THE RELATIONSHIP BETWEEN GREEN ARCHITECTURE AND ADAPTIVE FAÇADE DESIGN TECHNOLOGY

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
DLMAN AZEEZ MOHAMMED

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

NICOSA, 2017

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Approval of Director of Graduate School of Architecture

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my family...

ABSTRACT

A massive growth in the field of green architecture has been recorded over the past few years. The use of adaptive façade design has grown to be a tool used to solve building environmental lapses, thereby improving the energy efficiency, indoor air quality which entail lighting and ventilation management and the material selection also been a key aspect. Despite green building and its technological aspect rapid growth, and a large number of adaptive façade designs no statistical data has identified and justified the ability of green architectural principles in solving environmental degradation.

In this research, the relationship between green architecture and technology has been evaluated and discussed. The research takes into consideration a holistic approach towards understanding green architecture by making use of principles surrounding green architecture which influences technological aspects of buildings. To complete this thesis, the kinetic structure has been analyzed where adaptive façade design technology was critical. The aims of this thesis are exploring green architecture principles and adaptive façade design technology through case study analysis. An analytical study on each case study has been conducted, highlighting their green architecture principles and the clear-cut approach to aid sustainable development. The study focuses mainly on green architecture and adaptive façade design technology with the aim to validate their connectivity and enlighten their approaches. This research will help architects to understand the built environment in relation to the adaptive faced design technology and the green architectural principles.

Keywords: Adaptive façade; green architecture; green architecture principles; kinetic structure; technology.

ÖZET

Son yıllarda yeşil mimarlık büyük bir gelişme kaydetmiştir. Adaptif cephe tasarımı kullanımı, çevreye verilen zararın azaltılması için bir araç haline gelmiştir. Böylelikle, enerji verimliliğini iyileştirme, iç hava kalitesi, aydınlatma ve malzeme seçiminde de anahtar görevi görmüştür. Yeşil bina ve teknolojik özelliklerin hızla büyümesine ve çok sayıdaki adaptif cephe tasarımlarına rağmen, yeşil bina ilkelerinin çevre sorunlarını çözme yeteneğini haklı gösteren ve doğrulayan istatistiksel bir veriye rastlanmamıştır.

Bu araştırmada, yeşil mimarlık ile teknoloji arasındaki ilişki değerlendirilip tartışılmıştır. Bu araştırma, yapıların teknolojik özelliklerini etkileyen, yeşil mimarlık ilkelerinden yararlanarak yeşil mimarlığı daha iyi anlamak için bütüncül bir yaklaşımı benimsemiştir. Bu tezi tamamlamak için, adaptif çephe tasarımlarının önemli olduğu durumlarda kinetik strüktürler analiz edilmiştir. Bu araştırmanın amaçları, örnek inceleme çalışmasıyla yeşil mimarlık prensiplerini ve adaptif cephe tasarımı teknolojisini araştırmaktadır. Her örnek incelemesi için, yeşil mimarlık ilkelerini net olarak vurgulayan ve sürdürülebilir kalkınmaya yardımcı olmak için net bir yaklaşımla, ayrı ayrı analitik çalışma uygulanmıştır. Çalışma temel olarak, aralarındaki bağlantıyı doğrulamak ve yaklaşımlarını aydınlatmak için yeşil mimarlık ve adaptif cephe tasarım teknolojisi üzerine yoğunlaşmıştır. Bu çalışma mimarların, yapılı çevreyle adaptif cephe tasarımı teknolojileri ve yeşil mimari ilkeleri arasındaki bağlantıyı daha iyi anlamalarına yardımcı olacaktır.

Anahtar Kelimeler: Adaptif (uyarlanabilir) cephe; yeşil mimarlık; yeşil mimarlık ilkeleri; kinetik yapı; teknoloji.

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LIST OF ABBREVIATIONS

BRE:	Building Research Establishment
BREEAM:	Building Research Establishment Environmental Assessment Method
CABS:	Climate adaptive buildings shells
GHG:	Greenhouse gases
HVAC:	Heating, ventilation and air conditioning
ICF:	Insulated Concrete Form Systems
IEQ:	Indoor Environmental Quality IEQ
LEED:	Leadership in Energy and Environmental Design
SBAT:	Sustainable Building Assessment Tool
SIPS:	Structural Insulated Panel System
UNCED:	United Nations Conference on Environment and Development
UNESCO:	United Nations Educational, Scientific and Cultural Organization
USGBC:	U.S. Green Building Council
VOC:	Volatile Organic Compounds
WMO:	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Background

With the rapid growth of awareness in regard to the environmental problems facing the world, new solutions have been created to solve and decrease the environmental degradations, one of which is ‘green architecture’. Green architecture has been considered on a worldwide scale, where material, technologies, and new constructional process have been embedded into the society and the greenhouse gas emission has been a focus point to be reduced. The term sustainable architecture as a general terminology has been used to describe the green architecture, thus relates to the environmental conscious aspect of architecture (Akadiri et al, 2012). These days, most of the architectural designs are considerable to follow some basic standards, with the use of photovoltaic cells, green roofs, and many more technological concepts to attain green building (Nigra et al, 2015).

The effect of green architecture in the building sector was so powerful that the building environment is changing within a short while. New materials and techniques have evolved, mass fabrication, mechanized production techniques, energy saving buildings were a significant aspect of this trend. The information technology of such movement has spread towards the usage of computer in all sectors to create a new solution that affects the global scale to curb environmental degradation. New methods in design and construction to conserve energy, waste and water efficiency has been adopted in the built environment. The building envelope assumes a vital role in attaining indoor comfort for the occupants and energy efficient building. The most creative strategy of the building envelope is based on the dynamic and integrated solutions for thermal performance, exploitation of energy from renewable sources and the integration of the active systems. Efforts have been created toward the research development to achieve a sustainable (green) and an effective building envelope using adaptive façade design technologies.

Current patterns in architecture go toward dynamic and adaptive building envelopes, which reconfigure themselves to meet outside and inner changes in atmospheric conditions and user behaviour.

Despite recent developments and some landmark projects, the market is, where applicable, still dominated by traditional blinds and shutters. These systems however fail at high wind speeds and are restricted to planar façades and rectangular grids. However, contemporary high rise architecture shows a trend towards complex, curved and triangulated façade systems. This trend is particularly present in the Middle East, where external shading devices would seem essential.

Regardless of recent improvements and some great projects, there are still projects constructed and present using traditional blinds and shutters. These systems however come up short at high wind speeds and are limited to planar façades and rectangular grids. Today the computerized generative procedures are opening up new domains for reasonable, formal and structural investigations articulating an architectural morphology concentrated on the developing and adaptive properties of the form. Researchers are moving from the double skin façade to a more complex façade design where all functional strategies are improved, revised and integrated with active elements and the HVAC system. Adaptive façades are made of various subsystems and are sometimes designed, or operated as a whole integrated interactive system. Diverse adaptive façade technologies and solutions have distinctive synergy with the HVAC framework, inhabitant comfort desire, and other building subsystems. These results into extremely complex frameworks and subsystems which are hard to foresee controls and collaborations.

1.2 Problem Statement

In the world today green architecture is becoming a widely known trend in the construction and engineering sector and has been effectively present in the adaptive façade design technology. However, with the growing trend, different technological solutions to describe the green principle have been created. A plethora of architect have adopted some adaptive façade that has contributed to the advancement of solar shading device which has aided the energy consumption and lighting system in their designs. However, the design of the adaptive façade has become more complex and the development of different methods of construction, the requirements for highly controlled indoor environment, material selection, energy efficiency techniques and the production methods are to be clearly understood and related in design.

This research tends to explore the research about the technology of the adaptive façade design of several buildings in order to explore its characteristics, properties and application of green architecture and technology. A need for clear-cut attention in contemporary architectural trends of façade design to understand the positive and negative impact it has on society. If this aspect of adaptive design is set in place, architects would be able to employ all these new technologies and ideas into their present day work and for future development.

1.3 Aim of the Research

This research aims at exploring the means of green technology in adaptive façade design and the possibility of green technology evolving around architecture to achieve a greater sustainable outcome. It also endeavours to fill the gap between the relationship of green technology principle in adaptive façade design outcome, thereby initiating studies not only about green technology but also sustainable aspect of the façade design technologies as an aspect of green building practice.

This research also factors idea of creating a balance where the available green technological tools, materials, and techniques are made feasible by present day architects, by emphasizing the importance of new technologies and its usage in the development of architectural projects.

The research also sets to understand adaptive façade design system, concepts, and approaches that are relevant to green architecture. This understanding would enable us to think about the major aspects of adaptive façade designs and explore its potential toward its application in green architecture. This research would include:

- To analyse green building practices in adaptive façade designs
- To examine the basic principles of green architecture
- To identify case studies of green building and relate them based on their technologies.

1.4 Importance of the Research

The world is at a crucial stage of revolution in human society due to industrialization and new technology, changing the human society internationally. However, with the rapid growth of sustainable development at large scale, the ideology of architecture is given away to technologies, therefore in order to curb this high rate of lack of technical know-how towards the green architecture and façade design, a need to examine and structure an analysis of green architecture in respective to adaptive façade design principles would help control the social illiteracy using case study samples.

The growing rate of the green building community worldwide, calls for a proactive awareness in the relationship between green architecture and technology in the engineering and construction industry, in order to sustain the growth of the building environmental assessment standards. This research would, echo a conceivable outcome adding to a clear understanding of adaptive façade design outcomes and their clear cut principles towards sustainable development. By doing this, it would integrate an advanced method in analysing and understanding green buildings.

1.5 Limitations of the Research

The research major focus is the relationship between technologies of adaptive façade design and green architecture considering the techniques and principles. Therefore, the research shall not conceive the economic, social, and political aspect related to this topic. However, due to the fact that green architecture does not possess the attribute of cultural initiative or traditional aspects, this research is solely interested in proposed sample of green architecture and adaptive façade design in order to create adequate information related to the research objective.

1.6 Methodology of the Research

In order to achieve the goal laid down, to the study presented in this research, tracks the following steps:

Firstly, the inductive approach; which extrapolates the theoretical writings that are related to the search topic, with respect to the opinions of specialists on the green technology and adaptive façade design researches, its effects on architecture in general.

Secondly, a qualitative approach would be adopted in analysing the study principles and theories of green technology and its impact on the process of adaptive façade design and methods. Where review about most prominent architects who have benefited from this technology approach would be discussed and analysed.

Thirdly, a case study analyses would be implemented to analyse the principle of green architecture properties, material, and construction phase on the adaptive façade design. Study through five real examples will be analysed to determine the impact of green technology on architecture. Projects selected are: Simon Centre in New York, BIQ buildings, Institute du Monde Arab in Paris, Al-Bahr tower in Abu Dhabi and JSWD Headquarter Essen, in Germany. Case study selection was based on green technology overview where the buildings possess greater explanatory attributes that would contribute to the development of technology in green architecture, as well as these buildings are considered examples globally due to their high-level form of green and the use of green architecture standards.

1.6.1 Overview

This research provides in details the research methods and processes with regards to the title ‘green architecture and technology’. Research methodology involves the procedures, methods and research instruments selected for collection of data, for the purpose of answering research questions. Identifying what research methodology best suits the study is very pertinent.

A qualitative approach will be required for this research. The topic requires a case study research method with a descriptive approach. As per (Robert Yin, 2011), a contextual investigation is an observational enquiry that researches a contemporary phenomenon inside its genuine setting particularly when limits inside the marvel and setting are not plainly obvious. This was later on redefined by (Groat and Wang, 2006) as an empirical enquiry that investigates a phenomenon or setting (Omoyibo, 2011).

The qualitative method for research is what utilizes a natural environment that deals with understand phenomena in their context-specific settings. Qualitative method has been viewed as equipped for concentrating on complex circumstances, especially look into something including individuals and along these lines yield rich discoveries (Barrett and

Sutrisna, 2009). Qualitative research concentrates on the characteristics of the wonders under scrutiny as opposed to numeric estimation. In this strategy, the analyst's trust that this present reality wonders should be evaluated from inside the setting of that reality. The subjective approach manages the method for giving particular information and assessment of hypothetical issues and methodologies (Mckie, 2002). In wide terms, any sort of research that produces discoveries which are not acquired from factual methodology or other quantitative means can be viewed as a qualitative research. This infers the discoveries of a qualitative research are gotten from true settings where the marvels of intrigue unfurl actually.

There are two noteworthy destinations of a subjective research, which are portrayal and breaking down of the procedures through social truths are developed; and the social connections through which individuals are associated with each other.

The approaches to the qualitative research which would be used in this thesis is a case study. This allows an in-depth investigation of social phenomena using a combination of data gathering techniques. The cases approach postulate for an in-depth research of a particular issue within the context of its relationship with the real world.

1.6.2 Method of data collection

The data required for this research will include research on green architecture and its relationship with technology. Data would be presented in form of plans, images, and green architecture principles implored in relation to technology in each case study.

Case studies were evaluated according to the achieved parameters and criteria. The case study for this research was selected based on the location and their significant technology attributed to green architecture as the research objective, which is to identify the relationship between the green architecture and technology in contemporary buildings to ascertain the level of effects it has on the environment as a whole.

The sample of plans, collected and documented was analysed and interpreted, i.e. using a description and investigation of the social phenomena to determine the functional architecture of the building and the defined green architecture principle.

The method of data collection employed in this case study is qualitative method, focusing on the specific green architecture building samples, and was staged into different stages:

- Building selection according to technological inputs
- Site evaluation
- Drawing Plan of the building i.e. characteristics and function of the building

1.7 Scope of the Research

This aims to provide an initial database and the diagnosis of the relationship between green architecture and technology. To achieve these goals has been to focus on theoretical orientations through four hubs, focus the attention of the first axis to provide a basic knowledge of basic research of the vocabulary of the problem of the thesis, and its importance, the aims of the thesis, the limitations of the thesis.

This dissertation consists of four chapters:

Chapter One: This gives an introduction to the research subject, problems. It defines the topic generally and the state of green architecture and its technological relationship. The chapter then introduces the problem statement. This is followed by the aims, objective, importance, and methodology of the study. The chapter concludes with the limitation of the study.

Chapter Two: It presents a review of academic literature on green building and technological imprint of adaptive façade design. This shows a brief description of the new technology to give the ability for these green architecture buildings to utilize their new technology and the relationship between the new technology and the green architecture.

Chapter three: Introduces the theoretical and basis of the research. It discusses the green architecture and the adaptive façade techniques obtained data for each project, stating its design principles, material selection and tool implemented to create green architecture. It also draws a comparative analysis between the green architectural principles in determining their advantages and disadvantages.

Chapter four: It draws conclusions on the results achieved in the last chapter, and discussions about future research studies to be undertaken.

CHAPTER 2

LITERATURE REVIEW

2.1 Chronology of Green Architecture

To understand the chronology of green architecture we have to first define what it means. Green architecture sets to be an application to building in a way that it minimizes hazardous effect of the building on the health of human and the environment. According to (Roy ,2008) green architects' attempts to protect the water, air and the site by choosing appropriate and eco-friendly building materials and in their construction process.

In the late centuries alongside the fast development in the human populace, and the change in economic situations in result; the decline in the measure of non-renewable resources; a lot of harm created by ecosystem, global warming, soil disintegration, furthermore corrosive rains, the planet got to be distinctly compelled to encounter an environmental crisis, as a result of this different discipline gain to search for ways to reverse such situation. Architecture which was responsible for the construction of the built environment played a vital role in the environmental crisis. The focus of the technology and architecture in this period grew enormously creating different applicable tools, material, methods, and summits to curtail this environmental degradation.

After the industrial age, human became more conscious of their environment, and environmental degradation such as the decrease in the natural resource like fossil fuel, an increase in the waste volume, the quality of water and soil were consequences of a rapid. Over populated growth. In the early 20th century the effects of this environmental degradation and climatic change became rampant a mankind began to protect their environment through the use of technologically advancement methods and techniques to curb the over-exploitation of the crisis.

2.1.1 Earth day

Earth day seems to be one of the first ideologies in an attempt to clear and enlighten the world about the natural environment. This day and a series of it after which is now held worldwide set the tone for a greater awareness level about the natural environment. From research, it was stated that in the UNESCO Conference in San Francisco 1969, John McConnell first named 21st of March as the “earth day” for the first time. However, a new date for the “Earth day" came through Gaylord Neslson then, a U.S senator from Wisconsin after he witnessed a ravage of oil spillage in Santa Barba, California 1969. This sprung up student anti-war movement and he suggested the idea of introducing and creating awareness about air and water pollution, would spring up environmental protection into the national political agenda. April 22 in 1970 began a widespread advocate in the United States and became an international movement (Anon, 2016).

2.1.2 The Stockholm declaration (1972)

The United Nations Conference on the Human Environment, in Stockholm from 5-6 June 1972, was one of the first large-scale meeting that considered and inspired guidelines and principles for the world to preserve and enhance its human-natural environment. The conference was based on twenty-six principles which would aid sustainable development. Topics regarding equality, racial discrimination, air pollution, economic and social development, and discharge of toxic substances, human health, developing countries awareness, and education in environmental matters, safeguarding the natural resources and science and technology, scientific research in the development of environmental problems were key points of attention in the meeting. Thus this set the pace for green sustainable architecture (UNEP, 1972).

2.1.3 HABITAT I -Vancouver declaration on human settlements (1976)

The United Nations held the first habitat conference in 1976 in Vancouver, Canada, 31May to11 June on the issue of physical and spatial organization of human life on this planet, and on the national and international actions needed to accommodate the growing number of population in urban and rural communities.

The product of HABITAT comprises three elements:

- The Vancouver Declaration on Human Settlements, 1976: a statement of principles intended to influence national government objectives;

- Recommendations for National Action: a set of 64 recommendations, addressed directly to national governments, which propose concrete ways for national improvement of human settlements;
- Programs for International Co-Operation: proposals to set up mechanisms for international co-operation on human settlements matters, programs of study and research, exchange of technology, skills and experience.

Human settlements implies the totality of the human group - whether city, town or village - with all the social, material, hierarchical, profound and social components that support it. The texture of human settlements comprises of physical components and administrations to which these components give the material support (ESCAP, 2016).

HABITAT displayed a great degree of consensus on the human settlements issues. Thus HABITAT created some very positive impressions which could be characterized as agreements that:

- There is an urgent need to improve human settlements conditions around the world, especially to resolve the problems of imbalance; inaction will lead to deterioration of present standards, nationally and internationally, and even greater disparities.
- Improvement of the quality of life for every individual is the first and most essential target for each settlement policy.
- Solutions require an integrated approach to deal with human settlements problems comprehensively - they should be viewed as an primary part of the economic and social development of individual nations and the world community and they should incorporate a global view because of international economic, resource, ecological and social interdependence. Policies and programs for improvement of human settlements are the direct responsibility of national governments.
- Solutions to human settlements must involve the active and informed participation of the public in the planning and implementation processes.

The physical components specified as “infrastructure”, “shelter”, and “services”. Infrastructure in this aspect was defined as “the complex networks designed to deliver to or remove from the shelter people, goods, energy or information”. Shelter was defined as “the superstructures of different shapes, size, type and materials erected by mankind for security, privacy and protection from the elements and for his singularity within a community". Services was defined as "those required by a community for the fulfilment of its functions as a social body, such as education, health, culture, welfare, recreation and nutrition" (ESCAP, 2016).

