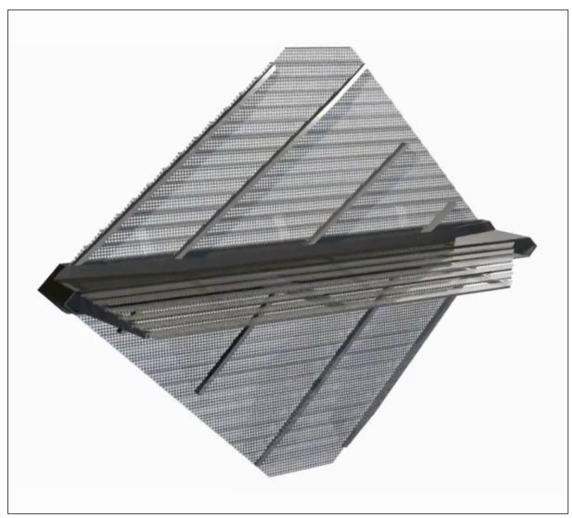

Figure (5.14) Helio Trace Centre adaptive shading unit

Figure (5.15) Helio Trace pattern movement phases

Evaluation:

Technology	**Kinetic quality**	• Triangular automated shading system • Shading oriented strategy • Light filtering
	Sun tracking	Sun path tracking and manual control
Generative and parametric modelling principles	**Generative system**	Biological approach based on cosine formula
	Morphology (Locative transformations)	Three-dimensional move, scale, and rotate
Materials	**Pattern material**	PTFE panels and aluminium
Application in project	**Location**	All external facades
	Size	Whole building
Representational aspects	**Representation type**	Analogue and symbolic

Table (5.1): Analysis of Al Bahar Towers

Technology	**Kinetic quality**	• Constantly evolving patterns • Completely mutable shading control • Controlling daylighting amount is the most focused technology
	Sun tracking	Sun tracking and sensors for environmental factors
Generative and parametric modelling principles	**Generative system**	Linguistic approach that based on shape grammars
	Morphology (Locative transformations)	Two-dimensional movement, it moves only in X and Y axis
Materials	**Pattern material**	Steel sheets and latticework
Application in project	**Location**	Southern facade
	Size	Part of the building, in entrance hall as a masterpiece
Representational aspects	**Representation type**	Analogue and symbolic

Table (5.2): Analysis of Simons Centre analysis

Technology	**Kinetic quality**	• Modular units that hide inside a single thin profile when retracted • Guarantee for an accurate equation between shade and sun • Controlling daylighting amount and quality
	Sun tracking	Sun path tracking and schedules for operations
Generative and parametric modelling principles	**Generative system**	Both biological and linguistic approaches
	Morphology (Locative transformations)	Three-dimensional move, scale, and rotate
Materials	**Pattern material**	Steel surfaces with perforated pattern
Application in project	**Location**	Southern facade
	Size	Whole building
Representational aspects	**Representation type**	Analogue and symbolic

Table (5.3): Analysis of Helio Trace Centre of Architecture

Due the fact that all of the previous mentioned case studies about adaptive patterns have got several strengths and weaknesses, the following principles are conclusion for designing adaptive patterns:

Technology: Every design has its own design kinetic features, it depends on design needs. All the designs have sun tracking sensors or a time schedule for sun path, it is an essential aspect for designing kinetic adaptive patterns.

Generative and parametric modelling principles: Pattern can be designed according to design concept formalization, it can use linguistic or biological or both approaches. Morphology also depends on design concept, its animation can be made in X, Y, and Z directions or any combinations of those.

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Materials:

Patterns can be made from variant materials, such as plastic, steel, metals, fabrics, etc., materials affected by climate, every location on earth has its suitable materials. As an example of material modification that enhances the quality of light diffusion perforations in material. Perforations in the pattern can also control the quantity of daylight, which effect on heating certainly, high amount of light can be gathered by using a high-density amount of perforations in the pattern and vice versa, this technique used in The Water Cube national water centre, Bejin. Last aspect is the adaptive pattern panels sections' thickness and length, increasing thickness and length will decrease amount of daylight and heat.

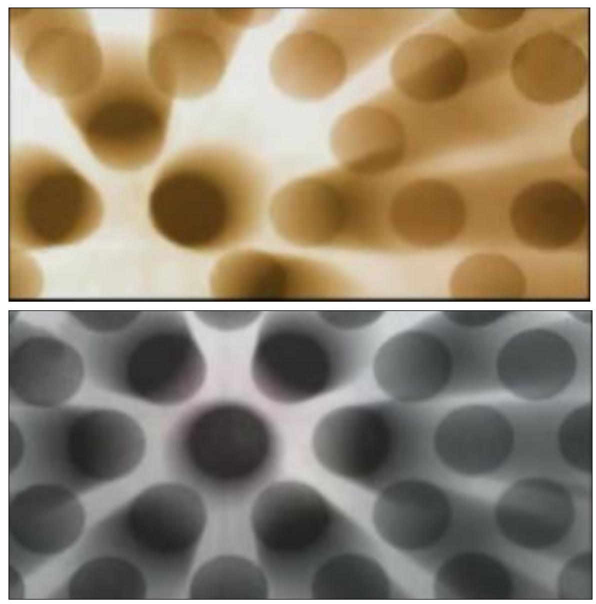

Figure (5.16) Example of patterns' perforations density

Application in project: Applying the daylighting adaptive pattern systems should be considering the fact that many of them can be used as a part of a building, a whole façade, or at all facades. Furthermore, it will be good to apply adaptive pattern systems as an interior solutions. It is better to design an adaptive pattern that suits different locations, to maximize the compatibility with variant situations.

Representational aspects: All designs need analogue and symbolic representation.

5.3 Daylighting parameters

Al Bahar Towers:

Shading system for this design has a sun path tracking and enhancing visual performance sensors, it has also other visual performance and comfort parameters except colour. Energy saving, social performance, and health parameters are achieved in this design by these sensors that control the spaces between pattern elements.

Simons Centre:

Shading system has set a variety of parameters, the first parameter is sun tracking, it has two types for tracking sun; sun path and environmental factors. For visual performance, pattern has set parameters for illumination, glare, and light distribution, but it has no parameters for light directivity.

Shading system also has many visual comfort parameters, they are privacy, appearance, and outdoor view. As a result of previous parameters, this design has energy saving features and the other visual comfort parameters which are health and social performance.

Helio Trace Centre:

This design shading system has a sun path tracking and a time schedule, it has also all visual performance parameters, and all visual comfort parameters except colour. Energy saving is achieved in this design, but the designer has focused more on visual performance and comfort.

Evaluation:

After classifying and analysing of case studies daylighting parameters were analysed:

Daylighting parameters		Al Bahar Towers	Simons Centre	Helio Trace Centre
Visual performance	Illumination	High	Medium	High
	Glare	High	Medium	High
	Distribution	High	Medium	High
	Directivity	High	Not exist	High
Visual comfort	Outdoor view	Low	Medium	Low
	Health	High	Medium	High
	Social performance	Medium	High	Medium
	Colour	Not exist	Not exist	Not exist
	Privacy	Medium	High	Low
	Appearance	Medium	High	Low
Energy saving	Lighting energy	High	Medium	Medium
	Thermal comfort	High	Medium	High

Table (5.4) Analysis of daylighting parameters

Visual performance: It can be noticed from daylighting parameters table that Al Bahar Towers and Helio Trace Centre are approximately at the same level of performance, but Simons Centre is less because it is concerning about form more than function, and making a masterpiece that suits the centre entrance. All of the four parameters are needed to be high efficient to deliver an appropriate daylighting.