2.1.4 First world climate conference (1979)

The first World Climate Conference about global climate issues in 12-23 February 1979, in Geneva was held by The World Meteorological Organization (WMO). This conferenced resulted into the birth of WMO World Climate Programme, including the WMO co-sponsored World Climate Research Programme and the Intergovernmental Panel on Climate Change (IPCC). The conference focused mainly on how climate change may affect humans, participants came up with a crucial resolution in the history of climate change internationally, "the Declaration of the World Climate Conference, and for the first time this historical draft identified carbon dioxide as a cause for global warming (Koo, 2011).

2.1.5 Brundtland report (1987)

United Nation set up World Commission on Environment and Development (WCED) after a heavy deterioration of human environment and natural resources has been of rampant act. UN decided to establish the Brundtland repot "Our Common Future": which put forward the definition of sustainable development. It was defined "as a development that addresses the needs of current eras without bargaining the capacity of future eras to address their needs and aspirations" (WCED, 1987).

2.1.6 Second world climate conference (1989)

World Meteorological Organization (WMO) second world climate conference took place in Geneva, was held on 29 October- 7 November 1990, in partnership with Global Climate Observing System (GCOS). This conference resulted in "United Nations Framework Convention on Climate Change", Earth Summit in 1992.

2.1.7 BREEAM by BRE (1990)

BREEAM (Building Research Establishment Environmental Assessment Method) was first developed in 1990, with the most recent updated version produced in 2014 (BREEAM, 2014). The main role of this assessment tool is primarily on building specification evaluation including the design, construction and use (BREEAM, 2013) based on four assessment tools that can be used at different steps of a building's life cycle. BREEAM methodology is calculated by awarding a point or credit that is based on the following categories (management, energy, health and wellbeing transport, waste, land use and ecology, water, material pollution and innovation) which determine the environmental impact of the building. The total number of credits awarded in each category is multiplied by an environmental weighting factor which characterizes the significance of the category. The category scores are added up to produce an overall score, designated as Unclassified, Pass, Good, Very Good, Excellent, and Outstanding. A star rating from 1-5 is also provided. The BREEAM International certification system also uses a star rating system (BREEAM, 2012). This rating framework is used measure the sustainability of non-domestic buildings in the United Kingdom and was being updated intermittently according to UK Building Regulation as in 2008 (BREEAM, 2013).

2.1.8 Rio earth summit (1992)

The United Nations Conference on Environment and Development (UNCED) was held in Rio de Janerio, Brazil, from 3 - 14 June 1992, it's also known as the Earth Summit (Yudelson, 2010).The concentration of this conference was the condition of the worldwide condition and the connection between financial aspects, science and the environment in a political setting (Meakin, 1992). The delegates reached an agreement on Agenda 21, which was an action plan for developing the planet sustainably through the 21st century, and on an expansive statement of principles for protecting forests (Hileman, 1992). United Nations Framework Convention on Climate Change and the United Nations Convention on Biological Diversity were the resulting document that was brought in the conference. Agenda 21 was the major comprehensive document that was established from Rio and was formulated to deal with some of the paramount difficulties of resource degradation and aid to the developing world. It also focuses on other issues with respect to the global sustainability which include aspect like financing, enactment of technology transfers and the institutional follow up to UNCED (Eco log, 1992). The primary goal of Agenda 21 was to ensure that act of development was portrayed and implemented through a sustainable manner: "the system of incentives and penalties which motivate economic behaviour must be reoriented to become a strong force for sustainability"(UNCED, 1992).

2.1.9 HABITAT II - Second United Nations conference (1996)

The second United Nations Conference on Human Settlements (Habitat II) was held in Istanbul, 3-14 June 1996. Habitat II concluded in the adoption of the Istanbul Declaration on Human Settlements (UN, 1997). The agenda of this conference was circled around achieving a twin goal which was “adequate shelter for all” and “the development of sustainable human settlements in an urbanizing world”, where the humans were the centre of discussing towards sustainable development (UN, 1996).

2.1.10 Kyoto summit (1997)

The Kyoto summit was held on 11 December 1997 in Japan. It was committed to the reduction of greenhouse gas emissions, as a problem of global warming and also the reductions of human-made CO_2 emissions.

The Protocol's major aspect was the required targets on greenhouse-gas emissions for the world's leading economies which have accepted it. These targets range from -8 per cent to +10 per cent of the countries' individual 1990 emissions levels "with a view to reducing their overall emissions of such gases by at least 5 per cent below existing 1990 levels in the commitment period 2008 to 2012"(UNFCC, 2014). The text of the Kyoto Protocol was adopted unanimously in 1997; it entered into force on 16 February 2005.

2.1.11 LEED by USGBC (1998)

LEED was founded by the U.S. Green Building Council (USGBC) in 1998. According to LEED (LEED, 2016) more than 72,000 LEED certified projects across 150+ countries, comprising over 13.8 billion square feet (approx.12.8 billion square meters) has been executed, which makes it one of the most widely used assessment tools. The latest version “LEED Version 4” (LEED, 2013) was officially launched in 2014, and includes schemes for Building Design and Construction, Building Operations and Maintenance, Interior Design and Construction, Neighbourhood Development and Homes. The LEED Neighbourhood Development scheme is one of the first developed schemes for community sustainability evaluation; however, it overlooks essential issues such as the local economy and the provision of jobs and affordable houses (Sharifi and Murayama, 2013). LEED consists of nine categories namely: integration process, location and transportation, sustainable site, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. Here, building grades are classified as follows: Certified (40-49points), Silver (50-59 points), Gold (60-79 points), and Platinum (80-above points) (LEED, 2013).

2.1.12 Green building challenge (GBC)

Green Building Challenge (GBC) started as an international competition for green buildings in 1995 and the victors were recognized in the conference.

In March 1996, a presentation made contributed to the change of concept for the GBC, where the competitions of buildings were changed to assessment frameworks to assess the characteristics of green building.

Green Building Challenge is a conglomerate of over twenty countries that is developing and testing new techniques for evaluating environmental performance of buildings.

The project GBC consisted of two stages (two 2-year processes). An initial two-year process, including 14 nations, for the GBC '98 conference, a noteworthy universal event in Vancouver in October 1998. Work coming about because of a moment two-year round of improvement which was shown and assessed at the international SB 2000 conference in Maastricht, the Netherlands, in October 2000.

The appraisal structure has been delivered as programming (GB Tool) that encourages a full depiction of the building and its execution, and furthermore enables clients to complete the evaluations with respect to local bench-marks. Taking an interest national groups test the evaluation framework on contextual investigation structures in every nation. At the GBC '98 conference, 34 projects were assessed top to bottom, and a further 36 projects were evaluated for the SB 2000 Conference.

The evaluation framework has been created as programming (GB Tool) that encourages a full depiction of the building and its performances, furthermore permits clients to complete the appraisals with respect to regional bench marks. Participating national groups test the evaluation framework on contextual analysis buildings in each nation. At the GBC '98 meeting, 34 projects were assessed, and a further 36 projects were evaluated for the SB 2000 conference.

“The three general goals of the GBC are:

- To advance the state-of-the-art in building environmental performance assessment methodologies.
- To maintain a watching brief on sustainability issues to ascertain their relevance to “green” building in general, and to the content and structuring of building environmental assessment methods in particular.
- Sponsor conferences that promote knowledge exchange between the building environmental research community and building practitioners, including a showcase for the performance assessments of environmentally progressive buildings (GBC, 2000).

“Two specific objectives of GBC 2000 process are:

- To develop an internationally accepted generic framework that can be used to compare existing building environmental assessment methods and used by others to produce regionally based industry systems.
- To expand the scope of the GBC Assessment Framework from green building to include environmental sustainability issues and to facilitate international comparisons of the environmental performance of buildings (GBC, 2000).

2.1.13 Istanbul +5 - United Nation General Assembly Special Session (2001)

After five years from the second United Nations Conference on Human Settlements (Habitat II) that was held in Switzerland, the United Nation General Assembly held a unique session for a general survey and examination of the application of the Habitat Agenda. This occasion, was held in New York from 6 - 8 June 2001, it united every member the United Nations and concluded in the United Nations Declaration on Cities and Other Human Settlements in the New Millennium, which reaffirms the will and sense of duty regarding actualize completely the Istanbul Assertion on Human Settlements, in the spirit of the United Nations Millennium Declaration (UN, 2017).

2.1.14 Rio+10 (2002)

Rio+10 conferences were held in Johannesburg in 2002, it was meant to review progress towards sustainable development. The focus was on poverty and the access of people to safe drinking water and sanitation. They also made specific agreement on issues like transport, Implement transport strategies for sustainable development. So as to improve the affordability, efficiency and convenience of transportation, as well as improving urban air quality and health, and reduce greenhouse gas emissions (WSSD, 2002).

A set of objectives defined in the meeting are as follows:

- To reduce the number of people that is not connected to clean drinking water supplies from over 1 billion to 500 million by the year 2015.
- To halve the number of people without proper sanitation to 1.2 billion.
- To increase the use of sustainable energy sources and restore depleted fish stocks (CIEC, 2017).

2.1.15 Green star by GBCA (2004)

Green Star is a building rating systems that assess evaluates the environmental design and construction of Australian buildings. Green Building Council of Australia (GBCA) a national and not-profit organization launched green star in 2002. The objective of creating the Green Star was to encourage sustainable building development while promoting green building technologies, practice and operations (GBCA and NZGBC 2009).

The evaluation procedure of Green Star offers candidates two chances to get a rating. The initial step is for the venture group to choose which rating device is most proper and show that the venture meets each of the four of the rating apparatus qualification prerequisites (GBCA 2009c). There are four rating device's prerequisites which are space use spatial differentiation, conditional requirements' and timing of certification. The Appraisal Board may grant a rating of one to six stars. Projects that are granted one to three stars may not be ensured, but rather those granted with at least four stars might be affirmed and are perceived. A 4 Star Green Star Affirmed Rating (score of 54 to 59) – Best Practice; 5 Star Green Star Confirmed Rating (score of 60 to 74) –Australian Excellence; 6 Star Green Star Certified Rating (score of 75 to 100) – World Leadership (GBCA, 2009).

2.1.16 Third world climate conference (2009)

The Third World Climate Conference-3 (WCC-3) was held in Geneva, Switzerland, from 31 August to 4 September 2009. It was structured by the World Meteorological

Organization (WMO), in a joint effort with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Council for Science (ICSU), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), and other intergovernmental and non-administrative accomplices.

The theme of the Conference was ‘Climate Prediction and Information for Decision Making’ and its vision was for “An international framework for climate services that links science-based climate predictions and information with the management of climate-related risks and opportunities in support of adaptation to climate variability and change in both developed and developing countries” (GFCS, 2016).It had a declaration strengthening the production, availability, delivery and application of science-based climate predictions and services (WMO, 2016).

2.1.17 Rio+20

The United Nations Conference on Sustainable Development (UNCSD or “Rio+20”) was held in Rio de Janeiro, Brazil June 20-22, 2012. This conference marked the 20th anniversary of the U.N. Conference on Environment and Development (UNCED) in Rio which was held in 1992 (Leggett and Carter, 2012).

The Conference likewise received pivotal rules on green economy approaches. Governments additionally have chosen to set up an intergovernmental procedure under the General Assembly to get ready choices on a technique for sustainable advancement financing.

Rio+20 were based on the objectives of sustainable development of the 1992 Rio conference that had not been achieved.

Rio+20 were based on three objectives:

- Securing renewed political commitment to sustainable development,
- Assessing the progress and implementation gaps in meeting already agreed commitments, and
- Addressing new and emerging challenges (Leggett and Carter, 2012).

2.1.18 HABITAT III - Third United Nations conference on housing and sustainable development (2016)

Habitat III the United Nations Conference on Housing and Sustainable Urban Development took place in Quito, Ecuador, from 17th - 20th October 2016. The UN Conference on Housing operates on a bi-decennial cycle (1976, 1996, 2016 and the next one should be 2036) (UN, 2017). The Habitat III Conference bolsters the worldwide responsibility regarding sustainable urbanization, to concentrate on the execution of “New Urban Agenda”. The objective of the conference is to secure recharged political duty for sustainable urban improvement, survey achievements to date, address destitution and distinguish and address new and rising difficulties. The gathering will bring about a compact, engaged, forward-looking and activity arranged result report. Habitat III was one of the first United Nations global summits after the implementation of the Post-2015 Development Agenda. It gave the prospect to open dialogs on critical urban difficulties and inquiries, for example, how to arrange and oversee urban communities, towns, and villages for sustainable improvement. The exchange of these inquiries shapes the usage of new worldwide advancement and environmental change objectives.

2.2 Green Building and Technology

Green building can be defined as a high-performance index that helps reduce the building impact on the environment and human health (Yudelson, 2008).

Technology is an application of understanding to applied necessities. Green technologies cover a plethora of aspects of technology which help us diminish the human effect on the environment and spawn ways of sustainable development. Environmental sustainability economic viability and social equitability are the main factors for green technologies (Das Soni, 2015).

The United States Environmental Protection Agency (2012) characterizes green buildings as the act of making structures and utilizing forms that are ecologically capable and asset proficient all through a building's life-cycle from siting to plan, development, operation, upkeep, redesign, and destruction. This practice extends and supplements the traditional building configuration worries of economy, utility, solidness, and solace. Green building is otherwise called sustainable or high-performance building.

Green building is design to response to global issues concerning energy consumption, material selection, and waste production by the reduction of energy, water use, and greenhouse gas emission. This can be accomplished through each phase of buildings from siting, designing, material determination to the genuine development and operation of green building.

Green building requires expanded planning and the determination of materials and operational frameworks may influence the building plan and require a clear understanding of the equipment from the part of the contractors. A sustainable green building must possess of the following attribute which includes the local climate factors, energy efficient system, water efficient system and the low impact material selections. The development of green building helps decreases on - site waste by recycling/reusing and conserving natural resources by the use of alternative materials. Green building accomplishes better performance with adequate design, insulation and energy efficiency system.

Green building and its technology covers an expansive range of invention and utilization technologies. The selection and utilization of green technologies includes the utilization of natural advances for observing and evaluation, contamination counteractive action and control, and remediation and reclamation. Observing and evaluation technologies are utilized to quantify and track the state of the environment, including the emission of characteristic or anthropogenic materials that harmful. Deterrence technologies evade the generation of ecologically precarious substances or modify human action in ways that limit harm to environment; it includes item substitution or the overhaul of a redesign of an entire production process instead of utilizing new equipment’s. Control technology renders perilous substances innocuous before they enter the environment. Remediation and rebuilding technologies encapsulate strategies intended to enhance the state of ecosystem, debased through normally prompted or anthropogenic impacts.

Greening the building area can be refined with existing technology that regularly offers an extraordinary degree of profitability. The energy efficiency area envelops an extensive variety of exercises including: green building plan and development; remodel and retro-fitting of existing structures; vitality administration and the assembling of items required for these exercises.

2.3 Green Building Assessment Tools

Green building appraisal apparatus offers a chance to make an ecologically productive building utilizing an incorporated approach of configuration with a specific end goal to control the negative effects of expanding on nature and inhabitants. It gives a convincing structure to evaluate building natural execution and coordinating economic advancement into building and development prepare as it can be used as a setup gadget by setting sustainable design needs and goals, making appropriate outline arrangement systems, and choosing execution measures to manage sustainable design and decision making process.

They additionally give a quantitative performance pointer to design options and a rating for the entire building performance. They offer a structure for ecological issue; a direct revelation of performance measures; a means to demonstrate commitment environmental policy and an opportunity to brand innovative materials and products (Cole, 2005).

Global resources such as wood, water, food, and many more are used up in an excessive manner through mans over exploitation, and the effect of this is increasing the green gas emission which is altering the global climatic condition in a critical manner (Ogunsote, Okwoh andUde, 2010).The building/construction sector to a large extent, are responsible for environmental degradation (Hirokawa, 2009), owing to the high rate of energy consumption in countries (Ogunsote, Okwoh andUde, 2010).To reduce the effect of these scenario on the built environment (Ojo et al , 2014), the green building has been enacted to guide the development in the building sector (Dobson et al, 2013), therefore the construction sector are responsible to enforce sustainable development (Zuo and Zha, 2014).

The concept of building evaluation system focuses on the increase in energy efficiency of a building, to reduce the use of resources, water, material, as well as decreasing the impacts on human health and environment during the building's lifecycle (Bowyer, 2008). The building lifecycle here means the total span of the building incorporating its design, construction, operation, demolition, and maintenance and waste treatments. All these are the primary important purpose why building evaluation system is needed in a society. However, efforts have been orchestrated worldwide in attaining a sustainable development in the construction sector with the aim of reducing energy consumption in both the construction and management of buildings. For instance the United Kingdom developed, Building Research Establishment Environmental Assessment Method (BREEAM), which was the forerunner of all Green building rating tools, it propelled its first office building assessment structure in 1993 (Lee, 2013), with the most recent updated version produced in 2014 after a twenty-year of International and local development program success (BREEAM, 2014).United States introduced, Leadership in Energy and Environmental Design (LEED), which was first introduced in 1998, with the latest version "LEED Version 4" (LEED, 2013) officially launched in 2014, and includes schemes for Building Design and Construction, Building Operations and Maintenance, Interior Design and Construction, Neighbourhood Development and Homes, and other building assessment tool and protocols like Green Star, CASBEE etc., have been implemented by a large number of countries over a period of 20-25 years.

The table below shows a list of few evaluation systems that have been launched to aid the course of building evaluation systems worldwide.

Table 2.1: Evaluation Rating Systems

EVALUATION SYSTEMS	COUNTRY/YEAR	LATEST VERSION YEAR
BREEAM BRE Environmental Assessment Method	UK/1990	2014(BREEAM, 2014)
HQE High Environmental Quality	France/1992	CERWAY, 2013
IDP Integrated Design Process	Canada/1993	-
LEED Leadership in Energy and Environmental Design	USA/1998	2014(LEED, 2013)
Green Leaf Eco-Rating Program	Canada/1998	-
CASBEE Comprehensive Assessment System for Building Environmental Efficiency	Japan/2001	2015(CASBEE, 2016)
AQUA Alta Qualidade Ambiental	Brazil/2001	-
GREEN GLOBES	Canada/2000	2013
VERDE Building Evaluation and	Spain	-

Environmental Certification Method		
ITACA	Italy	
Promise	Finland	
DGNB	Germany	
GREEN STAR	Australia	2002 (Green Star, 2016)
SBAT Sustainable Building Assessment Tool	USA	
GREEN MARK	Singapore	2010 (Green Mark,2016)
ESTIDAMA	Gulf Countries (Iraq, UAE, Kuwait, Qatar etc)	2010 (Estidama, 2010)
ECO- HOUSE TECHNICAL EVALUATION	China	

2.4 Principles of Green Architecture

Green architecture is surrounded by principle which promotes the understanding and activities. This principle begins the understanding of the site and all it complexities According to (Matthews et al, 2000), they estimated that at 2056 the global economic activity would have expanded five time more, with a population increase of over 50% and a global energy consumption rate and global manufacturing three time its present stage. The building industry has a rapid growth of energy use and fossil fuel resources at an infinite stage, which has raised a major concern and cause environmental degradation, depleting the ozone layers, carbon emission and global warming (Ilha et al 2009). A major contributor to this environmental degradation is the energy consumption in the building sector (Kukadia et al 2004; Pitt et al, 2009), also a major consumption of raw material with 3 billion tons consumed annually and 40% globally (Yahya and Boussabaine, 2010). And also generates a huge amount of waste (Osmani, 2008; Burgan, 2006). The following points that would be discussed would address the key principles, strategies and technologies that are associated with green architecture

2.4.1 Energy conservation

Green architecture is supported by a philosophy that promotes sustainable energy sources According to (Panwar, Kaushik and Kothari, 2010), sustainable development is highly entwined with the deliberation of energy, also sustainable energy sources like the waste-to-energy sources are highly significant in the improvement of sustainability. The fossil fuel consumption which is associated to GHGs such as (diesel, petrol, and natural gas) emits carbon (IV) oxide and carbon (II) oxide pollutes the environment adding negatively with the risk of global warming and climate change. However, plausible steps are taken to design energy efficient building, which includes the use of renewable energy sources like wind energy, where the energy confined in the force of the winds gusting across the earth's surface can be utilized, and the energy can be transformed into mechanical energy for various works such as, pumping water, electricity etc. According to (Uyigue, 2009), Modern wind turbines are being used to generate electricity in countries such as Germany, Denmark, India, China, and the United States to supplement more traditional sources of electric power. Solar energy- the energy can be converted either into a thermal process or a photoelectric (photovoltaic) and geothermal energy which is generated from the heat that originates from the earth crust. Energy conservation also a key aspect considering the climate conditions in the building. It helps protect the loss of cool or warm air, and help indicate appropriate insulating system and material to be installed to reduce the heat loss.

Due to its environmental impact, the energy category has part of the principles of green architecture possess the largest portion of credit distributed amongst the environmental assessment tools (USGBC, 2013). Therefore, vital importance is placed on the energy design, energy management, renewable energy strategies, energy conservation and monitoring (Lee, and Burnett, 2006). BREEAM and LEED as key assessment tool for evaluating green building made use of supplementary tools; such as Standard Assessment Procedure (SAP) for BREEAM and American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), American National Standards Institute (ANSI) and Illuminating Engineering Society of North America (IESNA) for LEED.

According to (Zeigler, 2012) basic strategies and techniques for this principle are:

- Reform of latent sun oriented introduction, building massing and the selection of outer shading gadget in a way that the outline of the building limits unpleasant sun powered increases amid the late spring time frame while expanding luring sun based additions amid winter.
- Upgrading the building introduction, outline, massing, inside hues, shape, and completes with a specific end goal to expand the use of controlled regular day

lighting which through and through reduces manufactured lighting vitality utilize in like manner decreasing the building's interior cooling burden and vitality utilization, light retire innovation can be considered for this approach.

- The utilization of superior Low-E coating, which can achieve essential year round vitality funds. A protected twofold coating, triple coating or a twofold sheet coating with a Low-E film can be considered for use in this application. Particular coatings offer perfect light transmittance while giving ostensible sun powered pick up and ostensible warmth transmission. For ideal vitality execution which comprises of the utilization of numerous warm breaks to lessen the vitality use, window casings and shade divider framework ought to be planned.
- The value of exterior insulation and the overall thermal performance of the exterior envelope assembly should be improved while considering the use of advanced high-performance envelope building systems such as the Structural Insulated Panel System (SIPS) and the Insulated Concrete Form Systems (ICF). These systems and other thermal envelope system help and offer the highest energy performance of a building.
- The utilization of vitality proficient bulbs, for example, T-8 and T-5, lighting controls and high productive electronic weights, enhances the light quality, lessen glare and enhance general vitality execution in spaces. Likewise the coordination of sensor, controlled and configuration circuits so that lighting along the spaces can be changed off exclusively from other inside lights when daylighting is satisfactory in the space.
- The utilization of high productivity, heating, ventilation and aerate and cool (HVAC), chillers, boilers, plumbing gear and water radiators, use variable speed drives on a fan and pump motors and furthermore the utilization of warmth recuperation ventilators and geothermal warmth pump for up to 40% vitality funds.
- Refrain from the utilization of HCFC and Halon based refrigeration, cooling and fire concealment frameworks, while propelling the utilization of normal ventilation and where productive utilize evaporative cooling, squander warm, and sun powered reinvigorated desiccant dehumidification or maintenance cooling is utilized.
- The use of energy saving and efficient appliances of lighting HVAC and other equipment’s

- Acknowledge on location little scaled wind, sun based and power module based vitality era and co-era. Put resources into naturally inviting force frameworks from confirmed inexhaustible and reasonable sources.

2.4.2 Material selection and waste management

The selection of material is imperative when tending to its sustainable impacts on the environment. It aides the reduction of waste products generated from construction. The material determination of a buildings lifecycle should be recyclable, energy efficient, cost saving and environmental friendly which also include both the structure and finishing materials.

As a consequence of the expanded utilization of a few materials they are debilitated to exhaustion. Moreover, the incautious utilization of materials can expand cost of building, so there is an awful requirement for legitimization of the utilization and maintain the materials According to (Elattar and Ahmed, 2014). There is basic principle to achieve a credible material selection for green architecture.

- *“Maximize the use of recycled content materials, modern resource efficient engineered materials, and resource efficient composite type structural systems wherever possible.*
- *Maximize and benefit from the wise use of reusable, renewable, sustainably managed, and bio-based materials. Considering that human creativity and our abundant labour force is perhaps our most valuable renewable resource. In order to achieve the best solution, it should be clear that it is not necessarily the one that requires the least amount of physical work.”* (Ortiz et al, 2009)

A large amount of mineral resources is consumed in the built environment and majority if these resources are non-renewable, therefore it becomes paramount to reduce the use of non- renewable materials. Specifically, expansive measure of minerals assets is devoured in the assembled environment According to (Abeysundara et al,2009). The selection of materials is very important, where the choice of the material and the environmental impacts should be considered and incorporated into the project initiatives and design stages.

The aim of this category is to ensure best practice for resources consumption in terms of materials. BREEAM relies on a Green Guide to Specification, which contains over 1500 building materials specifications and plays a vital role in decision making for materials and their environmental impacts (BRE, 2014). Meanwhile LEED focuses mainly on the reusability and maintenance of construction materials.

The thermo-physical properties of the building materials affect the rate of heat flow in and out of the building, and subsequently the indoor thermal conditions. These properties include the thermal conductivity, reflectivity, absorptivity and emissivity, surface convective coefficient and heat capacity of the material. External walls should be lightweight with a low heat capacity, light coloured and highly thermally resistive, preferable of locally sourced materials like stabilized adobe bricks. Internal walls could be heavy if annual range is above 20 ^{0}C (Givoni, 1976). Ceilings and roofs should also be lightweight and highly resistive. Reflective roof surfaces are an easy and cheap technique for reducing overheating and the dependence of cooling devices. External wall/structural materials should be impervious to climate extremes of rainfall and wind, preferably with the use of large roof overhangs.

Waste management in construction, where waste materials are recycled back to manufacturing process and waste management plans are implemented for demolitions. This aspect deals with the reduction of construction and demolition waste. Which can be done by the recycling and reusing of these waste products such as using idle demolition materials as base materials for parking areas and roadways.

Material such as wood, concrete and other types of masonry, and drywall can be recycled or reused in building process. According to the following researches (Ortiz et al, 2009) designers assumes a huge part in the minimization and lessening of development waste. Waste minimization ought to be tended to as a major aspect of the maintainability program all through the plan procedure utilizing three essential waste standards: Decreasing and recuperating development squander; Reuse and Reusing and the capacity and transfer of development waste. Current research has observed that open air burning of materials such as papers, construction debris etc., releases cancer and pose serious environmental and health damage to the people exposed to the smoke (Unaegbu, 2016). Also, from researches observed Obiegbu (2002), noticed that wastage in development firms has come to stay considering the way that no less than 5% is achieved while setting up the gauge for a venture which is typically not satisfactory.

As indicated by (Esin and Cosgun, 2007), reduction of the environmental influence of construction waste can be done principally by averting its generation. This will lessen reuse, reprocessing and removal needs accordingly and provides economic aid. According to (Pimenteira et al, 2005) recovery curtails the amount of waste, saves energy, Green House Gas (GHG) emissions, and reduces the use of raw materials. Recovery of beneficial energy and materials from wastes has additionally been stressed as a standout amongst the most imperative environmental practices for accomplishing energy savings to ease energy situations (Osmani et al, 2008).

Reuse and Recycling helps reduce environmental impacts. Concept of recycling and reuse of construction material has been described in a plethora of literatures (Hill and Bowen, 1997). The reuse of building materials can act as an substitute means for the reduction of construction and demolition waste products, when refurbishing and demolishing a building, by performing building deconstruction, which empowers the recuperation of building parts as useful segments, for example, blocks, windows, tiles, uniquely in contrast to conventional pulverizations in which parts are changed once again into raw materials to processing (Da Rocha andSattler, 2009).

The storage and disposal of construction waste need to be stored and kept under appropriate management (Esin, 2007). Special waste (non-hazardous construction debris and construction debris) should be used as landfilled in either municipal solid waste landfills or landfills that only accept such debris. Designers should be aware and review policies that would guide the material storage and disposal at the design stage of construction project.

Technologies and strategies for material selection where described by Zeigler (2012)

- Streamline the utilization of fabricated materials which make use of designing standards, for example, composite materials and auxiliary frameworks (solid/steel, other...), built trusses basic protected boards (stretch skin boards), ice ensured shallow establishments and protected solid structures, which have been exhibited to present high calibre and quality with insignificant measure of material.

- Recognize ways to deal with lessen the measure of materials used and abatement the measure of waste made through the use of a development squander diminishment arrange. Grasping approach of "waste equivalents sustenance" whereby no less than 75% of all constructional waste is separated for reuse/reusing and used as feedstock for some future thing as opposed to being landfilled. Establishing an antagonistic development squander reusing project and present clear dumpsters for each reused material. Prepare of all groups and subcontractors on strategies and uphold consistence.
- Distinguish approaches utilized for high-reused content materials in the building structure and wraps up. Consider everything from mixed solid utilizing fly fiery remains, slag, reused solid total, or diverse admixtures to reused content materials, for example, roof and floor, covering, cover cushioning, auxiliary steel, sheathing, and gypsum wallboard. Consider remanufactured office furniture and office parcel frameworks, seats and furniture with reused substance or parts.
- Investigate the utilization of some auxiliary protected boards produced using bio-based materials and the utilization of bio-based materials and completes, for example, different sorts of garboard (sheathing as well as protection board produced using agrarian waste and side effects, including straw, wheat, grain, soy, sunflower shells, nut shells, and different materials). The utilization of timber and wood items from affirmed backwoods where the woodland is controlled and timber is gathered using maintainable practices. The utilization of asset proficient built wood items in lieu of full measurement stumble which began from more established development timberlands.
- Assess all items and frameworks toward the finish of their helpful life. Slant should be given to items and frameworks that energizes simple, non-vitality serious division and reusing with insignificant defilement by remote garbage.
- Recognize that transportation turns out to be a piece of an item or building materials epitomized vitality. Where down to earth, determine and utilize privately collected, mined and fabricated materials and items to reinforce the regional economy and to abatement transportation, vitality utilize and discharges.

According to (Atanda, 2015), bamboo as a sustainable material can be used in building construction rather than steel; they protect the biodiversity and enhance sustainable development. Additionally, the utilization of compacted earth square (CEB) has been a typical pattern towards feasible improvement because of the abnormal state of inside warm solace it keeps up, paying little respect to winning sun oriented radiation outside. They can be left un-put, secured with mortar or can be secured with watered earth. Its façades in contrast with the contemporary homes offer a sentiment a cooler inside with an inside temperature lower than many bond piece houses.

2.4.3 Water efficiency

Water as a resource can be stored, filtered, captured and reused, this should therefore be considered as a principle of green building design. This category analyses the water consumption in and out of the building, water treatment, the health impacts and environmental pollution from waste water and solid waste, it also suggested methods of rainwater harvesting, grey water systems, and living pools (BCKL, 2009).

Water conservation through a building life span can be realized through the design of dual plumbing, which helps recycle water in toilet flushing. Wastewater, however, is minimized through the use of water preservation techniques such as ultra-low flush toilets and low-flow shower heads. Water treatment and heating help improve water quality and energy efficiency thereby reducing the amount of water circulated in the building. Whereas the use of a non-sewage and grey-water system for an on-site use such ass site irrigation would minimize the need on local aquifer (Harrell, 2008).

Other technologies and strategies to achieve water efficiency in a building were discussed by (Zeigler, 2012)

- The design for site and storm water management should be least costly, less time consuming and environmentally suited in the building, where the site improvements adhere to the existing natural flow and the land features rather than designing the building and the site improvements in disrespect of the site totally, which would result into a problematic, excessive, time-consuming excavation and earthmoving.

- A through site appraisal ought to be directed and building and site upgrades ought to be deliberately situated to save imperative characteristic hydrological highlights. Endeavours ought to be upset to save site territories that fill in as characteristic tempest water maintenance and groundwater invasion and revive frameworks on the site. Develop vegetation and existing woods that assume enter part in the normal water cycle by engrossing and dispensing up to 30% of site water through evapotranspiration ought to be sustained.
- A diminish in the structures impression, unearthing, site changes and development zone, soil unsettling influence and compaction of existing top soil which assume a part in assimilation and the hiding away up to 80% of the common precipitation until it has been consumed by the vegetation or went through site characteristic sub-surface ground water framework ought to be considered.
- Low affect storm water advancements that support nearby maintenance and ground water revive or evapotranspiration, for example, open verdant swales, rain gardens, bio-maintenance, pervious bituminous clearing, built wetlands, pervious solid clearing and walkways, living/vegetated rooftops and a great deal more ought to be composed and used to find building and site enhancements. Off the site, storm waters ought to be sifted and prepared actually of mechanically by expelling waste, flotsam and jetsam, oil and suspended solids.
- Water ought to be moderated; site and groundwater quality ought to be protected by utilizing household, dry spell safe bushes, tough trees, plant, and turf that require no manures, water system, herbicides or pesticides.

2.4.4 Indoor environmental quality

The quality of the indoor environment is regarded as a vital aspect of all assessment tools. It aims at delivering a healthy indoor space including lighting, noise, acoustics, ventilation rate, thermal comfort, quality of view, daylight and protection from hazardous substances on the occupant’s health life (BRE, 2014).

The following aspect that the Indoor Environmental Quality (IEQ) consists of are:

- **Light** – This aspect looks at the lighting system in a building if the spaces in the building have enough daylighting throughout the day and a comfortable level of artificial lighting should be provided. Daylight can be productively used to boost occupant comfort and to preserve energy. While designing windows to improve inhabitant comfort one must remember the measure of light required, kind of action in the room, and select materials with prescribed surface reflectance and matte finish O'Connor, (Lee, Rubinstein and Selkowitz, 1997).

- **Ventilation** – if the rooms are sufficiently ventilated, preferably naturally, but mechanically were impractically and quality fresh air should be provided for the occupants. The building occupant well-being is fundamental to acquire a required amount of fresh air, and how well the amount of air serves the building occupants is measured in terms of the ventilation effectiveness of the building (Kibert, 2005). According to a study by (Fanger, 2000), they suggested that an increased in the ventilation system can help decrease the Sick Building Syndrome (SBS) symptoms while enhancing the apparent air quality and productivity of the occupants.
- **Thermal comfort** – This entails the interior spaces of the building should be well insulated, shaded and conditioned in order to create a comfortable temperature over the year According to (Ramsey and Beshir, 1998). extreme hot and cold environment can affect the psychological behaviour of individuals and also it can also lead to the loss of performance level, slow production outcomes and affect manual agility or cause pain sometimes.
- **Materials** – This aspect entail the use of material and building finishes which possess a low level of Volatile Organic Compounds (VOC) and other hazardous components.
- **Noise** – This aspect describes the sufficiency of insulation from external noise sources and how it minimizes internal reverberation and noise levels. As described by (Kibert, 2005), discomfort and annoyances which may result in headaches and fatigue can be caused by noise from the HVAC, light and other appliances in the building, this should be avoided, while (Bruce, and Moritz, 1998) observed that continuous and chronic exposure to excessive noise can lead to permanent hearing loss to the occupants.
- **Air quality** – This aspect describes the indoor air most contain adequate level of oxygen and other acceptable pollutants from internal/external sources in the indoor air.

- **Occupant control** – The aspect describes the control level of occupants within the environment in terms of opening and closing of the windows and regulating the heating and cooling systems.
- **External views** – The distant view provided by the connection of the interior to the exterior environment.

According to (Zeigler, 2012) he stated some basic technologies and strategies used in indoor environmental quality.

Building materials, finishes, sealants and other adhesives which do not possess or generate and hazardous gaseous contaminant (volatile organic compounds) should be used.

The utilization of common daylighting in the building ought to be augmented, and a created sun based introduction and building configuration ought to be boosted keeping in mind the end goal to permit sufficient characteristic sunshine into the inside spaces. Shading gadgets or sunshine controls ought to be executed when required.

Regular ventilation and workable windows ought to be used in the structures. Ventilation frameworks that can work autonomously from the warming and cooling arrangement of the building ought to have introduced. The ventilation framework ought to have the capacity to expel and treat indoor contaminants and give adequate clean new cosmetics air to inhabitants inside and different areas the building. Temperature, stickiness, and carbon dioxide level ought to be observed so that the ventilation framework in the building can be responsive when the condition inside the spaces falls outside the ideal range.

A smoke free building ought to be given and if smoking is permitted a space ought to be completely devoted for such action. HVAC framework ought to be introduced in structures and ought to stay under negative weight. Air from smoking regions ought to no move around or re-enter the living spaces through entryways, windows or natural air. Open air smoking territories ought to be found that non-smokers wear not have to experience these districts while using fundamental building doors and ways out.

A building plan that treats just air temperature and furnishes sufficient ventilation as for ecological conditions that influence human wellbeing, warm solace, for example, the indoor air stickiness, indoor air temperature, indoor air speed and the mean brilliant temperature of the inside spaces ought to be actualized. A building that is receptive to occasional change in the indoor air level, temperature and speed can bring about a critical vitality sparing as enhancing the solace level of the tenant's outcomes in less vitality use in the structures air-side warming and cooling framework.

The inhabitant's wellbeing, solace, and execution ought to be of key significance by furnishing them with legitimate ventilation, day lighting and fake lighting when required, singular spaces and a controlled warming zone.

Pollution of the working amid develop ought to be avoided. Steps ought to be taken to limit the advancement and spread of development clean and soil. The building and its warming, cooling, and ventilation framework ought to be kept from been tainted. Development material ought to likewise be ensured all together for them not to end up plainly moist or smelly.

A clean and healthy building ought to dependably be accommodated tenants. Environmentally biodegradable cleaning specialists that don't have of VOCs or other hurtful substances ought to be utilized. Space ought to be perfect from any pollution and air channels ought to be introduced before inheritance. Fresh open air ought to be normally or mechanically used to wash down the working for any current airborne vaporous or particulate contaminants.

2.4.5 Site design

The intent of this principle is to reduce potential site pollution from construction activities by controlling soil erosion, waterway sedimentation, biodiversity and airborne dust (USGBC, 2013). However, it entails detailed aspects such as the control of erosion in order to reduce its impact on water and air quality, the reduction of environmental impacts from the building site. Continually the development of urban areas with existing infrastructure to protecting greenfield, valuable lands, preserve habitat and natural resources and also engages in the reduction of pollution and land development impacts from automobile use.

According to (Zeigler, 2012) some basic technologies and strategies used in site design namely:

Make more gainful use of space in existing involved structures, revamp and re-use existing empty structures, and related foundation and consider re-headway of brownfield locales. Structures ought to be composed and remodelled so as to lift future flexibility and reuse in this way broadening valuable life.