Visual comfort: There are a variant levels of visual comfort for the patterns, Simons Centre focused on appearance, privacy, and social performance more than the other designs. Visual comfort needs change from a project to another, so it depends on design requirements. Smart Energy Glass by Peer+ is an example for an additional solution for solving visual comfort problems, it is a green building smart glass that has the ability to control solar radiation, to change the view into three options; bright, dark, and privacy.

Figure (5.17) Smart energy Glass by Peer+

There is no design concerns about lighting colour, it can be applied upon being a part of design requirements also, or coloured glass can be added to a pattern to control the daylighting colour parameter.

Figure (5.18) Coloured Glass

Energy saving and thermal comfort: Regarding lighting energy saving and thermal comfort, Al Bahar Towers focused more than Simons centre or Helio Trace Centre on saving energy, adaptive patterns should at least reduce lighting loads, decreasing of mechanised cooling, and heating loads if it is possible to provide an appropriate environment for users.

5.4 Mechanism

Al Bahar Towers:

Al Bahar Towers component has three types of movement: fixed, semi-moving parts, and moving parts, fixed parts are supporting structure frames and mesh, semi-moving PTFE panel that make movement by actuator, and moving parts which are actuators, actuators make animation mainly by a single cylinder that keeps pulling and pushing fabric meshes.

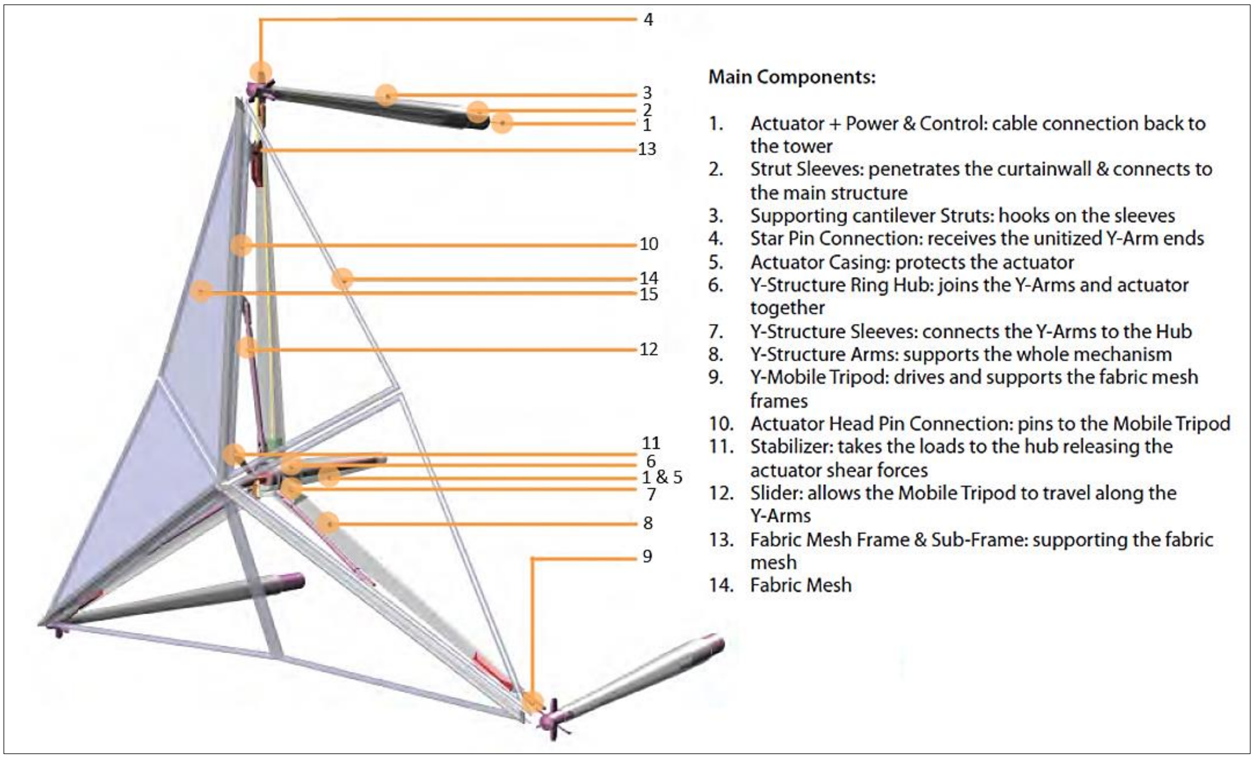

Figure (5.19) Al Bahar pattern unit main components

Simons Centre:

Simons Centre façade consists of three layers, first and last layer are tempered glass, the pattern located in the middle and pattern has three components: steel frame, actuator, and Tessellate module. Actuator keeps revolving to maintain Tessellate module pattern transformation.

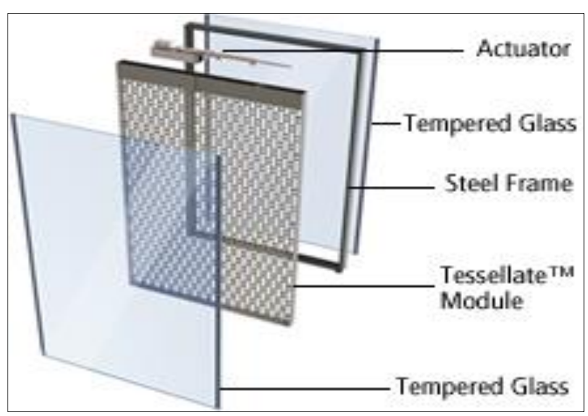

Figure (5.20) Simons Centre Pattern main components

Helio Trace Centre:

Helio Trace centre has Strata technology that contains modular units, when retracted, the units hide within a single section of the module. When activated, the units extend to form a continuous surface that consists of a series of slices, and when retracted the units disappear, actuator movement is exactly like car wiper. Strata has the ability to be formalized into non-rectangular shapes, this underpins that Helio Trace Centre has been designed according linguistic generative system approach.

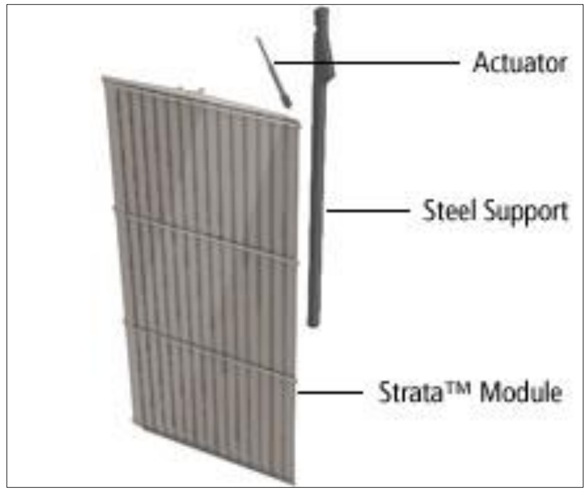

Figure (5.21) Helio Trace pattern main components

Evaluation results

Mechanism is the way in which the system does work to deliver preferred daylighting under various situations, which means that under various existing daylight. Mechanism required to be capable of providing preferred daylighting and that depends on design needs, so there is no general rule for specifying pattern mechanism.