Right when new improvement winds up noticeably unavoidable, maintain a strategic distance from site that assume a key part in the provincial biological system. Important Greenfield and wetlands locales ought to be distinguished and shielded from advancement. A lessened urban sprawl and green space protection can help disturb higher thickness advancement in urban ranges. Time and vitality must be contributed to look for changes and administrative change where required.

Each site must be assess to comprehend its area, introduction of structures and upgrades keeping in mind the end goal to create suitable utilization of normal daylighting, aloof sun oriented vitality, common breezes and ventilation.

Make best use of existing mass travel frameworks and structures and locales ought to be passer-by and bicycle neighbourly. Programs that advance auto pooling ought to be produced, and furthermore space for refuelling or energizing option fuel vehicles must be distributed.

Decrease the urban warmth island affect by diminishing the building and site progression advancement impression, growing the usage of pervious surfaces, and using light shaded rooftop, walkways and clearing. Give regular shading of structures and cleared regions with trees and other scene highlights.

Change the utilization of on location storm water treatment and ground water revive. The limit of development zones ought to be limited, needles compaction of leaving top soil ought to be evaded, and the compelling sedimentation and residue control ought to be executed in all periods of the site development and improvement.

Common natural surroundings and legacy ought to be saved for the utilization of satisfactory scene outlines while highlighting the utilization of neighbourhood strong, bushes, dry spell safe trees, plants and turf.

Diminishment of light time light contamination ought to maintain a strategic distance from over-brightening of the site and utilize low profile off outside lighting apparatuses which coordinate light descending, not upward and outward.

2.5 Adaptive Façade Design

For over a few years now, the importance of low-energy building has expanded vastly because of the raising climatic challenges. Buildings are guilty of an expensive part of the global energy use. The building industry needs to concentrate more on reasonable plans to bring down the negative climatic affect. Low-energy structures can generally be recognized in two types: active technology and passive design strategies. Active technology is the most famous approach, where by creative specialized devices that improve the productivity of the change of resources or make utilization of renewable sources to supply energy are the two fundamental sorts. Meanwhile, passive design strategies concentrate on the design of the building and its development to catch, store and circulate solar and wind energy (Ibáñez-Puy et al, 2015). However, over the last few years' passive design strategies have gained a lot of attention from scientist and researchers which has helped propel the topic greater and this would bring about a considerable measure of promising future applications.

As a result of the climatic change adaption came into design of buildings. Adaptive design means to consistently changing the design of structures to perform better. Adaptive buildings are more proficient by the smart utilization of light and space. Due to the changed approach in the building designs, the façade is no longer observed as only a static obstruction isolating the interior building environment from the exterior. The façades have the capacity to adjust to climatic changes. To design a façade that reacts to changing climatic conditions, various aspects are vital, for example, the building environment and the building occupants (health, wellbeing and comfort). The connection between these various points of view makes a decent design a mind boring issue (Kirkegaard, 2011). It is undeniable that the adaptive design system should be advanced for the particular sort of climate in which they will be utilized. Beside the kind of climate, the season and the daytime or evening time assume a fundamental part for the façade (López et al, 2015).

Adaptive façades are building envelopes that can adjust to changes in climatic conditions daily, seasonally or yearly. As defined by (Loonen et al, 2013) "A climate adaptive building shell has the ability to repeatedly and reversibly change some of its functions, features or behaviour over time in response to changing performance requirements and variable boundary conditions. This is done with the aim of improving overall building performance in terms of primary energy consumption while maintaining acceptable thermal and visual comfort conditions. This façade can seize the opportunity to save energy by adapting to prevailing weather conditions, and support comfort levels by immediately responding to occupants' wishes." Adaptive here has been described as the ability to respond and benefit from the external climatic condition to meet effortlessly and importantly occupants comfort and well-being as basic requirements.

(Kirkegaard, 2011) describe the subject adaptive buildings as a system that can "adapt their performance, in real time, to environmental changes and use less energy, offer more occupant comfort, and feature better overall space efficiency than static buildings do" Also (Knaack et al, 2007) supports the use of the terminology 'adaptive' in his work where the describes it has "Buildings able to adapt to changing climatic conditions are called intelligent buildings. Since the term intelligent can be misleading when used in the context of buildings or façades, we will use the term adaptive façade instead. Adaptation generally means that buildings and façades adapt to current weather conditions."

Hoberman centres with his Adaptive Building Initiative around adaptive façades and building envelopes. He advances the utilization of adaptive systems by stating that: "By controlling light levels, solar gain and thermal performance, our adaptive systems reduce energy usage, enhance comfort and increase the flexibility of the built environment" (Hoberman, 2014).

The term Adaptive has been used in so many form in literature by researchers such as dynamic, active, advanced, smart, intelligent, responsive, adaptive, and interactive. However, these terminologies are not pure synonyms because they differ a bit in meaning (Loonen et al, 2013).

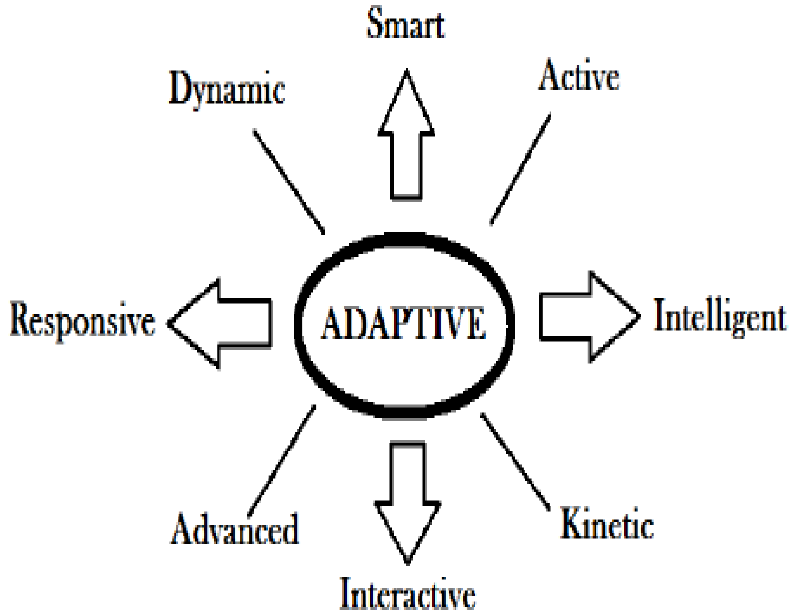


Figure 2.1: Alternatives for adaptive (Loonen et al, 2013)

The requirements of adaptive façade were discussed by De Boer in his work stating that "Adaptive façade technology for increased comfort and lower energy use in the future is that buildings with climate adaptive thermal and daylight properties will have a much better energy performance while maintaining a high comfort standard. The development of CABS (climate adaptive buildings shells), based on theoretically 'ideal' adaptive properties, enables maximizing indoor comfort and minimizing energy use for heating, cooling, ventilation and lighting. This enables the realization of nearly zero energy, or even energy producing buildings in the near future." (De Boer et al, 2012).

According to (Luible, 2014), adaptive façades are multi-parameter high performance envelopes that, inverse to fixed façades, respond mechanically or chemically to external climatic conditions to meet the internal load and needs of the occupants. **(**Ogwezi et al, 2013) discussed about the performance of adaptive façade while presenting different performance metrics and indicators surrounding this type of façade, discussed the performance of adaptive façades and presented different performance metrics and indicators for this type of façades. The life cycle of an adaptive façade can be divided into eight phases (Attia, Walter andAndersen, 2013). The first three phases deal with the design and the performance simulation of the façade. Architect and engineers here define the material, geometry of the façade and the aesthetic qualities of the façade.The next phase focuses on the construction.Then to the commissioning phase where field inspection and performance testing are carried out. Commissioning phase is utilized to ensure that the façade system is erected and installed based on the design requirements and to ensure that all systems are interacting to achieve the expected performance requirement. The final phase, consist of the occupancy and operation performance assessment, before finally dismantling the façade.

Phase 1: Design Development

Phase 2: Construction Documents

Phase 3: Design Assist

Phase 4: Construction

Phase 5: Commissioning

Phase 6: Monitoring and Post Occupancy Evaluation

Phase 7: Soft Landing

Phase 8: Dismantling the façade

2.5.1 Kinetic structure

In the most recent decade, researches and technological innovation has been a noteworthy advancement in the performance of specific building elements such as the building envelope, and the building equipment's such as cooling equipment, ventilation, heating and lighting. Most building component offers an insignificant productivity change; in any case, the best potential lies with the innovative arrangements that advances the mix of the dynamic building components with the building administrations. The term dynamic here converts into truth that capacity include and thermo-physical conduct of such building segment which changes after some time and adjusts to various building and inhabitant necessities, (for example, ventilation, warming, cooling and lighting and so forth.) and diverse conditions (internal heat, meteorological, pollution loads, etc.) (Van Der and Heiselberg, 2008).

This type of dynamic architecture trend emerged from the Nicholas Negroponte which he named responsive architecture, he proposed that architecture may benefit from the integration of computer power transferred into built spaces and structures and a better performance and a more rational building would be developed (Fox, 2001; Pellegrino and You, 1997). This sort of intuitive spaces is based on the merging of entrenched reckoning and kinetics that fulfils adjustment within the logical system of people and environmental synergy. The geometric forces of the envelop can be changed through folding, expanding, deploying and reconfiguration of the kinetic structures which contributes in making tie adaptable, i.e. favourable against external climatic features in order to advance the indoor environment and climate enactment of the building. The structural solution for the kinetic structure should be considered side to side while addressing the ways and means for kinetic operability. The ways as stated earlier could be sliding, expanding, folding and transforming in shapes and sizes, while the means of structural formation could be magnetic, chemical, pneumatic, mechanical or natural (Fox, 2001).

Kinetic structures can also be categorized in accordance to their structural systems, there four main groups namely: foldable plate structures consisting of hinged plates, strut-cable (tensegrity) structures, spatial bar structures consisting of hinged bars and membrane structures (Pellegrino and You, 1997). Many researches have set to improve efficiency in kinetic structural system which erupts into the search of a responsive architecture that would physically hide and adapt them to continual and reoccurs change in conditions and requirements. Also a notable number of researches and research projects of recent have showed interest in the understood of kinetic structure systems (Asefi and Foruzandeh, 2011). The application of adopting of kinetic approaches has been embraced by a large amount lately (Knippers et al, 2012).

Table 2.2: Terms and typologies related to kinetic architecture (Megahed, 2016)

Terms	Descriptions
Adaptable	Structures intended to be effectively changed or adjusted to fit distinctive social capacities previously, then after the fact inhabitance. Versatile ventures are by and large private, socially spurred, and regularly proficient through portable divider frameworks
Deployable	Structures that can overlay for transportation or capacity. The primary clash is between the meanings of transformable and deployable, which are regularly utilized conversely. Deployable structures are self-sufficiently equipped for significant setup changes
Intelligent	Structures that can learn and in addition react in time as per the handled data measured or got from the outside or inside situations by multi-input data identifiers and sources, keeping in mind the end goal to satisfy the clients' needs
Mobile	Pre-assembled structures that are implicit a manufacturing plant on a for all time connected skeleton before being transported to the site.
Performance-based	Structures that utilization advanced innovations to challenge the way the constructed condition is outlined, while profiting the earth, clients, and society
Responsive	Structures intended to react to the social or potentially natural incitement at a particular place amid the plan period of a project
Transformable/ transportable	Structures that can rapidly go up against new shapes, structures, capacities, or qualities in a controlled way by modifications in the structure, skin, or potentially inward surfaces associated by enunciated joints. Transformable activities are by and large less centred around stylish impacts than on satisfying the practical prerequisites of the venture

2.5.2 Kinematic approaches to adaptability

The sun diverges in its altitude angle throughout the day and year, depending on the efficiency of sun shading device the panels need to be tilted so that on average they receive the most sunlight. This angle is typically the same as your local latitude. Therefore, adaptive façade design are more reasonable features that adjust to the changes in solar radiation and climatic factors, permitting an individual control, ideal shading and maximization of daylight use (Schnittich et al, 2006).

(Schleicher, 2015) describes that the use of adaptive façade design system may affect the climatic performance of a building although they are not generally used. Modern building recently with complex geometries, pose a geometrical and mechanical limit to the shading design system.

Shutters, louvers and blinds which are shading devices are common standard component for solar shading devices. These elements are usually based on modular grid, which are majorly restricted to planar surfaces with orthogonal axes and right angles. These products are widespread and perform well when applied on planar façades. These elements offer no standard solutions to be applied in curved surfaces or free form envelopes that are used mostly in contemporary architecture. The use of computational design practices and digital technologies offers a better planning for the building structure which results into a better coherent and complex building system. Customary louvers connected on this new generation of buildings appear in the vast majority of the cases incomprehensible or inadequate. To illuminate this issue, new potential outcomes of shading systems must be created which accomplish a higher level of adaptation and adaptability to conform to complex geometries.

To summarize this chapter discusses the chronology of green architecture from different organizations, stating its usefulness in the building environment and the world at large. It also continues in the detailed overview of green architecture principles where energy conservation; material selection and waste management; indoor environmental quality; water efficiency and site design were discussed. Stating their effectiveness and requirements in the building environment. The chapter then extends to the definition of the terminology adaptive façade and kinetic structure. This examined the general definition and structural overview of the terminologies which aided the discussion of the thesis as it preceded.

CHAPTER 3

CASE STUDIES

3.1 Introduction

The principles that define green building as seen in Chapter 2.4 is extracted and compared with the kinetic structural system (adaptive façade designs). Five projects are selected in order to be introduced and analysed, the projects are selected according to their special features of kinetic architecture, which displays the strength and relationship between green architecture and technology and the success of the design construction.

3.2 Case Study Selection Criteria

In this research, the case studies were selected based on the significant impact they have in portraying the relationship between the green building design and the technology involved. The case studies were purposely selected based on the technology associated with their façade design, which is a key attribute while identifying the case study this helps to streamline the research objective.

3.3 Case 1: Simon Center for Geometry and Physics

Name: Simon Center for Geometry and Physics

City: New York, USA

Architect: International design and architecture firm Perkins Eastman

Year of construction: 2010

Building Function: Center for Geometry and Physics

Façade Type: Tesselatted Kinetic surface (produced by Zaher and ABI)

Function : Natural daylighting, sun control, natural ventilation,

Awards: Gold certificate by LEED BD+C: New Construction v2 - LEED 2.2. 2014

(Architype Review ,2017)

The Simon Centre for Geometry and Physics is a centre for theoretical physics and mathematics at Stony Brook University in New York. The building was completed in September 2010 and attained a LEED Gold certification. The building is adjacent to the physics and mathematics departments for easy collaboration with the mathematics department and the C. N. Yang Institute for Theoretical Physics. The building offers 40,000 square feet (3,700 m^2) of floor space, consist of six stories, houses a 236–seat auditorium, a 90–seat lecture hall, offices, seminar rooms, and a café. (Stony Brooks, 2010)

Figure 3.1: The front façade (Stony Brooks, 2010)

Green Building Principles and Technology

Energy Efficiency

The building utilizes different imaginative mechanical frameworks for cooling to decrease the vitality heap of the building

- Air-handlers use a few warmth dismissal techniques – ice stockpiling, geothermal wells, and water highlight that capacities as a cooling tower.
- Active chilled shafts were consolidated into the workplaces to give low-dampness cooling. Chilled beams work similarly to radiators, but for the purpose of cooling, rather than heating. These units have chilled water running through them with a low volume of air that runs over them, creating a stream of cold air. They are more efficient than traditional systems because the chilled beams have no moving parts that require power or maintenance.

- Outdoor and ventilation air are maximized.

The estimated energy use of the building is 33% less than a comparable building (SCGP, 2016).

Material

A particular green rooftop above Floor 5 and grower on Floor 2 contribute towards accomplishing manageability. Live Rooftop indicated built soil and a mix of low-developing shallow root sedums and sempevivums were utilized to make a characteristic cover on the rooftop (SCGP, 2016).

Water Efficiency

A rainwater harvesting tank of 15, 1417 litres was used to maximize the collection of rain water from roof drains, estimated at more than 113562.35 litres annually, in order to provide water for toilets and irrigation (SCGP, 2016).

Indoor Environment Quality

The interior atrium integrates the three stages of offices. Natural daylighting is given in this three-story space with a south-bound clerestory and intelligent bended roofs at the top floor.

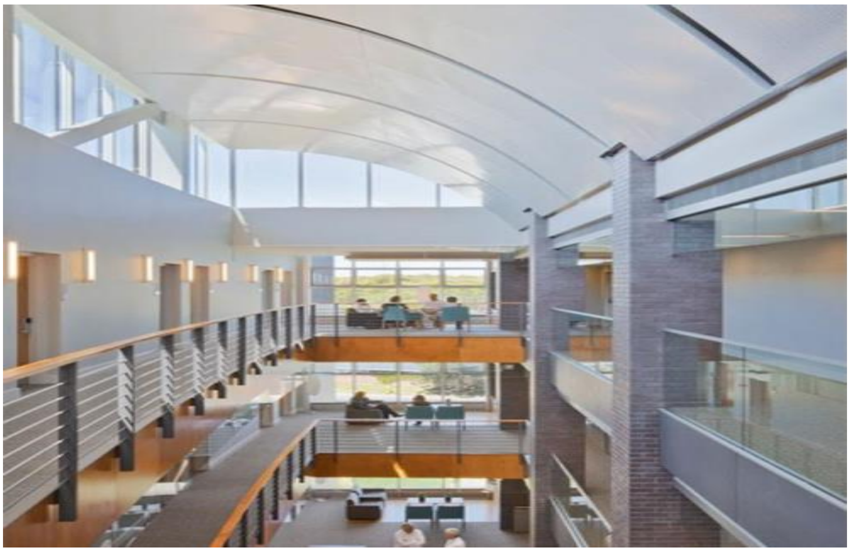


Figure 3.2: The Atrium (Architype Review, 2017)

The glass façade on the south side was intended to amplify sun control while looking after perspectives. A flat sun-shade louver framework that incorporates support grates enables more sun to penetrate the inside amid the winter months and less presentation in the late spring months and takes into consideration the drape divider framework to be cleaned. Operable windows were provided for occupants to moderate their own natural ventilation. In addition, the floor-to-floor heights were substantially reduced during the design phase from 4.3m to 3.7m. The reduction in the overall volume of the building reduced the amount of energy required to heat and cool the space as well as reducing the quantity of materials to build it (SCGP, 2016).

Figure 3.3: The solar shading device (SCGP, 2016)

Site Design

Within the design of the building transportation was considered as an aspect that aided the green architecture, with an easy access to facilities and services (Figure 3.8).The site consisted of tree planting to help improve the building green space.

Technology (Kinetic Structural System)

The building façade is constructed using vibrant stainless steel tessellated kinetic surface which was produced by Zahner in joint venture with ABI. The technique of tessellate façade was to use locally adaptive penalization to achieve a dynamic regulation of daylight in the building. This was accomplished by the use of perforated patterned panels, which consistently evolves and changes positions. The panels were framed in groups this allowed them to overlap and alignment to form a kaleidoscopic effect. The effect was responsible for the formulating of light, while diffusion of mesh contributed in regulating the heat gain from the amount of solar radiation that penetrates into the building's skin and controls the air flow and in addition the levels of privacy.

(Huberman, 2008) stated that “Using Tessellate in a building envelope can lower overall energy consumption by 6%, and it can reduce the cooling load by 15%-20%, when compared with fixed shading. The shifting geometries are also designed to be appealing to the eye, creating a kind of functional artwork.

The kinetic surfaces were built in response to environmental changes (such as temperature, moisture, and light) by opening or closing an aperture on the surface of the building itself.

Each of the mechanized boards spins around each other in a built track characterized by the composed parts. The visual impact resembles that of a bloom, blooming into a burst of examples - hexagons, circles, squares, and triangles. At a certain point in the cycle, the punctured examples all are adjusted, permitting the most extreme open space. At the flip side of the cycle, the example turns into a dark work (Zahner, 2016).

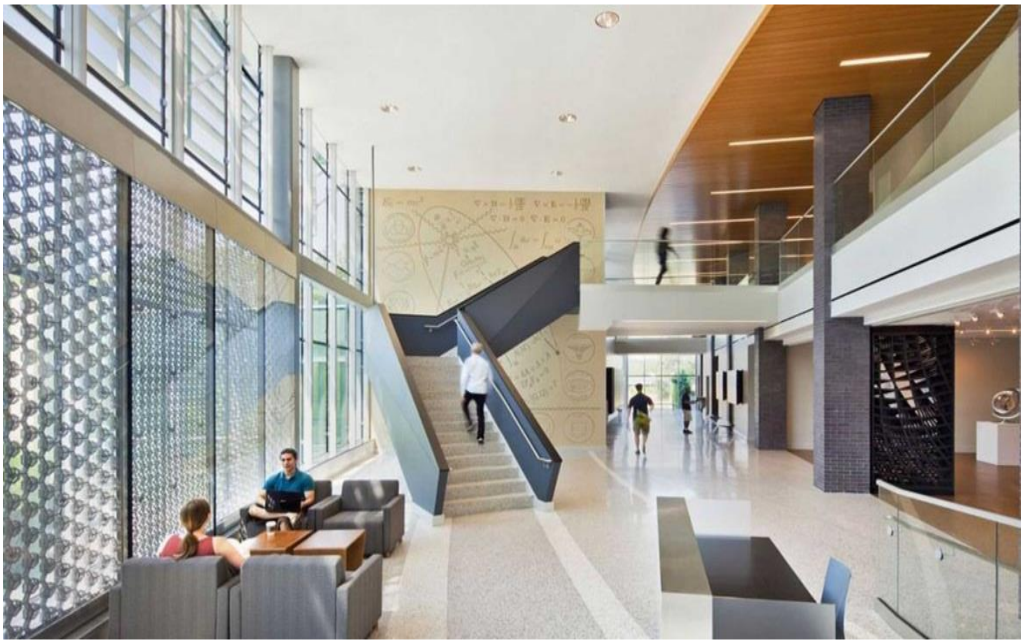


Figure 3.4: Kinetic surface in the lobby (Zahner, 2016)

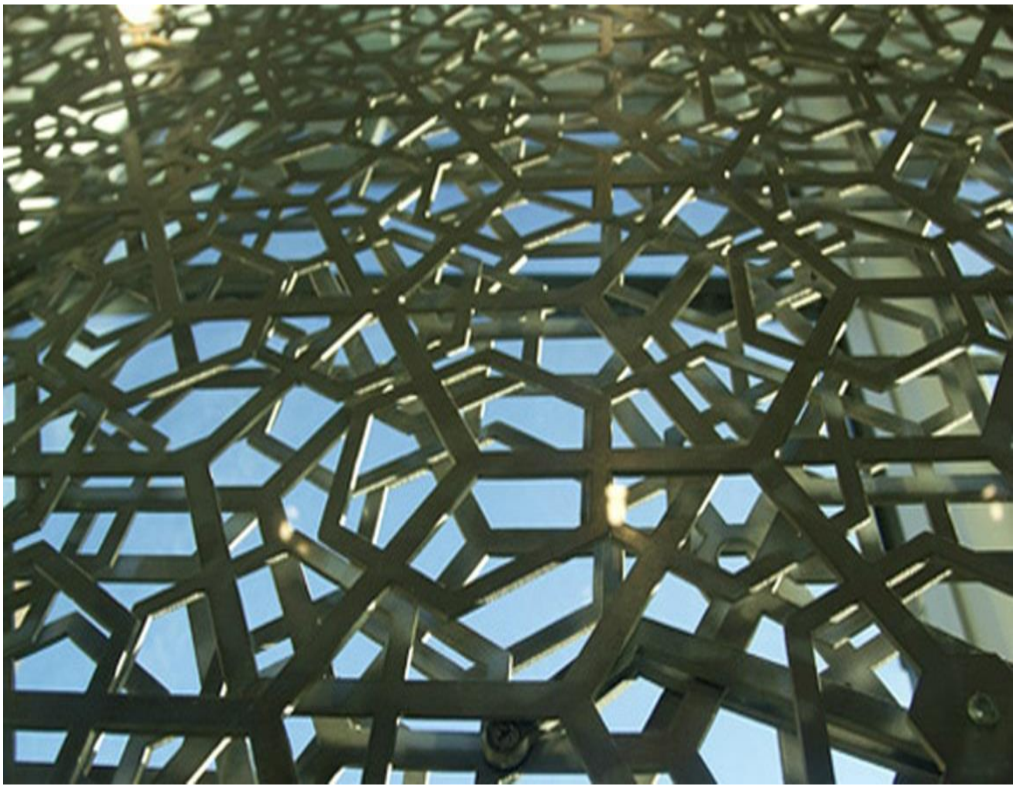


Figure 3.5: Detail of the kinetic surface (Zahner, 2016)

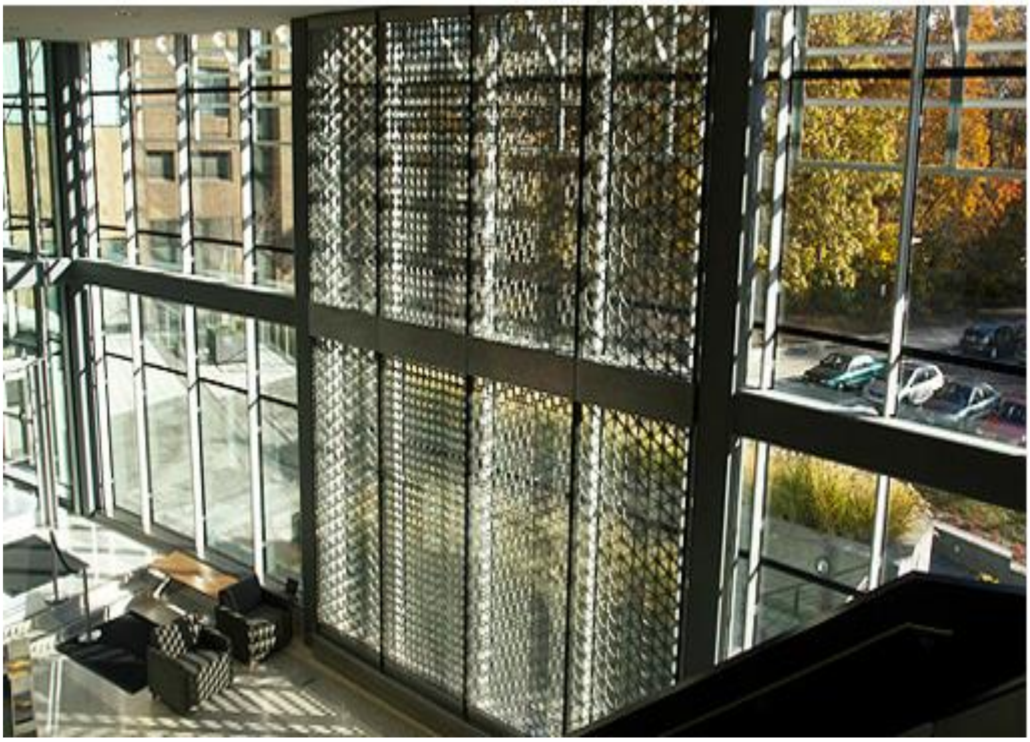


Figure 3.6: Detail of the kinetic surface (Zahner, 2016)

Figure 3.7: Detail of the kinetic surface (Zahner, 2016)

The kinetic surface spans 124 square meters and imbues the building with the functional capacity to dynamically change its opacity and sculpt the quality of light within (Zahner, 2016).

Table 3.1: Principles and façades techniques in Simon Centre

Principles and façades techniques	Simon Centre
Energy Conservation	- The use of air handlers as a heat rejection method -The use of active chilled beams to provide low-humidity cooling -33% less of energy use than a conventional building
Material Selection and Waste management	- Animated stainless steel with tessellating kinetic surface and panels -Modular green roof - Zero waste and resources conservation
Water Efficiency	-Rainwater harvest tank
Indoor Environmental Quality	- Solar shading –the use of horizontal and sun shades louver system -Operable windows for natural ventilation -Natural daylight provided using reflective curved ceiling
Site Design	-Site and building were considered (due the orientation of the building façade and its well-arranged landscaping) -Easy transportation

In this building, the relationship between the principle of green architecture and the adaptive façade are more concentrated on the tessellation kinetic surface of the façade of the building, where the shading element acts as a solar shading device and help improve the daylight and also increase the energy conservation of the building.

3.4 Case 2: Q1, Thyssen Krupp Quarter Essen

Name: Q1, ThyssenKrupp Quarter Essen

City: Essen, Germany

Architect: SWD Architekten + Chaix and Morel et Associés

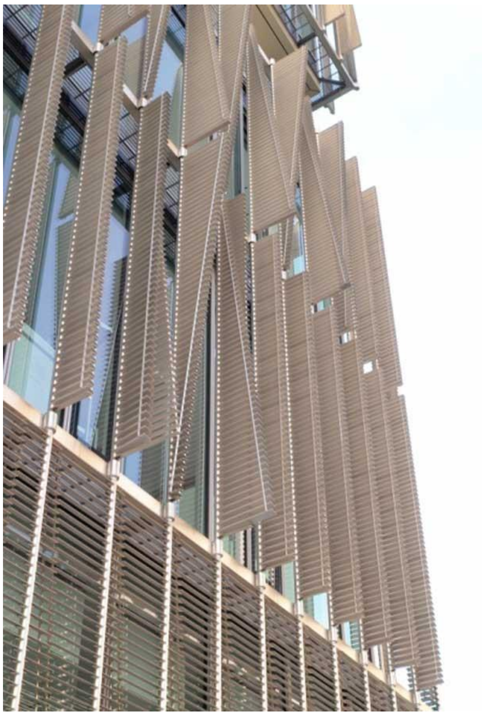
Building Function: Office building

Year(s) of construction: 2010

Façade Type: Curtain wall**:** Feather shading system (stainless steel lamellas)

Function: Thermal (solar control), Optical (daylight control)

Awards: Gold certificate by the German Society for Sustainable Building, BDA Essen Award, 2012 German Steel Construction Award, LEAF Award



(Arnoldius, 2011)

The ThyssenKrupp Quarter is designed by SWD Architekten + Chaix and Morel et Associés in Essen, Germany for ThyssenKrupp AG, completed between 2009/2010. The building trails the idea of a campus architecture consisting of an arrangement of individual buildings embedded into a green carpet lined with trees, connecting paths and small squares. The buildings outline the central axis with the large water basin and are within short distances from each other. The building is composed of L- shaped elements enclosing a shared central space giving a clear alignment of the building (Archdaily, 2013). The Q1 building was awarded a gold certificate by the German Society for Sustainable Building (DGNB). The building received the BDA Essen award, the “2012 German Steel Construction Award” and one of the “LEAF Awards”.

Figure 3.8: The front façade (Christian Richters, Günter Wett, Michael Wolff, 2013)

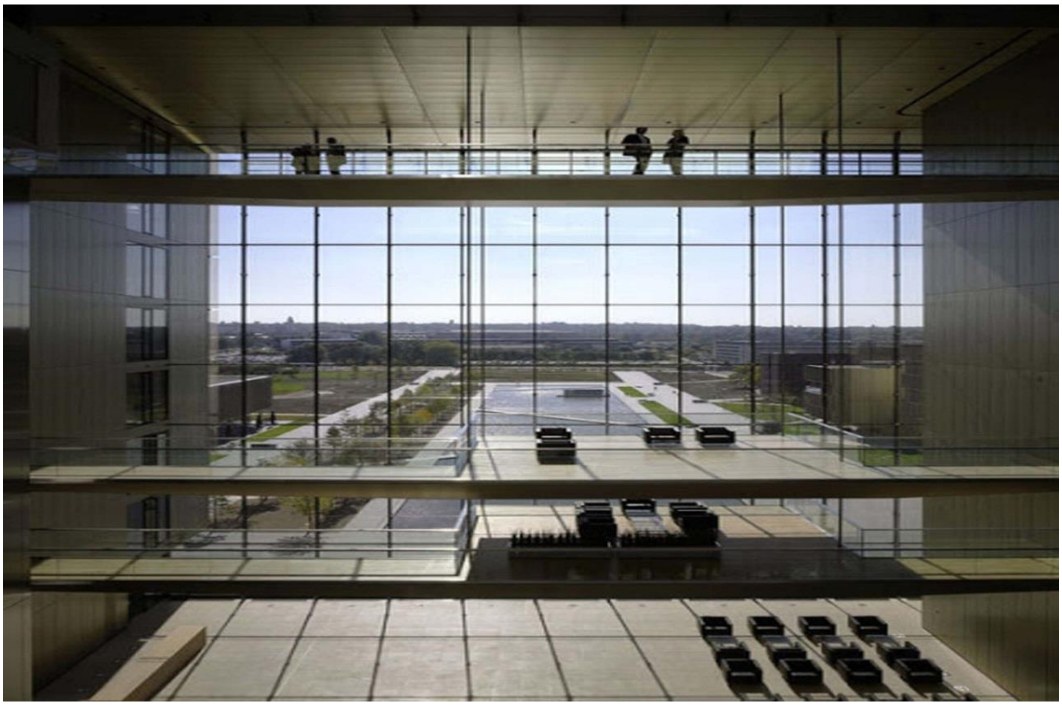


Figure 3.9: View of the main axis pool through the panorama window at Q1 (Christian Richters, Günter Wett, Michael Wolff, 2013)

The large atrium area of Q1 shimmers as a result of its pearl-metallic gold colour internal cladding (Figure 3.10). The building is dominated by panorama windows and two large tensed cable curtain walls. The building is 50-meter-tall and both glass constructions are 28 and 26 meters wide the panorama windows were designed and engineered by Werner Sobek.

Green building principle and technology (feathers)

Energy conservation

The Q1 Headquarters building in Germany uses a sun shading system that comprises of 400.000 metal "feathers" which are connected to stainless steel stalks that can move through a controller. The 1,280 mechanized components can be shut to make a more strong fenced in area, take the position of the sun, or be altogether open to permit most extreme sun oriented introduction. The difference of the shape metal feathers blocks the sun light, while the adding to the cooling down of the interior. They lower the energy demand for operating air conditioning and climate control systems, though their capacity to direct the natural light inside the building lessens the requirement for electric lighting.

Material Selection and Waste Management

The use of stainless steel shading devices was used as feathers and also pearl metallic gold material was used to form the steel panels.

Water Efficiency

The building house 75,000m^2 of green space, with a green carpet lined with trees, connecting paths and small squares, and a water basin of 7,300m^2 with a water depth of 0.15m. 15 different tree types of trees were planted to provide water efficiency in the building.

Indoor Environmental Quality

In bright sun, the balances of the sun shading framework overlap level against the working to hinder however much warmth as could reasonably be expected. On the shaded side of the building, the balances open to permit in the greatest measure of light.

Site Design

The building possesses a good orientation where it is protect from the sun rays.

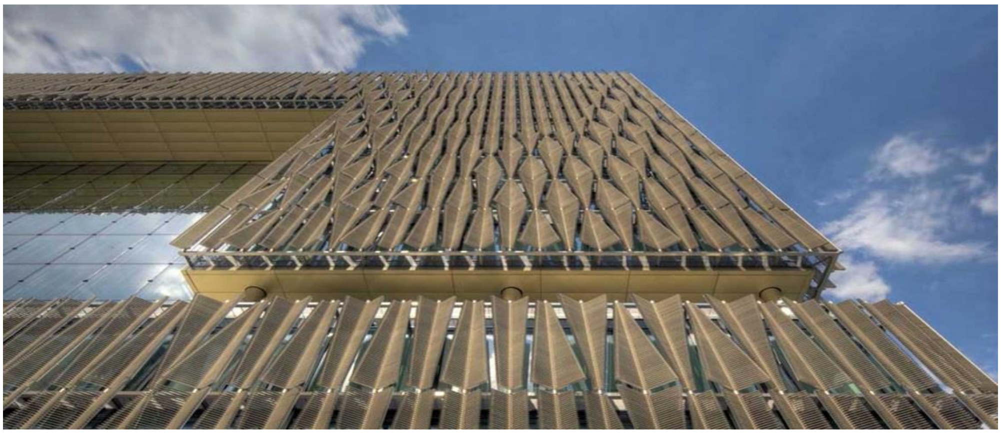


Figure 3.10: Headquarters feather shading system – general view of façade (Arnoldius, 2011)

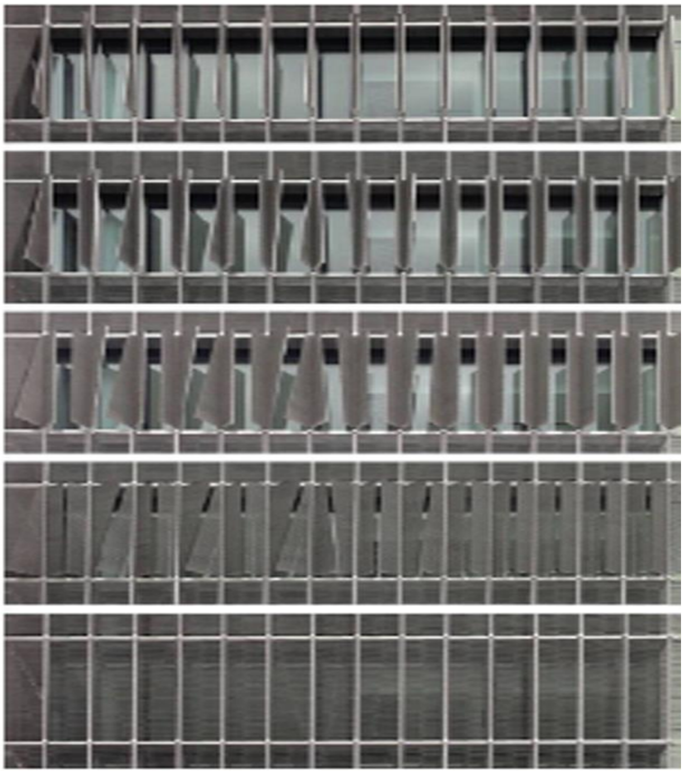


Figure 3.11: Q1 Headquarters, feather shading system positions (Christian Richters, Günter Wett, Michael Wolff, 2013)