6.0 Chapter six: Design Implementation and framework

6.1 Application of the findings

The explanation of kinetic patterns has leads the scope of this pattern design, for the reason that the design is based on daylighting, there will be constraints on the design, colour and lighting will be neutral and close to reality, the focus of the animations is on visualizing the and movement of patterns. The main aim of this design is to create an adaptive kinetic pattern system that could be applied to any building type, whether existing or new, in order to improve environmental performance through daylighting passive design of the building. This system would be applied to a building to utilize natural lighting and shading conditions, the design must deliver diffused light, not direct sunlight. According to previous chapters' findings, there are steps for creating adaptive kinetic patterns by parametric design software, they are listed below:

First step: Design concept

There are two types of pattern design in this application: first one is focused more on function and delivering the best suitable daylighting, and the other one is focusing more on aesthetic aspects.

Second step: Setting the parameters

Creating the sun path

For designing an accurate adaptive pattern that based on daylight, sun path is needed, sun path is recognised in parametric software as an attractive point that creates pattern movements according to its position. For designing a pattern that suits any location in the world sun path must has date, time, time zone, longitude, latitude, and site north angle parameters.

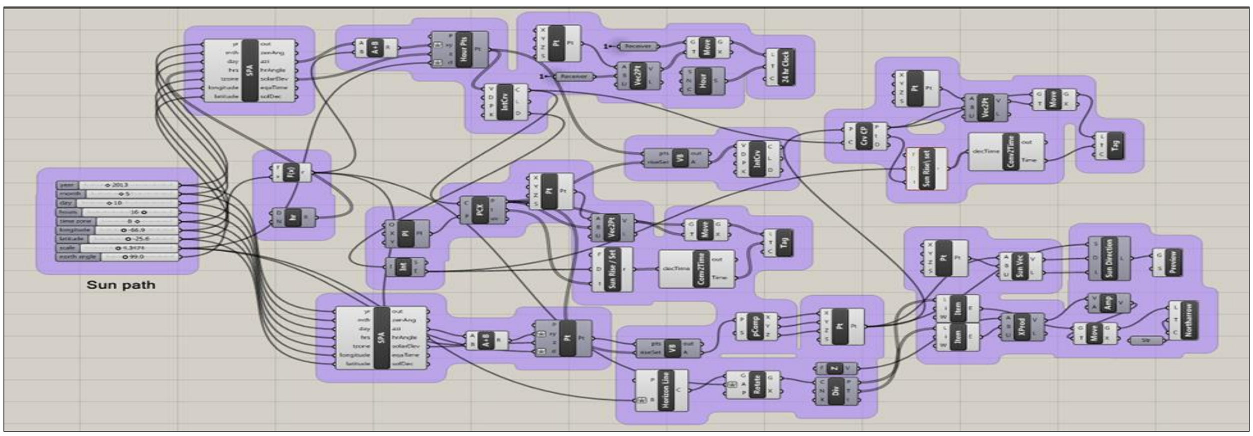

Figure (6.1) Parametric definitions for sun path using Grasshopper software

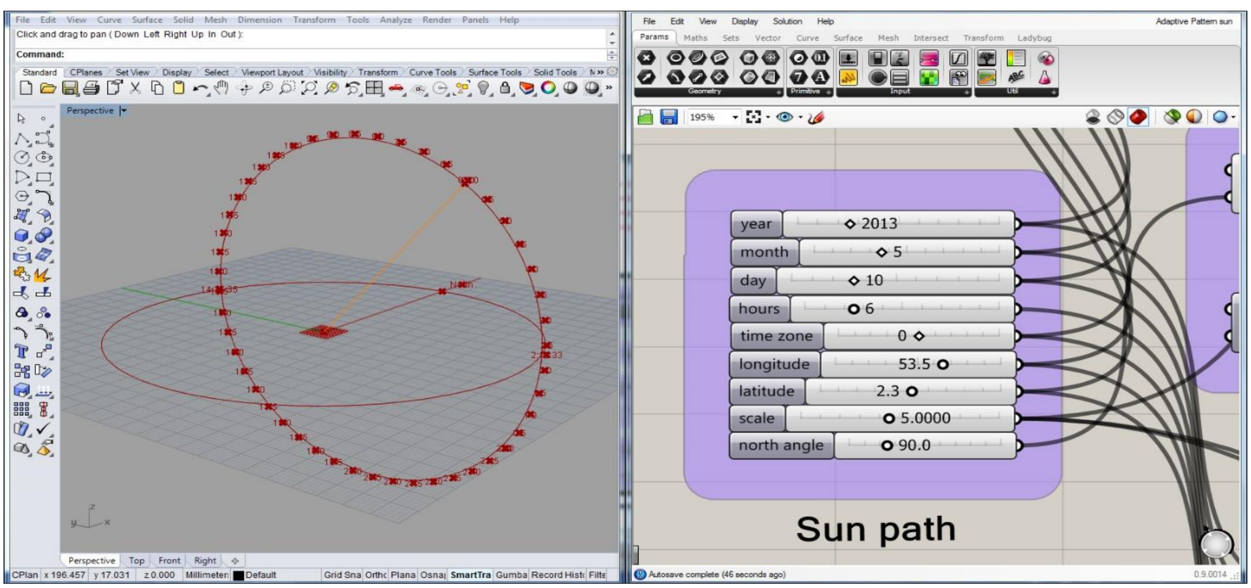

Figure (6.2) Sun path parameters' sliders in Grasshopper software on the right, sun path illustration in Rhinoceros software on the left

Creating light parameters

After defining sun path, daylight parameters are needed to be set which are visual performance and visual comfort. Daylight parameters are:

Illumination, glare, distribution, direction, outdoor view, colour, privacy, and appearance.

Third step: Creating the pattern

First design alternative

After setting parameters, creating the pattern will be the next step, the design is divided into units in order to flexibility to design, and design parameters will contain:

- Unit 'X' and Unit 'Y' counts: this parameter will set the number of pattern units in X and Y axis. Changes in this parameter are depend on the required size of pattern.
- Unit Width, Unit length, and Unit Thickness: these parameters will control the dimensions of pattern unit. Increasing thickness and length will decrease amount of daylight and heat.
- Perforations density: to maximize the performance of the pattern perforations can control the quantity of daylight, which will enhance cooling and heating, high amount of light can be obtained by using a high-density amount of holes in the pattern and vice versa. Pattern rotation,
- Opening and Closing: rotate parameter will revolve units around their axis, opening and closing pattern will be based on scaling pattern units retracting and expanding them.