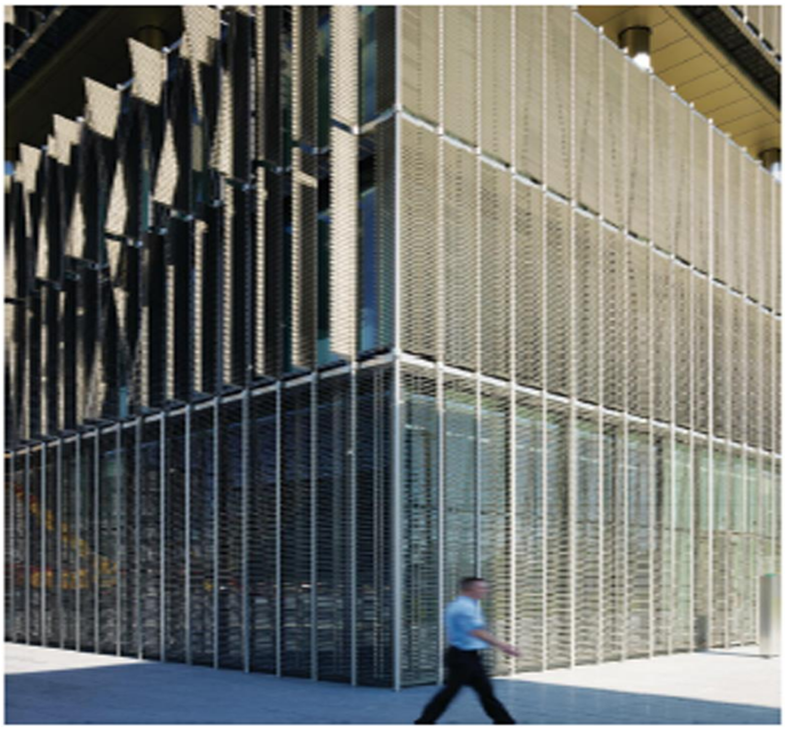


Figure 3.12: Q1 Headquarters, Side Façade (Christian Richters, Günter Wett, Michael Wolff, 2013)

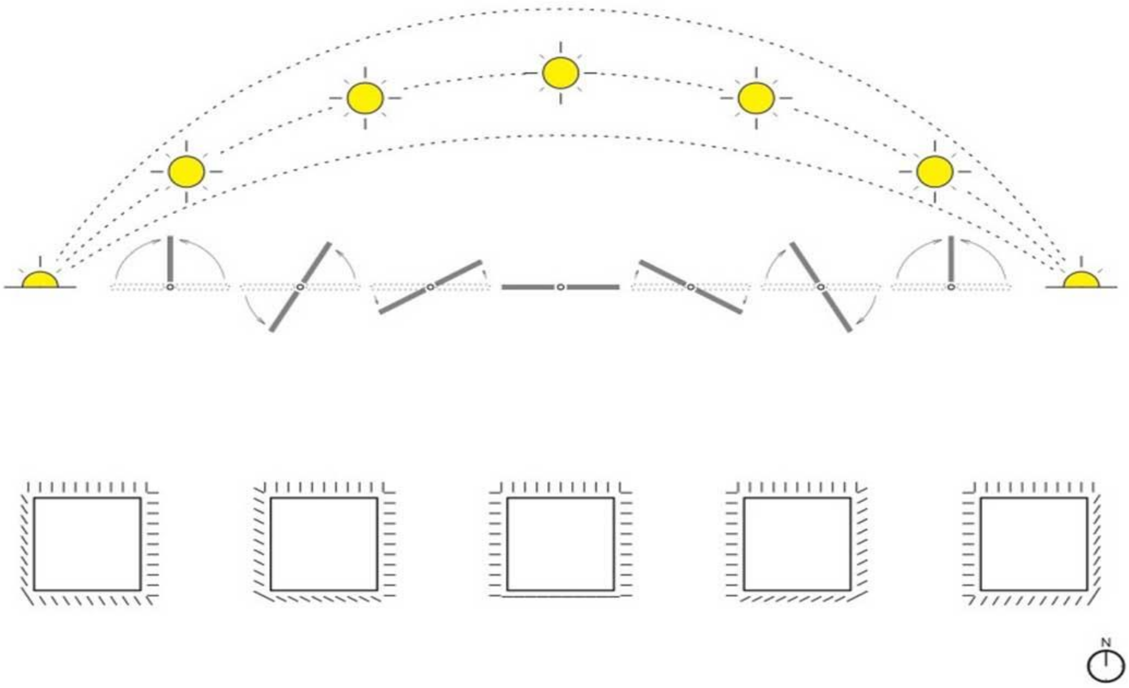


Figure 3.13: Q1 Headquarters control the rotation angle by sun direction (Arch daily, 2013)

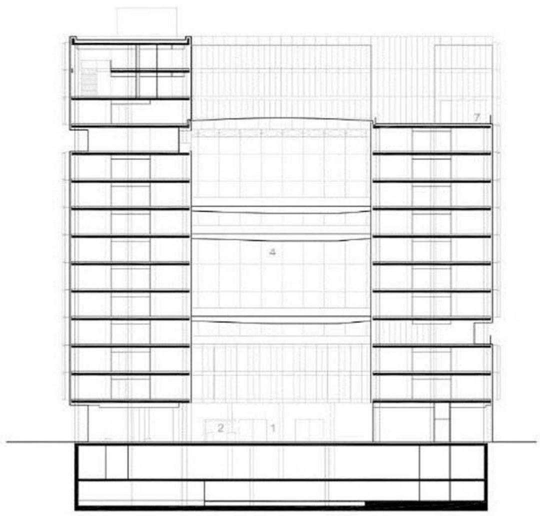


Figure 3.14: Q1 Headquarters, Section (Arnoldius, 2011)

Table 3.2: Principles and façades techniques of Q1, JSWD Headquarters

Principles and façades techniques	Q1, JSWD Headquarters
Energy Conservation	- Sun protecting system, reduced energy demand and use of air condition and electric lighting - Approx.1, 000 square meter geothermal field for power supply and power consumption is minimized via energy-saving fluorescent lamps.
Material Selection and Waste management	- Stainless steel shading devices (feathers) -Pearl Metallic Gold material (PLADUR® ZM)used in form of formed steel panels
Water Efficiency	- 75,000 m² of green space - 7,300 m² water basin, water depth 0.15 m - “Avenue of the worlds” being built along the water basin: 68 trees from five continents (15 different tree types) to provide water efficiency in the building

Indoor Environmental Quality	- Sun shading system to reduce direct sunlight into the building - Use of panorama windows for day lighting - Openness and transparency with its intricate façade structures of glass and metallic materials
Site Design	- Good orientation of the building for sun protection

The relationship between the principle of green architecture and the adaptive façade technique in this building is the use of feather shading system for sun protection, thereby reducing the energy demand of the building. It also helps reduce the sunlight penetration into the building

3.5 Case 3: BIQ (BUILDING INTELLIGENT QUOTIENT)

Name: BIQ Building

City: Hamburg, Germany

Architect: SPLITTER-WERK

Year(s) of construction: 2013

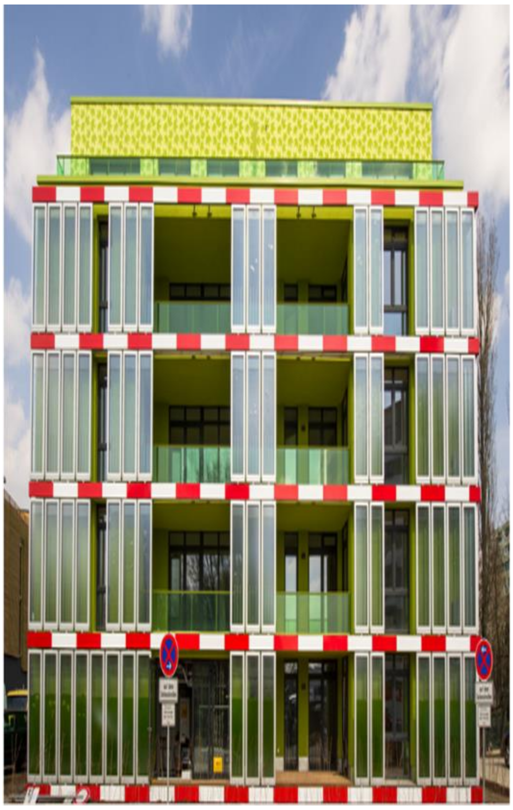
Building Funation: Residential

Façade Type: Curtain wall: Bio-adaptive façade

Presence: South façade

Function: Air flow (CO_2 balance), Thermal, Acoustic performance

Awards: Zumtobel Group Award 2014



(IBA Hamburg GmbH Johannes Arlt, 2013)

BIQ is a cubic, five-story uninvolved house with two contrastingly outlined façade sorts planned by the structural firm SPLITTER-WERK, Graz. It is the primary bio-versatile façade and first green growth controlled working on the planet. The sides of the building that face the sun have a moment external shell that is set into the façade itself. Because of the unfaltering development of green growth, each façade is continually moving and changing its shading. Microalgae (small plants), are created inside this shell, encourage the working to supply its own vitality.

BIQ has 15 condos, some of which depend on the idea of switchable spaces with capacities that can be on the other hand or at the same time changed to an "unbiased" zone. Every loft's capacities: lounge room, room, kitchen, and washroom, are arranged in inherent furniture that is passed on inside the unbiased space and can likewise be sorted out around it. Development started in December 2011-finished in April 2013, and it was inherent Hamburg, Germany.

Figure 3.15: South façade of BIQ (IBA Hamburg GmbH Johannes Arlt, 2013)

Green building principle and technology (Bioreactor Façade)

Energy Concept: The fundamental thought behind the vitality idea is the mix of various vitality sources with the goal that they will cooperate. BIQ has a comprehensive energy idea, along these lines equipped for uniting, in one circuit, sunlight based energy, geothermal energy, a gathering heater, locale warming, and the generation of biomass in the bioreactor façade. It draws the greater part of the energy expected to produce power and warmth from inexhaustible sources. Aside from creating energy utilizing the green growth biomass reaped from its own façade, the façade then gathers strength by retaining the light that is not utilized by the green growth and produces warm, similarly a sun oriented warm unit does, which is then either utilized specifically for boiling hot water and warming, or stored in the ground utilizing borehole warm exchangers (IBA-Hamburg, 2013)

The bioreactor façades on the southeast and southwest sides of the building are utilized for creation of biomass and heat. The bioreactor façade comprises of 129 reactor modules, called photo bioreactors (PBRs). The panels are 70 cm wide, 270 cm high and 8 cm thick, organized in a group. The PBRs are mounted on a steel frame that is at the same time utilized for wiring. The PBRs are loaded with water (culture medium), in which microalgae are developed. As a supplement, CO_2 is added to the culture, for which flue gas from a biogas-fuelled micro-CHP (combined heat and power unit) is utilized. The CO_2 converts the growing algae to biomass. In addition, the façade also serves for the conventional purposes of insulating the building against sound, heat, and cold, and provides shade in bright sunlight. The living space has under floor heating.

Energy cycle and the renewable systems of the BIQ building

The vital point of all energy resources are from the algae reactor modules PBRs. Heating and electricity needs are covered by converting and distributing different types of energy. The integrated energy cycle is given below according to (BUILDUP, 2015).

Bioreactor façade: Because of daylight and a consistent turbulence to maintain a strategic distance from green growth conglomeration, microalgae becomes inside the PBRs delivering heat (38% of proficiency versus 60-65% with a customary sun oriented warm) and biomass (10% of effectiveness versus 12-15% with an ordinary PV). The bioreactor façade is focused in contrast with different innovations, due to the façade giving a comparable proficiency level and expelling a high measure of CO_2 by utilizing pipe gas conveyed in the gas burner to create biomass in the PBRs. It accomplishes up to 6 tons for each time of CO_2 lessening.

Algae Biomass: The biomass coming about because of the development (30KWh/m2.year) is naturally gathered through a green growth separator and gathered in a temperature-controlled compartment. At that point, this sum is expelled to an outside biogas plant to produce biogas.

Heat: The related warmth creation of around 40ºC (150KWh/m2y) is reintroduced to the framework by means of the warmth exchanger in the warming system or put away in the geothermal boreholes.

Biogas: Upon landing to the outside biogas plant, up to 80% of biomass is changed over into methane.

Boreholes for capacity: The boreholes comprise of wells situated under the building subsoil and are utilized to store warm from 16 to 35 degrees relying upon the season.

Heat pump: When a higher temperature is required for warming or boiling hot water, a profoundly productive warmth pump is utilized as a part of pumping it once again into the framework.

Gas burner: A unit is worked to give the CO_2 supplement (vent gas) required by the microalgae in the bioreactor façade and, in the meantime, to cover the supply of boiling hot water at 70ºC or warming in the vitality arrange.

Control focus: A focal building administration framework (BMS) called Rockwell SPS deals with every one of the procedures important to work the bioreactor façade and to completely coordinate it with the vitality administration arrangement of the building. This incorporates the control of the green growth cell thickness and the temperature in the way of life medium.

District heating system: Wilhelmsburg Focal Coordinated Vitality System is the name of the nearby system which gives/gets warmth to/from this building.

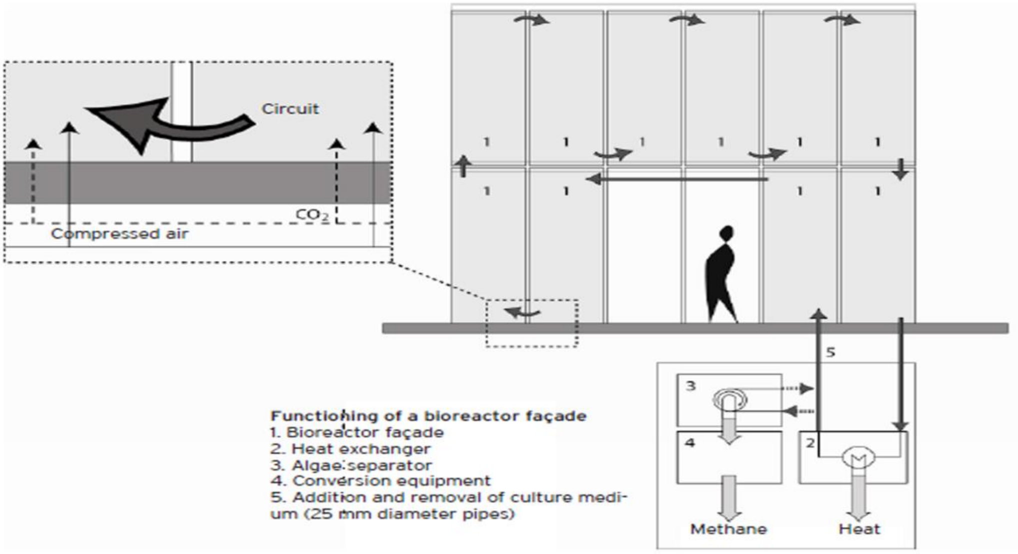


Figure 3.16: Functioning of a bioreactor façade (Arup GmbH of IBA-Hamburg, 2013)

Material Selection and Waste Management

The use of large reactor modules PBR (photo bioreactors) was used for the facade (algae panels) with a steel frame for wiring the PBR's.

Indoor Environmental Quality

The orientation of the panels facing the south and west end of the building helped it create an indoor environment that was efficient. Algae bio-façade gives the building warm insulation; shading from sunlight also reduces the noise pollution and will generating a ready-to-harvest biomass. The façade system insulates the building from sound, heat, cold and shades from bright sunlight.

Site Design

There were no basic site design, basically the use of algae panels on the building façades helped create the site design. The algae panels facing the south and east side help protect the building from the sun, thereby creating a shading element.

Figure 3.17: East façade of BIQ (IBA Hamburg GmbH / Martin Kunze, 2013)

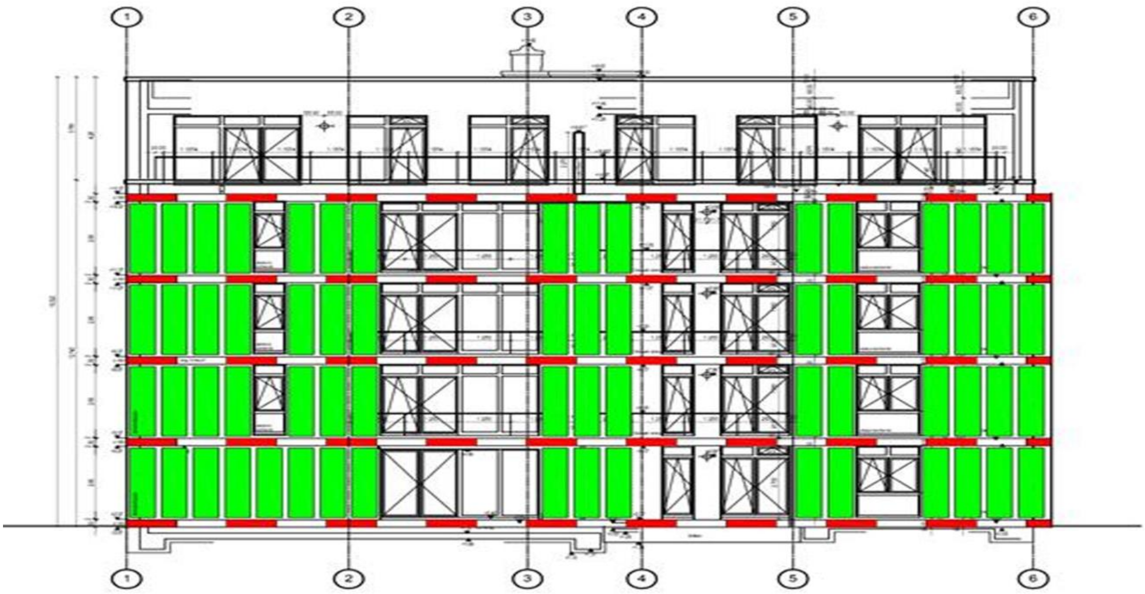


Figure 3.18: Section of BIQ (http://www.ongreening.com)

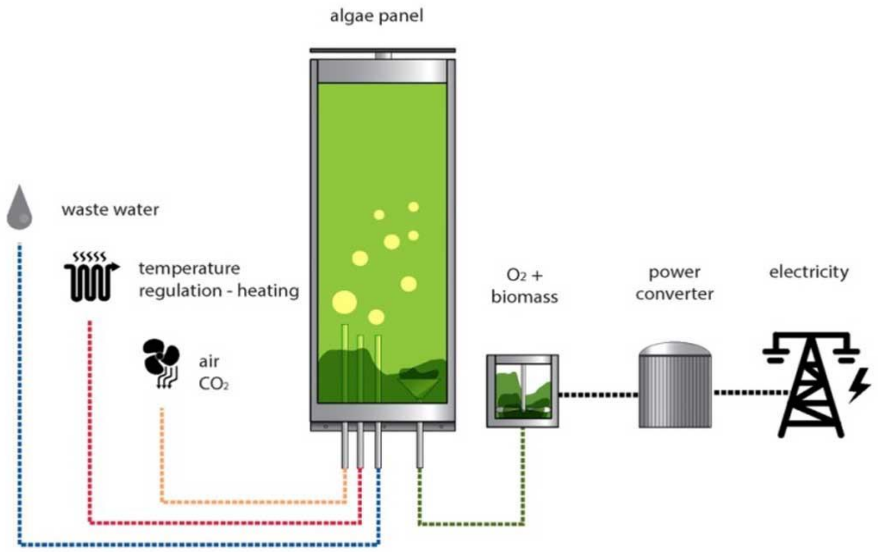


Figure 3.19: Diagram-Algae-Panel-System (Arup GmbH of IBA-Hamburg, 2013)

Table 3.3: Principles and façades techniques for BIQ building

Principles and façades techniques	BIQ building
Energy Conservation	- Use of a large reactor modules PBR (photo bioreactors)
Material Selection and Waste management	- Contribution of different energy sources: solar energy, geothermal energy, condensing boiler, distinct heating, production of biomass in the bioreactor façade - Steel frame and wiring for the PBRs
Water Efficiency	- Steel frame and wiring for the PBRs
Indoor Environmental Quality	- Bio-reactive panelling - The orientation of the panels are at the south and west side of the building
Site Design	- The use of Algae panels (that are directed towards the sun direction to protect the building)

The relationship between the principle of green architecture and adaptive façade in this building is reflected in the use of photo bioreactor panels to contribute to the energy production of the building. The building generates its own energy using algae panel system.