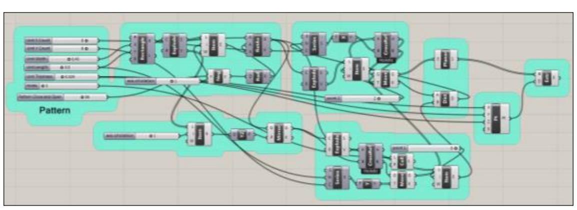

Figure (6.3) Pattern parameters in Grasshopper software

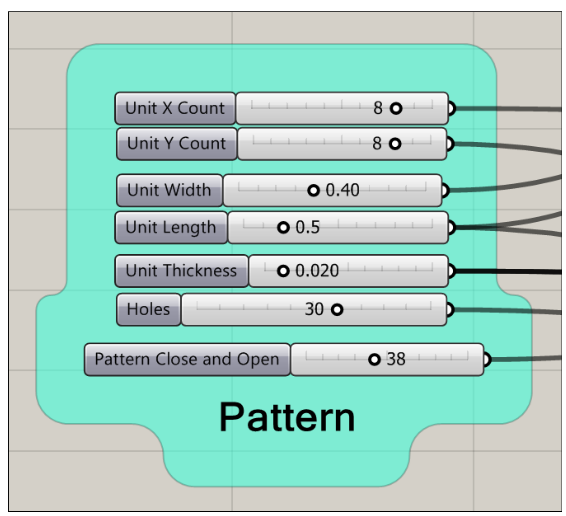

Figure (6.4) Parametric definitions for pattern design using Grasshopper software

Second design alternative:

Here the design is based on the main pattern units, this design is focused more on the aesthetic aspects, and customizing the required privacy, this design is applying shape grammars definition, design parameters contains:

Pattern define: this parameter is to define an existing pre-modelled pattern or to model a pattern form that based on parametric or algorithmic formulas.

- Pattern closing and opening: retracting and expanding pattern according to desired direction.
- Gradient: adjusting variant gradients for pattern that will give flexibility and enable a customized shading and privacy according to context, for example if the gradient has a high bottom density that will provide a privacy and indirect light for the space behind.

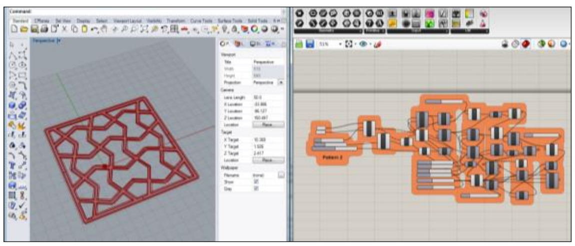

Figure (6.5) Pattern parameters in Grasshopper software on the right, viewport pattern illustration in Rhinoceros software on the left

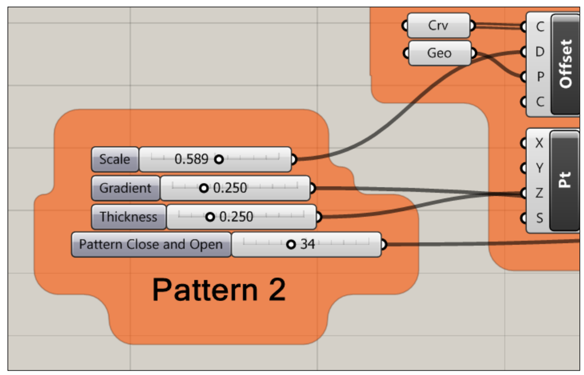

Figure (6.6) Parametric definitions for pattern design using Grasshopper software

Forth step: Selecting pattern material

Patterns can be made from variant materials, materials affected by climate, every location earth has its suitable materials. In this design implementation selected material is steel.

Fifth step: Visualising the pattern

While adjusting the parameters for the required design, viewport in modelling software will animate the changes of pattern in real time, final visualising for realistic images can be created by using render engine or by any other presentation method.

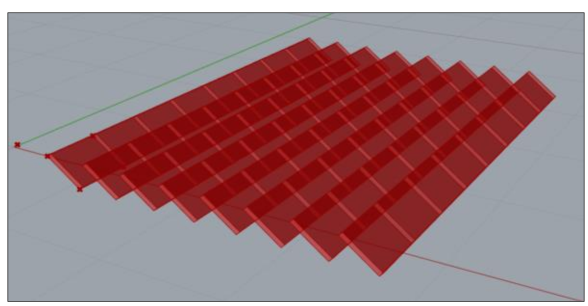

Figure (6.7) First design alternative modelled pattern by Grasshopper in Rhinoceros viewport

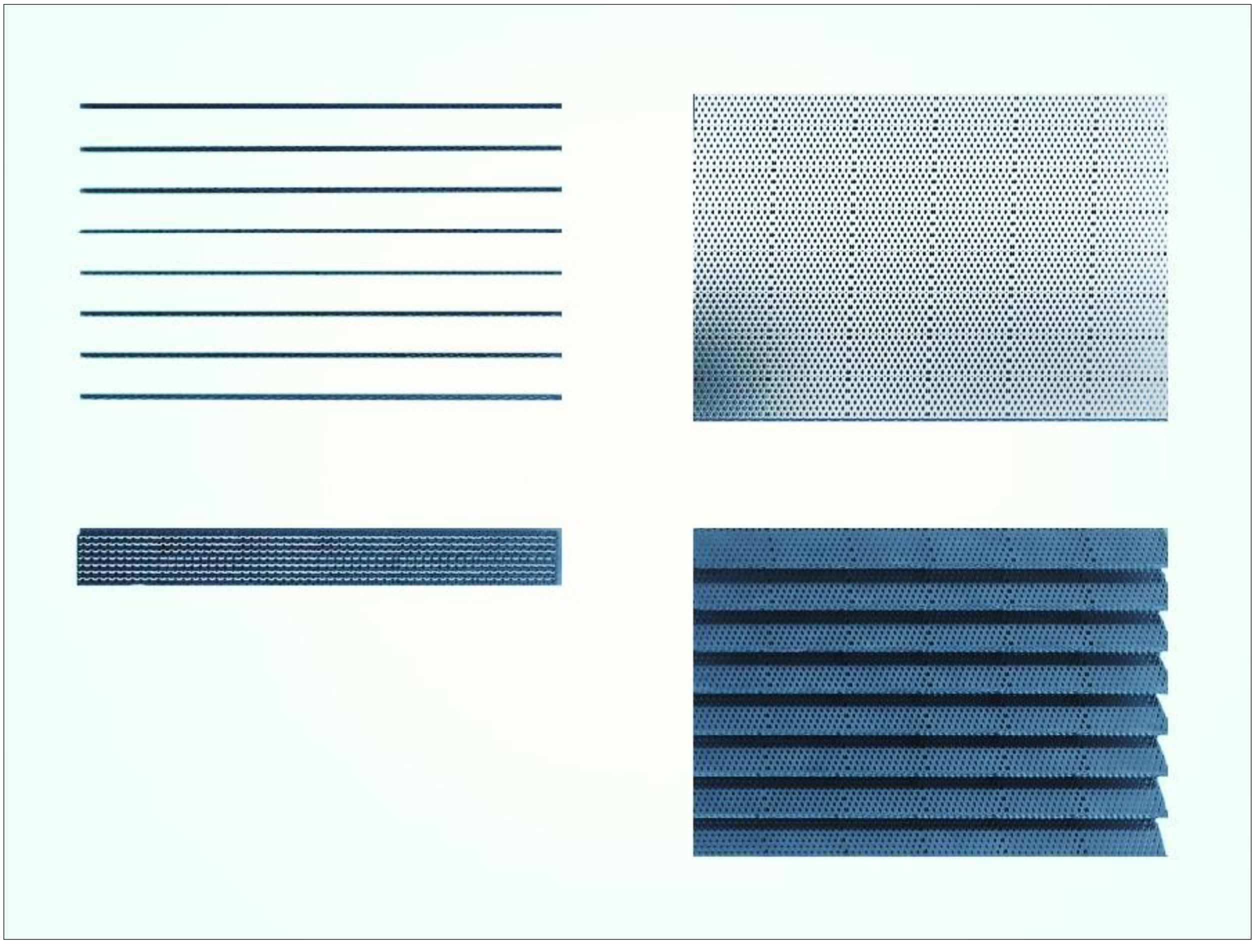

Figure (6.8) Realistic render for first design alternative kinetic pattern positions

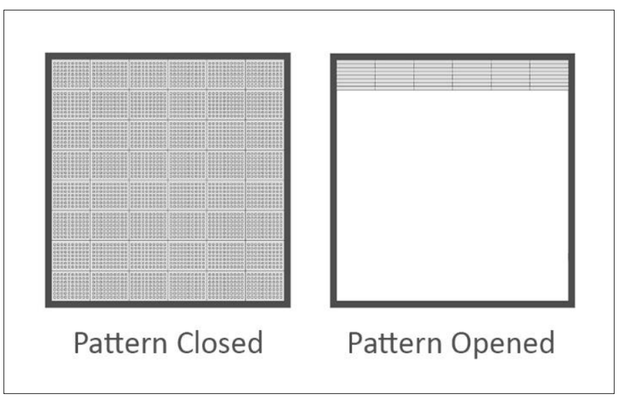

Figure (6.9) Analytical drawings of first design alternative pattern in two positions; closed and opened

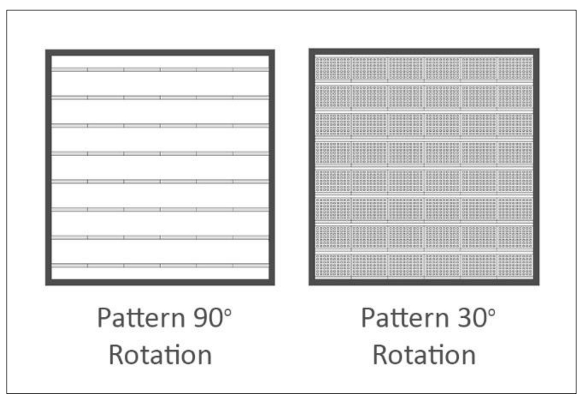

Figure (6.10) Analytical drawings of first design alternative pattern in two positions; 90 degrees rotation, and 30 degrees rotation.

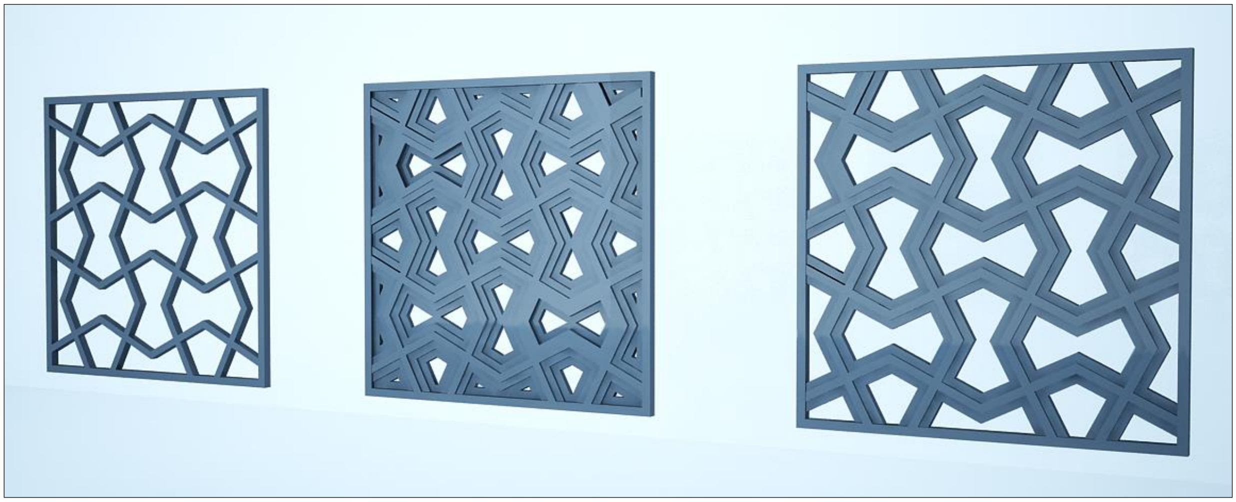

Figure (6.11) Realistic render for second design alternative kinetic pattern thicknesses

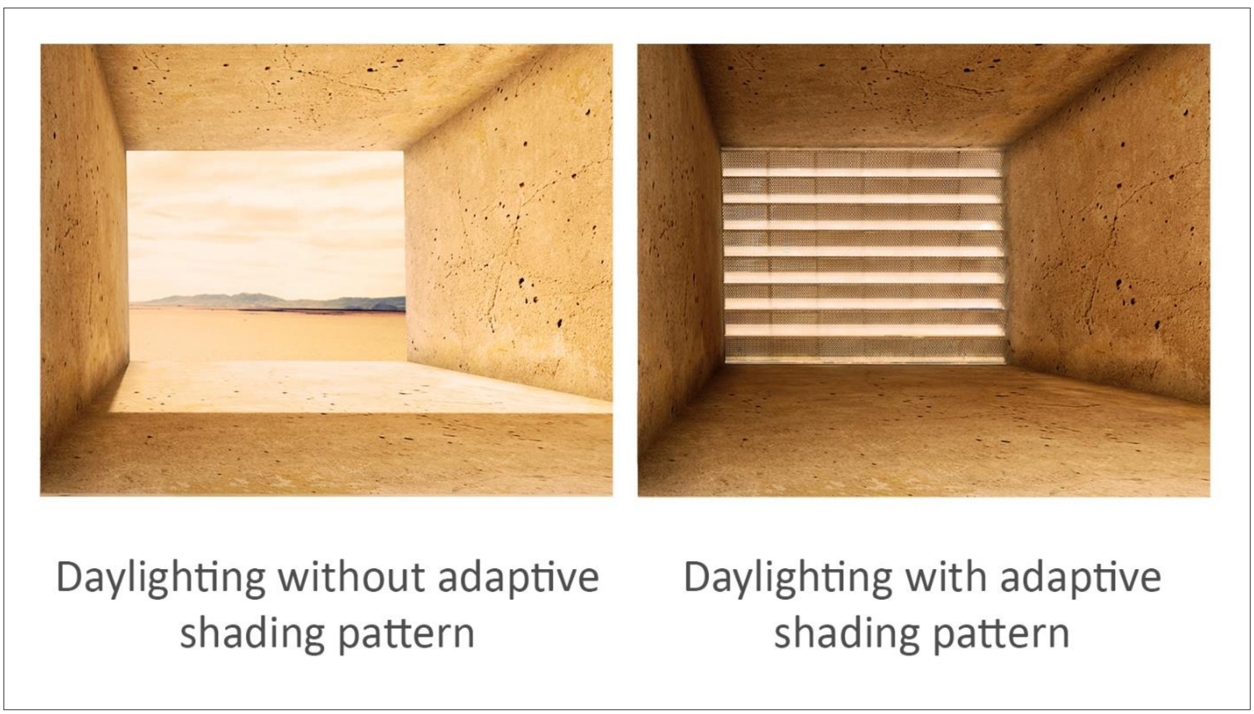

Figure (6.12) Realistic render for first design alternative adaptive pattern displaying daylight simulation