3.6 Case 4: Institute du Monde Arabe

Name: Institute du Monde Arabe

City: Paris, France

Architect: Jean Nouvel, Architecture-Studio, Pierre Soria and Gilbert Lezenes

Year(s) of construction: 1987

Building Function: Research and information centre about the Arab world

Façade Type: Double-skin : Advanced responsive metallic brise soleil (south façade)

Function: Thermal (solar control)

Awards: Aga Khan Award for Architecture 1989, Equirre d'Argent for French architecture 1987

(arch daily,2011)

The Insitute du Monde Arabe a building in Paris, France was built by Jean Nouvel, Architecture Studio in 1987. One of the basic roles for the construction of this venture was to make a destination committed to the relationship of the Bedouin culture with France. The building is arranged at the edge of the chronicled peripheries of Paris along the Stream Seine, it responds to it's incite setting both in plan and rise. In plan it takes after the stream of the street, whose shape is coordinated by the waterway. Its two essential volumes incorporate an inward yard with the north mass rising nine stories and the southern piece rising to eleven stories. The inside spaces incorporates a library, workplaces, eatery, historical centre, and assembly room. A multi-story glass chamber is wrapped with a steel staircase highlighting uncovered elevator on the interior.

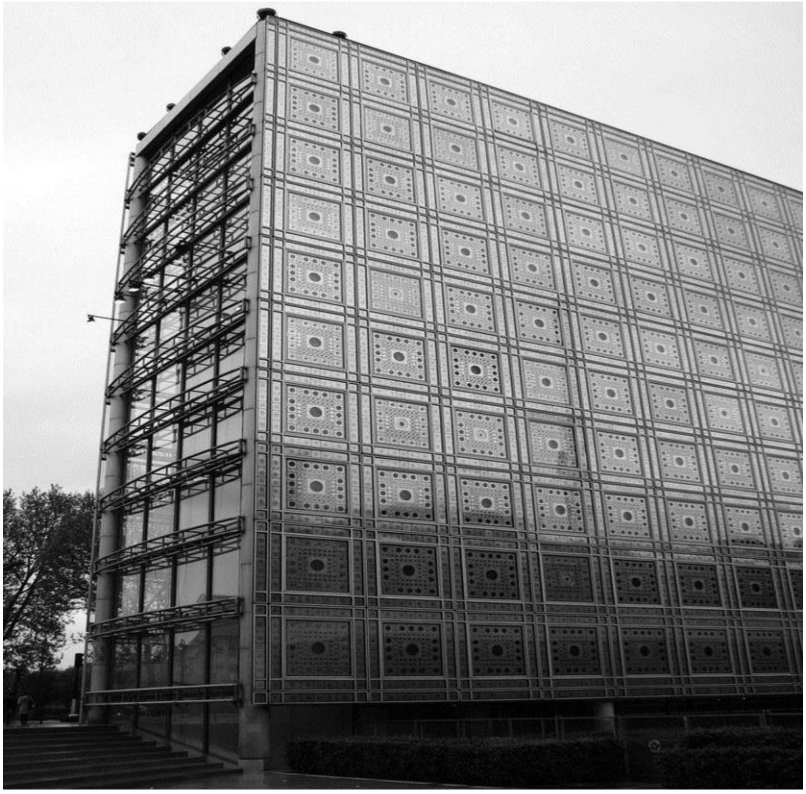


Figure 3.20: The south façade (BUILDUP, 2015)

Green building principle and technology

The main feature and innovative element of the IMA are the advanced responsive metallic brise soleil on the south façade. The approach in the IMA drew inspiration from traditional latticework used in the Middle East to shield tenants from the sun and to furnish them with protection. The framework consolidates a few hundred light delicate diaphragms that control the measure of light that is permitted to enter the building. The shift in the geometric pattern is formed in various phases of the lens and showcases a both light and void. The use of circle, squares, and octagonal shapes were used to produce fluid motions and light was adjusted in parallel. The interior spaces were modified dramatically along with the exterior appearance. The ocular device creates an aesthetical appearance while been functional from the environmental conditions, solar gain is effortlessly relieved by closing or decreasing the aperture sizes (Archdaily, 2011).

Figure 3.21: The façade elements exterior (BUILDUP, 2015)

Energy efficiency

The sensors in the building depended on element atmosphere commitments to reduce vitality requests yet just when basic so that visual solicitations are moreover met. The façade is portioned into a few sensor readings: the development inside each square is a withdrawal and expansion of material impacted by atmosphere while each cove is autonomously controlled by the occupants (Archdaily, 2011).

Material selection and waste management

The use of advanced responsive metallic Brise Soeil (Figure 4.26) at the south façade drawn from the traditional lattice works used in the Middle East to shield tenants from the sun.

Indoor environment quality

The cultural centre's southwest façade mimics the lens of a camera or an eye, which controls the entering of daylight into the building. The first layer towards the exterior is a simple protective barrier consisted of glass units that prevent the rain and the wind to enter. On the other hand, the second layer is a more complicated construction of panels that consist of 25000 photoelectric diaphragms. The themes on the façade have photosensitive crevice which opens and close to control the daylight infiltration. The façade establishes a play of light and shadows in the library, invigorating inhabitants inside the building as daylight channels through the dynamic mashrabiyya "*can be ordered into three sorts: cantilevered, screen boards, louvered timber dividers and louvered windows. Their sizes additionally rely on upon the span of the opening, which is principally impacted by the kind of atmosphere*" (BUILDUP, 2015). The façade connects with the occupants to associate with the bay of panels yet for the every square of the panel to react to the atmosphere. The level of development is little however compelling in constantly changing the environment through rich and energetic methods for filtering light (Gunderson, 2015).

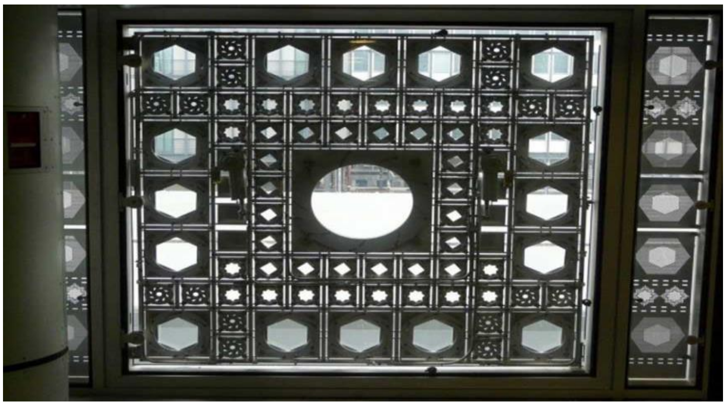
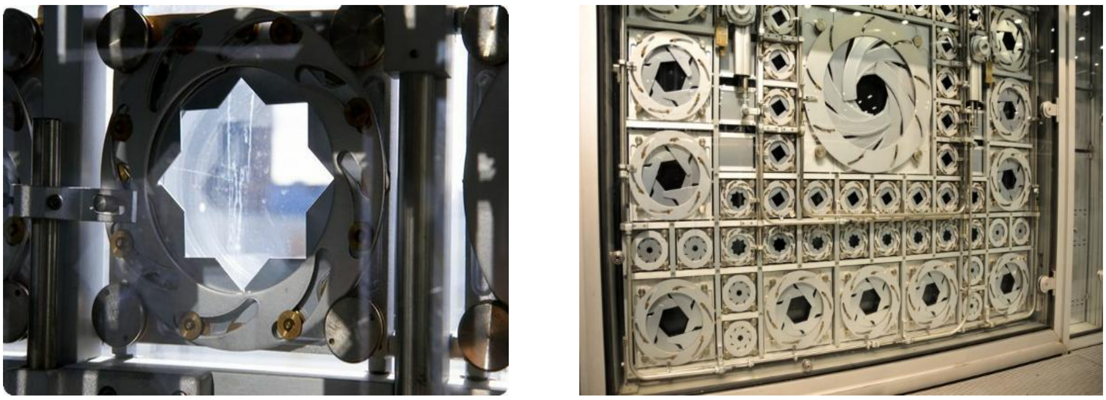


Figure 3.22: The façade elements interior (Gunderson, 2015)



(A) (B)

Figure 3.23: (A-B) opening system details (BUILDUP, 2015)

Site Design

The building was oriented in such a way the South faces the sun direction where the responsive façade is designed to help the building conserve its energy and shade itself.

Figure 3.24: The façade structure interior (Gunderson, 2015)

Figure 3.25: The west façade (Archdaily, 2011)

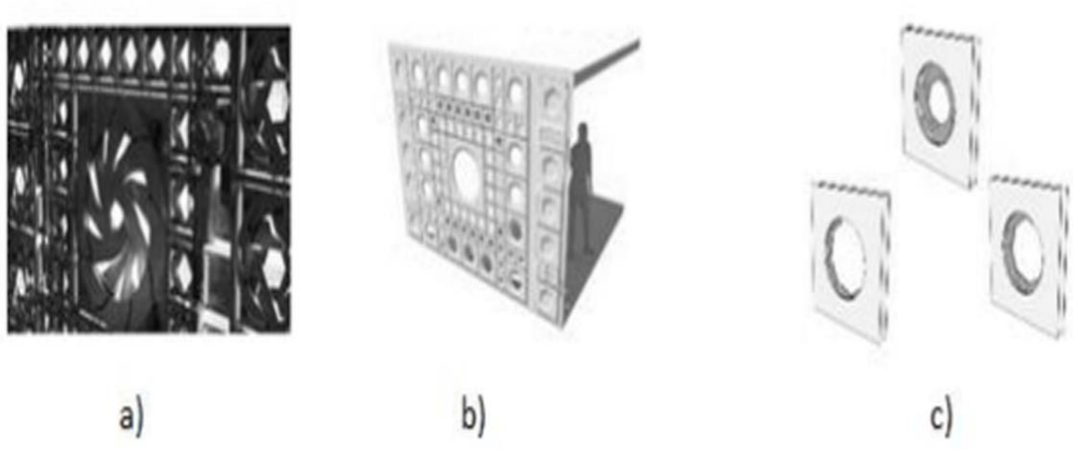


Figure 3.26: Diaphragm system: a) real design, b-c) virtual drawings (Velasco et al, 2015)

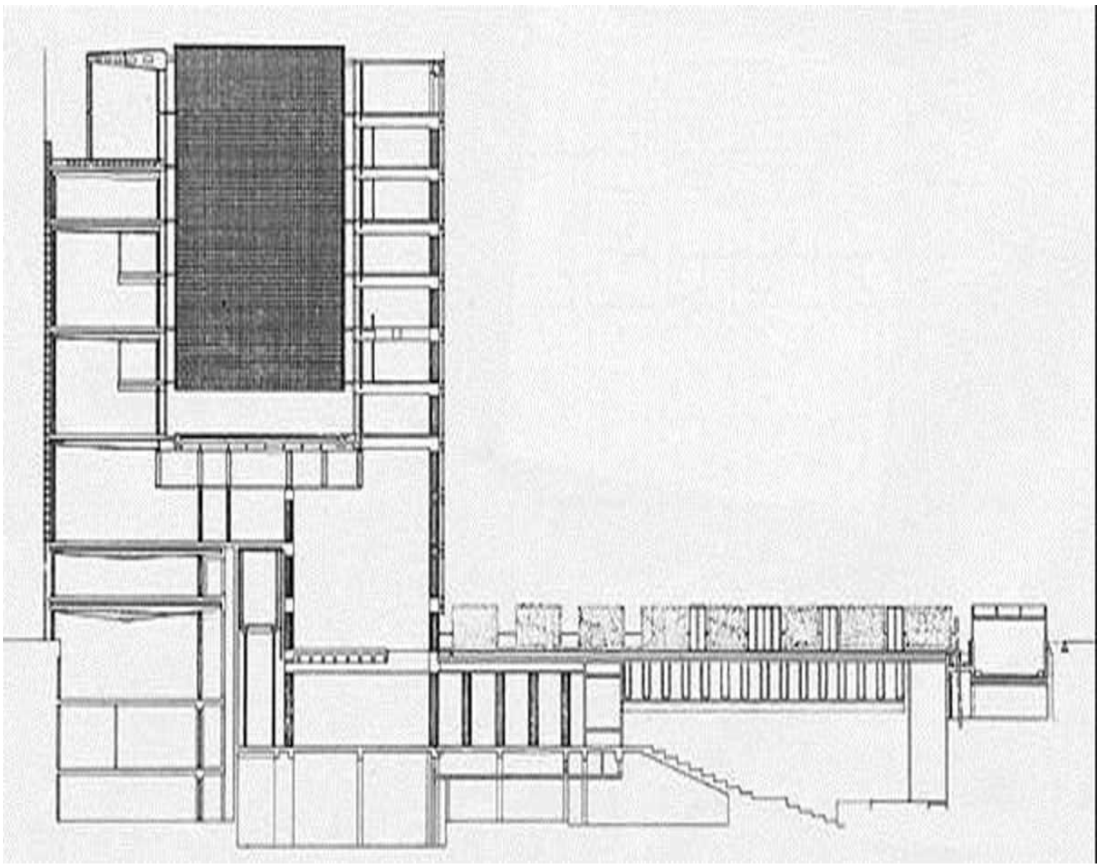


Figure 3.27: Section of Institute du Monde Arabe (Archnet, 2017)

Table 3.4: Principles and façades techniques for Institute du Monde Arabe

Principles and façades techniques	Institute du Monde Arabe
Energy Conservation	- Sensor system based on dynamic climate to contribute to the diminishing of energy demand
Material Selection and Waste management	-Advanced responsive metallic brise soleil
Water Efficiency	-Nil
Indoor Environmental Quality	- Solar gain is relieved by closing the aperture sizes to control the lighting the building - Use of Photosensitive crevice which open and close to control daylight infiltration
Site Design	- Orientation of the building where the south façade with the responsive façade faces the sunlight direction

The relationship of the principle of green architecture and the adaptive façade design in this building is visible in the use of the brise soleil as the south façade of the building. This help reduces the sunlight penetration into the building and also contributes to the energy conservation of the building.

3.7 Case 5: Al Bahr Towers

Name: Al Bahr Towers

City: Abu Dhabi, United Arab Emirates

Architect: Aedas +Arup

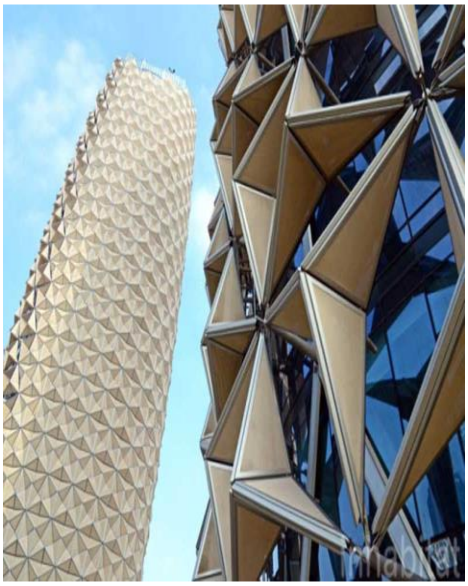
Year(s) of construction: 2009-2012

Building Function: Office building

Façade Type: Curtain wall: Crystalline Honeycomb Shell

Function: Thermal (solar control), Optical (daylight control, glare)

Awards: CTBUH 'Innovation' award 2012, Tall Building Innovation Award 2012



Bahar tower Façade (Inhabitat, 2014)

The Al Bahar towers were built by Aedas +Arup (façade Consultant), construction was completed in 2012, and designed for the Commercial Office Building in Abu Dhabi, United Arab Emirates. It is a 145-meter tower with the concept of Mashrabiya shading system implemented using computational design. The façade design used parametric description for the geometry of the actuated panels to simulate the response in operating to sun exposure and changing incidences angle during different periods and days of the year.

Figure 3.28: Perspective view of Al Bahar Tower (Archdaily, 2012)

Green building principle and technology

Energy conservation

The screen was estimated to reduce solar gain by 50% or more, thereby been the energy-draining air conditioning. Also, screen used enabled the designers to use natural tinted glass, that allowed more light into the building and better view and less natural light were enabled.

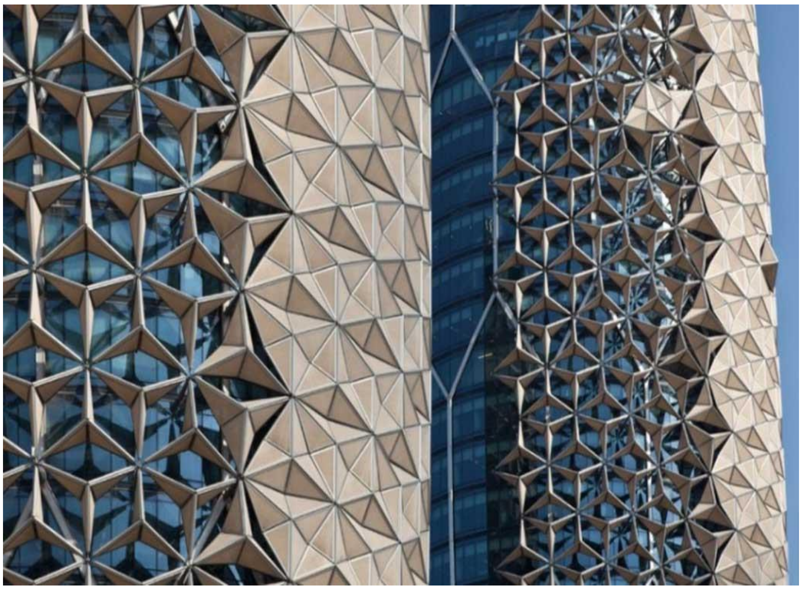


Figure 3.29: Façade detail (Arch daily, 2012)

Material selection and waste management

The building made use of naturally tinted glasses, also the dynamic mashrabiyya was made of PTFE-coated fibre glass mesh.

Water Efficiency

The solar thermal panel was used for hot water heating. An independent secondary chilled water system was used to act as a resilient backup for the cooling system.

Indoor Environmental quality

The building has a dress with a crystalline honeycomb shell that protects it from the sun and it help reduce heat gain and glare. The pattern of the building skin was taken from a dynamic mashrabiyya which is mathematically executed; it opens and closes with the sun path. This advanced mashrabiyya is made of translucent PTFE coated fiberglass mesh. The building utilizes linear actuators and input from the building's control framework to separately move the skin panels to five positions, between fully open or closed as the sun moves across the building. It is estimated that the screen reduces cooling loads by 25% and between 20-50% reductions in solar heat gain compared with other traditional curtain wall buildings (Gunderson, 2015).

The reaction of the envelope produces a wave of movement as the sun hits the structure; however, the façade stays static until the skin is modified to move. The façade additionally shows up very light on the outside yet it’s surrounded with the Y-shaped structural arms that block and detach the inhabitants on the interior to the exterior environment.

The screen works as a drape divider, sitting two meters outside the building outside and can be basic work as a free edge. The two towers comprise of more than 1,000 shading gadgets separately that are being controlled by the building administration framework. Each triangle is secured with fiberglass and altered to respond to the development of the sun as an approach to lessen sun based pick up and glare, and at night, every one of the screens will close. The building likewise consolidates the utilization of sun based warm boards for boiling hot water warming.