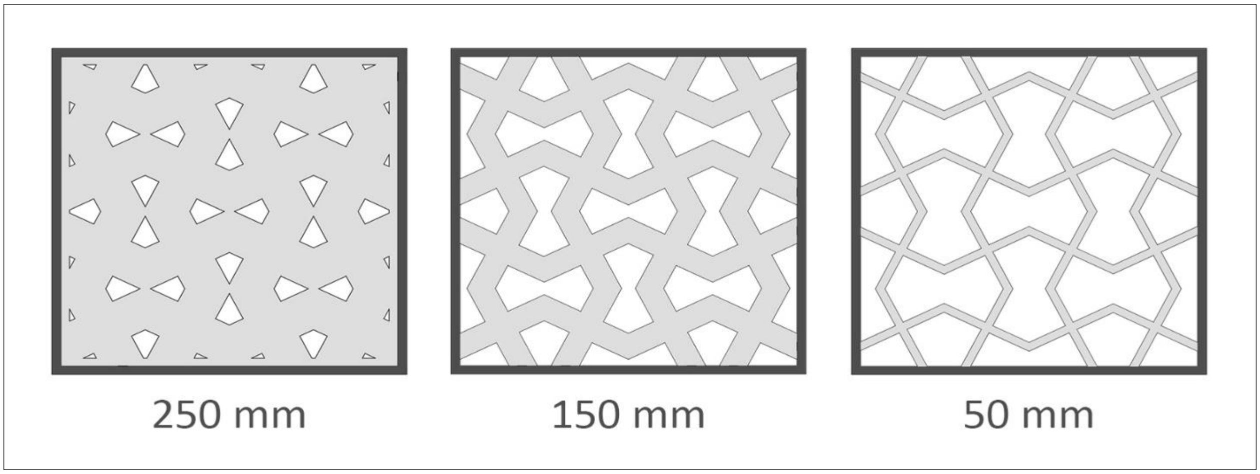

Figure (6.13) Analytical drawings of second design alternative pattern in three thicknesses 50 mm, 150 mm, and 250 mm

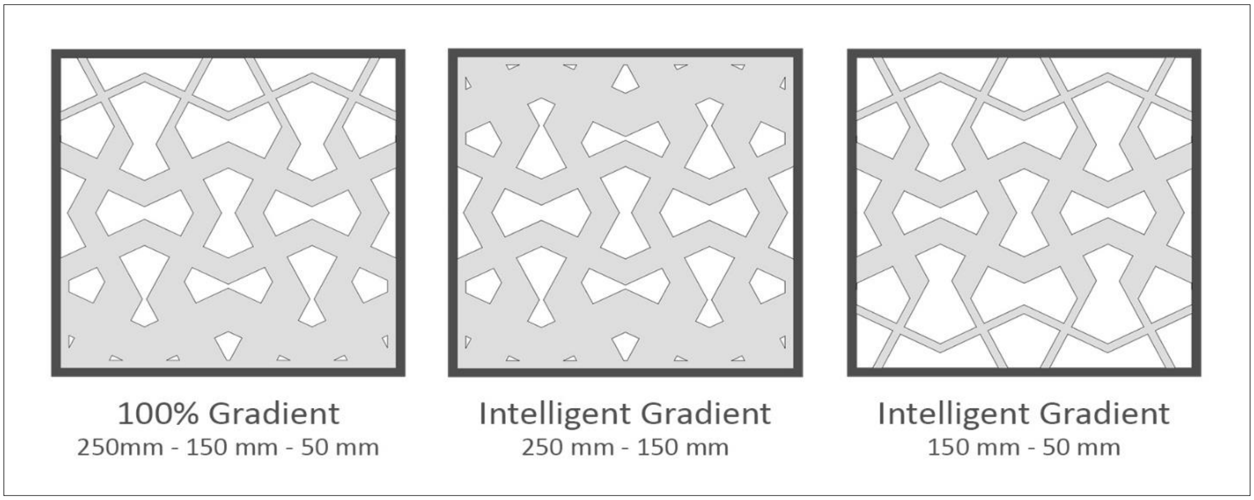

Figure (6.14) Analytical drawings of second design alternative pattern in gradient phases

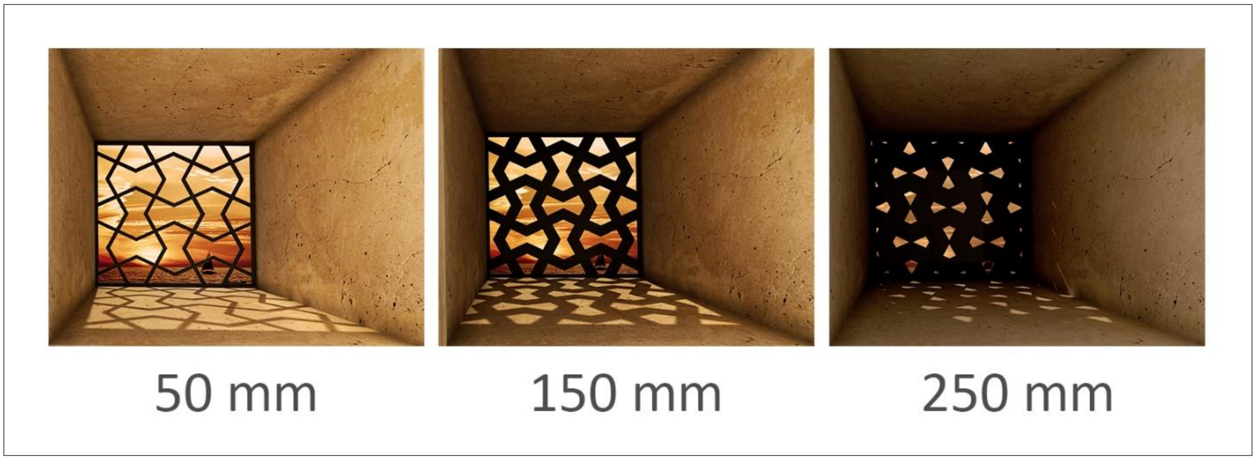

Figure (6.15) Realistic render for second design alternative adaptive pattern displaying daylight simulation for three thicknesses 50 mm, 150 mm, and 250 mm

6.2 Design Framework

After analysing data for determining general theories of designing kinetic patterns, case studies, and design implementation a frame work has been created regarding the outcomes of these analysis.

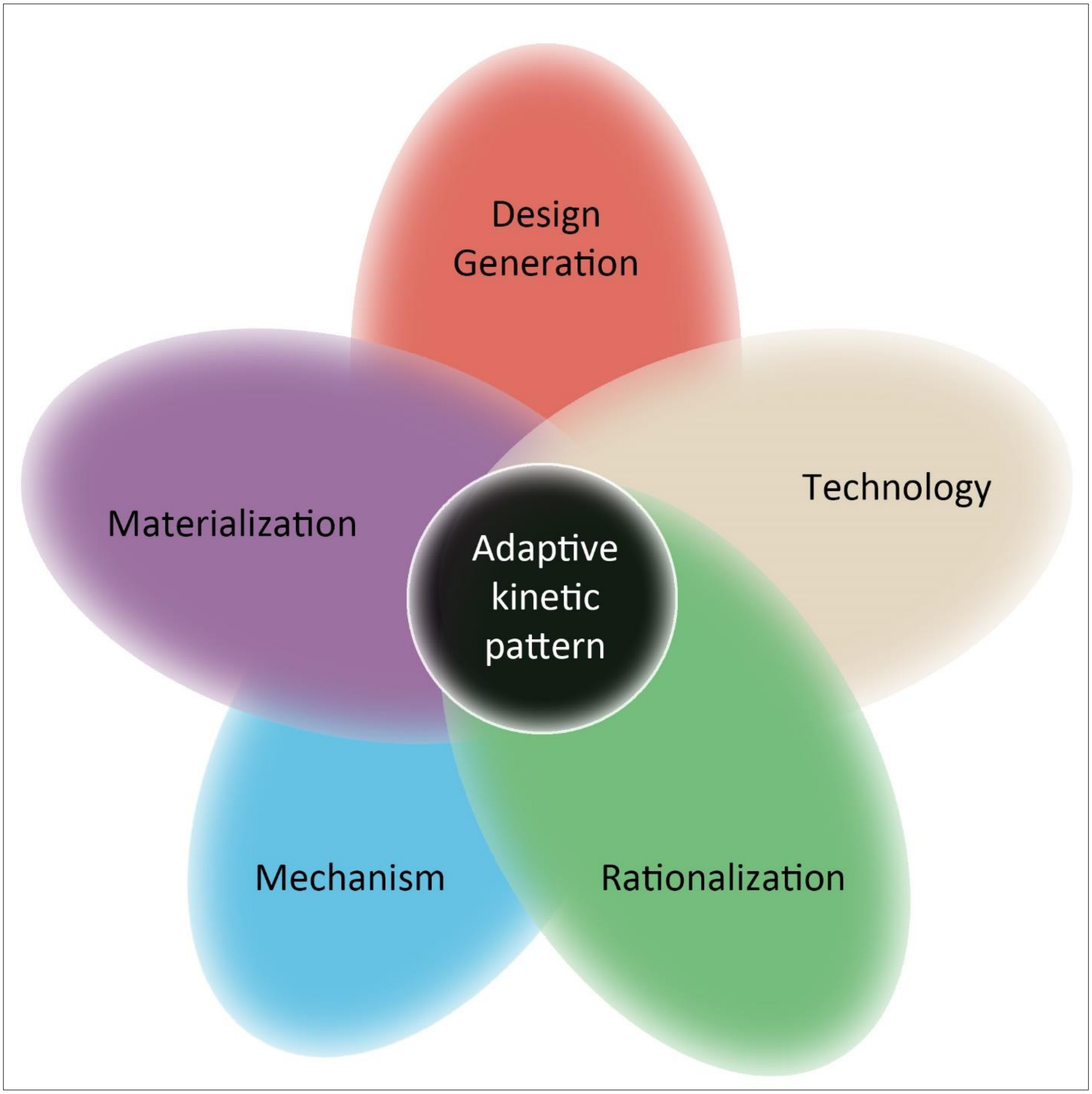

Figure (6.16) Adaptive kinetic pattern design framework

The description of the framework:

Design generation: design approach and specification of the formal aspects of the designer, by starting with an idea, sketching a form, choosing a function.

Technology: how the designed pattern has been represented for following stages. It is about converting design concept to an actual design, in this phase kinetic pattern will be presented as a parametric or a generative model with its morphology.

Rationalization: transforming the free-form and conceptual sketches into rational adaptive kinetic pattern joined with a supporting structure. In this phase an actual detailed model must be done, daylighting and environment parameters meant to be set.

Mechanism: selection of the technical machines aspects, processes, tools, systems and strategies.

Materialization: decisions regarding the formal and interactive attributes of the structural system, the elements, and selecting materials.

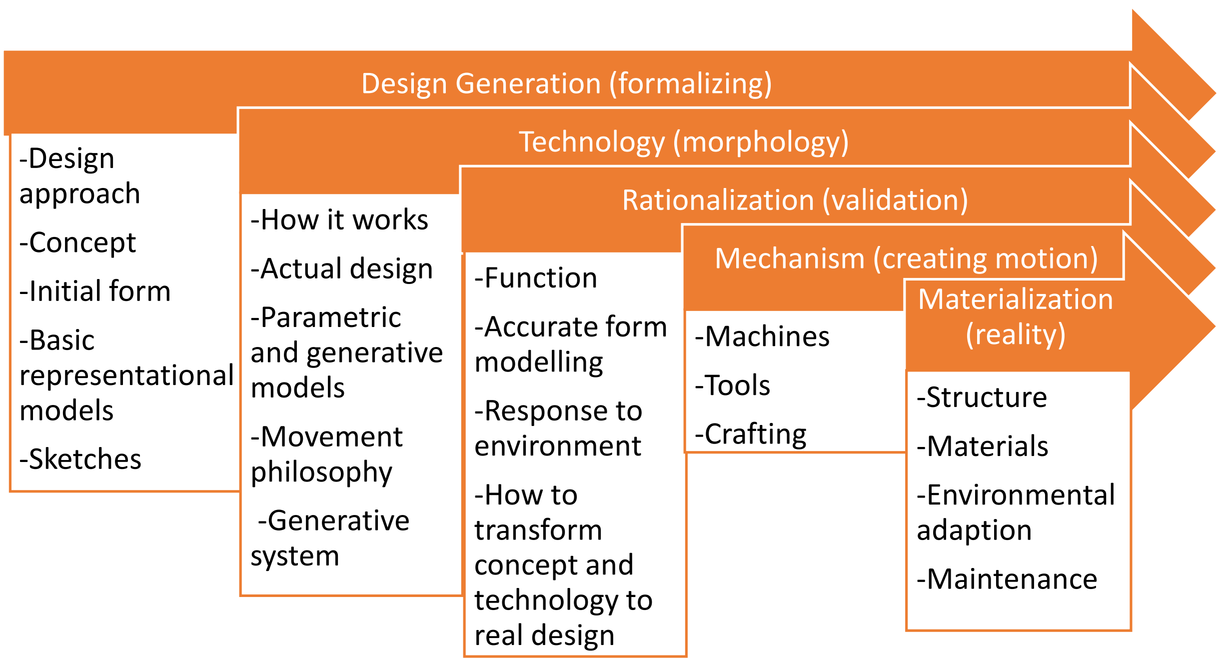

Figure (6.17) Main points for design framework aspects

Every category consist of different concepts, approaches, procedures, systems, etc., following the explanation of Lawson (1980), there are relations between these concepts that is the core of design strategy instead of the secluded concepts themselves. Designer specifies design procedures as the ways in which several concepts react in projects.