Figure 3.30: Apparent Umbrella-like add-ons that open and close in step with the sun’s path (Cook, 2013)

As stated by (Peter Oborn 2012) “*At night they will all fold, so they will all close, so you’ll see more of the façade. As the sun rises in the morning in the east, the mashrabiya along the east of the building will all begin to close and as the sun moves round the building, then that whole vertical strip of mashrabiya will move with the sun,”*

Site Design

The building is designed in a responsive and dynamic skin, able to react differently according to the sun’s orientation and to adapt to varying external conditions throughout the year.

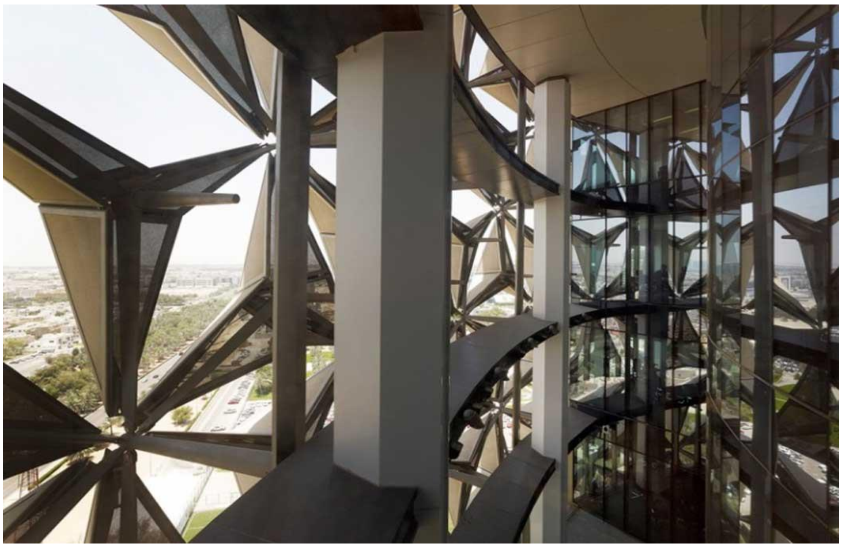


Figure 3.31: Façade detail inside view. (Cook, 2013)

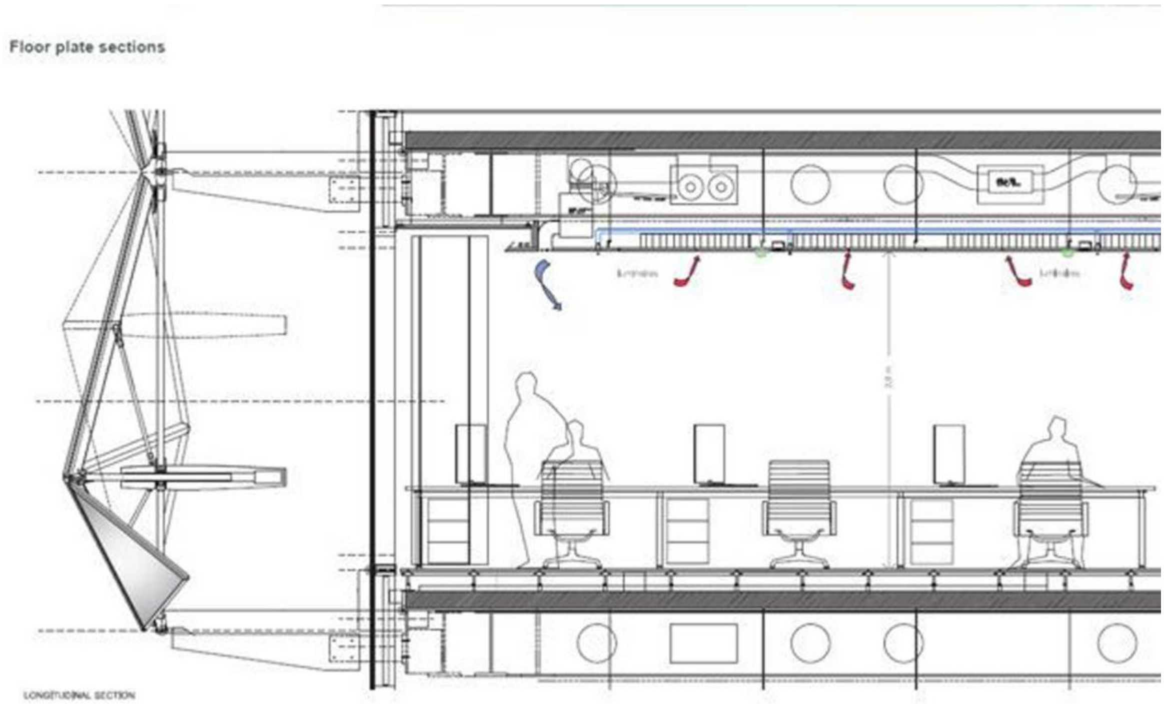


Figure 3.32: Façade details section (Cook, 2013)

Table 3.5: Principles and façade techniques for Al Bahar Towers

Principles and façades techniques	Al Bahar Towers
Energy Conservation	- The screen reduces the solar gain by 50% or more -The screen reduces the cooling load by 25% and 20-25% for the reduction of solar heat gain - Crystalline honeycomb shell helps reduces the heat gain and glare
Material Selection and Waste management	- Dynamic mashrabiyya made of PTFE coated fiberglass mesh was used -Naturally tinted glass was used
Water Efficiency	- Solar thermal panel was used for hot water heating -An independent secondary chilled water system was used to act as a resilient backup for cooling system
Indoor Environmental Quality	- Use of natural tinted glass to allow more light into the building - The glass performance in this area was improved by applying additional fitting with a variable pattern according to the level of solar control required. This reduced the g-value (coefficient commonly used in Europe to measure the solar energy transmittance of glass) and contains the solar gains - The foyer space incorporates a large raised floor void which is used as a supply air plenum (it helps facilitate air circulation for heating and air condition system, thereby providing pathway for the heated and conditions return of airflow) for a displacement-based HVAC system.
Site Design	- The building is designed with a responsive and dynamic skin; it is able to react differently according to the sun's orientation and to adapt to varying external conditions throughout the year.

The relationship between the principle of green architecture and adaptive façade of this building is related to the use of the crystalline honeycomb, which is used to reduce the heat gain and glare also the use of glass helps in the solar control.

3.8 Comparative Interpretation

According to the case studies described above they depict that zero-energy building can be constructed not only residential or small-scale buildings but can also be achieved on large scale and commercial/public buildings. The case studies were selected from different geographical regions in the world with different climatic conditions (humidity, hot and tropical climate), to support the principle thought that it could be feasible for large scale and high rise building to be absolutely sustainable and ventilated even in extreme atmosphere considering the role of building façade to accomplish (Table 3.6), where each case study has a distinctive building façade to achieve a significant decrease in indoor environmental quality, energy conversation, and a net zero energy building.

3.8.1 Energy efficiency

This aspect consists of the natural resources (renewable energy). Energy performance of the building which looks into the lighting, ventilation, and HVAC, it also includes an operational aspect of the building where energy is monitored and CO_2 reduction strategy is implemented.

(Wigginton and Harris, 2002) establish seven related functions that address the impact of façade design on building energy efficiency namely:

1 **Function as a thermal valve:** the building envelope, through its thermal resistance (R value) regulates the flow of thermal energy from the interior to the exterior environment (or vice versa).

2 **Function as a radiant filter:** the envelope transmits, absorbs or reflects radiant energy.

3 **Function as air infiltration barrier:** the envelope breathes by allowing exterior air to seep through cracks and openings or by intentionally introducing air through vents and fans. The design of the envelope is one of the principal factors that determine the level of air infiltration into a building. The envelope also acts as a barrier to airborne substances, such as pollutants and odours.

4 **Function as a moisture membrane:** the envelope controls moisture content within the building.

5 **Function as energy collection or distribution device:** many solar thermal systems collect radiant energy at the building envelope to enhance the building's thermal performance.

6 **Function as a thermal, electrical, or chemical store:** the building envelope can store energy. For example by using mass walls, the skin is utilized to provide thermal capacity in which heat can be stored for later use.

7 **Function as a dynamic filter:** buildings envelopes have been able to change their faces in the past using shutters, awnings and other movable devices (Wigginton and Harris, 2002).

The adaptive façade aids in the controlling of solar gains, it helps in the energy balance of the building, its benefit from passive solar energy while avoiding indoor overheating. In case study 1; the use of tessellated façade in the building helps creates the balance between the solar gain in the building (Figure 3.4). In case study 2; the use of the stainless steel devices (feathers) acted as the shading devices, this also helps reduce the energy demand on the use of air conditions (Figure 3.11).

Case study 3, in this building the use of PBR (photo bioreactors) as a shading device, was adopted, this a different type of adaptive façade where algae panels were used and several energy sources were derived from the panels (Figure 3.16). Case study 4, an advanced responsive metallic brise soleil façade was used as a solar shading device to protect the building façade from daylight, (Figure 3.23). Case study 5, in this building a crystalline honeycomb shell was used to reduce the heat gain and glare, and the glass in the façade are improved by the application of additional fritting according to the solar control, this reduces the g-value and solar gains (Figure 3.30).

3.8.2 Indoor environmental quality

This aspect consists of the control ventilation, lighting and illumination, noise and acoustics contaminate level and thermal comfort within a building.

The exterior shading device works as a determinant for the access of natural daylighting, prevention of glaring, illuminance and creates a view from the outside. This system allows designers to understand the intensity and direction of the sunlight, thereby calculating and bypassing the inherent compromises that should be noted when decisions of façade system are made. In case study 1, the use of horizontal and sun-shaded louver system, with operable windows to control the natural ventilation into the building. Natural daylight in the building was provided via reflective curved ceiling in the atrium (Figure 3.2). In case study 2, the shading device in this building façade is used to reduce direct sunlight into the building, and the use of panorama windows are used for daylighting in the building (Figure 3.9). The technology of the façade aids the building in the indoor environmental quality which entails the ventilation, lighting and the thermal comfort within the building.

In case study 3, the use of the algae panels as the building façade components helps improve the sunlight entering the building and gives the building warm insulation. Also, the system also insulates the building from sound, heat, and cold which are associated with the thermal comfort in the building (Figure 3.20). In case study 4, the façade system helps control the building from lighting with the aid of the closure of the aperture sizes (Figure 3.24). In case study 5, the façade design in a honeycomb shell is used as a shading device, this helps reduced the light into the building, also the use of natural tinted glasses also aids this course (Figure 3.32).

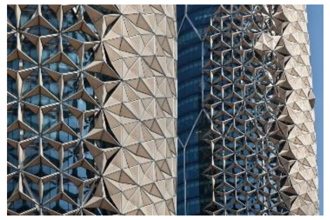
The façade design can take a type of (i) a binary action (transparent vs. non-transparent, on-off) for the most part performed by the mechanical arrangement of louvers, rollers and sunshades, or (ii) the continuous control of light transmission generally performed by the physical framework through in part opened frameworks or semi-transparent/translucent components. On days with irregular mists, the outside daylight illuminance can vacillate quickly. For effective daylight management, it is vital that the shading framework can synchronize with these quick varieties in the request of seconds.

These attributes described above fit into the category of energy conservation (natural resources, energy performance and operational) and the indoor environmental quality (ventilation, lighting, illumination, and thermal comfort) in green building principles, and depicts the relationship of the technology of adaptive façade design with great importance on the exterior shading device.

3.8.3 Material selection and waste management

These aspects consist of the material used for the façade design of each building. The material selection plays a vital role in the use of building towards achieving green architecture. In case study 1, the use of an animated stainless steel with a tessellating kinetic surface and panel aids the green technology aspect within this building, the kinetic tessellating surface made of steel (Figure 3.5) and also the modular green roof aided in the attaining the green architectural principles. In case study 2, the use of a stainless steel sharing devices in feather-like form was used they panels were made of pearl metallic gold materials, this aided the building to able to function technologically within green architecture while abiding with the principles surrounding it (Figure 3.10).In case study 3, the use of PBR photobioreactors was used and bio-reactive panelling with algae panels (Figure 3.19). This was a special type of façade, the material used were in algae form and help the building adapt to the environmental conditions and also reduces the energy consumption within the building. In case study 4, the use of an advanced responsive metallic Brise Soleil was used, this was made of steel material in helping prevent the sun from entering the building with its shading technology (Figure 3.23). In case study 5, a dynamic mashrabiyya made of PTFE-coated fiberglass was used and naturally tinted glasses, this aided the building to function both in technology and to aid green architectural principle in terms of energy conservation and the indoor environmental quality (Figure 3.30).

Table 3.6: Comparative findings

Principles and façades techniques	Case Studies				
	Simon Center	**JSWD**	**BIQ**	**IMA**	**Al Bahar**
					
Energy Conservation	- The use of air handlers as a heat rejection method -The use of active chilled beams to provide low-humidity cooling -33% less of energy use than a conventional building	- Sun protecting system, reduced energy demand and use of air condition and electric lighting Approx.1,000 square meter geothermal field for power supply and power consumption is minimized via energy-saving Fluorescent lamps.	- Use of a large reactor modules PBR (photobioreactors) -Contribution of different energy sources: solar energy, geothermal energy, condensing boiler, distinct heating, production of biomass in the bioreactor façade	- Sensor system based on dynamic climate to contribute to the diminishing of energy demand	-The screen reduces the solar gain by 50% or more -The screen reduces the cooling load by 25% and 20-25% for the reduction of solar heat gain - Crystalline honeycomb shell helps reduces the heat gain and glare
Material Selection and Waste management	- Animated stainless steel with tessellating kinetic surface and panels -Modular green roof - Zero waste and resources conservation	- Stainless steel shading devices (feathers) -Pearl Metallic Gold material (PLADUR® ZM)used in form of formed steel panels	-Steel frame and wiring for the PBRs - Bio-reactive panelling -Algae panels	-Advanced responsive metallic brise soleil	- Dynamic mashrabiyya made of PTFE coated fiberglass mesh was used -Naturally, tinted glass was used
Indoor Environmental Quality	- Solar shading –the use of horizontal and sun shades louver system *Operable windows for natural ventilation -Natural daylight provided using reflective curved ceiling	-Sun shading system to reduce direct sunlight into the building -Use of panorama windows for day lighting -Openness and transparency with its intricate façade structures of glass and metallic materials	-Algae bio-façade gives the building warm insulation, shading from sunlight, also reduces the noise pollution and will generating a ready-to-harvest biomass. -The façade system insulates the building from sound, heat, cold and shades from bright sunlight	- Solar gain is relieved by closing the aperture sizes to control the lighting the building - Use of Photosensitive crevice which open and close to control daylight infiltration	- Use of natural tinted glass to allow more light into the building - The glass performance in this area was improved by applying additional fritting with a variable pattern according to the level of solar control required. This reduced the g-value and contains the solar gains- The foyer space incorporates a large raised floor void which is used as a supply air plenum for a displacement-based HVAC system.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This thesis has studied the relationship of green architecture and building façade taking into consideration the green building principle present and where it has been introduced in the development of the adaptive façade design, with is governing concept, this also focuses on the core relationship aspect where natural ventilation, energy conservation and daylight control enhances the internal environment in the building.

many of concept has emerged from green architecture such as sustainable development and green design which has been introduced to the architectural practice, one of the practices which has been adopted in the technological aspect. It can have been concluded that the technological aspect of building façade was influenced by green building principles, were the principle of energy conservation /efficiency and indoor environmental quality play a major role in the actualization of the adaptive façade design system as seen in the five case studies selected. Case study 1, the Simon centre in New York with the use of tessellate surface achieved this aspect in its façade design. Case study 2, JSWD headquarters Q1 utilized the feather façade design in the reduction of energy demand and lighting in the building, case study 3 the BIQ building used the algae panel with photo bioreactors which draw energy from different sources. Case study 4 Institute du Monde Arabe (IMA) utilized an advanced responsive metallic brise soliel which allows the aperture to close and open for the control of day lighting into the building. Case study 5 Al Bahar building utilized a honeycomb shells structure with tinted glass system.

In this research, as stated earlier the case studies were selected based on the significant impact they have in portraying the relationship between the green building design and the technology involved. The basic relationship between green building and technology as seen in (Table3.6) depicted a clear cut analysis was from each case study. Where the energy conservation, indoor environmental quality and material and waste management were the core connection that related the green building principles and technology. The technology of conserving energy with the use of shading devices and algae panels was visible. Also, the use of basic material and technological movement of the façade helped form the relationship of the green building principle and technology. The indoor environmental quality was controlled using technological advancement mechanism for solar shading, daily lighting, ventilation and insulation of the buildings. The study therefore identified these connection through the definition of terms such as adaptive façade with was the technological background that aided the connective of the principle of green architecture and the technological framework it portrays.

The case studies were purposely selected based on the technology associated with their façade design. Accordingly the case studies analysed the use of adaptive building façades which played a key role in building energy efficiency and overall performance were:

- The use of adaptive façade permits natural light into the building either they are residential or commercial building. It also aid in implementing effective ventilation system, thermal comfort control of the occupants and daylighting absorption into the building if properly designed

- The use of external shading system in the adaptive design also reduces the heat and glare in the building, where the use of mechanical air conditioning are used. Shading device which is mostly over hanged or moveable also aid in the flexibility of the devices to adapt to different climatic conditions.

In this thesis, a detailed analysis of the general aspects of the adaptive kinetic façade design showed that there are several environmental benefits that encompass this system. There are several ways and technique to achieve this ideal envelope which influences the natural ventilation, lighting condition, energy conservation, sound insulation, relative humidity and heat gain regulation. All these aspects are almost impossible in a regular conventional building with static façade designs that are achieved in this system nowadays. Moreover, it has been demonstrated through the analysis described from the existing case studies that adaptive façade is one of a few solutions that can help contribute to the energy performance of a building to maximize benefit with various climatic factors such as the sun light and wind.

Conclusively, adaptive kinetic façade is a solution to sustainable development strategy through green building principles which approached an ideal thermal comfort of the occupants within the building by responding to different climatic conditions and by been able to adjust to the demands of the occupants too.

All these are perspectives that are practically unthinkable for a straightforward static envelope to manage these days. Moreover, it has been demonstrated through the investigation from effectively existing review cases that the dynamic envelope is the one that can convey an answer for these issues and in the meantime add to the energy execution of a working as it can be used, in such a route, to endeavour greatest advantages from the atmosphere viewpoints, for example, daylight and wind. At last the active façade is an answer that can approach the perfect warm solace for the inhabitants of a working by reacting both to fluctuating states of the outer atmosphere and by having the capacity to change in accordance with the requests of the person too.

4.2 Recommendations

The external façade design technology has resulted in a situation where green architecture is shaping the character of the façade design with the use of technological initiative, material, energy and indoor environmental qualities, thus can be further analysed through the following set of recommendations.

- The façade design technology taking into consideration the environmental, economic and climatic conditions can serve as a tool. The geographical location should be a core value when determined the use of adaptive façade technology in designing any building.
- Architects should analyse best possible energy conservation techniques to enhance the application of green building principle in the design of the buildings.
- All green building principles should be noted in the derivation of the adaptive façade design which would serve the target of the specific building.
- Assessment of the adaptive façade system should be detailed and clear, due to varieties of techniques adopted in this system.
- An appropriate ventilation, lighting strategy should be designed to suite the building usage.

- An update in computer modelling knowledge should help designer understand the performance character of the façade strategy.
- Also, a post occupancy analysis should take into consideration to understand how occupants react to such space and how effectively they perform.

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