Design Generation	**Design Concept**	Function based or aesthetic based or both
Technology	**Generative system**	Linguistic or biological or both
	Morphology (Locative transformations)	Three-dimensional move, scale, and rotate
	Modelling	Parametric and generative
	Representation	Analogue and symbolic
Rationalization	**Daylighting parameters**	Sun path, visual performance, visual comfort, energy saving and thermal comfort parameters
Mechanism	**Machine system**	Actuator and pattern components
Materialization	**Pattern material**	plastic, steel, metals, fabrics, etc.

Table (7.1): design framework categories

7.0 Chapter seven: Conclusion and recommendations

This chapter presents the conclusions that can be extracted from this research, it also highlights the limitations and includes recommendations for future studies.

7.1 Meeting the aim and objectives

1. **To analyse theories in general that is related to adaptive kinetic pattern design, parametric generative design tools in architecture, and daylighting performance parameters.**

Main essential aspects can be extracted in theories of designing adaptive kinetic patterns from this research:

Morphology discovering the achievable range of planned shapes within geometric limitations, it defines the pattern spatial transformations which are the principles of creating a kinetic element.

Spatial transformation has three basic geometric transitions in place: move, rotate, and scale which are merged to generate more complicated movements, like twist or roll. Motion through material deformation is considered to be a complex geometric transformation.

Generative design process has four phases, input is first phase, by starting setting parameters and conditions in designing patterns. The second phase is generation technique, using algorithms and set of rules. The third phase is output, it is the action of generating variants. The last phase is selecting the most efficient variant.

Generative design systems divided into two types; linguistic and biological. Linguistic has a grammar-based shape formalism like shape grammar, on the other hand, biological has organic-based shape formalism and it is has its own shape transformations. Both systems can be used to formalize a kinetic pattern.

Representational design has two types: analogue and symbolic, both of them are used in designing adaptive kinetic patterns.

Timing is a main aspect in designing kinetic patterns, for adaption, the design has to create a relation between sun and pattern movement, that will be done by tracking sun and consider it as an attraction point that influence pattern motion, or by creating a timer based on space occupants' comfort.

Controlling the illuminance, distribution, glare, and light directivity by adaptive patterns depends on the spaces between pattern surfaces which can be adjusted by pattern movement.

Adjusting the spaces between pattern surfaces will change the privacy level. Appearance and colour can be controlled by parameters that vitiate according to the design concept. Outdoor view can be maximised and minimised regarding the spaces between pattern surfaces. Social performance, health, energy saving, and thermal comfort parameters are controlled indirectly, they will be changed as a result of varying previous parameters.
Kinetic adaptive patterns have a theoretical design strategy allocated by generative design process, pattern morphology is defined by generative design system, if the system is linguistic, morphology will be based on grammar formalism that generates complex geometries, on the other hand, if it is biological, it will has a nature shape formalism.
Daylighting parameters and rules will be defined in the generative design process within input and technique phases. The representation of the design process has an analogue and symbolic types that presented by parametric design software.

2. **To analyse contemporary adaptive kinetic patterns' projects that are related to the research aim.**

After analysing and evaluating contemporary case studies, the following design principles can be educed:

Regarding design concept, it will be a more compatible and harmonious design if the design concept interpreted into a good form, function, and pattern transformation, by making a combination between them as an integrated concept.

For technology aspect, every design has its own design kinetic features, it depends on design needs. All the designs have sun tracking sensors or a time schedule for sun path, it is an essential aspect for designing kinetic adaptive patterns.

Pattern can be designed according to design concept formalization, it can use linguistic or biological or both approaches. Morphology also depends on design concept, its animation can be made in X, Y, and Z directions or any combinations of those. Patterns can be made from variant materials. It is better to design an adaptive pattern that suits different locations, to maximize the compatibility with variant situations. All designs need analogue and symbolic representation.

All of visual performance parameters are needed to deliver high efficiency and to deliver an appropriate daylighting. Visual comfort needs change from a project to another, so it depends on design requirements, and they are relied on visual performance parameters. There is no design concerns about lighting colour, it can be applied upon being a part of design requirements also, or coloured glass can be added to a pattern to control the daylighting colour parameter.

Concerning lighting energy saving and thermal comfort, adaptive patterns should at least reduce lighting loads, decreasing of mechanised cooling, and heating loads if it is possible to provide an appropriate environment for users.

Mechanism required to be capable of providing preferred daylighting and that depends on design needs, so there is no general rule for specifying pattern mechanism.

3. **To create a design implementation regarding the findings of the first two objectives using a parametric generative digital design tool.**

Design implementation was done by five phases: defining design concept, setting up the parameters in parametric generative modelling software including which are sun path and other environmental daylighting parameters, creating the pattern units and morphology, choosing pattern materials, and finally visualising the pattern in a virtual simulation software or realistic rendering by render engine. A personal application is needed to emphasise understanding of design strategy.

4. To establish a design framework that provides a design strategy for adaptive kinetic pattern systems.

The process of designing adaptive kinetic patterns has five phases: Design generation, Technology, Rationalization, Mechanism, and Materialization.

Starting by design approach and specifications of the formal aspects of the designer, and how the designed pattern has been represented for following stages. Transforming the free-form and conceptual sketches into rational adaptive kinetic pattern joined with a supporting structure. Then selection of the technical machines aspects, processes, tools, systems and strategies. And finally taking decisions regarding the formal and interactive attributes of the structural system, the elements, and selecting materials.

Research Aim

It can be noticed that research aim has been accomplished by achieving research objectives.

Adaptive kinetic pattern design framework divided into five categories: Design generation, technology, rationalization, mechanism and materialization.

7.2 Limitations to the research

Through this research, there are a number of limitations found, they are:

- Lack of available sources for this research as the topic is a very new topic.
- It was difficult to collect appropriate supporting data and case that is related to the research aim.
- It was difficult to collect appropriate supporting data and case studies for this research because of privacy and confidentiality.

7.3 Recommendations for Future Study

Bearing in mind the limitations of this research, there is still a big probability for devolvement and researches can be established later. In the future, the improvement of designing adaptive kinetic patterns is going to absolutely occupy the agenda of computational design in both theory and practice and specially generative and parametric design systems. Establishing a new strategy for pattern parametric design may be difficult, the most convenient way to understand the conception of parametric systems would be to use a generative tactic, however, it is greatly possible that a similar design strategy can make a guide line for designing kinetic patterns generated by scripts or algorithms.

Another recommendation is to make a research on physical models for adaptive kinetic patterns and how computational modelling phases turn into a real machinery design.

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